Assessment of the state of the Rangitaiki River within the Ngati Manawa rohe

NIWA Client Report: HAM2009-100
May 2009

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Executive Summary

With its partners, Ngati Manawa seeks to secure the health and well-being of the Rangitaiki River and its biota. As a step towards fulfilling this vision, Ngati Manawa contracted a multidisciplinary team from the National Institute of Water and Atmospheric Research (NIWA), Manaaki Whenua Landcare Research (Landcare Research) and GNS Science to establish the current state of the Rangitaiki River and tributaries within its rohe (boundaries). This report presents and assesses existing information on the characteristics of the Rangitaiki River catchment upstream of Aniwhenua Dam. It includes historical information on soils, land-use, rainfall, surface and groundwater hydrology, water quality, instream ecology including periphyton (algae etc. attached to substrate), macrophytes (submerged aquatic plants), macro-invertebrates (small aquatic animals such as insects and worms), and fish. Additional data were obtained in late summer 2009 to provide current information. Knowledge gaps and recommendations for enhancing the heath and well-being of the Rangitaiki River and biota are presented.

The geology of the upper Rangitaiki River catchment consists of a superficial cover of: holocene age pyroclastic materials (largely pumice and ash, deposited less than 10,000 years ago), overlying pleistocene age ignimbrite sheets, which un-conformably overlie mesozoic age greywacke basement rock. The upper Rangitaiki River flows north over the Kaingaroa Plateau and on through the Galatea Plains. It is bounded on the east by the uplifted greywacke rocks of the Ikawhenua Range mountains and on the west by the Kaingaroa fault on the east side of the Taupo Volcanic Zone. A series of faults run along the catchment.

Surface soils in the upper Rangitaiki catchment have all been strongly influenced by volcanic activity. Apart from a few isolated areas in the east where basement rock has been exposed, soils have all developed from pumice derived from airfall volcanic materials. Land use essentially follows the three broad land features of the catchment with exotic forest covering the majority of the Kaingaroa Plateau (52% of the catchment), native forest on the eastern ranges (25% of catchment) and agricultural grassland on the Galatea Plains and a small portion of Kaingaroa Plateau. Available evidence suggests that land use has stabilised in the last two decades, with forest harvesting accounting for the majority of recorded changes. While there has been some intensification of farming practices in recent years, the full extent and impact of the changes have not been quantified and require further investigation. In general, to minimise further adverse impacts of land use, the areas of unprotected native land cover should remain in an undisturbed state and should preferably be protected from grazing stock. In view of the erosion potential and leaching properties of the predominantly pumice soils of the Kaingaroa Plateau, this area should be retained as forestry. Conversion from forestry to other land uses, especially pasture, should be restricted to areas with low or at worst moderate erosion potential, such as the Kaingaroa gravelly sand, west of Galatea.

Rainfall in the upper Rangitaiki River tends to be lower and subject to fewer extreme events than in the Whirinaki River catchment. This, combined with geological differences between the two sub-catchments, results in more stable, groundwater-dominated flows in the Rangitaiki but flashy discharges in the Whirinaki River. Examination of the close to six decades of flow records did not reveal any significant alterations to the overall flow regime of the Whirinaki River at Galatea, but the flow regime of the Rangitaiki River has been significantly affected by the hydro-electric developments. It is unclear how these alterations have affected the ecology of the river. The increasing demand for water to support the intensification of dairying in the Galatea Plains has the potential to significantly increase pressure on the Rangitaiki River itself, as well as on many of the tributaries. Based on the objective of protecting instream habitat for fish, no further allocation of water should be allowed from the Whirinaki River. On the Rangitaiki, using the same criteria and available abstraction records, only 2.5 $m^3 s^{-1}$ remains un-allocated. Although the potential effects of water abstraction on the Rangitaiki and Whirinaki are reasonably well documented, impacts on smaller tributary streams are unclear and need considerably more attention.

Ground water quality records from the upper Rangitaiki catchment indicate that most wells produce water suitable for drinking and other purposes. Iron appears to be the main exception to this general "fitness for use". The only other noteworthy issue is the concentration of nitrogen compounds, and although concentrations are generally low, there is considerable variation in ammonia and nitrate concentrations over time. In view of land use in the area, this may indicate sporadic inputs of nitrogen into the groundwater system from agricultural operations, and further investigations should be undertaken. Overall, current consented groundwater allocation is small compared to surface water flows, but available information does indicate that a potential exists for adverse impacts on groundwater quantity and quality in the Galatea Plains. Experience from other regions has shown that it is much easier, cheaper and faster to prevent degradation of groundwater than to remediate it once it has been degraded. It is therefore recommended that better information on catchment hydrogeology, groundwater to surface water relationships, and long-term sustainable groundwater yield be obtained. As the few wells that are monitored are in up-gradient parts of the Galatea Plains, the current groundwater monitoring network is not well-suited to detect anthropogenic changes, and monitoring of additional down-gradient wells and streams is recommended.

Differences in flow characteristics of the Rangitaiki and Whirinaki rivers have a major influence on the water quality of the respective waterways. In general, clarity is slightly higher in the Rangitaiki River than the Whirinaki River, and suspended solids concentrations are slightly lower. Water in the Whirinaki River also tends to have more coloured dissolved organic matter than that of the Rangitaiki River. Concentrations of nitrogen (nitrate-N and total-N) are considerably (and consistently) higher in the Rangitaiki River than the Whirinaki River. Trend analysis indicates that concentrations of N (and phosphorus) in both the Rangitaiki and Whirinaki are increasing. This is likely due to changes in land use in these catchments, and in particular, intensification in land use in the upper Rangitaiki River catchment. In this respect, in the preceding two-year period, three consents have been granted to "discharge untreated dairy effluent to pasture irrigation and sludge to land" in the upper Rangitaiki

River catchment near SH5. The limited data available from Otamatea River catchment, where these new consents are located, indicates a sharp increase in the concentration of nutrients between about 2000 and 2004. Unless better controls are implemented (e.g., provision of buffer strips along stream margins and creation of nutrient stripping wetlands), further increase in sediment, nutrient and faecal contaminants from the upper catchment can be anticipated.

Concentrations of indicator organisms, particularly *E. coli*, are typically well below threshold guideline concentrations upstream of Murupara, but subject to large increases during short-term high flow events. No surface water resource should be considered safe for consumption without treatment, but the water generally poses low risk to contact recreational users.

While nuisance periphyton growths have not been observed catchment-wide, growth above the recommended guidelines for trout habitat and angling value was observed at some locations. In addition, extensive cyanobacterial mats occurred in many places. The dominant taxon was a strain most resembling *Phormidium autumnale* (the species implicated in the dog deaths in the lower river around 2007). While it is not known whether the cyanobacterial mats in the Wheao and Rangitaiki Rivers produce toxins, given the occurrence of toxins associated with this species in other New Zealand rivers, it is very probable. By reducing nutrient concentrations, retaining and enhancing overhanging riparian vegetation, and providing flushing flows, periphyton biomass may be reduced to levels that will maintain river health and values.

In Lake Aniwhenua, periphyton, in particular *Phormidium*, is not thought to be problematic. Little substrate is available for the growth of benthic algae, and light penetration to the bottom of the lake is considerably reduced by the dense macrophyte beds. Epiphytes are present, but do not appear to develop to levels that would cause stress to the macrophytes. To date, no monitoring of phytoplankton (algae that floats in the water column) growth in the lakes has occurred. As blooms of phytoplankton (particularly cyanobacteria) can occur in lakes, it is recommended that summer-time monitoring be undertaken in future.

The creation of canals and lakes for hydro power generation in the upper Rangitaiki River has modified the habitat for macrophytes markedly. Over the years these habitats have also been invaded by non-native species notably hornwort. These have changed the habitat markedly and have impacted not only the other aquatic life but also recreational and commercial users. Increasing water abstraction and nutrient levels are expected to favour more abundant macrophyte growth in the future, and plant control measures are advocated.

A diverse aquatic macro-invertebrate community is present in the upper Rangitaiki River and provides an abundance of food for fish and other wildlife. Inter-annual variability in community provides no indication of a decline in the condition of the river over recent years. However, any future activity which further alters the natural hydrology, water chemistry or substrate is likely to impact on these communities. Conversely, there is scope for improving the ecological condition of some reaches by rehabilitating them to a more natural condition.

Indigenous fish, in particular tuna (eels), are taonga for Ngati Manawa and an important food resource. A number of other species (e.g., kokopu) were not only traditionally harvested but also recognised for their importance in the ecosystem. Over time, the diversity, distribution and quality of these fish has declined. The deterioration has been linked to a range of factors including: disruption of connectivity for diadromous species, over-exploitation, loss of and changes in habitat, and competition from introduced species. Many of these pressures may also be impacting on the status of the introduced trout which now support significant recreational fisheries within the catchment. Recovery of the tuna population through the manual transfer of elvers to the upper catchment has been successful, but has resulted in an increase in the ratio of shortfins to longfins. Improving successful downstream migration of mature adult tuna is, however, still required. Furthermore, it is not known if isolated populations of native kokopu-type species still remain and if so, how to protect them and their habitat. Overall recovery of indigenous fish populations and maintenance of the trout fishery in the upper Rangitaiki catchment will require an integrated approach that will include conservation, enhancement and management. There is also a requirement to restore habitats, and connectivity between habitats.

In undertaking the present review we are likely to have failed to capture a number of reports and findings. Certainly, through the study we became aware of a number of potential sources of additional information that we could not access. Consequently, we hope that this report becomes a living document and urge all researchers and users of the upper Rangitaiki River to contribute to a common knowledge base and transmit additional information they hold and/or gather in the future to Ngati Manawa and Environment Bay of Plenty (EBOP).

1. Introduction

Jacques Boubée, Paul Franklin and Neale Hudson, NIWA

As a taonga, the Rangitaiki River is significant to the cultural identity, history, beliefs and practices of Ngati Manawa. Competing interests from energy production, forestry, agriculture and recreational developments have placed increasing demands on the river and its resources. This has increased pressure on the health and well-being of the river, which is a matter of concern for Ngati Manawa.

Ngati Manawa seeks to restore the health and well-being of the Rangitaiki River and its tributaries in consultation with the Crown as part of a wider process aimed at redressing grievances. Fundamental to this process is the requirement to clearly establish the current state of health and well-being of the Rangitaiki River and its tributaries. Comprehensive assessments of the state of the Rangitaiki River were undertaken in 1993 (Te Ika Whenua Energy Assets Report) and 1998 (Te Ika Whenua Rivers Report), but significant development has occurred in the catchment since this time such that some of the information the reports contain may now be outdated. It is therefore imperative that the current state of the environment is established for the Rangitaiki River.

1.1 Study brief

The focus of this project is to review the current state of the Rangitaiki River and its tributaries and to identify the factors impacting on its overall health and well-being. The project has been carried out by a multidisciplinary team, comprising project teams from National Institute of Water and Atmospheric Research (NIWA), Manaaki Whenua Landcare Research (Landcare Research) and GNS Science (GNS). The scope of the work was to:

- Review existing data and information relating to the status of the Rangitaiki River and its tributaries.
- Conduct an analysis of the data to determine current knowledge of the state of the environment in the Rangitaiki River and its tributaries.
- Determine the main factors impacting on the health and well-being of the Rangitaiki River.
- Identify current knowledge gaps with regards to determining the current status of the river and the mechanisms of change.

The assessment takes account of hydrology, groundwater, land-use, soils, water quality and aquatic ecology, including fish, macrophytes, periphyton and macroinvertebrates.

1.2 Study area

The Rangitaiki River catchment is located in the Bay of Plenty region of the North Island of New Zealand (Figure 1—1). The Ngati Manawa rohe and area of interest generally encompasses the majority of the Rangitaiki catchment upstream of Aniwhenua Dam. Consequently, this report focuses on this area of the catchment, but necessarily refers to features of the wider catchment for interpretation of observed features and trends in the upper catchment above Aniwhenua (Aniwaniwa).

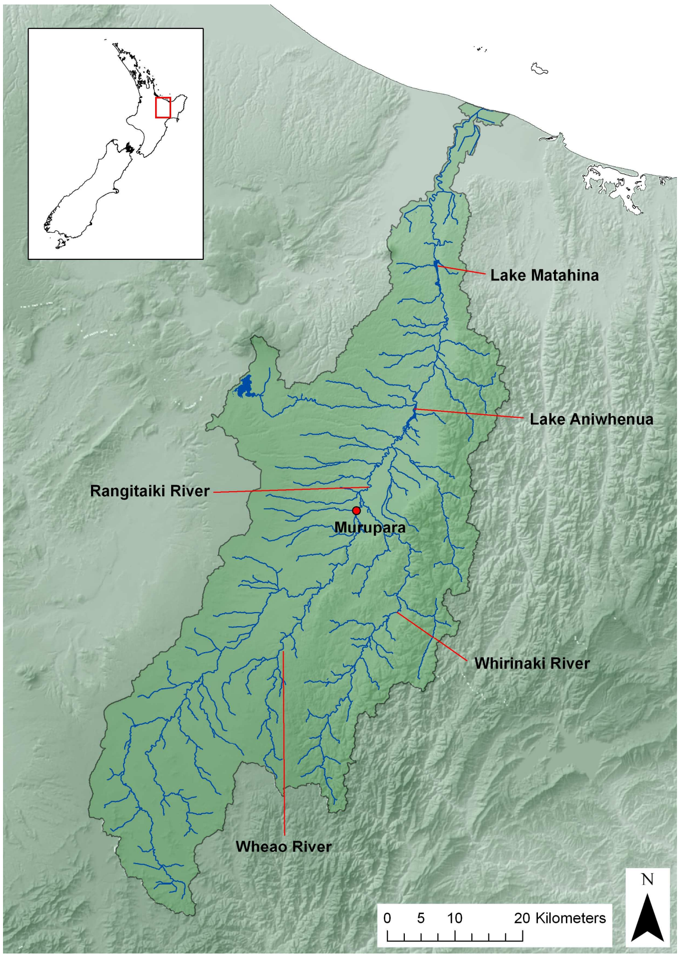

Figure 1—1: Location and main features of the Rangitaiki River catchment.

The main Rangitaiki River drains a large area of the Central Volcanic Plateau. Flows are relatively stable due to the pumice soils and ignimbrite geology which allow rapid infiltration and hence a dominance of base flows from groundwater. The geology produces streams primarily characterised by sandy runs with occasional outcrops of bedrock and cobbles.

Land-use in the catchment is dominated by forest, with approximately 52% of the catchment under exotic forest and 25% under native forest. The remainder of the catchment is primarily agricultural. The eastern tributaries of the Rangitaiki, such as the Whirinaki River and Horomanga River, draining the Ikawhenua Ranges, are typically characterised by a variable flow regime. The geology of these sub-catchments is characterised by a greater proportion of impermeable greywacke base rock. This results in a more rainfall driven flow regime with larger and more frequent flood events and lower baseflow. River morphology also tends to be of a more characteristic riffle-pool type, with substrate dominated by cobbles and boulders. These sub-catchments are mainly native forest before reaching the agricultural areas of the Galatea Plains.

The Rangitaiki River has been subject to the development of significant hydro-electric power infrastructure. The Matahina Dam was completed and became operational in 1967. The 86 m high earth dam has two generators producing 80 MW to give an average annual output of 290 GWh. The existing resource consent for Matahina expires in late 2009 and negotiations are currently underway with affected parties and interested groups as part of the re-consenting process. The Aniwhenua Power Scheme was constructed in the late 1970s and commissioned in 1984. The scheme involved damming the Rangitaiki River above Aniwhenua (Aniwaniwa) Falls to create a 255 hectare storage lake. The average annual output of the scheme is 135 GWh. The lake is now a major recreational resource for the area supporting a regionally significant trout fishery, duck shooting and water skiing. In the upper catchment, the Wheao Power Scheme diverts water from the Rangitaiki River, Wheao River and Flaxy Creek to the Wheao powerhouse, producing an average annual output of 111 GWh.

1.3 Report structure

Each component of the review is presented as a separate chapter, detailing existing knowledge and describing current status. The report follows a logical structure, progressing from catchment soils and land-use (Chapter 2), through to rainfall and surface hydrology (Chapter 3), groundwater and geology (Chapter 4), water quality (Chapter 5), and then the different components of instream ecology, including periphyton (Chapter 6), large aquatic plants (Chapter 7), macroinvertebrates (Chapter 8) and fish (Chapter 9). Chapter 10 makes recommendations for future action based on identified issues and information gaps.

2. Soils, land use and terrestrial biodiversity

2.1 Soils

Scott Fraser, Landcare Research, Hamilton

Soils in the upper Rangitaiki catchment (upstream from Lake Aniwhenua) have all been strongly influenced by volcanic activity. Apart from a few isolated areas in the east where basement rock has been exposed, soils have all developed from pumice derived from airfall volcanic materials (ash – up to 2 mm in diameter, lapilli – 2–64 mm, and blocks – more than 64 mm) commonly referred to as tephras. The upper tephra layers are mostly derived from eruptions in the last 10 000 years from the Okataina (between Rotorua and Kawerau) and Taupo volcanic centres. Some soils have older tephric materials within the soil profile (top metre) but in most cases, tephras form layers below the soil profile. These soil parent materials can be subdivided into airfall tephras, including flow tephras ("nuee ardente" – a glowing avalanche of hot pumiceous materials), and alluvial (water-deposited) or colluvial (transported down slope by gravity) materials derived from airfall tephras.

2.1.1 Topography

The largest area within the upper Rangitaiki catchment is the Kaingaroa Plateau, forming the eastern sector of the Volcanic Plateau. It rises steadily in the west towards Reporoa and Taupo and to the south towards and beyond the Napier-Taupo road (State Highway 5), including the upper Rangitaiki Plains. Alluvial deposition in the Galatea Basin has formed a plain extending as far north as the Aniwhenua Dam, lying between the Ikawhenua Ranges and the Volcanic Plateau. Aerially deposited tephra layers form terraces above the adjacent flood plains.

The Ikawhenua Range rises steeply to the east, forming the western boundary of the Urewera steeplands.

2.1.2 Soil orders

The New Zealand Soil Classification (NZSC) replaced the New Zealand Genetic Soil Classification in 1983. It differs from its predecessor in that it groups soils into classes based on similarities of measurable or observable properties rather than presumed genesis

(McLaren & Cameron 1996). The NZSC is a hierarchical system containing 15 soil orders, which are further subdivided into groups and subgroups (Hewitt 1998). For the purposes of soil mapping, subgroups are divided further into soil series that are generally given geographic names indicating the locality where the soil was first recorded, e.g., Kaingaroa series, in the Welded Impeded Pumice subgroup of the Pumice Soils group.

Five soil orders (Pumice, Podzol, Recent, Raw and Gley) have been mapped within the study area (Table 2—1). Approximately 90% of the soils are within the Pumice soil order, and most of the remaining soils (approximately 7%) are within the Podzol (highly leached) soil order. The Podzols of this region have all developed on pumiceous parent material.

Pumice soils

Pumice soils are dominated by pumice or pumice sand and have sandy or gravelly textures. These relatively young soils have formed in volcanic materials that were erupted between 700 and 3500 years ago. They are generally weakly developed with coarse textures throughout the profile, low clay content (less than 10%), and low bulk densities. They generally have low cation exchange capacity (CEC) and low natural reserves of both major and minor nutrients, including trace element deficiencies (cobalt, copper, molybdenum, boron, iodine and selenium). Due to the physical nature of these soils, they are particularly prone to erosion from water such as rill and gully erosion, but also to a lesser extent sheet due to wind erosion if soil is disturbed through cultivation. The Pumice soils in the upper Rangitaiki catchment are mostly Immature Orthic (weakly developed), Welded Impeded (compact welded layer – ignimbrite), or Podzolic Orthic (strongly leached).

Podzols

Podzols are characterised by a soil horizon (E) that is strongly leached and often bleached, with horizons beneath that show accumulation of organic and mineral complexes that have been leached from overlying horizons. These soils form in high rainfall regions in the North Island high country. The E horizon is sometimes missing or has been masked due to erosion, cultivation, or some other type of disturbance. Podzols are acidic, have low base saturation, and generally require large inputs of fertiliser and lime to bring them into pastoral production. These soils have developed under native vegetation that produces acid leaf litter low in calcium such as rimu and beech. Most of the Podzols in this region occur in the eastern steeplands of the Ikawhenua Ranges.

Recent soils

Recent soils show minimal profile development due to the short time that the parent materials have had to weather. The recent soils of the upper Rangitaiki have developed on alluvial materials deposited on the flood plains of the Rangitaiki River and its tributaries.

Raw soils

Raw soils lack distinct topsoil development due to rockiness, active erosion or deposition. In the Rangitaiki catchment, Raw soils all occur along river flood plains and have formed through rapid accumulation of alluvial materials.

Gley soils

Gley soils occur where there is poor drainage and when soil profiles are saturated for long periods. The soil environment becomes oxygen limited, producing greyish colours throughout the soil profile from the chemical reduction of iron particles.

2.1.3 Geographic distribution of soils

The soils of the upper Rangitaiki catchment can be grouped under the various landforms in which they are found. In the following sections, the main soils of the region are described under the various landforms where they are found. Table 2—1 lists the soils found in the study area, listing their NZSC classification, soil series names, and the initials used to identify them on the soil series map (Figure 2—1).

Soils of the Kaingaroa Plateau

To the south and west of the Galatea Basin, the land rises onto the Kaingaroa Plateau. This landscape is mantled in deep layers of volcanic tephras deposited over the last 2 million years. To the west of the Galatea Plains, the soils are predominantly Immature Orthic Pumice soils and a layer of Tarawera ash covers older Kaharoa and Taupo deposits

(Matahina series). Further south, the Tarawera Tephra thins rapidly with Kaharoa and Taupo tephras becoming the dominant surface tephras. These soils are largely Welded Impeded Pumice (Kaingaroa series) and Immature Orthic Pumice (Taupo, Te Rere and Pekepeke series) with some Podzolic Orthic Pumice soils (Pukerimu series). The welded pumice occurs where flow tephras have deposited hot (600–700 ºC) ash and pumice fragments that have welded together after deposition. Both the Welded Impeded Pumice and Podzolic Orthic Pumice soils are strongly leached soils. There are some hill soils on steeper country between the flat to rolling plateaus and also some steepland soils in steep valleys cut into the plateaus, particularly on the northern Kaingaroa Plateau (Rijkse 1995 & 1997).

Fluvial soils

Fluvial soils have developed on alluvial deposits adjacent to river and stream beds throughout the region. The Rangitaiki series are recent sandy and gravelly soils found along the lower flood plains of the Rangitaiki and its tributaries. These soils have formed in recently deposited pumiceous alluvium and show little profile development due to a rapidly accumulating A horizon[1] from sediment deposited during floods (Rijkse 1995).

The Poronui and Otamatea series have formed on water-sorted Taupo Pumice. Poronui soils are found on undulating river terraces on the southern Kaingaroa Plateau, upper Rangitaiki Plains and along the Whirinaki River. The Otamatea series are similar to the Poronui, but are found further from the river and on large areas of the upper Rangitaiki Plains (Rijkse 1992).

Terraces and rolling hills

Thick tephra layers consisting of sands and gravelly pumiceous materials mantle the landscape, forming terraces that are above the influence of periodic flooding. Soils such as the Galatea, Kopuriki and Horomanga series are found in the Galatea Basin above the flood plains of the Rangitaiki and its tributaries. In the south, strongly leached Oruanui soils occur on and around the upper Rangitaiki Plains. In the adjacent steeper country and higher rainfall areas, Tihoi hill soils predominate. These are podzols and are more leached than the Oruanui series (Rijkse 1992 & 1995).

[1] top layer of a soil profile

Eastern Hill country

The hills to the east of the catchment have a thick mantle of tephra on the easier slopes, while in the steep hill country the tephra layers are thinner due to erosion. In places, the underlying greywacke has been exposed and thin soils have developed from the greywacke. Lower slopes are dominated by colluvial material that has accumulated from the surrounding slopes and ridges. On the valley floors, the parent materials are mostly tephric alluvium but may be intermixed with some greywacke alluvium. The hill soils are mostly Oruanui, Pukerimu and Tihoi series, while in the steeplands, soils are generally Urewera or Te Teki series. Apart from a few recent soils on floodplains, all soils in this region are strongly leached podzolised Pumice Soils or Podzols (Rijkse 1992 & 1995).

Table 2—1: Soil orders, groups and series in the study area from the New Zealand Soil Classification (NZSC).

Order	Group symbol	Group	Series	Map symbol (s)	Modifying symbols ‡	Area (ha)
Gley	GAO	Peaty Acid Gley	Pouarua	Pa		459
Podzol	ZOH	Humose Orthic Podzol	Tihoi	To	H	5232
			Te Teki	Tt	S	8216
Pumice	MIW	Welded Impeded Pumice	Kaingaroa	Kg	G, R	66138
	MOBA	Buried Allophanic Orthic Pumice	Motumoa	Mo	S	233
	MOI	Immature Orthic Pumice	Galatea	G	M, R	8715
			Horomanga	H	R	1059
			Kawhatiwhati	K		484
			Kopuriki	Kp		1040
			Matahina	M	G, H	5709
			Otanewainuku	O	S	3697
			Pekepeke	P	H	17652
			Taupo	Tp	H	6707
			Te Rere	Te		6086
	MOT	Typic Orthic Pumice	Pukemaku	Pk	S	651
	MOZ	Podzolic Orthic Pumice	Oruanui	Oi	H	13616
			Otamatea	Om	G, R	9865
			Poronui	Poi		3906
			Pukerimu	Px	H	18938
			Ruakituri	Ru	H	1177
			Urewera	U	S	42907
Raw	WF	Fluvial Raw	Rangitaiki	R	G	196
Recent	RFM	Recent Fluvial Mottled	Rangitaiki	R	M	171
	RFT	Typic Fluvial Recent	Rangitaiki	R		3896
	RTM	Mottled Tephric Recent	Horomanga	H	M	585

‡ G – gravelly soils, H – hill soils, M – mottled soils, R – rolling phase, S – steepland soils

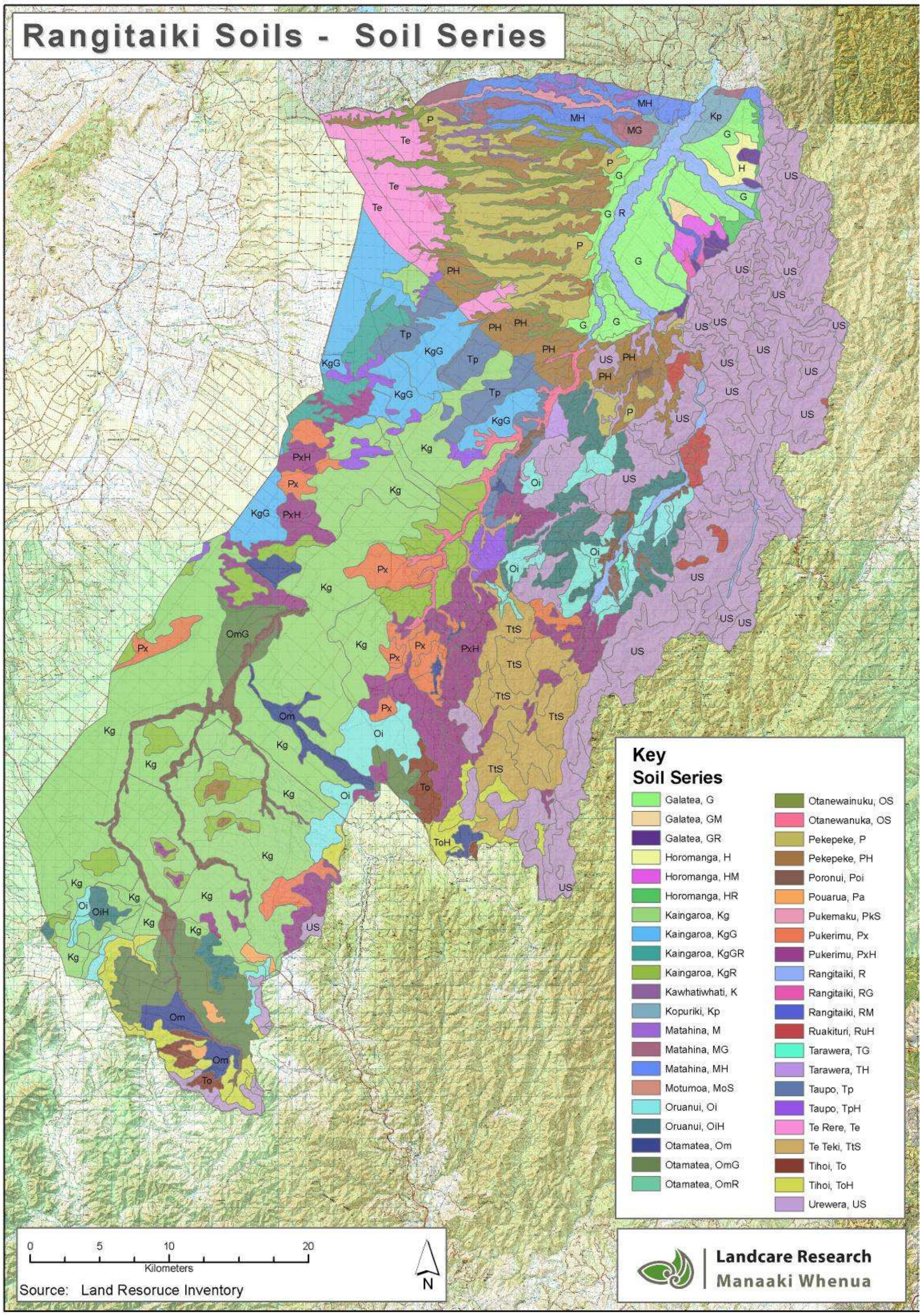

Figure 2—1: Soil series occurring in the study area. Note that the extent of some soils is too small to be visible at this scale.

2.1.4 Land-use suitability and limitations

Overview

For this report the soils of the study area have been categorised in terms of their similarities with respect to both their land use limitations and suitability. These categories are consistent with the NZSC orders, and have been grouped here by relevance to land use and limitations of soils in the study area. Figure 2—2 shows the distribution of the different soils throughout the region by suitability/limitation categories. Specifically, these soil categories are: Pumice, Pumice – Welded, Pumice – Leached, Podzol, Recent/Raw and Gley. Table 2—2 lists the by their land use limitation/suitability category (including the NZSC classification soil sub-groups represented), soil series names, main limitation/s and suitability for various land uses. These categories are discussed below with respect to their land-use limitations and suitability.

The erosion potential for soils in the upper Rangitaiki catchment have been calculated as either low, medium or high based on their land use capability classes as listed in the New Zealand Land Resource Inventory. A map of the erosion potential across the region is presented in the chapter on land cover and land use (Figure 2—9).

Pumice

Apart from a very small area of Typic Orthic Pumice (North West Kaingaroa Plateau) and Buried Allophanic Orthic Pumice (valleys of the central region), the soils of this category are all Immature Orthic Pumice. The soils on the Galatea Plains are probably the most versatile in the region, due to the topography and their physical properties. The pumice soils (Galatea and Horomanga) on the plains have moderately high profile available water (PAW) and low to medium phosphate retention, but generally have low soil carbon and cation exchange capacity (CEC). Being well to excessively well drained, these soils are subject to severe moisture deficits in times of low rainfall. There is significant potential for nitrate leaching from free-draining pumice soils with low levels of soil carbon, particularly with intensification of livestock farming, with urine patches accounting for most of the losses (Ledgard et al. 1999). Most leaching is likely to occur between autumn and spring, although irrigation may lead to increased losses during summer. The structural properties of Pumice soils means there is a low risk of bypass flow. In bypass flow, organic matter and pathogens can enter ground and surface waters from activities such as effluent irrigation

Where the soil water deficit can be addressed through irrigation, and with regular addition of fertiliser, these soils are very productive and are most suitable for high production pastoral use.

The soils to the west of the Galatea Plains are predominantly Immature Orthic Pumice and the main limitation here is susceptibility to erosion, particularly on the hill and steep land soils. These soils also have low natural nutrient status and are best suited to forestry, particularly as forest species can access nutrients in sub-soil tephra layers that are not accessible to pasture species. Steep land soils have a high risk of slip erosion if vegetation is removed and these soils are best retained for conservation purposes.

Pumice – welded

The welded Pumice soils (Kaingaroa series) are the dominant soils on the Kaingaroa Plateau. The Kaingaroa series has a compact layer of ignimbrite within the profile that may act as a root barrier and limits its usefulness for forestry unless soils are ripped; this is not a major limitation for pastoral land use. The Kaingaroa soils also tend to have low PAW and are susceptible to summer droughts. These soils require high levels of fertiliser and lime if converted to intensive pastoral use and there is a high risk of sheet, rill and gully erosion on bare ground.

The welded Pumice soils are best suited to forestry; however, they are also suitable for conversion to pasture where their high erosion potential is adequately addressed.

Pumice – leached

These soils are all Podzolic Orthic Pumice soils and their distribution is mainly in the Ikawhenua Ranges where they are hill (Pukerimu, Ruakituri) and steep land (Urewera) soils, or on and adjacent to the Upper Rangitaiki Plains (Oranui, Oranui hill, Poronui, Otamatea). The hill and steep land soils are particularly erosion prone, have low pH and nutrients, and are most suitable for forestry (on gentler slopes) or conservation land use.

The main limitation of the leached Pumice soils on the flatter land is their low pH and nutrient status, particularly with the Otamatea and Poronui series, which may be excessively well drained. Drought is also a major limitation for pastoral land uses. The leached pumice soils of the flat to rolling land are suitable for pastoral uses and to a lesser extent arable cropping. Care must be taken when cultivating these soils to prevent sheet erosion, and the cool climate of the upper Rangitaiki Plains limits the seasonal growth period. Because these soils have moderate to high erosion potential, there is also potential for phosphate loss with intensifying pastoral land use. Phosphate moves with sediments rather than via leaching, and if buffer zones are not maintained around riparian margins, high sediment loads can enter waterways. With intensifying pastoral use there is also significant potential for nitrate leaching into ground waters and ultimately into surface waters.

Podzols

While the main limitation of Podzols generally is their low nutrient status and low pH due to extreme leaching, in the Rangitaiki catchment erosion is the major limitation to land use. All Podzols in the region occur in hill country and steep lands (Figure 2—2), and due to the pumice parent materials these soils are highly erodible.

The steep land Podzols of the Ikawhenua Ranges belong to the Te Teki series, while the Tihoi series are Podzols that occur on the hill country to the south and east of the upper Rangitaiki Plains.

Raw/recent

All the soils categorised as Raw/Recent are distributed along the floodplains of the Rangitaiki and its tributaries. The Rangitaiki soil series occurring along the lower floodplains tend to have higher nutrient status but less PAW than the soils of the surrounding terraces. They are prone to flooding, and if unprotected are also prone to stream bank erosion. The Horomanga series include some recent soils and these are limited by their excessive drainage characteristics. Raw/Recent soils in the region are suitable for pastoral land use apart from isolated areas particularly susceptible to flooding and erosion where riparian planting would be the most suitable land use.

Gley soils

The Pouarua series (Peaty Acid Gley) are the only Gley Soils mapped in the study area. These soils are limited by their poor drainage and low natural nutrient status. This category represents a very small area of poorly drained soils found in depressions on the upper Rangitaiki Plains.

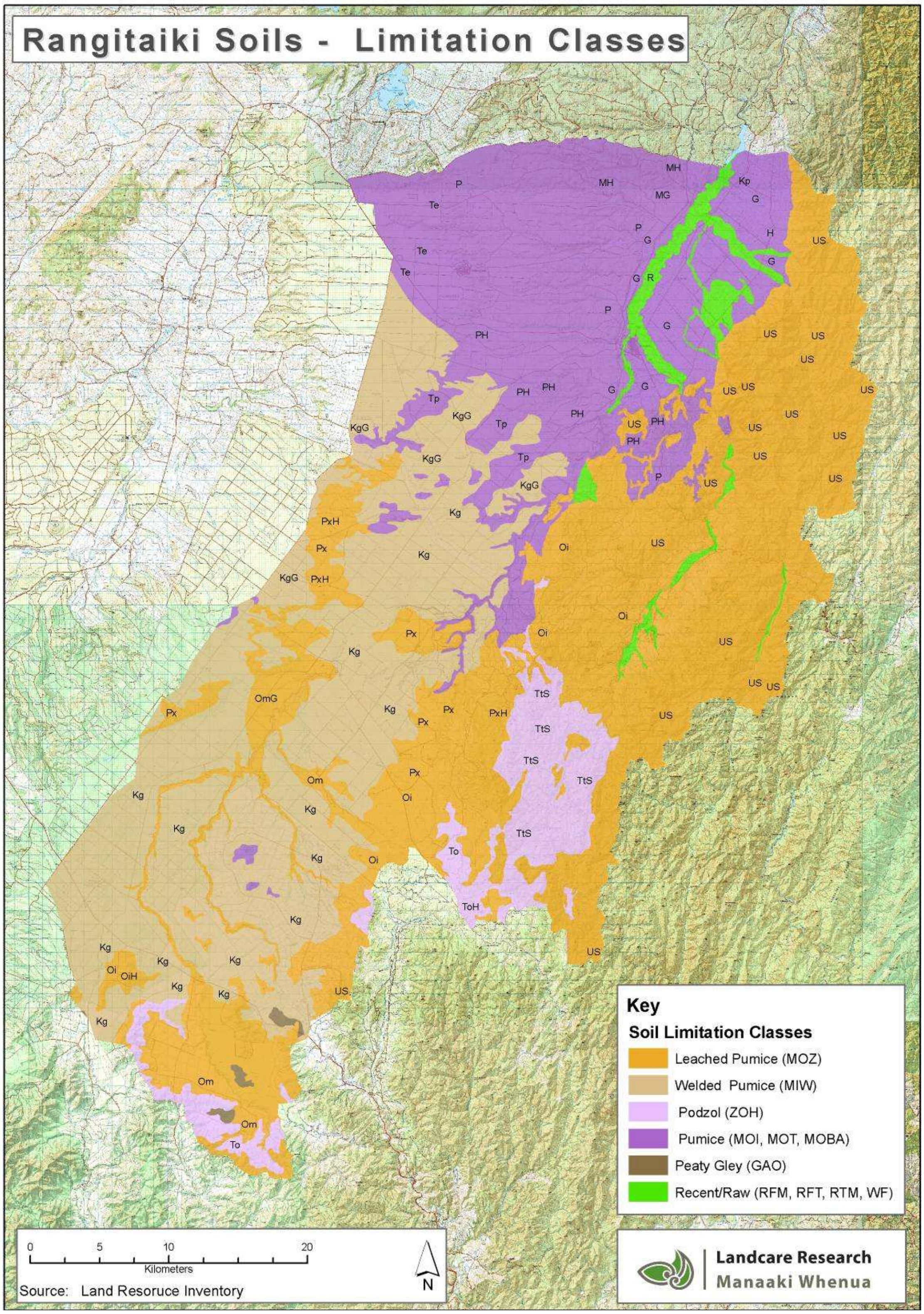

Figure 2—2: Soils occurring in the study area categorised by limitation class.

Table 2—2: Land use limitations and suitability of soils in the study area (same order as in Table 2—1).

Land use limitation/suitability category	Series	Main limitations	Land use suitability			
			Arable	Forestry	Horticulture	Pastoral
Gley (GAO)	Pouarua	Drainage	Low	Low	Low	Medium
Podzol (ZOH)	Te Teki	Slip erosion	Low	Medium	Low	Low
	Tihoi		Low	Medium	Low	Low
Pumice – welded (MIW)	Kaingaroa	Root penetration, sheet, rill and gully erosion	Low	Medium	Low	Medium
Pumice (MOBA, MOI, MOT)	Motumoa	Gully erosion	Low	Medium	Low	Low
	Galatea	Drought	Medium	Medium	Low	High
	Horomanga	Drought	Medium	Medium	Low	High
	Kawhatiwhati	Erosion	Low	Medium	Low	Low
	Kopuriki	Drought	Medium	Medium	Low	High
	Matahina	Drought, moderate erosion	Medium	High	Low	High
	Otanewainuku	Slip and sheet erosion	Low	Low	Low	Low
	Pekepeke	Erosion	Low	Medium	Low	Low
	Taupo	Drought, sheet and gully erosion	Medium	High	Low	Medium
	Te Rere	Nutrient	Low	High	Low	Medium
	Pukemaku	Slip erosion	Low	Medium	Low	Low
Pumice – leached (MOZ)	Oruanui	Moderate nutrient, drought and erosion	Medium	Medium	Low	Medium
	Otamatea	Sheet, rill and gully erosion, drought, nutrient	Low	Medium	Low	Medium
	Poronui	Drought, gully and stream bank erosion	Low	Medium	Low	Medium
	Pukerimu	Gully, sheet and rill erosion	Low	Medium	Low	Low
	Ruakituri	Slip erosion	Low	Medium	Low	Medium
	Urewera	Slip erosion	Low	Low	Low	Low
Raw/Recent (RFM, RFT, RTM, WF)	Horomanga	Flooding, moderate stream bank erosion, drainage	Medium	Low	Low	High
	Rangitaiki	Flooding, moderate stream bank erosion	Medium	Low	Low	High

2.2 Land use and land cover

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Information regarding land cover and land-use for the study area comes from two data sources: the New Zealand Land Cover Database (LCDB) (Thompson et al. 2003) and the Protected Areas Network (PAN-NZ) Database (Rutledge et al. 2008). The LCDB mapped 41 different classes of land cover from two time periods only: 1996/1997 and 2001/2002. The Ministry for the Environment (MfE) is currently scoping potential development of LCDB Version 3.

The PAN-NZ database is a database maintained by Landcare Research. It includes the locations of legally protected areas including Crown conservation estate managed by DOC, private covenants (Queen Elizabeth II National Trust, Nga Whenua Rahui), and regional parks. The database currently lacks the location of district and city council parks and reserves.

New Zealand lacks an official land-use database (Rutledge et al. in press). Therefore we developed a modified, 7-category land-use classification from a combination of information from the LCDB and the PAN-NZ databases (Table 2—3). Analogous to the process following for land cover, land-use information came from 2 different time periods: land cover from 1996/1997 and 2001/2002. The PAN-NZ database provided information on conservation areas from 2008 only. Currently there is no readily available database regarding historical changes to legally protected areas. The land use classification included two land cover classes (Unprotected Exotic Cover, Unprotected Native Cover) where we could not to infer a particular land use. The Ministry for the Environment is currently developing land use information as part of the Land Use and Carbon Analysis System (LUCAS) project[2]. The main purpose of LUCAS is to map changes in New Zealand's carbon stocks to comply with accounting and reporting requirements under the Kyoto Protocol.

The land cover/land-use change analysis was performed by overlaying all input land cover and land use data layers in a geographic information system (GIS) using a purpose-built, in-house combinatorial analysis programme. The programme identified all unique combinations of input data layers and stores the information in an associated database and spatial data (i.e., GIS) layer. The database and spatial data layer provided the basis for the summary information and maps of land cover and land presented in this chapter.

[2] http://www.mfe.govt.nz/issues/climate/lucas/

2.2.1 Land cover

Land cover in the study area comprised predominately exotic plantation forests (*Pinus radiata*) along the Kaingaroa plateau in the west, pastoral grasslands in the north central and southwest, and indigenous forest in the east, primarily associated with the large block of Conservation estate within Urewera National Park and Whirinaki Forest Park (Table 2—4). The Galatea Plains contain a scattering of other land covers including croplands and urban areas, primarily Murupara (Figure 2—3, Figure 2—4).

The predominant type of land-cover change observed during the period 1996/1997 to 2000/2001 resulted from forestry practices, including harvesting, replanting, and regrowth (Figure 2—5, Table 2—4).

2.2.2 Land use

Most of the developed land in the catchment is in exotic forestry plantation on the Kaingaroa Plateau in the west. Pastoral farming dominates in the Galatea Plains and near Rangitaiki at the base of the Ahimanawa Range, where there is also some arable land use. Conservation lands cover much of the eastern portion of the study area. There are also substantial amounts of unprotected native cover (Figure 2—6, Figure 2—7, Table 2—3).

From 1996/1997 to 2001/2002 net land-use change comprised less than 0.01% of the study area (Figure 2—8). Some of the small changes recorded may have resulted from inaccuracies in the underlying databases rather the representing real changes. Forestry showed the largest net change, losing 30 hectares.

More recent land-use trends in the study area were assessed using the Agribase database from Agriquality. Agribase provided primary farm type (e.g., dairy, sheep and beef) for many farm enterprises within the study area. A 2007–2008 version of Agribase did not show any major changes in land use from those depicted in 2001–2002 (Figure 2—7). Lands on the Galatea Plains remained almost entirely pastoral, primarily dairy farming but including some beef, deer, and grazing for others. The area around Rangitaiki also remained in pastoral uses, including sheep and beef, dry stock dairy, and dairy. Forestry continued to dominate the Kaingaroa Plateau.

2.2.3 Potential impacts of future land-use change and management

The main impacts to soil and water resources in the study area would primarily result from the following changes in land use and management practices:

1. poor forestry management practices;

2. conversion of forestry to non-forestry uses;

3. intensification of pastoral areas.

In general, limited environmental impact occurs under land use for forestry. Care must be still be taken to manage risks properly, especially during harvesting and re-planting, as there is significant potential for severe erosion in exposed and unprotected soils. While areas of accelerated erosion in the catchment are relatively minor, Figure 2—9 shows a high potential for erosion over much of the study area if soils are not managed carefully. The Pumice soils of the region are particularly prone to fluvial erosion such as rill (generally cultivated land), gully (unprotected disturbed sites such as roads and tracks on steeper contours and associated culverts and drains), and stream bank (where riparian margins are unprotected and/or grazed). There is also significant potential for sheet erosion (wind and water) from bare soil surfaces when land is disturbed, therefore appropriate measures should be taken to minimise exposure of bare surfaces such as planting temporary cover.

Conversion of forestry to pastoral or arable farming in some areas could create significant potential for soil loss through erosion particularly if soils are cultivated (Figure 2—9). Soils of the Ikawhenua Ranges under indigenous vegetation are unlikely to be converted to other land uses. Many of those soils occur in steep hill country and are strongly leached and would not be suitable for any other land use Table 2—2). Soils in the Ikawhenua Ranges under forestry land use are also largely on steep hill country. Some areas may be more suitable for restoration to indigenous vegetation, while most of these soils would not be suitable for conversion to pastoral land use due to the high risk of erosion (Figure 2—9).

Intensified pastoral farming could increase nutrient loss to waterways and groundwater in the region. On the Galatea Plains, where dairy farming is the predominant land use, there is an added risk of nutrient loss if soils are irrigated. The additional costs of irrigating also generally necessitate land-use intensification to utilise the extra production potential. Although stream and river banks in the region are easily eroded when vegetation is removed or animals are allowed access to waterways, erosion issues are largely mitigated where natural vegetation is allowed to remain. There is also potential for sheet erosion (wind and water) from areas where heavy stocks concentrate and create tracks.

The young volcanic soils of the region, some of which are excessively drained, often have soil water deficits in low rainfall periods. These soils generally have low natural fertility, but they do have favourable physical properties and generally respond well to fertiliser application. However, Pumice soils have significant potential for nitrogen leaching and, where surface erosion occurs, for phosphate loss as well.

Table 2—3: Land use and land-use change in the study area from 1996/1997 to 2000/2001.

Land use	Area (hectares)		
	1996/1997	2001/2002	Net gain/loss
Arable	1471	1471	-
Conservation*	65 515	65 515	-
Forestry	118 621	118 878	-30
Horticulture	12	12	-
Pastoral	37 601	37 607	7
Unprotected Exotic Cover	679	689	10
Unprotected Native Cover	69 750	69 761	11
Urban	1053	1055	2

*Conservation was defined by legally protected areas in the PAN-NZ database from a single time period (2008). Therefore no change was possible.

Table 2—4: Land cover and land cover change in the study area from 1996/1997 to 2000/2001.

Land cover	Area (hectares)		
	1996/1997	2001/2002	Net gain/loss
Afforestation (imaged, post LCBD1)		46	46
Broadleaved Indigenous Forest	3030	3030	-
Built-up Area	239	239	-
Deciduous Forest	287	287	-
Forest - Harvested	18959	24073	5114
Gorse and/or Broom	282	293	11
Grey Scrub	7	7	-
Herbaceous Freshwater Vegetation	539	539	-
High Producing Exotic Grasslands	34317	34277	–40
Indigenous Forest	60303	60303	-
Lake and Pond	212	212	-
Landslide	17	17	-
Low Producing Exotic Grasslands	3284	3330	47
Major Shelterbelts	827	827	-
Manuka and/or Kanuka	5410	5421	11
Matagouri	4	4	-
Mixed Exotic Shrubland	102	102	-
Orchard and Other Perennial Crops	12	12	-
Other Exotic Forest	2579	2809	230
Pine Forest – Closed Canopy	77492	56619	–20873
Pine Forest – Open Canopy	18765	34218	15453
River	177	177	-
River and Lakeshore Gravel and Rock	58	58	-
Short-rotation Cropland	1471	1471	-
Surface Mine	38	38	-
Transport Infrastructure	721	724	3
Urban Parkland / Open Space	55	55	-

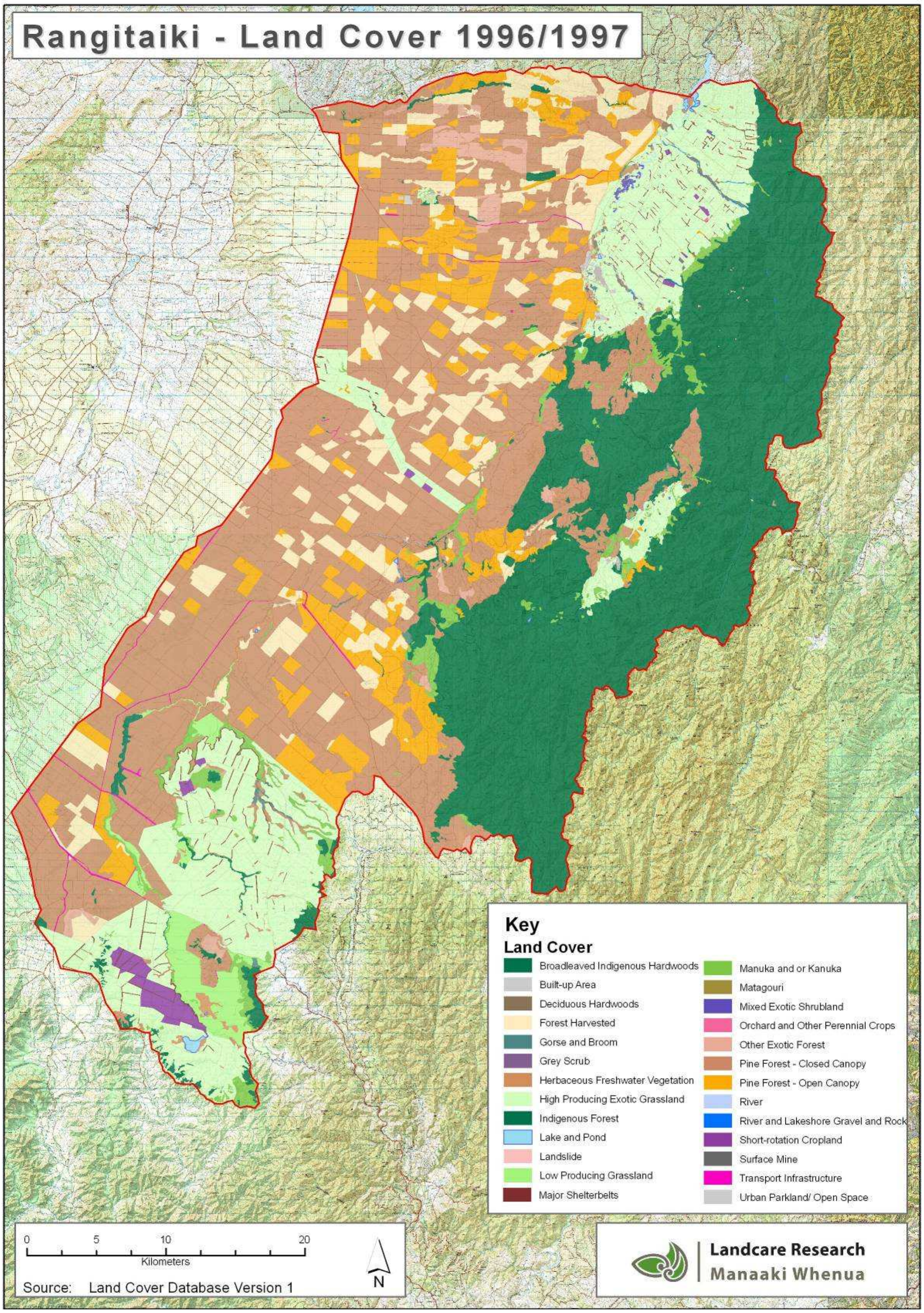

Figure 2—3: Land cover in the study area as at 1996/1997.

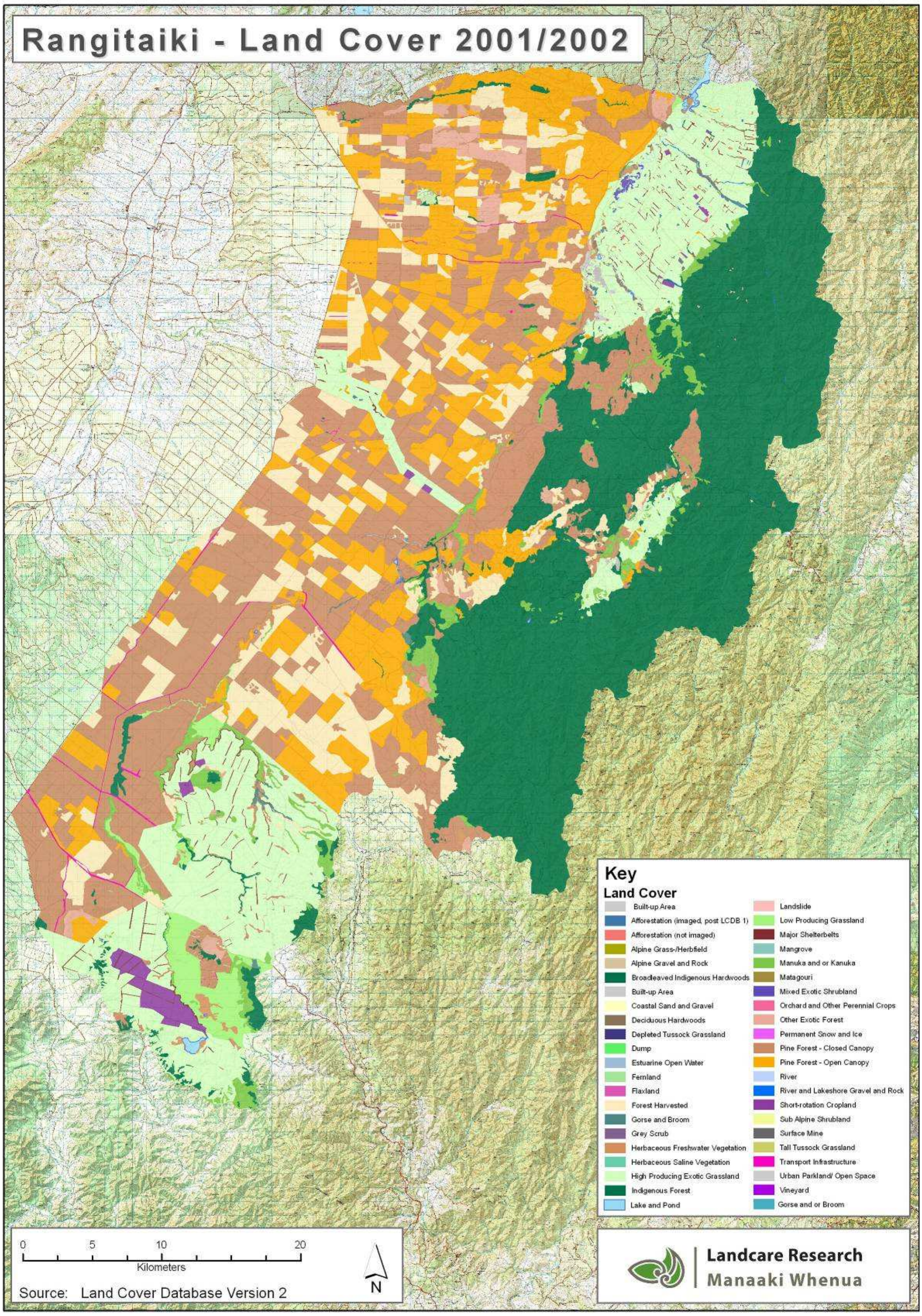

Figure 2—4: Land cover in the study area as at 2001/2002.

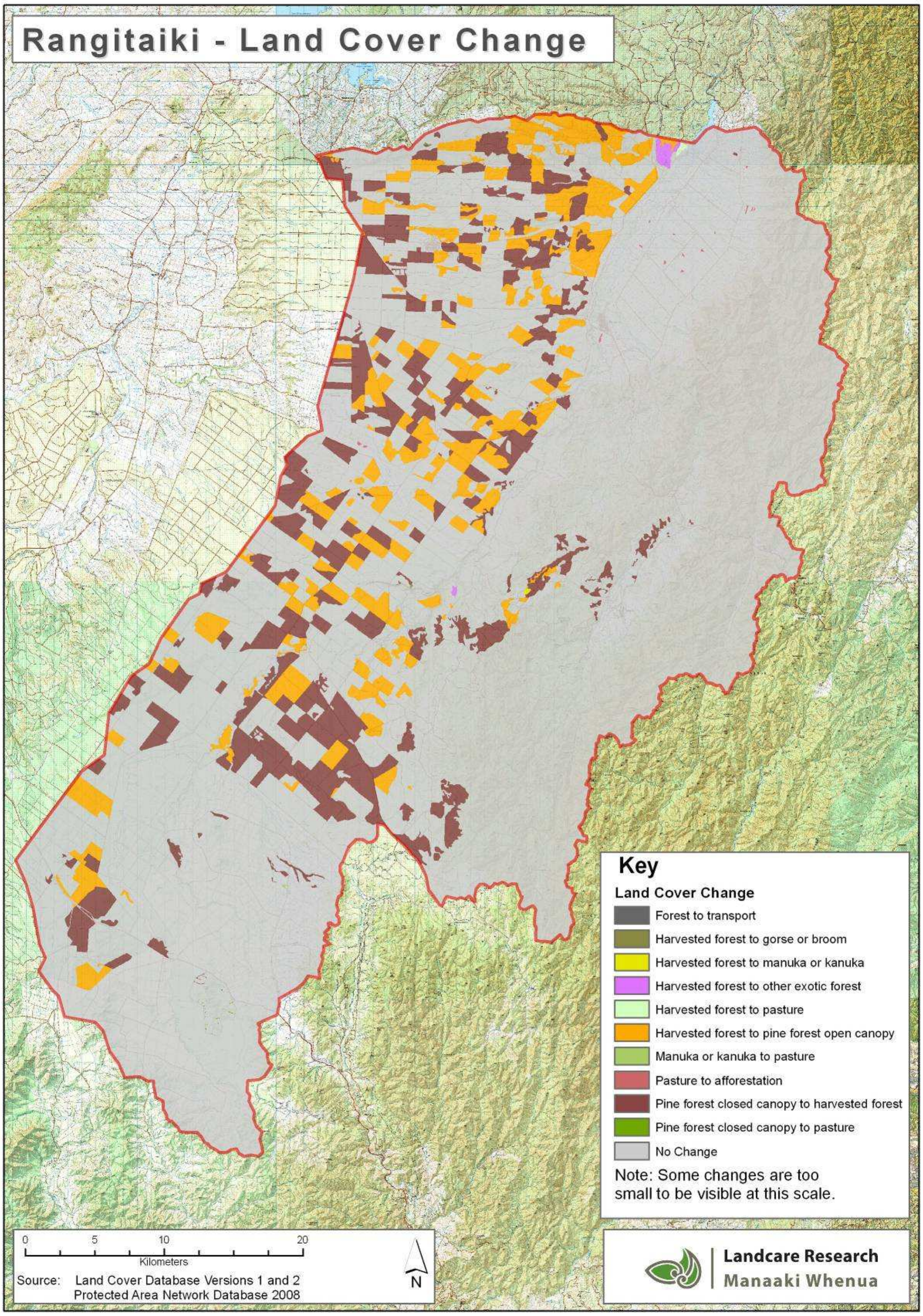

Figure 2—5: Land cover change in the study area from 1996/1997 to 2001/2002.

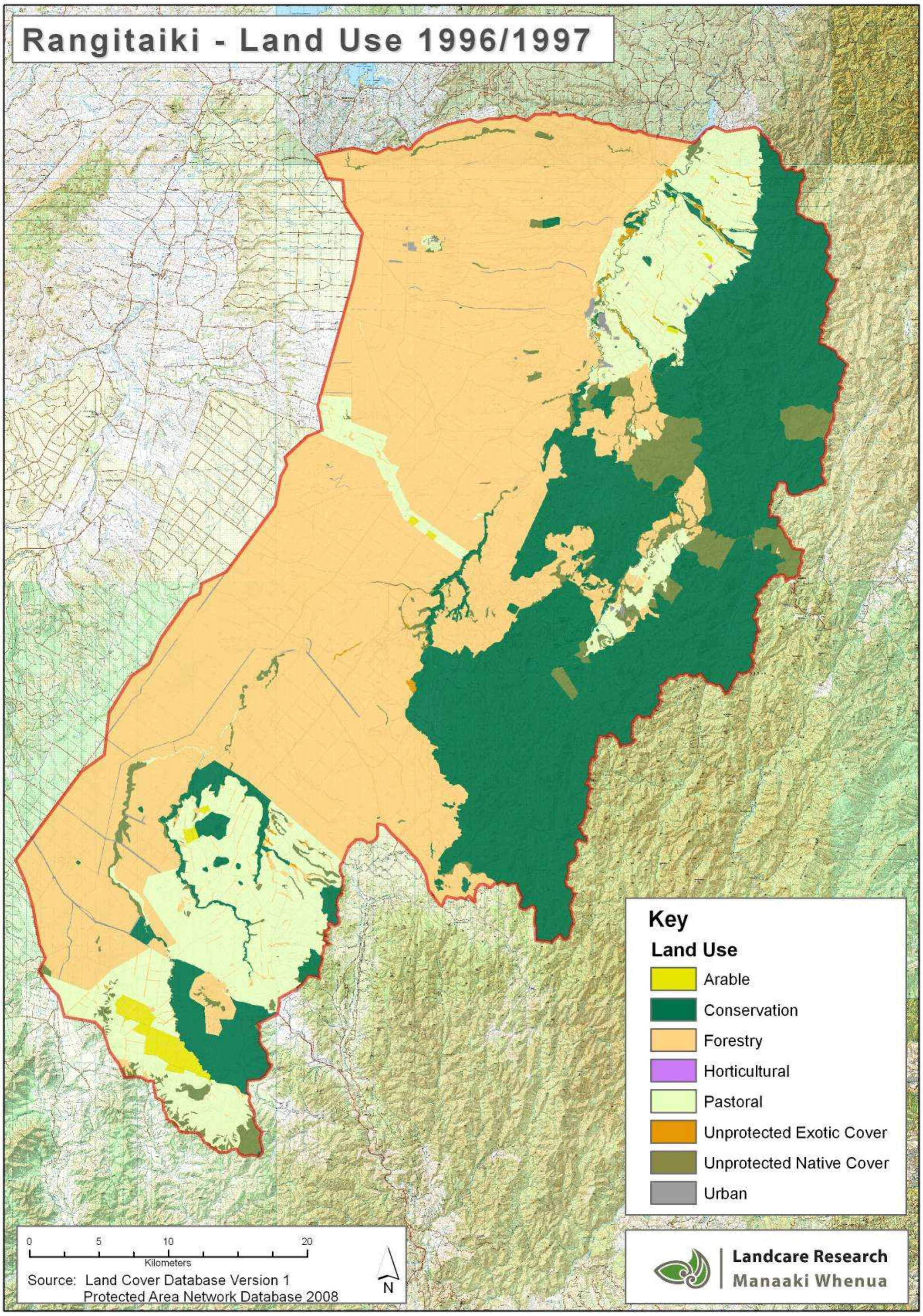

Figure 2—6: Land use in the study area as at 1996/1997.

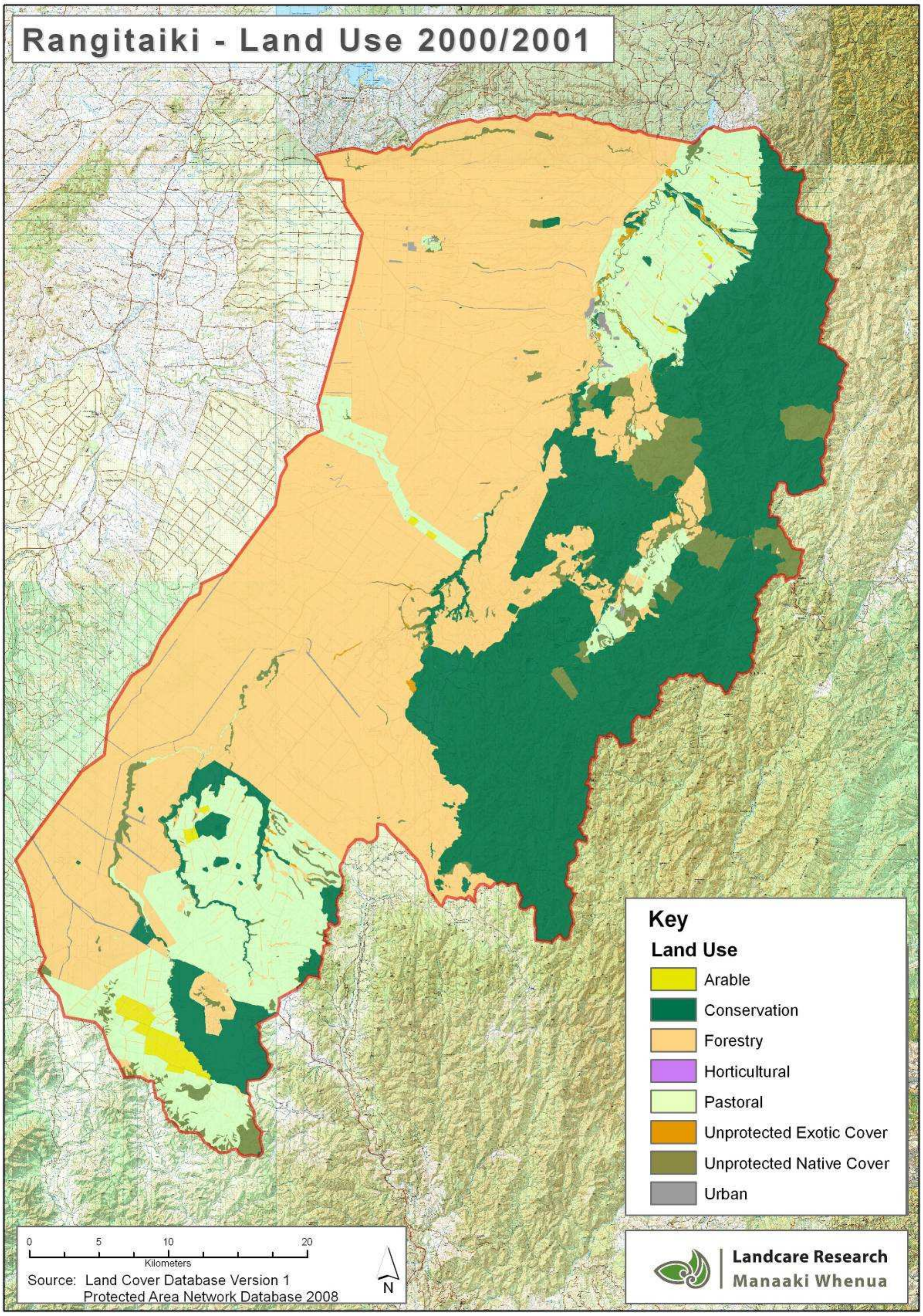

Figure 2—7: Land use in the study area as at 2001/2002.

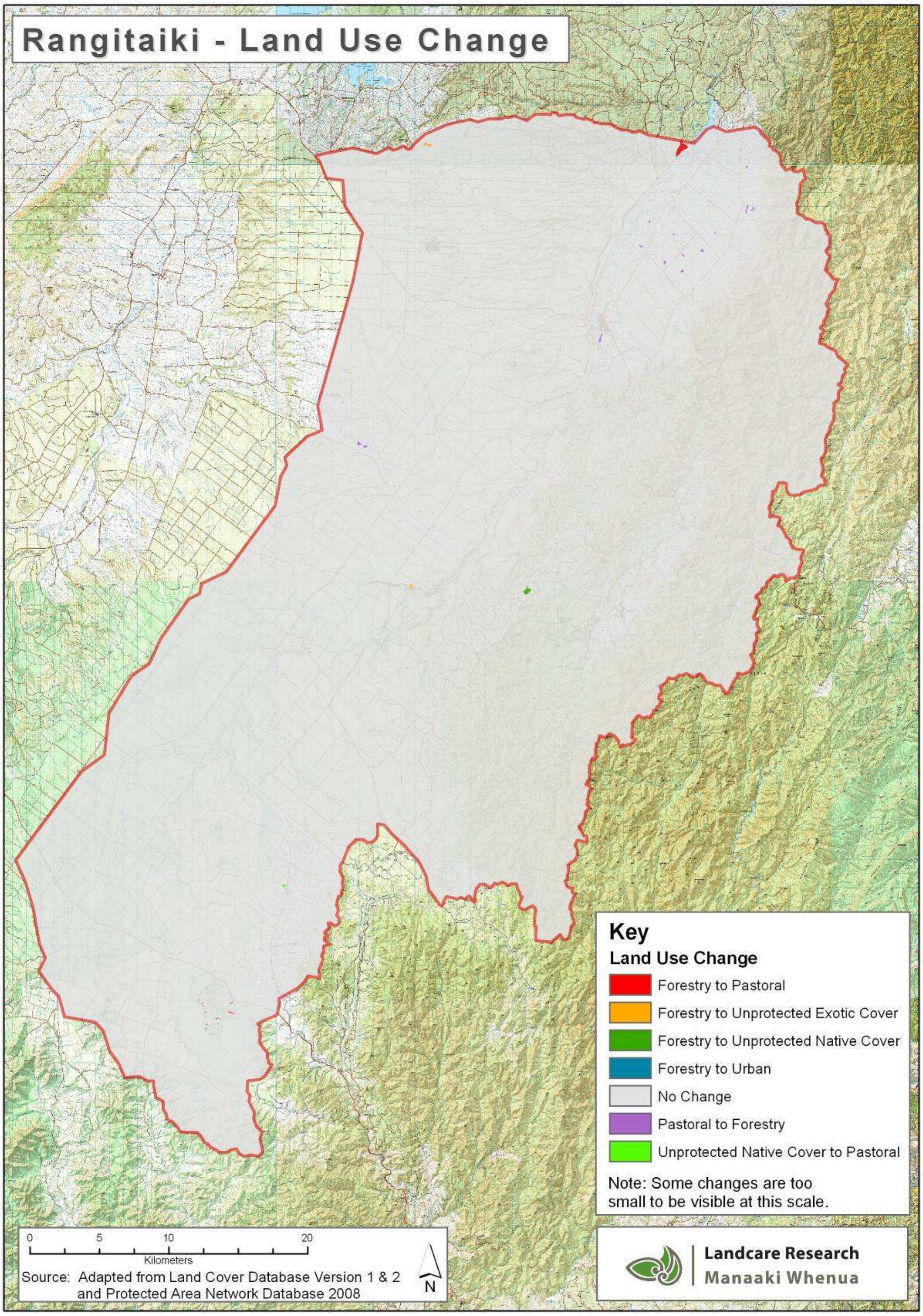

Figure 2—8: Land use change in the study area from 1996/1997 to 2001/2002.

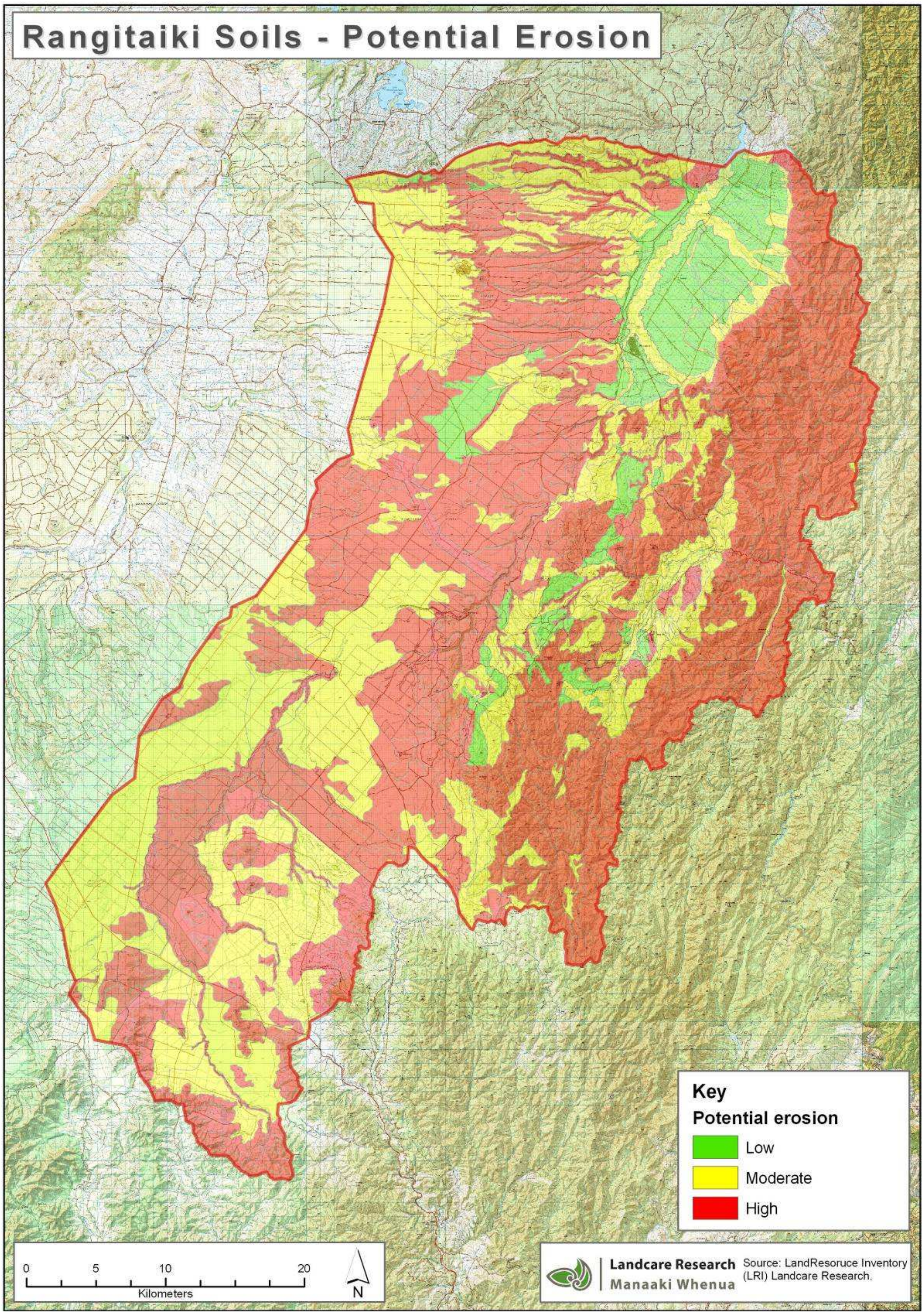

Figure 2—9: Soil erosion potential in the study area.

2.3 Terrestrial biodiversity

Mark Smale and Daniel Rutledge, Landcare Research, Hamilton

2.3.1 Vegetation

Historic vegetation

The study area falls neatly into three broad biogeographic zones that reflect major differences in geology, soils, and climate:

- the extensive, rolling Kaingaroa Plateau in the west;
- the much smaller Galatea Basin in the centre north; and
- the Urewera steeplands in the east.

After human settlement, they had very different vegetation histories. Native forest had re-established over most of the Kaingaroa Plateau since the last Taupo volcanic eruption (c. AD 200) by the time of Māori settlement. By 1840, the Kaingaroa Plateau, the Galatea Basin and the lower Whirinaki River valley were essentially deforested as a result of a long fire history (Henry 1955; Nicholls 1985). Those areas supported a mosaic of low-growing shrubland dominated by manuka, tutu, and monoa (‘Leptospermum scrub or fern’, ‘Grassland and Dracophyllum’: Figure 2—10), fernland (bracken/aruhe) (‘Leptospermum scrub or fern’: Figure 2—10), and tussock grassland communities (silver tussock/wi) (‘Grassland and Dracophyllum’, ‘Short tussock grassland’: Figure 2—10) of various ages on various sites (Ure 1950). Shrubland on warmer sites with cold air drainage were dominated by manuka and tutu, and on colder sites with cold air ponding (‘frost flats’) by Monoao. Recently burnt warmer sites carried bracken/aruhe, and recently burnt colder sites supported silver tussock/wi. Rare fragments of native forest survived in places like the upper Oruatewehi valley (Troutbeck’s Bush) (Nicholls 1986) and Motukuri Bush (Shaw & Nicholls 1986) in Kaingaroa, where they were protected from fire.

The eastern portion of the district was mostly forested in 1840. Parts of the rolling plateau of Whirinaki Forest and some river terraces in the Urewera supported very tall forest of rimu, miro, matai, totara, and kahikatea, with matai and totara dominant in the colder basins (‘Podocarp forest’: Figure 2—10). Much larger areas supported tall tawa forest with scattered emergent rimu and matai, and a variety of other broadleaved trees like hinau, rewarewa, and maires (Nicholls 1969a) (‘Lowland podocarp-broadleaved forest (and scrub)’: Figure 2—10).

Fires from the Galatea Basin had regularly swept up the western margin of the Urewera steeplands (the Ikawhenua Range), producing a mosaic of regenerating shrubland (‘Mixed indigenous scrub’: Figure 2—10) and forest communities of various ages. Kanuka and fivefinger/whauwhau dominated more recently burnt short forest communities on drier sites; kamahi/tawhero and rewarewa dominated on damper sites. Lower-elevation forests were dominated by tall tawa and kamahi/tawhero, with scattered emergent rimu and northern rata except where crown fires had killed them (‘Lowland podocarp-broadleaved forest (and scrub)’: Figure 2—10). The mid-elevation forests were dominated by mixtures of tall red beech/tawhairaunui, tawa, and tawari with scattered emergent rimu (‘Lowland podocarp-broadleaved-beech forest (and scrub)’: Figure 2—10). Forests at higher elevations were dominated by red beech/tawhairaunui, with plentiful kamahi/tawhero and tawari and scattered rimu and miro (‘Lowland podocarp-broadleaved-beech forest (and scrub)’: Figure 2—10). At the highest elevations, as on the summits of the Ikawhenua Range, Hall’s totara replaced rimu as the conifer accompanying shorter red beech/tawhairaunui, with plentiful kamahi/tawhero, tawari, and tawheowheo (Nicholls 1969a & 1969b) (‘Beech forest’: Figure 2—10).

Small areas of wetlands were scattered throughout the study area around the Rangitaiki River and its tributaries. A few substantial wetlands used to occur on the southern Kaingaroa Plateau, particularly in the headwaters of the Otamatea River near the junction of State Highway 5 and Matea Road.

Current vegetation

The three geographic zones have also had very different recent vegetation histories.

In the 1920s and 1930s, after early attempts at farming failed because of cobalt deficiency, known as ‘bush sickness’ (Aston 1924), vast areas of shrubland, fernland, and tussock grassland on the Kaingaroa Plateau were planted in exotic conifers, mostly radiata pine (‘Exotic forest’, ‘Exotic forest and scrub’: Figure 2—10). Since the 1960s, pasture has been developed including draining some significant wetlands towards the southern end of the plateau (‘Improved pasture’, ‘Unimproved pasture’: Figure 2—10). Only fragments comprising in total some 2% of the area of the earlier open vegetation remain (Nicholls 1990), mostly in places like road verges and riparian margins. Notable exceptions include the frost flat reserves – Otangimoana (Clarkson 1984) and Waimarama (Smale & Shaw 1988) in the south (‘Grassland and

Dracophyllum', 'Short tussock grassland': Figure 2—10), and Otupaka (Nicholls & Smale 1991; Nicholls 1994) and Waione (Cameron 1988) in the east, and scattered wetlands like Whirinaki Bog (Beadel 1999) (the larger ones are south of the study area).

Although some of the native biodiversity of the short, open communities that existed before re-afforestation has been greatly reduced, the new forest environment has seen a huge expansion of many other native species, both plants and animals, into the understoreys of older compartments. In the south at Iwitahi the "orchid reserve," a stand of old-growth Corsican pine that provides habitat for a remarkable array of orchids (Irwin 2003). This is a good example of plant species benefiting from re-afforestation of the plateau. The New Zealand falcon/karearea is an example of an animal species that has also benefited (Seaton et al. 2009). The cyclical nature of plantation forestry, however, means that many species must migrate continually around the landscape as older compartments are clearfelled and then replanted. More recently, some areas of exotic plantation have been converted to high-producing pasture for dairying, almost totally negating the gains for native biodiversity produced by re-afforestation.

The Galatea basin was not re-afforested, but rather successfully converted to high-quality pasture for dairying (Figure 2—10).

Although the vast bulk of native forest in the eastern part of the Ngati Manawa rohe remains, two factors have led to changes. The first and less important is timber extraction, which began at Whirinaki in the 1930s and continued until 1984. Some partially cutover forest was subsequently cleared and re-afforested in exotic plantation, but larger areas have been left to recover. The second and more important factor affecting vegetation and biodiversity in the long term was the introduction of a range of mammal species (King 2006), beginning in the early 1800s with pigs, and comprising herbivores like red deer (consuming plants), carnivores such as ship rats (consuming animals), or omnivores such as possums (consuming both). Mammal populations have spread throughout the area in the past 200 years and have had major impacts on many species of plants and animals. For example, in recent decades browsing possums have killed much northern rata, long a feature of parts of the Urewera region, while Hall's totara is now succumbing to possum herbivory. Populations of palatable plants in forest understoreys continue to be decimated by deer (Allen et al. 1984). Even relatively unpalatable species such as tawa, an important canopy tree in these forests, now appear to be under threat (Smale 2008). As elsewhere, bird populations continue to decline due to predation from ship rats, mustelids, and possums.

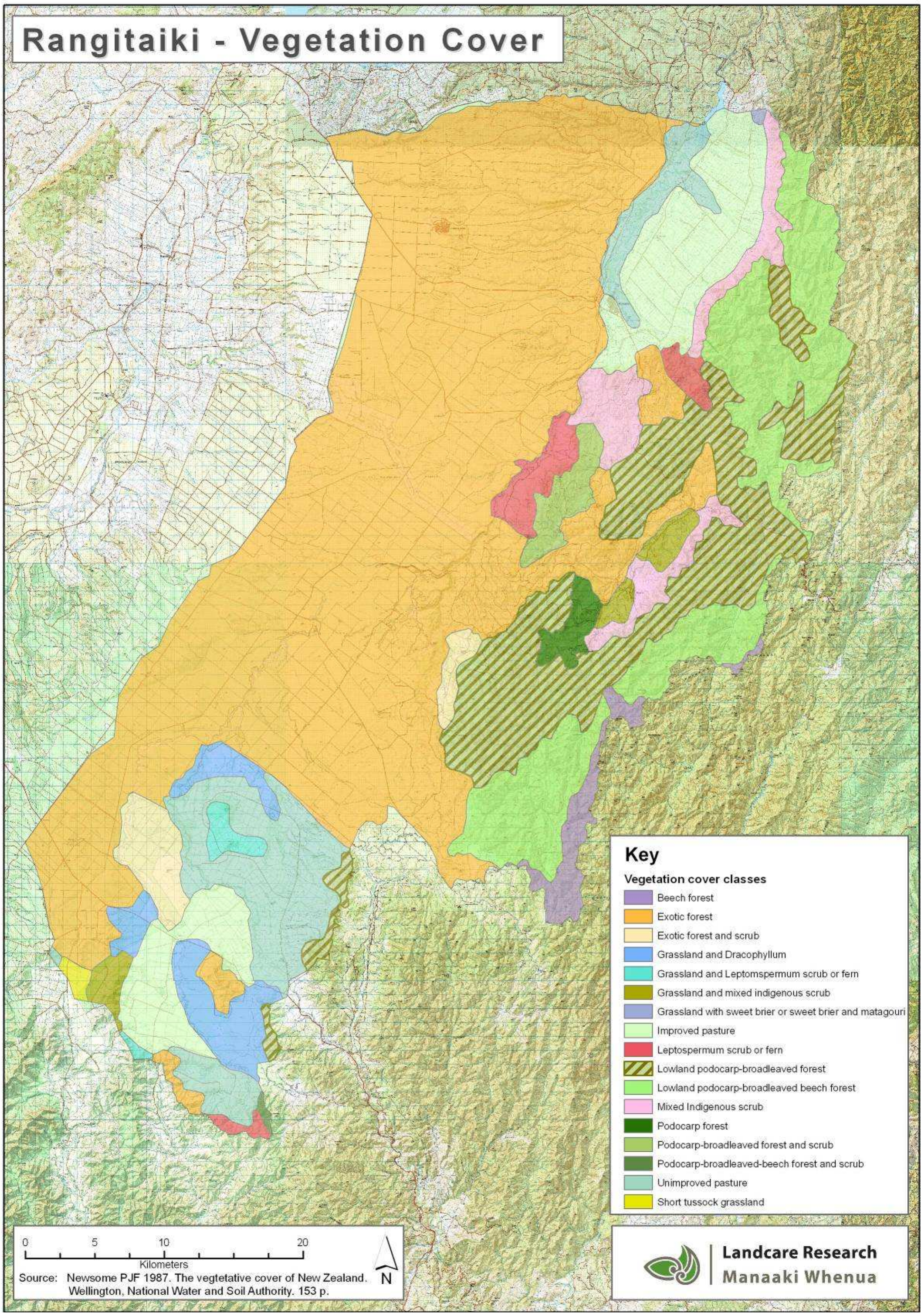

Figure 2—10: Vegetation cover classes in the study area circa 1987 (after Newsome 1987).

2.3.2 Land environments

Land environments of New Zealand (LENZ) classifies New Zealand into areas with similar environmental character based on shared characteristics of climate, landform, and soils (Leathwick et al. 2003a & 2003b). LENZ is a hierarchical system that classifies New Zealand into four levels:

- Level I – 20 environments.
- Level II – 100 environments.
- Level III – 200 environments.
- Level IV – 500 environments.

Climatic differences account for most of the variation in LENZ environments at higher levels. Differences in landform and soils, combined with more subtle variations in climate including the balance between rainfall and moisture deficit, subdivide land environments at lower levels, e.g., Levels III and IV. LENZ relies heavily on soil information derived from the Land Resource Inventory and the related New Zealand Soil Classification. Hence the descriptions below reflect discussions provided earlier for soil resources of the study area. LENZ is used widely for biodiversity conservation and planning, and underpins the national guidelines for protection of native biodiversity on private land.

The study area contains seven Level I land environments that are further divided into 22 Level IV land environments (Figure 2—11, Table 2—5). A brief description of each of the seven Level I land environments in the study area follows. More detail on the Level III and IV land environments can be found in the LENZ Technical Guide, available online[3] from the Ministry for the Environment or Landcare Research.

Western and southern North Island lowlands (Environment C)

This land environment consists mainly of low-lying areas predominately in the lower half of the North Island. Within the study area, it occurs along the Rangitaiki River in the north central portion of the watershed, represented by two Level IV environments (C1.2b, C1.2c).

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[3] http://www.landcareresearch.co.nz/databases/LENZ/downloads/LENZ_Technical_Guide.pdf

The climate is mild and sunny, with rainfall distributed evenly throughout the year. Soil parent material in the study area consists of water-sorted tephra, leading to soils with poor or impeded drainage and moderate natural fertility.

Northern hill country (Environment D)

This land environment encompasses the low- to moderate-elevation hill country of the upper North Island. It is represented in the study area by a single occurrence of one Level IV environment (D4.1b) occurring along the Wheao River just upstream from its confluence with the Mangamingi Stream.

The climate is mild and sunny. Annual variation in rainfall can lead to slight water balance deficits and occasional dry spells. Terrain is hilly with moderate to steep slopes. Soil parent material varies, with older volcanic material being most common in the study area, producing soils that are well drained and of low to moderate natural fertility.

Central dry foothills (Environment E)

This land environment occurs in mid-elevation dry foothills and basin floors of the eastern North and South islands. The majority of this environment occurs on the South Island in Marlborough, Nelson, and Canterbury. On the North Island it is represented mostly in western Hawke’s Bay. Environment E1.1d found in the study area is one of the northern-most examples on the North Island and comprises a very small area in the north central study area, approximately 5 km northwest of Galatea.

These environments have a somewhat cooler and sunny climate on average, tending towards drier conditions. Soils in the study area of this environment are volcanic in origin, well drained and of moderate natural fertility.

Central hill country and Volcanic Plateau (Environment F)

This land environment occurs throughout the central North Island, extending from the Coromandel Peninsula in the north to the coastal hills of Hawke’s Bay, Manawatu and Wellington. It is also found along the coastal hills of Nelson, Marlborough, and the Banks Peninsula. This environment encompasses 86% of the study, including the majority of the Kaingaroa Plateau and Ikawhenua and Animanawa ranges, and is divided into ten Level IV environments (F6.1a, F6.1c, F6.1d, F6.1e, F6.2a, F7.1a, F71.b, F7.1c, F7.2b, F7.3b).

The climate is mild, with comparatively high levels of solar radiation. Soil parent materials vary widely but are dominated by volcanic tephras in the study area, and the resulting soils are generally well drained, with low natural fertility.

Northern recent soils (Environment G)

This land environment occurs in narrow alluvial floodplains throughout the northern two-thirds of the North Island. It is represented in the study area by a single Level IV environment (G3.3a) occurring in two large patches: along the Rangitaiki River in the Galatea Plains just north of the Aniwhenua Dam and along the Whirinaki River from Te Whaiti to south of Minginui.

The climate is warm with high annual solar radiation and low average water deficits but is prone to periods of drought. The terrain is typically flat to rolling, and soils are derived from fine-textured alluvium with low natural fertility.

Central sandy recent soils (Environment H)

This environment includes areas of recent soils derived from sandy materials primarily along flat to gently rolling river floodplains. On the North Island, this environment is associated with the Taranaki ringplain and areas affected by the Tarawera eruption. In the study area, four Level IV environments (H1.2a, H2.1a, H2.1c, H2.2a) occur and are co-located with Environment G along the Rangitaiki and Whirinaki rivers.

The climate is comparatively mild, sunny, and moist. Parent materials are generally sandy but can vary widely depending upon the actual source material. Environment H1.2a derived from water-sorted pumice, resulting in recent well-drained, alluvial soils of low fertility. Environments H2.1a and H2.1c include recent, imperfectly drained soils derived from mud and mixed alluvium.

Central mountains (Environment P)

This environment encompasses the high-elevation central mountain ranges of both the north and south islands. It is represented in the study area by three Level 4 environments (P71.a, P7.1b, P7.1c) that include all the high-elevation areas of the Ikawhenua and Animanawa ranges. After Environment F, this is the second most extensive environment in the study area.

The climate reflects the higher elevations and is therefore cold and relatively wet with high annual solar radiation. Terrain is mountainous and steep, with well-drained, soils of naturally low fertility derived from rhyolitic and andesitic tephras.

Table 2—5: Area of land environments in the study area.

Land environment	Area (hectares)	Area (% of total)
C1.2b	137	0.1
C1.2c	1203	0.5
D4.1b	6	<0.1
E1.1d	2	<0.1
F6.1a	274	0.1
F6.1c	4563	2.0
F6.1d	2	<0.1
F6.1e	165	0.1
F6.2a	12074	5.3
F7.1a	25358	11.1
F7.1b	72084	31.5
F7.1c	81633	35.7
F7.2b	11	<0.1
F7.3b	54	<0.1
G3.3a	2691	1.2
H1.2a	82	<0.1
H2.1a	756	0.3
H2.1c	788	0.3
H2.2a	265	0.1
P7.1a	374	0.2
P7.1b	26236	11.5
P7.1c	3	<0.1

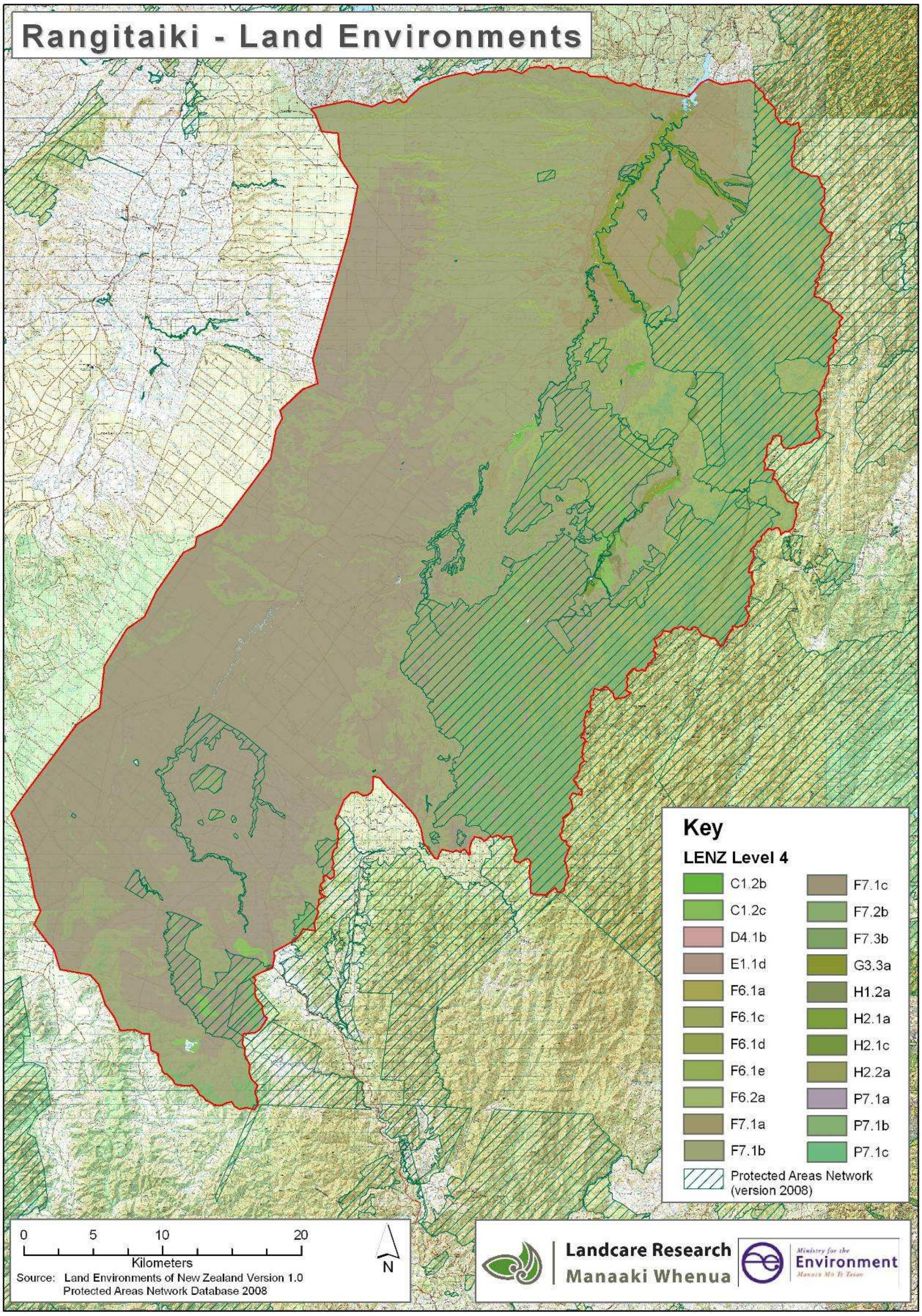

Figure 2—11: LENZ Level IV land environments occurring in the study area.

2.4 Future management and potential impacts

Daniel Rutledge, Mark Smale Craig Briggs and Scott Fraser, Landcare Research, Hamilton

The study area encompassing the Ngati Manawa rohe, and that portion of the Rangitaiki River catchment north of Lake Aniwhenua, has been substantially changed by human land management practices. The extensive use of fire management by Māori altered natural vegetation succession pathways initiated by the Taupo eruption in AD 200. Following European settlement, the study area has experienced further changes including establishment of pastoral areas in the level plains along major rivers and exotic forestry along the Kaingaroa Plateau.

Available evidence suggests that land use has stabilised over the past 10–15 years, with forest harvesting accounting for the majority of recorded changes. However authoritative datasets, especially the LCDB, provide comprehensive information only to 2001/2002. More recent information on land use and land cover and how they have changed would be highly beneficial. Also those datasets only provide information on readily observable changes, e.g., forest harvesting, conversion to pasture. More difficult to detect changes, such as changes to soil quality resulting from different land management practices, would require further investigation.

The potential for future land use change and associated impacts to soil, land, and water resources will vary across the study area. From the perspective of future land use options and corresponding management, it is useful to divide the watershed into three general zones: the Aniwhenua (Aniwaniwa) and Ikawhenua Ranges, the Kaingaroa Plateau, and the level plains along the Rangitaiki and Whirinaki rivers near Galatea, Rangitaiki, and Minginui.

Aniwhenua (Aniwaniwa) and Ikewhenu Ranges

The steep lands in the Aniwhenua (Aniwaniwa) and Ikewhenua ranges in the eastern part of the study areas carry high risk from future land use change, particularly regarding the potential for erosion. Most of those lands are legally protected (Figure 2—11), and therefore highly unlikely to experience future land use change. These areas support substantial amounts of the remaining native biodiversity in the study area, especially the significant podocarp forest remnants represented in the Whirinaki Forest in the south.

Remaining areas of unprotected native land cover (Figure 2—7) would be best suited to remaining in an undisturbed state to both safeguard biodiversity values and water quality by limiting the potential for future soil erosion.

Kaingaroa Plateau

The extent of exotic forests of the Kaingaroa Plateau appeared stable based on the available evidence. Generally this area is better suited for forestry among the possible productive land uses given the erosion potential and leaching properties of the predominantly pumice soils (Table 2—2). Retention in forestry would reduce the possibility for erosion and subsequent siltation of downstream receiving waters, especially if good management practices are followed. These would include minimising the amount of time that bare soils are exposed during harvesting, planting of temporary cover under forest cover is restored, reducing the amount of overall disturbance, and maintaining adequate riparian buffer strips. Maintaining exotic forest cover would also provide on-going benefits for native biodiversity.

Conversion from forestry to other productive land uses, especially pasture, should be restricted to areas with low or at worst moderate erosion potential, such as the Kaingaroa gravelly sand west of Galatea (Symbol KgG: Figure 2—2, Figure 2—9) and gentle slopes. Conversion of areas with high soil erosion potential should be avoided as much as possible.

Galatea and Rangitaiki Plains

The key risk in these areas stems from potential intensification of existing pastoral areas, especially conversion to or intensification of dairy farming. Intensification would require additional inputs, including fertilisers and other compounds, that may leach from the soil and impact downstream water quality. Increasing irrigation will compound these problems by permitting increased stocking rates, leading to higher amounts of fertiliser inputs and increased nitrate leaching. Intensification around Galatea, by virtue of its position near the lower end of the watershed within the study area, would affect less of the overall area defined by the study boundary, but would obviously have effects farther downstream.

Conversion or intensification around Rangitaiki would affect a much larger portion of the study area. The soils in that area have naturally low fertility and would require significant inputs, but generally do not have a great capacity to store nutrients. They are also well to excessively-drained and have issues with drought, which can also enhance nutrient losses from the topsoil when vegetation cover is minimal.

Ultimately conversion to or intensification of any pastoral use, regardless of location, will increase the risk for future impacts to river resources. The nature and degree of the risk will vary by site, and any potential change should undergo more detailed analysis to outline the potential benefits and costs, both economic and otherwise. In the interim, however it would be prudent to have regard for the outcomes of surface water monitoring in the adjacent Taharua River catchment. It was recently reported:

> *"The poor ecological health of the Taharua @ Wairango is likely to be a reflection its size, habitat quality and surrounding land use pressures as this site represents the smallest stream being surrounded by intensive dairy farming. Features which cause a low habitat value at this site include the presence of artificial drainage, poor bank stability, a high potential for sediment inputs, a lack of stable bottom substrate and low stream side shading all of which can affect the instream ecology. The site itself is not far from the headwaters which emanate in the middle of a paddock which is grazed by stock. Without adequate protection of the entire stream catchment with fencing and riparian buffers this small upper reach of the Taharua River is likely to be adversely affected by disturbances caused by stock."*[4]

2.5 Assessment of likely impact of potentially contaminated sites

Neale Hudson, NIWA

Certain historical use practices within the Rangitaiki River catchment involved the use of potentially harmful materials. These chemicals include liquid hydrocarbon fuels (e.g., petrol and diesel), timber treatment chemicals (preservatives and anti-sapstain chemicals), as well as herbicides and insecticides. Proper use and storage of these materials, and correct disposal of containers and residues of these materials reduces the risk of environmental damage. In some cases, historical storage and disposal practices has created localised areas containing contaminated soils. These soils may in some cases represent sources of ongoing contamination.

[4] Draft "Esk and Mohaka Catchments Surface Water Quality and Ecology State of the Environment Report", Brett Stansfield, Hawke's Bay Regional Council, pers. comm.. June 2009.

Management of potential contaminated sites is undertaken by EBOP, with involvement of MfE in some circumstances. Remediation of proven contaminated sites is generally the responsibility of the site owner.

Basic information regarding known or potentially contaminated sites was provided by EBOP[5]. Information regarding the nature of the sites and likely contaminants are summarised in Table 2—6. This table also indicates the likely environmental and human health risk potential currently represented by the various sites.

While considerable volumes of identified hazardous materials have been used at specific sites, and unknown volumes of these and other materials may have been disposed of at others, the investigation and assessment work undertaken to date indicates that human and environmental health risks are low. Contamination is largely restricted to the immediate area of use or disposal, i.e., no evidence exists of off-site contamination or ongoing release of contaminants to the environment. The risks posed by contaminants at the various sites are currently being managed appropriately through a range of measures, including:

- requirements for ongoing monitoring and assessment at some sites;
- ongoing remediation at some sites; and
- control of land use and restriction of access to minimise human exposure to contaminants.

A number of these sites are currently still being actively investigated and assessed. Information and data derived from these assessments may alter the future status or risk potential of a site. Concerned parties should therefore seek current information from EBOP. This will allow the current status and risk potential of any specific site to be assessed.

The available data (historical long term monitoring and specific surveys) does not provide any evidence of off-site impact by any of the sites identified in Table 2—6, or any other potentially contaminated site. While the information currently available from assessment of these sites indicates the potential for off-site impact is low, this could only be confirmed by undertaking quite specific surveys. On the basis of information currently available, we do not regard such surveys to be necessary.

[5] Paul Futter, Senior Project Implementation Officer, EBOP; e-mail of 5/06/2009.

Table 2—6 Summary of known potentially contaminated sites, risk potential and status of investigations.

Nature of site	Historical use	Likely contaminants	Risk potential	Status of investigation
Service station (closed)	Storage of hydrocarbon fuels in underground storage tanks, sale of fuels	Petroleum hydrocarbons	Low (site-use dependent)	Partly investigated
Depot (closed)				
Sawmill (closed)	Milling native timbers, radiate pine, copper-chrome-arsenic timber treatment	copper-chrome-arsenic timber treatment chemicals; asbestos	Low (site-use dependent)	Partial, ongoing
Solid waste storage area (active)	Disposal of solid wastes – currently still used as disposal/transfer station	Metals	Low (site-use dependent)	Ongoing, scheduled for closure once alternative site is available for transfer station
Solid waste storage area (closed)	Disposal of mixed wastes since 1960s. Early disposal largely unregulated, more recently subject to consent conditions. Currently being capped, ongoing monitoring.	Unconfirmed at present, but evidence exists of historical disposal of hydrocarbons	Low (site-use dependent)	Subject to ongoing routine monitoring
Sawmill (closed)	Treatment of lumber with copper-chrome-arsenic (recent) and pentachlorophenol (historical)	copper-chrome-arsenic timber treatment chemical, pentachlorophenol (confirmed)	Low (site-use dependent)	Partly investigated, ongoing remediation
Timber treatment facility (closed)	Treatment of lumber with copper-chrome-arsenic	copper-chrome-arsenic timber treatment chemical	Unknown, but likely to be low	Incomplete
Service station (closed)	Storage of hydrocarbon fuels in underground storage tanks, sale of fuels	Petroleum hydrocarbons	Low (site-use dependent)	Partly investigated
Bulk hydrocarbon fuel storage (closed)	Storage of hydrocarbon fuels in underground storage tanks, dispensing of fuels	Petroleum hydrocarbons	Low (site-use dependent	Completed

3. Rainfall and surface hydrology

Paul Franklin and Doug Booker, NIWA

3.1 General description of rainfall

Two stations were selected to characterise the rainfall in the Ngati Manawa rohe. The considerable increase in elevation from the mid reaches of the catchment (at Aniwhenua (Aniwaniwa)) to the upper catchment (plateau reach around SH5 and headwaters of the Whirinaki River) suggested that multiple sites would be required to adequately characterise rainfall.

Two sites with sufficiently long records relevant to the Rangitaiki River catchment were identified:

- Aniwhenua (station B86271, altitude 158 m), located immediately downstream of the rohe, at the Aniwhenua Power Station; and
- Taupo Automatic Weather Station (AWS) (station B86704, altitude 400 m), located at Taupo airport.

While the Taupo AWS station is outside the Rangitaiki River catchment (about 18 km from the catchment divide, and over 60 km to the SH bridge), it is likely to be reasonably representative of rainfall in the upper Rangitaiki River catchment. Rainfall records of 28 and 18 complete years are available for Aniwhenua (Aniwaniwa) and Taupo AWS stations respectively. Annual rainfall statistics for the two stations are summarised in Table 3—1.

Table 3—1: Annual rainfall statistics, Aniwhenua (Aniwaniwa) and Taupo AWS rainfall sites.

Statistic	Station	
	Aniwhenua	Taupo AWS
No. of complete years of record	28	18
Minimum (mm)	1069	764
Average (mm)	1562	991
Median (mm)	1607	971
Maximum (mm)	2029	1389

The temporal characteristics of rainfall at the two stations is indicated in Figure 3—1. The difference in annual total rainfall is clearly evident, with annual rainfall at Aniwhenua (Aniwaniwa) ranging from an additional 31% to 103% relative to Taupo AWS.

Figure 3—2 indicates considerable month-to-month variability at both stations, but with the Aniwhenua (Aniwaniwa) Station subject to much greater maximum monthly rainfall, including a number of months where monthly total rainfall has exceeded 300 mm.

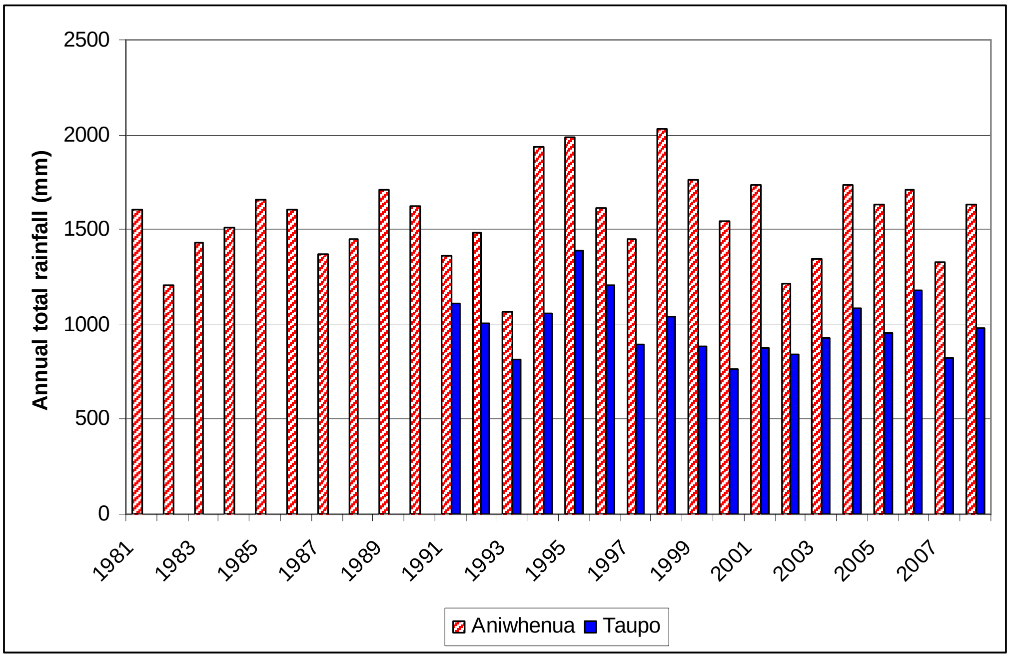

Figure 3—1: Trend in annual total rainfall, Aniwhenua (Aniwaniwa) and Taupo (complete years of record only).

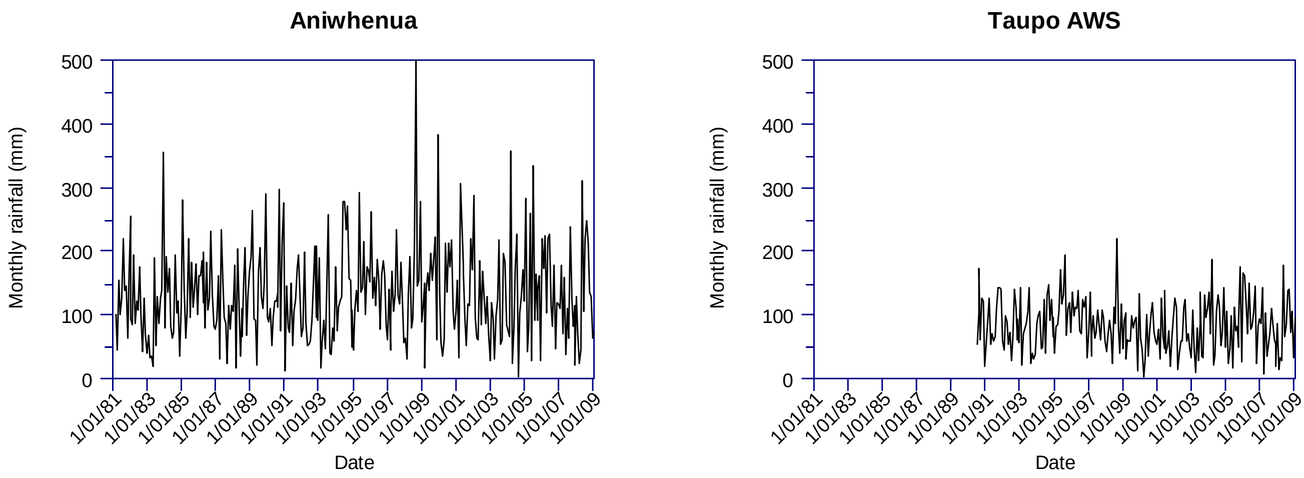

Figure 3—2: Monthly total rainfall, Aniwhenua (Aniwaniwa) and Taupo.

The distribution of rainfall through the year is seasonal at both sites. Figure 3—3 indicates that monthly maximum rainfall is likely to occur in June at Aniwhenua (Aniwaniwa), and during July at Taupo. Minimum monthly rainfall is likely during February at Aniwhenua (Aniwaniwa), but during November at Taupo AWS. While rainfall is seasonal at both stations, rainfall may be anticipated throughout the year. The length of the whiskers for the Aniwhenua (Aniwaniwa) Station also indicates that well above average rainfall may occur throughout the year.

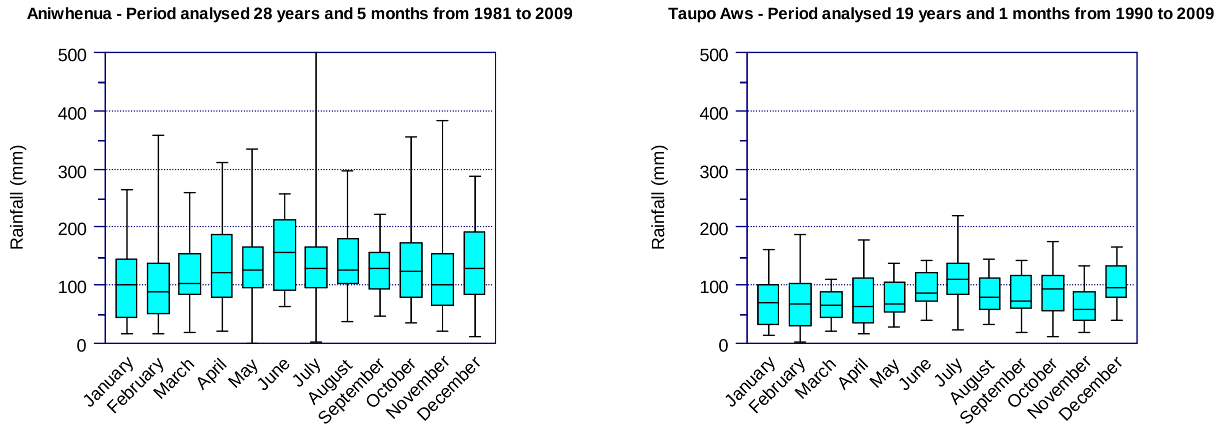

Figure 3—3: Characteristics of monthly rainfall, Aniwhenua (Aniwaniwa) and Taupo stations.

The influence of the rainfall distribution is evident in the water quality data (Section 5):

- the water quality in the Rangitaiki River appears less variable than that of the Whirinaki River - while the soils and the geology of the two catchments is different, the generally less "extreme" nature of the rainfall in the upper Rangitaiki River, plus groundwater dominance owing to the soils, undoubtedly contributes to this behaviour;
- water quality in the Whirinaki River appears subject to a larger number of short duration extreme events, evidenced by a greater number of observations of elevated suspended solids concentrations. This reflects the topography and geology of the catchment, resulting in a flow regime dominated by surface water inputs;
- a strong positive correlation between river discharge and concentrations of soluble and particulate-bound nutrients is evident in the Whirinaki River, but not the Rangitaiki River;
- colour is lower in the Rangitaiki River than the Whirinaki River, while clarity is greater in Rangitaiki River as well - this is consistent with less extreme rainfall, catchment geology and topography, as well as regulation of flows within the mid-reaches of the Rangitaiki River.

3.2 Surface water hydrology

This chapter investigates the nature of river flows in the upper Rangitaiki catchment and considers their relationship with instream ecology and other uses of the river. Advocates of the natural flow paradigm argue that the ecological community of a river is adapted to the natural flow regime, including low flows, high flows and the variability of these flows (Bunn & Arthington 2002, Poff et al. 1997, Richter et al. 2003). Any deviation from the natural flow regime can therefore have an impact on the ecological integrity of a river system. Changes in flows can also impact on other uses of the river, for example fisheries or recreational activities such as rafting.

The current review is limited to the Rangitaiki River and its tributaries upstream of Aniwhenua Dam. The scope of the work is as follows:

- Characterise the nature of the flow regimes in the Rangitaiki River and its tributaries.
- Evaluate the impacts of water allocation and use on flow regimes in the catchment.

- Consider the relationships between flows, instream ecology and other river uses.
- Identify knowledge gaps.

3.2.1 The importance of flow

The flow regime of a river has been called a master variable that limits the distribution and abundance of riverine species and regulates the ecological integrity of flowing water systems (Poff et al. 1997). Numerous flow characteristics are presumed important for the maintenance and regeneration of riverine habitats and biological diversity (Bunn & Arthington 2002, Poff & Ward 1989, Richter et al. 1997). These characteristics can be defined by five critical components: magnitude, frequency, duration, timing and rate of change of hydrologic conditions (Poff et al. 1997, Richter et al. 1996). The natural flow paradigm suggests that the full range of natural intra- and inter-annual variation in these characteristics is critical in sustaining the full indigenous biodiversity and integrity of aquatic ecosystems (Poff et al. 1997, Richter et al. 1997) because indigenous riverine species develop life history traits that enable individuals to survive and reproduce within a certain range (i.e., the natural range) of environmental variation (Stanford et al. 1996, Townsend & Hildrew 1994).

The development and management of water resources by humans can alter the natural flow patterns of rivers, with consequential impacts on river biota (Petts & Maddock 1994, Poff et al. 1997). For example, modification of the timing, frequency or duration of floods can eliminate spawning or migratory cues for fish; increased frequency or duration of high flows may displace velocity-sensitive species; and increased frequency and duration of low flows may increase sediment deposition, smothering deposited eggs (Bunn & Arthington 2002). Consequently, there is growing recognition and acceptance that rivers are legitimate ‘users’ of freshwater and that they require ample water to maintain essential ecosystem goods and services (Arthington et al. 2006, Baron et al. 2002, Postel & Richter 2003).

The allocation of water for environmental or ecological needs has increasingly become a key element of integrated water resources management. Historically, the provision of ‘environmental flows’ has frequently equated to ‘ecological flows’, i.e., the quantity of water required to sustain instream ecological values. However, the concept of environmental flows has now grown to encompass a broader range of values; of which ecological flows is only one component. The Ministry for the Environment states that environmental flows may provide for ecological, tangata whenua, cultural, recreational, amenity, landscape and natural character values associated with a particular water body (MfE 2008). The values provided for, and the level of protection afforded to each, will depend on the characteristics of an individual water body and may be determined in a variety of ways.

Methods for estimating the environmental flow requirements for rivers have traditionally focussed primarily on one or a few species, with the intent of establishing the minimum allowable flows (Jowett 1997, Poff et al. 1997, Tharme 2003). However, it is increasingly recognised that a focus on one or a few species and on minimum flows fails to recognise that what is good for the ecosystem may not consistently benefit individual species, and what is good for individual species may not be of benefit to the ecosystem (Arthington et al. 2006, Poff et al. 1997). Subsequently, more holistic approaches targeting preservation of aquatic species at the community level and recognising the importance of flow variability have developed (Arthington et al. 2006, Richter et al. 1997). Further to this, frameworks have been developed that begin to deal with the integration of societal and developmental values into the water allocation decision making process (King & Brown 2006, Poff et al. 2003, Postel & Richter 2003).

Policy context

In New Zealand the process of water allocation is covered under the Resource Management Act 1991 (RMA). The Ministry for the Environment document ‘Flow guidelines for instream values’ (MfE 1998a & 1998b) summarises the relevant matters of the RMA that relate to the protection of instream values and provides guidelines on approaches to determining flow needs for different instream values. Under the RMA regional councils are the primary water management agencies and have responsibility for allocating water and determining flow regimes. These responsibilities are implemented through rules in regional plans and resource consent conditions. The current Proposed National Environmental Standard (NES) on Ecological Flows and Water Levels is designed to reinforce this existing regional planning process by setting interim limits on alterations to flows and water levels where none already exist and by providing direction for approaches to evaluating ecological flow requirements (MfE 2008).

The Rangitaiki River is covered by the EBOP Water and Land Plan (EBOP 2008) and chapter five details the rules regarding water allocation. Objective 41 of the plan states that:

> *“Water flows in streams and rivers are maintained to:*
>
> *(a) Provide protection for existing aquatic life in the water body.*

> *(b) Maintain identified significant ecological values, landscape values, recreational values, and Maori customary values and traditional instream uses of rivers and streams.*
>
> *(c) Maintain water quality relative to the assimilative capacity of the water body, and the Water Quality Classification of the water body.*
>
> *(d) Avoid or mitigate adverse effects on downstream environments, and existing uses of the water resource."*

Objective 42 states:

> *"Instream flow variability is maintained to sufficient levels to allow for instream biota and stream flushing requirements."*

Instream minimum flow requirements (IMFR) are to be established to satisfy these objectives. The IMFR preferably needs to be determined following Method 177[6] of the plan but, where it has not been established, the default protection level is an IMFR equivalent to 90% of the Q_5 7 day low flow[7]. Once established, IMFRs are to be included in Schedule 7 of the plan (Method 180). For the main stem of the Rangitaiki River above Matahina Dam, the Whirinaki River and Haumea River, the plan states that public notification of the determined IMFRs for inclusion in Schedule 7 should take place by December 2009 (EBOP 2008).

Conditions (Policy 69) are also presented within the plan for existing hydroelectric power schemes as listed in Schedule 11 of the plan. This states that no additional surface or groundwater beyond that already allocated is available for allocation from the Rangitaiki River or its tributaries upstream of Matahina Dam. In addition, when existing resource consents for the power schemes (Wheao, Aniwhenua and Matahina) come up for renewal, they will be subject to Policy 66(d). This policy states that water will be allocated "… *to avoid, remedy or mitigate adverse effects on the environment, while having regard to relevant instream minimum flow requirements set in accordance with this regional plan, and the value of investment by the existing consent holder.*"

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[6] Method 117 is based on the Ministry for the Environment guidelines MfE (1998b). Flow guidelines for instream values - Part A. 146 p.
, MfE (1998a). Flow guidelines for instream values - Part B. 216 p.
[7] The 7 day low flow is the lowest average flow measured over seven consecutive days and Q_5 means a likely occurrence of once in every five years.

3.2.2 Minimum flows

Minimum flow requirements have traditionally been the focus of instream flow studies, based on the assumption that populations are limited by factors such as competition and stress during low flows (Jowett & Biggs 2008). As discussed in the previous section, the establishment of minimum flows provides the basis for the protection of instream values under the EBOP Regional Water and Land Plan (EBOP 2008). Two studies investigating the minimum flow requirements for instream ecology in parts of the Rangitaiki River and the Whirinaki River have been carried out (Wilding 2004 & 2006). These studies only considered flow requirements based on the needs of fish populations.

In the two studies undertaken by Wilding (2004 & 2006), instream habitat modelling using RHYHABSIM was used to predict changes in fish habitat that may occur with changes in flows. This was done for two reaches in the Rangitaiki River and one in the Whirinaki River. The method used meets the requirements for objective scientific approaches for determination of IMFRs as set out in the EBOP Regional Water and Land Plan. The IMFR for the three reaches which have been assessed are presented in Table 3—2.

The IMFR based on fish habitat for the reach considered in the Whirinaki River is greater than the 7 day mean annual low flow (MALF) and Q_5 (Table 3.1). This indicates that natural variability in aquatic habitat is likely to be a primary control on fish populations in this reach of the river and indicates that no water would be available for allocation if full protection is to be granted to fish populations.

Of the two reaches of the Rangitaiki River assessed for minimum flow requirements, the first is representative of the river from about 5 km upstream of Murupara down to Murupara. The second reach is representative of the Rangitaiki River between the confluence with the Whirinaki River and Lake Aniwhenua. In the reach upstream of Murupara, the IMFR for fish is equivalent to 81% of Q_5. Assuming full protection is afforded to fish populations, this would mean 19% of Q_5 or 2.5 $m^3 s^{-1}$ could be allocated for other uses or values in this reach.

The IMFR for fish in the second reach of the Rangitaiki that was assessed lower than for the upstream reach. This is likely to reflect an abundance of higher water velocity and depth, related to higher discharge, which exceed the optimal preferences of trout. Due to the number of tributaries joining the Rangitaiki River in this reach, the IMFR will decrease as a proportion of Q_5 with distance downstream. It is estimated that it could range from 50% to only 29% of Q_5 as further tributaries enter the Rangitaiki. If the IMFR is determined solely on habitat requirements for fish, this potentially leaves a high proportion of Q_5 in this reach available for alternative uses.

Table 3—2: Flow statistics and IMFR (m^3 s^{-1}) for the Rangitaiki River and Whirinaki River. MALF is the 7 day mean annual low flow. Q_5 is the 1 in 5 year 7 day low flow. *No flow record exists between Murupara and Aniwhenua (Aniwaniwa) thus flow statistics were estimated. Lower estimate = flow of Whirinaki at Galatea + flow of Rangitaiki at Murupara. Upper estimate = flow of Rangitaiki downstream of Aniwhenua (Aniwaniwa). The difference reflects the contribution of tributaries joining the Rangitaiki between Murupara and Aniwhenua (Aniwaniwa).

Site	Median flow	MALF	Q_5	IMFR
Rangitaiki River (upstream of Murupara)	20.6	14.7	13.0	10.5
Rangitaiki River (Murupara to Aniwhenua)	32.3 - 48.7*	19.9 - 33.8*	17.3 - 29.7*	8.7
Whirinaki River	11.7	5.2	4.3	6.5

Other areas of the catchment have not yet been assessed using methodologies that comply with the requirements of the regional plan and thus the default IMFR of 90% of Q_5 should be applicable (EBOP 2008). It should also be noted that currently, the IMFRs only take account of one value, freshwater fish. The determination of the full IMFR for these reaches should, however, take account of all values associated with a water body.

3.2.3 Flow variability

Methodology

The natural flow paradigm states that "a range of ecologically important streamflow characteristics constitute the natural flow regime" and that "the native biodiversity and integrity of river ecosystems depends on the full range of natural variation in the hydrological regime" (Poff et al. 1997). This philosophy can be employed when assessing the impact of flow alterations on ecological values given the assumption that river ecosystems are evolved from, and adapted to, the natural flow regime. Olden and Poff (2003) described and compared many environmental flow setting methods which are based on hydrological statistics. One method for describing the hydrological characteristics of a river is the Range of Variability Approach (RVA), which can be applied using the Indicators of Hydrological Alteration (IHA) (Richter et al. 1996, The Nature Conservancy 2007). This method has been applied in Canada (Bradford et al. 2007), South Africa (King et al. 2003), Taiwan (Shiau & Wu 2004), the UK (Black et al. 2002) and the US (e.g., Richter et al. 1998). Although the RVA has not routinely been applied in New Zealand, this approach is included in the National Environmental Standards (NES) schedule of methods for rivers with a high instream values (Beca 2008). The draft guidelines for selection of methods to determine ecological flows state that "while analysis of hydrological variation will not by itself allow the setting of ecological flows, it will act as a 'flag' to other methods to illustrate the extent of hydrological change, and how these hydrological parameters may be affected by the ecological flow decision" (Beca 2008).

The RVA method requires a time-series of flows for the river or site under investigation. A set of statistical parameters are used to characterise hydrological conditions in each year of the time-series. These parameters provide information designed to describe fully the natural flow regime, including those components that are ecologically significant. Measures of spread are then used to quantify the variation in these parameters between years. Different measures of spread can be employed depending on whether it is assumed that the data are parametrically or non-parametrically distributed. The parameters and their range of variability are "intended for use with other [unspecified] ecosystem metrics" in order to inform management activities and for setting environmental flow regimes (Richter et al. 1996). Where pre-impact and post-impact flow data are available, the degree of hydrological alteration can be assessed by comparing distributions drawn from annual time-series for each scenario and for each of the parameters.

An assumption of the RVA is that the annual time-series data are stationary (have a constant probability distribution through time). When applied without the appropriate data exploration, application of the RVA could erroneously ignore long-term trends and serial dependencies (The Nature Conservancy 2007). Long-term trends have previously been identified in some hydrological time-series in New Zealand. Analysis has shown links between the Interdecadal Pacific Oscillation (IPO) and hydrological patterns in New Zealand (McKerchar & Henderson 2003). Specifically, when the periods 1947–1977 and 1978–1999 were compared for all of New Zealand, decreases in flood size for in the Bay of Plenty region, and increases in flood size and low-flow magnitude for most rivers with headwaters draining the main divide of the Southern Alps and Southland were found. However, no consistent pattern of shifts was identified for the remainder of the country.

A number of hydrological parameters were calculated from mean daily flows for each whole year of the flow record following the methods of Richter et al. (1996 & 1997) and The Nature Conservancy (2007) (Table 3—3). It was assumed that, when analysed together, these parameters could be used to describe the full range of hydrological conditions in each year of record.

The RVA typically involves comparison of two scenarios, which are used to describe pre-impact and post-impact conditions. The Wheao Power Scheme was constructed during the early 1980s and became operational in 1984. The effects of this scheme on the flow regime of the Rangitaiki at Murupara were assessed by dividing the flow record into two periods. The beginning of the flow record until the operation of the dam (1949–1983) was used to represent pre-scheme conditions. The period after the scheme was operational until present was used to represent post-scheme conditions (1984–2008).

The annual time-series for each of the parameters in each of the periods was assessed for the presence of temporal trends. Statistically significant trends over time were identified within each data set by applying linear regressions against year of record. Slope parameters with p-values less than 0.05 were deemed to have statistically significant trends over time. The presence of temporal trends within the pre-scheme period could suggest an alteration in the hydrological cycle, e.g., in response to climate change or change in landuse/abstraction practices within the catchment. The presence of temporal trends within the post-scheme period could suggest the influence of the same processes, with the possible addition of change due to routine operation of the scheme. Absence of temporal trends within the two periods would support the hypothesis that hydrological patterns within the two periods can be treated as stationary (constant with time).

For each parameter, we applied analysis of variance (ANOVA) tests to assess the hypothesis that there was no significant difference in the mean values for each of the parameters between the pre and post-scheme period.

Table 3—3: IHA parameters used in this study.

Group	Parameter description	Parameter label
1) Magnitude of monthly water flows	Median value for each calendar month	e.g., MedianJan
2) Magnitude and duration of annual extreme flows	Annual minima 1-day means	Mean1DayFlowMins
	Annual minima 3-day means	Mean3DayFlowMins
	Annual minima 7-day means	Mean7DayFlowMins
	Annual minima 30-day means	Mean30DayFlowMins
	Annual minima 90-day means	Mean90DayFlowMins
	Annual maxima 1-day means	Mean1DayFlowMaxs
	Annual maxima 3-day means	Mean3DayFlowMaxs
	Annual maxima 7-day means	Mean7DayFlowMaxs
	Annual maxima 30-day means	Mean30DayFlowMaxs
	Annual maxima 90-day means	Mean90DayFlowMaxs
	Base flow index: 7-day minimum flow/ mean flow for year	BFI
3) Timing of annual extreme flows	Julian date of annual 1-day minimum	JulianMin
	Julian date of annual 1-day maximum	JulianMax
4) Frequency and duration of high and low pulses	Number of low pulses within each water year	nPulsesLow
	Median duration of low pulses	MedianPulseLengthLow
	Number of high pulses within each water year	nPulsesHigh
	Median duration of high pulses	MedianPulseLengthHigh
5) Rate and frequency of flows changes	Median of all positive differences between daily values	MedianPos
	Number of all positive differences between days	nPos
	Median of all negative differences between daily values	MedianNeg
	Number of all negative differences between days	nNeg
	Number of hydrologic reversals	Reversals

When conducting an RVA study, the distribution of each parameter drawn from the two time periods (or flow scenarios) is compared. For normally distributed variables, this comparison can be made by comparing the frequency with which a parameter calculated from the post-impact scenario falls outside a range defined by the mean plus or minus one standard deviation, for the same parameter calculated for the pre-impact scenario. The probability of occurrence of events from within a normal distribution occurring more than one standard deviation from the mean is approximately 0.16.

However, hydrological parameters are rarely normally distributed, therefore an alternative method should be applied in these situations. The Nature Conservancy (2007) states that:

> *"In an RVA analysis, the full range of pre-impact data for each parameter is divided into three different categories. The boundaries between categories are based on either percentile values (for non-parametric analysis) or a number of standard deviations away from the mean (for parametric analysis), which are specified by the user. As an example, the default in non-parametric RVA analysis is to place the category boundaries 17 percentiles from the median. This yields an automatic delineation of three categories of equal size: the lowest category contains all values less than or equal to the 33rd percentile; the middle category contains all values falling in the range of the 34th to 67th percentiles; and the highest category contains all values greater than the 67th percentile."*

Hydrologic Alteration Factors (HAFs) are then calculated for each parameter by calculating the proportion of years (and therefore the probability of occurrence) from the altered scenario which falls into each category:

$$\text{HAF} = \frac{\text{Observed frequency - Expected frequency}}{\text{Expected frequency}}$$

We calculated HAFs by delineating the pre-impact distributions into three equal categories based on the 34th and 67th percentiles, as suggested by The Nature Conservancy (2007).

3.2.4 Rangitaiki results

Daily flow records

Visual inspection of the daily flow records for the Rangitaiki at Murupara both before and after implementation of the Wheao Power Scheme show a relatively steady flow regime with gradually varying flows and relatively infrequent high flow events (Figure 3—4 & 2). Visual inspection of the data suggests that operation of the scheme resulted in some alterations to the magnitude of seasonal patterns of flow, but also introduced a large number of frequent, but relatively small magnitude, flow fluctuations.

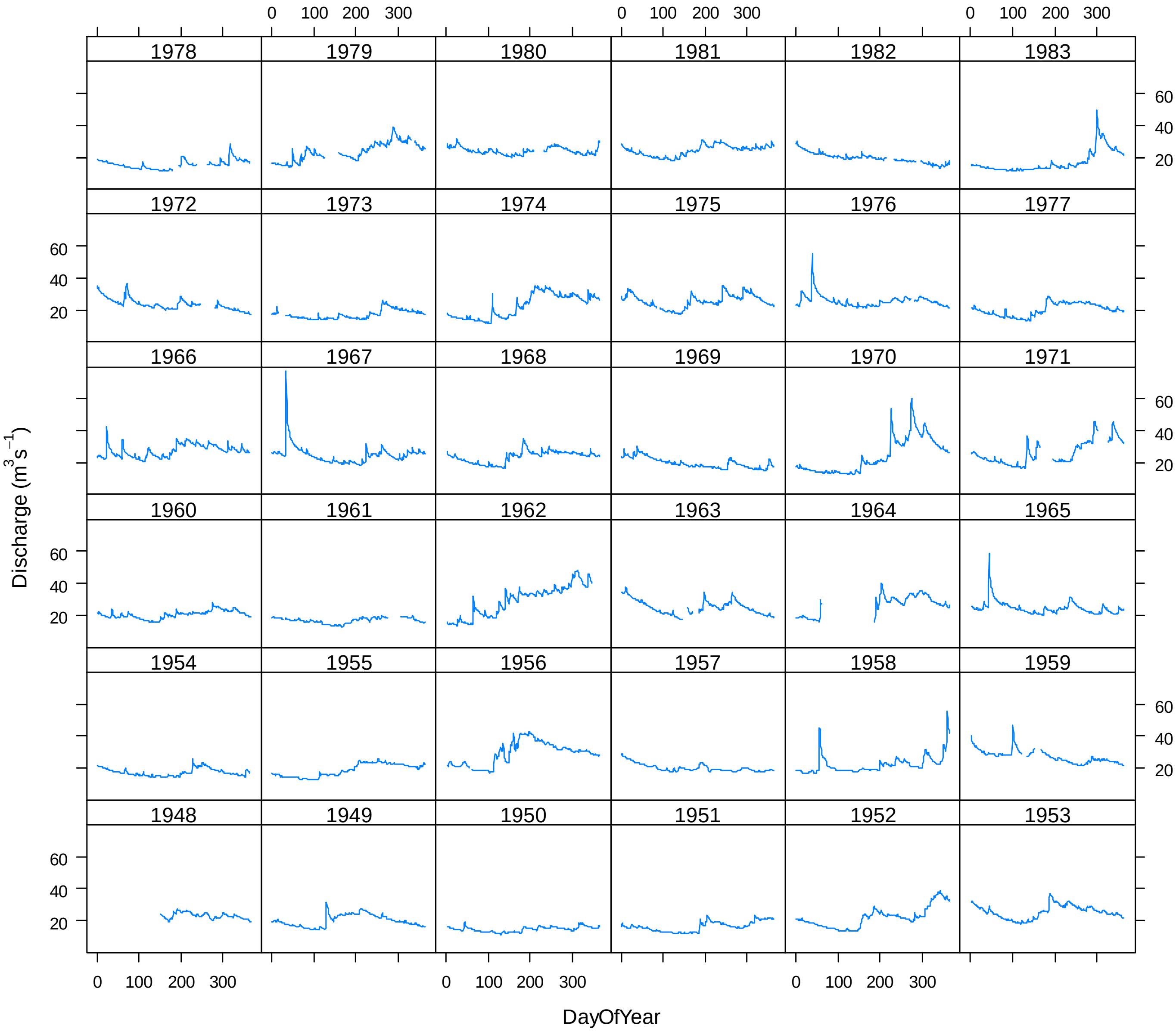


Figure 3—4: Recorded mean daily flows for the Rangitaiki at Murupara (1948–1983).

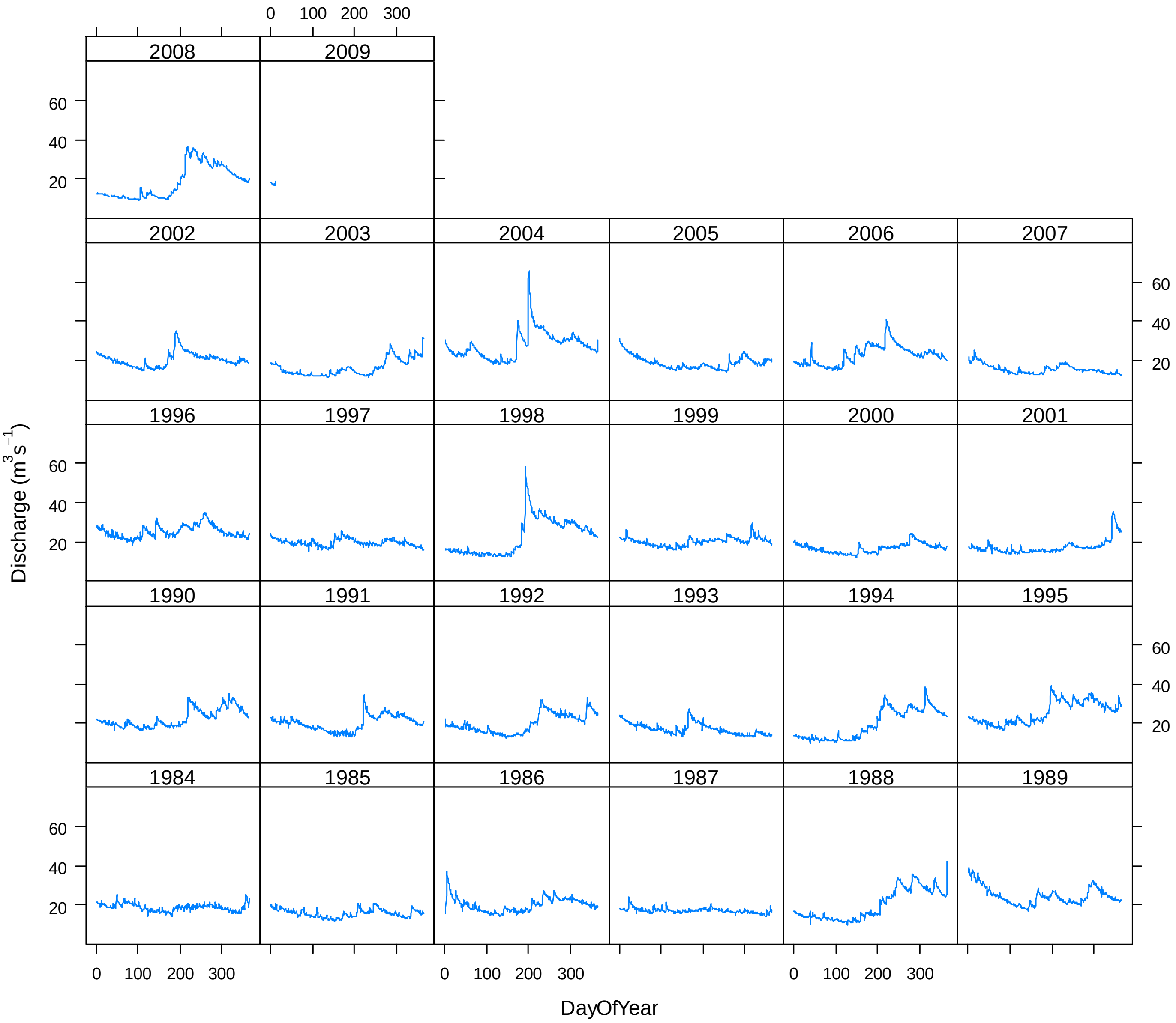


Figure 3—5: Recorded mean daily flows for the Rangitaiki at Murupara (1984–2009).

The records for each (pre and post-scheme) period varied in length (Table 3—4). However, they both covered reasonably long time-periods (33 and 25 years). This compares well with the advice of Kennard et al. (2007) who suggested that bias in hydrological parameters rapidly decreased and precision and overall accuracy markedly increased with increasing record length, but tended to stabilise in records greater than 15 years in length and did not change substantially in records greater than 30 years in length. Summary flow statistics were calculated for the entire pre and post-scheme periods. Results showed a reduction in the magnitude of all flows including high, medium and low flows (Table 3—4). This reduction in flow magnitude is reflected in the pre and post-scheme flow duration curves (Figure 3—6).

Table 3—4: Summary of all mean daily flows pre- and post-scheme for the Rangitaiki at Murupara.

Period		**1949-1983**	**1984-2008**	**% change**
Daily flows (m^3s^{-1})				
	Minimum	11.17	9.377	-16.0%
	1st Quartile	17.58	16.12	-8.3%
	Median	21.58	19.05	-11.7%
	Mean	22.21	20.18	-9.1%
	3rd Quartile	25.73	23.26	-10.0%
	Maximum	77.64	65.40	-15.8%
Record length				
	Years	33	25	
	Start Year	1949	1984	
	End Year	1983	2008	
	Gap Days	303	5	
	Missing Years	2	0	

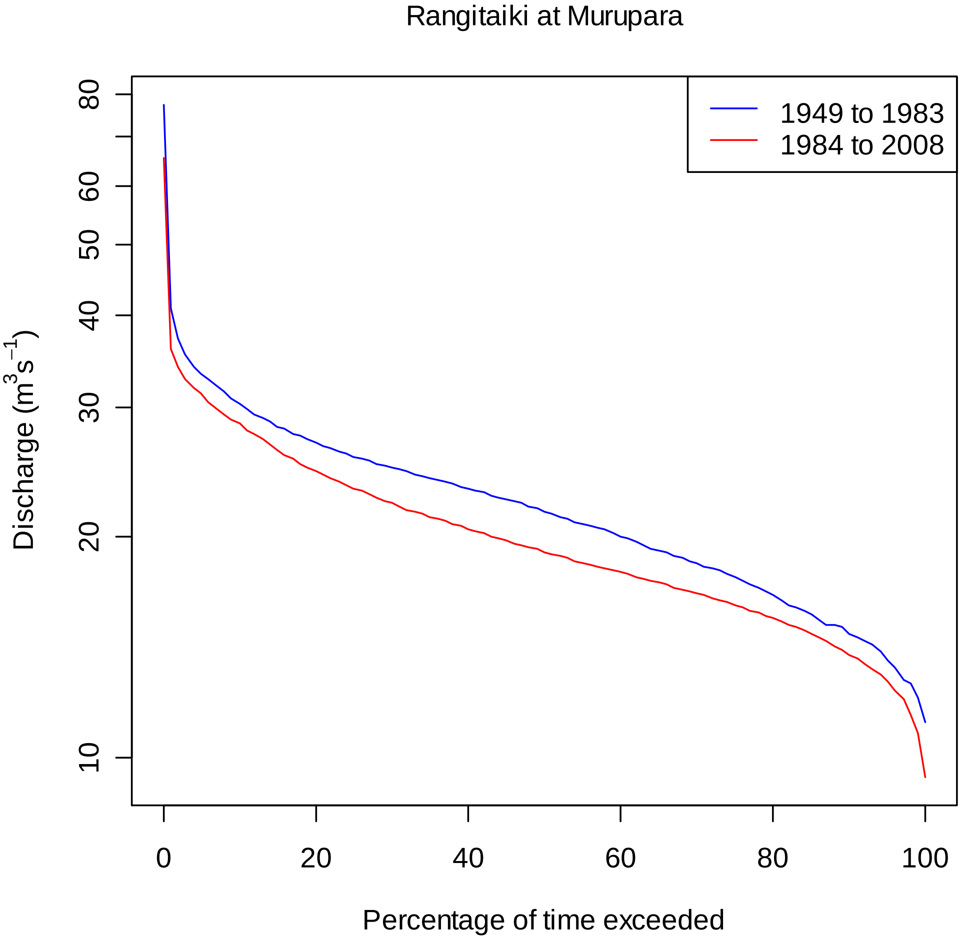


Figure 3—6: Flow duration curves all mean daily flows pre- and post-scheme for the Rangitaiki at Murupara.

Prior to calculation of the IHA parameters, two years of data (1964 and 1971) were removed from the analysis because they had more than 50 days of missing data. IHA parameters were calculated for each year from mean daily flows. Linear models were applied to test for the presence of consistent temporal trends within the pre-scheme (Table 3—5) and post-scheme periods (Table 3—6). The impact of scheme implementation was assessed by applying analysis of variance (Table 3—7) and by calculating HAFs for each parameter (Table 3—8). Initial inspection of the HAFs reveals that there are some changes to the seasonal flow patterns and an overall reduction in both high and low flows. However, the greatest changes between the two periods were in the rate and frequency of changes in daily flows.

Table 3—5: Results from linear regression between each IHA parameter and year during the period 1949–1983 for the Rangitaiki at Murupara.

Group	Parameter	Estimate	Standard error	t value	p value	Significant trend
Seasonal						
	MedianJan	0.060	0.093	0.641	0.526	FALSE
	MedianFeb	0.052	0.098	0.528	0.601	FALSE
	MedianMar	0.055	0.082	0.672	0.507	FALSE
	MedianApr	0.073	0.076	0.955	0.347	FALSE
	MedianMay	-0.004	0.079	-0.055	0.956	FALSE
	MedianJun	-0.042	0.093	-0.447	0.658	FALSE
	MedianJul	-0.074	0.099	-0.741	0.464	FALSE
	MedianAug	-0.030	0.099	-0.305	0.762	FALSE
	MedianSep	0.055	0.091	0.612	0.545	FALSE
	MedianOct	0.107	0.100	1.063	0.296	FALSE
	MedianNov	0.062	0.104	0.598	0.554	FALSE
	MedianDec	-0.006	0.101	-0.060	0.953	FALSE
Extremes						
	Mean1DayFlowMins	0.019	0.052	0.377	0.709	FALSE
	Mean3DayFlowMins	0.019	0.052	0.368	0.716	FALSE
	Mean7DayFlowMins	0.021	0.052	0.398	0.693	FALSE
	Mean30DayFlowMins	0.028	0.054	0.519	0.607	FALSE
	Mean90DayFlowMins	0.035	0.058	0.603	0.551	FALSE
	Mean1DayFlowMaxs	0.185	0.219	0.845	0.404	FALSE
	Mean3DayFlowMaxs	0.166	0.194	0.854	0.400	FALSE
	Mean7DayFlowMaxs	0.125	0.164	0.761	0.452	FALSE
	Mean30DayFlowMaxs	0.060	0.122	0.492	0.627	FALSE
	Mean90DayFlowMaxs	0.049	0.099	0.492	0.626	FALSE
	BFI	-0.001	0.002	-0.369	0.715	FALSE
Timing						
	JulianMin	-0.071	1.765	-0.040	0.968	FALSE
	JulianMax	-0.962	2.053	-0.469	0.642	FALSE
Pulses						
	nPulsesLow	-0.017	0.038	-0.435	0.667	FALSE
	MedianPulseLengthLow	2.775	2.535	1.094	0.282	FALSE
	nPulsesHigh	**0.141**	**0.058**	**2.450**	**0.020**	**TRUE**
	MedianPulseLengthHigh	0.140	0.416	0.336	0.739	FALSE
Flow changes						
	nPos	**1.076**	**0.243**	**4.434**	**0.000**	**TRUE**
	medianPos	-0.004	0.003	-1.707	0.098	FALSE
	nNeg	**-1.566**	**0.303**	**-5.166**	**0.000**	**TRUE**
	medianNeg	**-0.006**	**0.001**	**-4.251**	**0.000**	**TRUE**
	Reversals	**1.772**	**0.238**	**7.457**	**0.000**	**TRUE**

Table 3—6: Results from linear regression between each IHA parameter and year during the period 1984–2008 for the Rangitaiki at Murupara.

Group	Parameter	Estimate	Standard error	t value	p value	p < 0.05
Seasonal						
	MedianJan	-0.086	0.130	-0.664	0.513	FALSE
	MedianFeb	-0.092	0.106	-0.871	0.393	FALSE
	MedianMar	-0.098	0.099	-0.991	0.332	FALSE
	MedianApr	-0.098	0.085	-1.155	0.260	FALSE
	MedianMay	-0.004	0.092	-0.041	0.967	FALSE
	MedianJun	-0.020	0.110	-0.181	0.858	FALSE
	MedianJul	0.186	0.179	1.037	0.311	FALSE
	MedianAug	0.176	0.188	0.937	0.359	FALSE
	MedianSep	0.018	0.156	0.113	0.911	FALSE
	MedianOct	0.001	0.155	0.007	0.994	FALSE
	MedianNov	-0.016	0.150	-0.106	0.916	FALSE
	MedianDec	-0.001	0.120	-0.010	0.992	FALSE
Extremes						
	Mean1DayFlowMins	-0.006	0.070	-0.090	0.929	FALSE
	Mean3DayFlowMins	-0.014	0.072	-0.194	0.848	FALSE
	Mean7DayFlowMins	-0.023	0.072	-0.313	0.757	FALSE
	Mean30DayFlowMins	-0.036	0.077	-0.469	0.644	FALSE
	Mean90DayFlowMins	-0.038	0.083	-0.454	0.654	FALSE
	Mean1DayFlowMaxs	0.317	0.279	1.138	0.267	FALSE
	Mean3DayFlowMaxs	0.350	0.253	1.386	0.179	FALSE
	Mean7DayFlowMaxs	0.305	0.228	1.338	0.194	FALSE
	Mean30DayFlowMaxs	0.206	0.165	1.246	0.225	FALSE
	Mean90DayFlowMaxs	0.169	0.124	1.368	0.185	FALSE
	BFI	-0.001	0.003	-0.497	0.624	FALSE
Timing						
	JulianMin	-4.082	3.452	-1.182	0.249	FALSE
	JulianMax	-0.995	3.439	-0.289	0.775	FALSE
Pulses						
	nPulsesLow	-0.428	0.248	-1.721	0.099	FALSE
	MedianPulseLengthLow	1.035	2.936	0.353	0.728	FALSE
	nPulsesHigh	-0.059	0.125	-0.472	0.641	FALSE
	MedianPulseLengthHigh	0.530	0.536	0.989	0.333	FALSE
Flow changes						
	nPos	-0.540	0.317	-1.702	0.102	FALSE
	medianPos	**-0.010**	**0.003**	**-3.603**	**0.001**	**TRUE**
	nNeg	0.475	0.305	1.557	0.133	FALSE
	medianNeg	**0.006**	**0.002**	**2.366**	**0.027**	**TRUE**
	Reversals	**-1.343**	**0.449**	**-2.992**	**0.007**	**TRUE**

Table 3—7: Analysis of variance (ANOVA) results comparing each set of IHA parameters for the periods 1949–1983 and 1984–2008 for the Rangitaiki at Murupara.

Group	Parameter	Degrees of freedom	Mean Sq	F value	p value	p < 0.05
Seasonal						
	MedianJan	1.000	30.537	1.159	0.286	FALSE
	MedianFeb	1.000	81.786	3.249	0.077	FALSE
	MedianMar	**1.000**	**78.722**	**4.206**	**0.045**	**TRUE**
	MedianApr	1.000	54.000	3.431	0.069	FALSE
	MedianMay	**1.000**	**91.162**	**5.398**	**0.024**	**TRUE**
	MedianJun	**1.000**	**128.178**	**5.444**	**0.023**	**TRUE**
	MedianJul	1.000	63.110	1.676	0.201	FALSE
	MedianAug	1.000	1.117	0.029	0.866	FALSE
	MedianSep	1.000	24.278	0.830	0.366	FALSE
	MedianOct	1.000	6.995	0.210	0.648	FALSE
	MedianNov	1.000	58.136	1.749	0.191	FALSE
	MedianDec	1.000	37.113	1.337	0.253	FALSE
Extremes						
	Mean1DayFlowMins	**1.000**	**43.543**	**5.541**	**0.022**	**TRUE**
	Mean3DayFlowMins	1.000	29.806	3.704	0.059	FALSE
	Mean7DayFlowMins	1.000	23.488	2.890	0.095	FALSE
	Mean30DayFlowMins	1.000	21.220	2.350	0.131	FALSE
	Mean90DayFlowMins	1.000	27.649	2.683	0.107	FALSE
	Mean1DayFlowMaxs	1.000	103.568	0.742	0.393	FALSE
	Mean3DayFlowMaxs	1.000	97.523	0.865	0.356	FALSE
	Mean7DayFlowMaxs	1.000	62.582	0.751	0.390	FALSE
	Mean30DayFlowMaxs	1.000	73.521	1.638	0.206	FALSE
	Mean90DayFlowMaxs	1.000	63.782	2.259	0.138	FALSE
	BFI	1.000	0.000	0.000	0.998	FALSE
Timing						
	JulianMin	1.000	15344.773	1.194	0.279	FALSE
	JulianMax	1.000	17915.566	1.223	0.274	FALSE
Pulses						
	nPulsesLow	**1.000**	**873.484**	**21.782**	**0.000**	**TRUE**
	MedianPulseLengthLow	**1.000**	**94011.535**	**5.308**	**0.025**	**TRUE**
	nPulsesHigh	1.000	0.015	0.001	0.976	FALSE
	MedianPulseLengthHigh	1.000	130.095	0.260	0.612	FALSE
Flow changes						
	nPos	**1.000**	**96481.900**	**387.040**	**0.000**	**TRUE**
	medianPos	1.000	0.030	1.388	0.244	FALSE
	nNeg	**1.000**	**75350.514**	**193.160**	**0.000**	**TRUE**
	medianNeg	**1.000**	**1.482**	**151.964**	**0.000**	**TRUE**
	Reversals	**1.000**	**228030.613**	**497.272**	**0.000**	**TRUE**

Table 3—8: HAFs expressed as percentage changes, from the pre-impact to the post-impact periods, showing the proportions of the distribution of each parameters that fell within the lower third (bottom 33%), middle third (33–67%) and upper third (top 67%) ranges as defined by the pre-impact scheme.

Group	Parameter	Lower third	Middle third	Upper third
Seasonal				
	MedianJan	-22.3	71.6	-51.4
	MedianFeb	-7.8	92.1	-87.1
	MedianMar	7.1	68.0	-77.2
	MedianApr	8.3	48.4	-58.2
	MedianMay	33.9	37.3	-72.4
	MedianJun	91.7	-44.8	-51.3
	MedianJul	84.6	-59.2	-23.6
	MedianAug	47.0	-57.5	12.3
	MedianSep	42.2	-16.1	-25.6
	MedianOct	28.8	-35.4	7.7
	MedianNov	32.9	-14.6	-17.9
	MedianDec	-8.7	16.5	-8.3
Extremes				
	Mean1DayFlowMins	37.5	39.5	-78.2
	Mean3DayFlowMins	28.0	42.7	-72.0
	Mean7DayFlowMins	22.7	47.2	-71.4
	Mean30DayFlowMins	24.8	40.0	-66.0
	Mean90DayFlowMins	25.9	37.5	-64.5
	Mean1DayFlowMaxs	-2.8	26.0	-23.9
	Mean3DayFlowMaxs	-9.1	54.8	-47.4
	Mean7DayFlowMaxs	6.5	37.1	-44.7
	Mean30DayFlowMaxs	34.4	11.0	-45.8
	Mean90DayFlowMaxs	40.1	-9.9	-29.9
	BFI	5.6	-25.5	20.7
Timing				
	JulianMin	58.2	-58.3	1.9
	JulianMax	-43.8	26.1	16.9
Pulses				
	nPulsesLow	-71.4	-2.5	96.5
	MedianPulseLengthLow	106.1	-37.2	-73.7
	nPulsesHigh	44.4	-37.3	-17.2
	MedianPulseLengthHigh	61.6	-13.2	-51.2
Flow changes				
	nPos	-100.0	-100.0	203.0
	medianPos	-46.1	-2.8	49.0
	nNeg	-100.0	179.7	-100.0
	medianNeg	188.6	-86.0	-100.0
	Reversals	-100.0	-100.0	203.0

Seasonal patterns

Seasonal patterns of flow were examined by comparing the distribution of monthly median flows calculated from each year of the gauged record. Results showed that, over the entire gauged period, there was great inter-annual variability in median monthly flows for the majority of months (Figure 3—7). Linear regressions between year and each annual time-series of monthly median flows showed very few consistent trends through time. When the entire (1949–2008) period was considered, a significant linear trend ($p < 0.05$) was only found for one month of the year. This month was June, which on average reduced over the entire record length. No statistically significant ($p < 0.05$) linear trends were found in the median flows for any month were found when the record was split into pre and post-scheme periods (Table 3—5 and Table 3—6). This suggests that no consistent changes in seasonal flow patterns occurred on a year-to-year basis either within the pre-impact time-period or within the post-impact time-period. When ANOVA was applied to test for difference in the means of the annual time-series of the median flows for each month, statistically significant ($p < 0.05$) differences between pre- and post-scheme conditions were found for March, May and June (Table 3—7). This finding supports the hypothesis that flows in these months were lower during the post-scheme period relative to the pre-scheme period.

When using the RVA it is suggested that inter-annual variability is considered when annual time-series of hydrological parameters are compared. Inter-annual variability in the monthly median flows was compared for the two time-periods using kernal density distribution plots (Figure 3—8). The same data were also compared by calculating the Hydrologic Alteration Factors (HAFs) for the monthly medians. These HAFs were calculated using the default method for non-parametric analysis in the RVA: i.e., by delineating the distribution of each pre-impact parameter (the blue lines in Figure 3—9) into three categories of equal size and then calculating what proportions of the post-impact distribution fell into these categories. The HAFs can be shown in terms of percentage change from the pre-impact period to the post-impact period (e.g., Table 3—8). For example, these results show that before 1984, 33 % of the median flows for July were lower than 19.4 $m^3 s^{-1}$. During the post-impact period the likelihood of flows being less than 19.4 $m^3 s^{-1}$ was around 61%. This implies that the likelihood of lower flows occurring is increased by 85%. During the post-scheme period, increases in the likelihood of lower flows occurred for all months except December, January and February. The likelihood of lower monthly medians during the post-scheme period was particularly great in the winter months. The post-scheme period showed more variability in winter and spring months and less variability in autumn and summer relative to the pre-scheme periods (Figure 3—9).

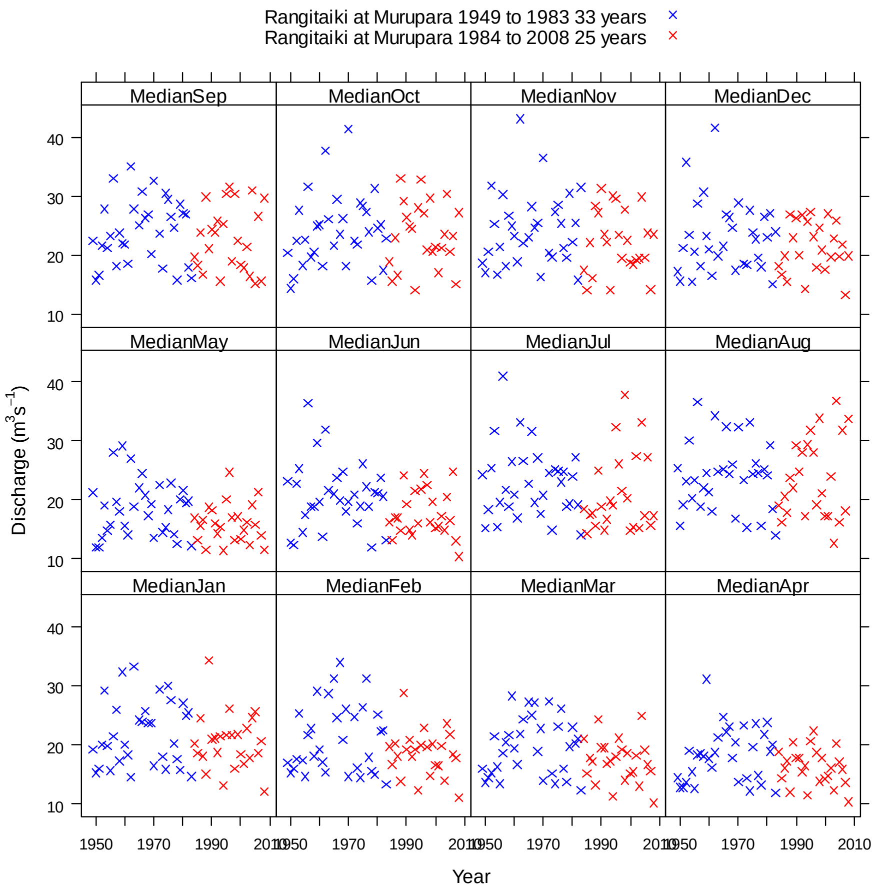


Figure 3—7: Time-series of monthly median flows pre and post-scheme for the Rangitaiki at Murupara.

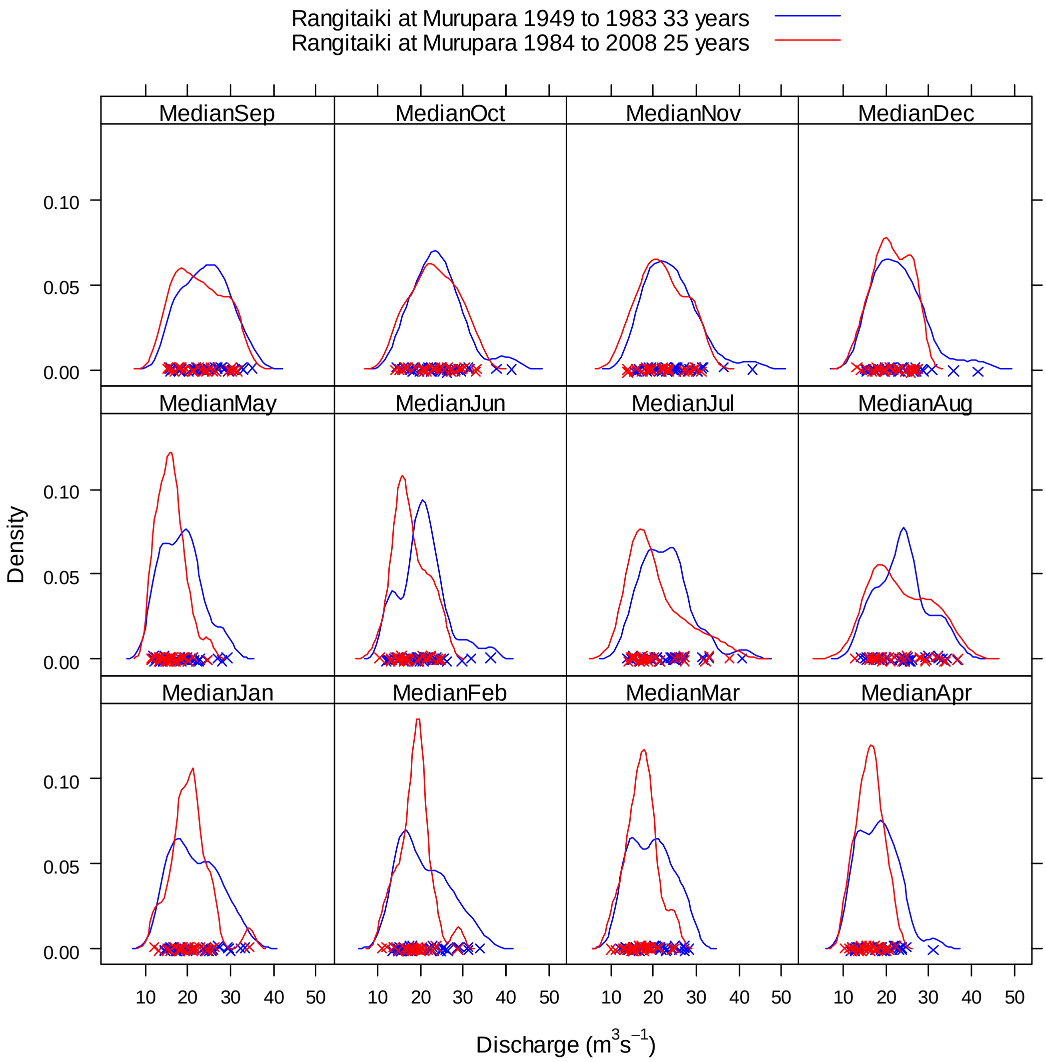


Figure 3—8: Density plots of annual median flows for each month during pre and post-scheme periods for the Rangitaiki at Murupara.

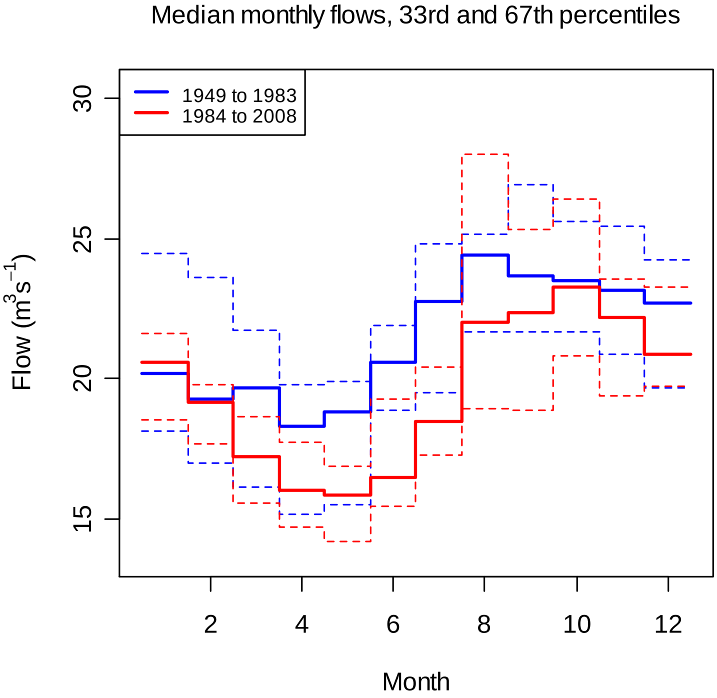


Figure 3—9: Seasonal patterns of monthly median flow.

Low flow extremes

There was correspondence in the behaviour of the five low flow parameters used to assess low flow conditions within the RVA (Figure 3—10). Great inter-annual variability in these parameters was observed without any statistically significant linear trends in time throughout the record, regardless of the pre and post-scheme periods (Table 3—5 and Table 3—6). When ANOVA was applied to test for difference in the means of these low flow parameters, statistically significant ($p < 0.05$) differences between pre and post-scheme conditions were found for only the 1 day flow minima (Table 3—7).

When distribution in low flow parameters for the pre and post-scheme periods were compared, a tendency for a reduction in low flows in the post-scheme period was observed relative to the pre-scheme period (Figure 3—11, Table 3—8). A narrowing in the range of low flows during the post-scheme period was also observed. This indicates that low flows were more consistent during the post-scheme period than during the pre-scheme period.

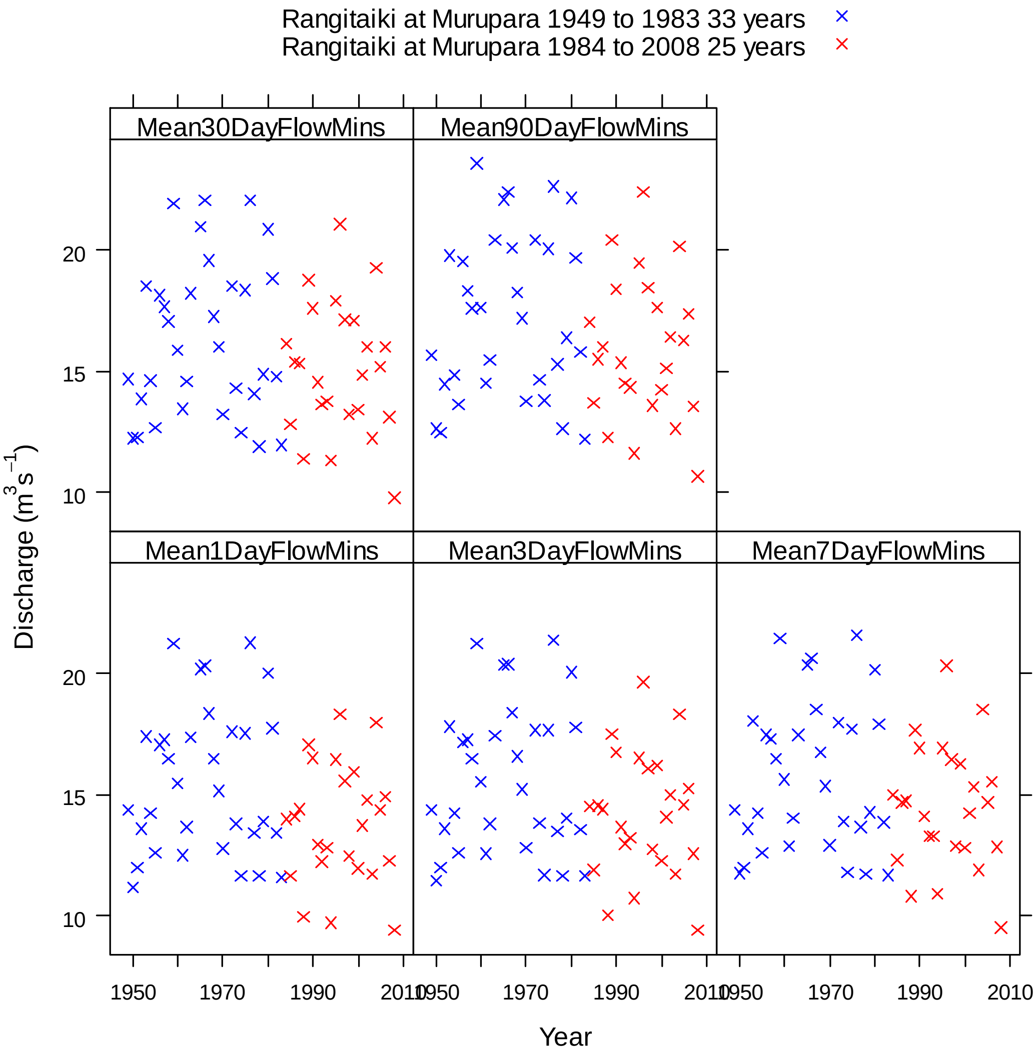


Figure 3—10: Time-series of low flow parameters during pre and post-scheme for the Rangitaiki at Murupara.

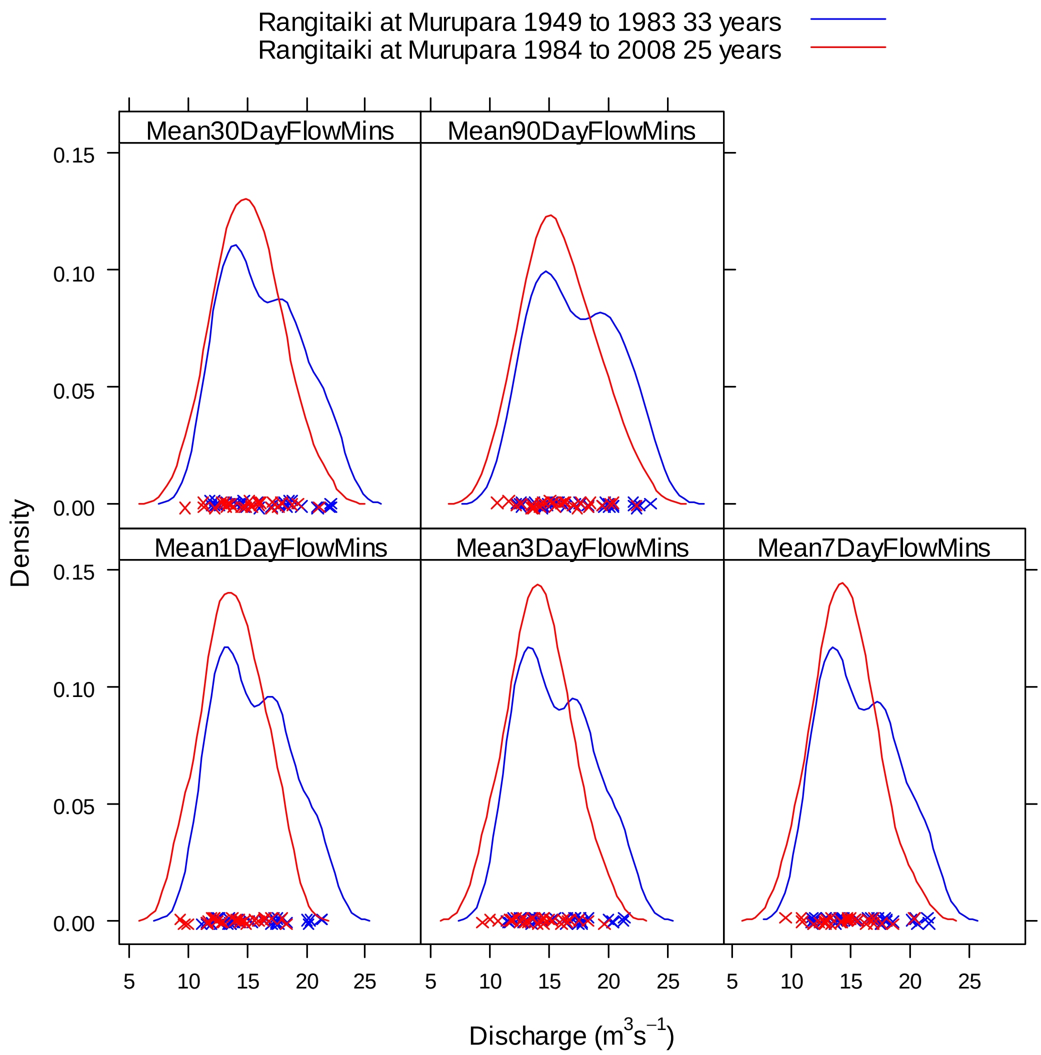


Figure 3—11: Density plots of low flow parameters during pre and post-scheme periods for the Rangitaiki at Murupara.

High flow extremes

For the high flow parameters, statistically significant linear trends in time were not observed, regardless of the pre- and post-scheme periods (Table 3—5 and Table 3—6). Inter-annual variability decreased as the time period over which the high flow statistics were calculated was increased (Figure 3—12). When ANOVA was applied to test for difference in the means of these high flow parameters, no statistically significant differences between pre and post-scheme conditions were found (Table 3—7). When the distributions of the high flow parameters for the pre- and post-scheme periods were compared, a slight tendency for a reduction in the magnitude of the highest flood events in the post-scheme record was observed (Figure 3—13, Table 3—8).

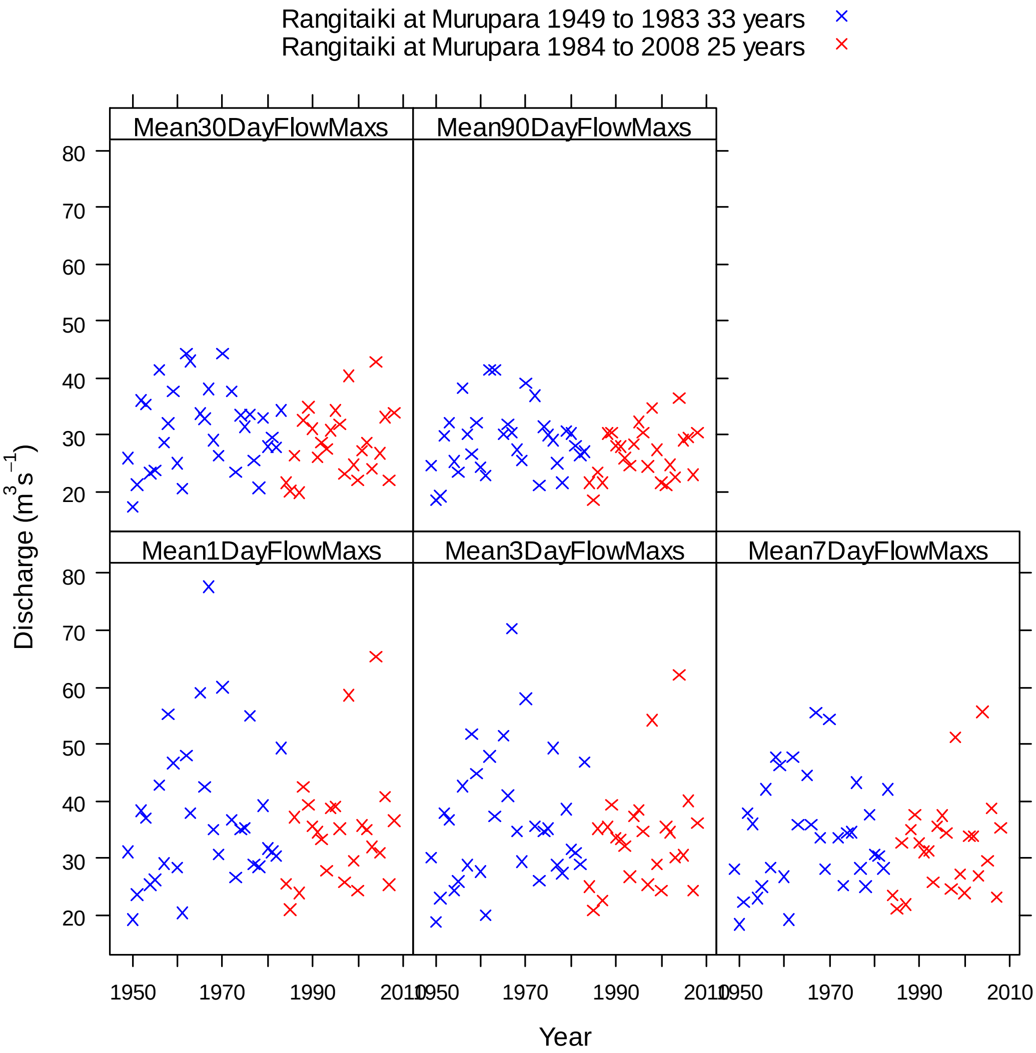


Figure 3—12: Time-series of high flow parameters during pre and post-scheme periods for the Rangitaiki at Murupara.

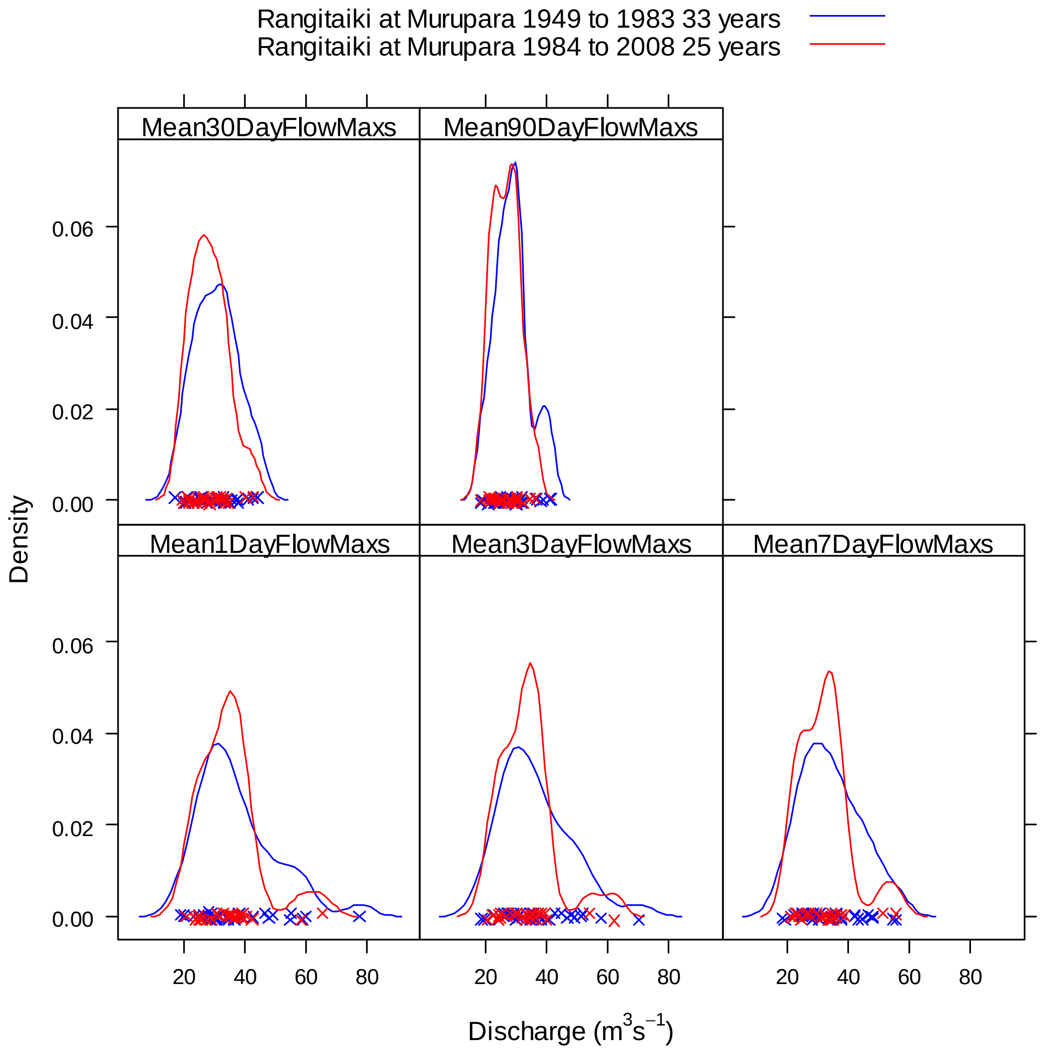


Figure 3—13: Density plots of low flow parameters during pre and post-scheme periods for the Rangitaiki at Murupara.

Frequency and duration of high and low pulses

High and low pulse events were classified as those events with a peak flow greater than 25.5 $m^3 s^{-1}$ and 17.4 $m^3 s^{-1}$ respectively. These flows correspond to the 25th and 75th percentiles of flow which are not exceeded during the pre-scheme period (Figure 3—6). Linear regressions with time showed that there was a statistically significant ($p < 0.05$) trend towards an increase in the number of low pulse events during the pre-scheme period (Table 3—5), although visual inspection of the data (Figure 3—14) suggests that this trend may be a result of heteroscedasticity (increasing variance with time) in the data. Results from ANOVA showed that there was a highly significant difference between the means of the number of low pulse events when pre and post-scheme periods were compared (Table 3—7). This difference in the number of low pulses, but not the number of high pulses, is reflected in the HAFs (Table 3—8) and kernel density distributions (Figure 3—15). The HAFs for the number of low pulses show that following 1984 there was an increase in the frequency of these low pulse events.

The median duration of high and low pulses is strongly linked with the frequency of high and low pulses respectively. For example, all daily flows in 1965 were greater than 17.4 $m^3 s^{-1}$ therefore there was only one event during this year that was greater than this threshold. This event lasted all year. The distribution of the median pulse lengths for both the pre and post-scheme periods are clearly not normally distributed, therefore results from ANOVA (Table 3—7) should be interpreted with caution. However, the HAFs suggest a considerable decrease in the duration of both low and high pulse events for the post-scheme period compared with the pre-scheme period (Table 3—8).

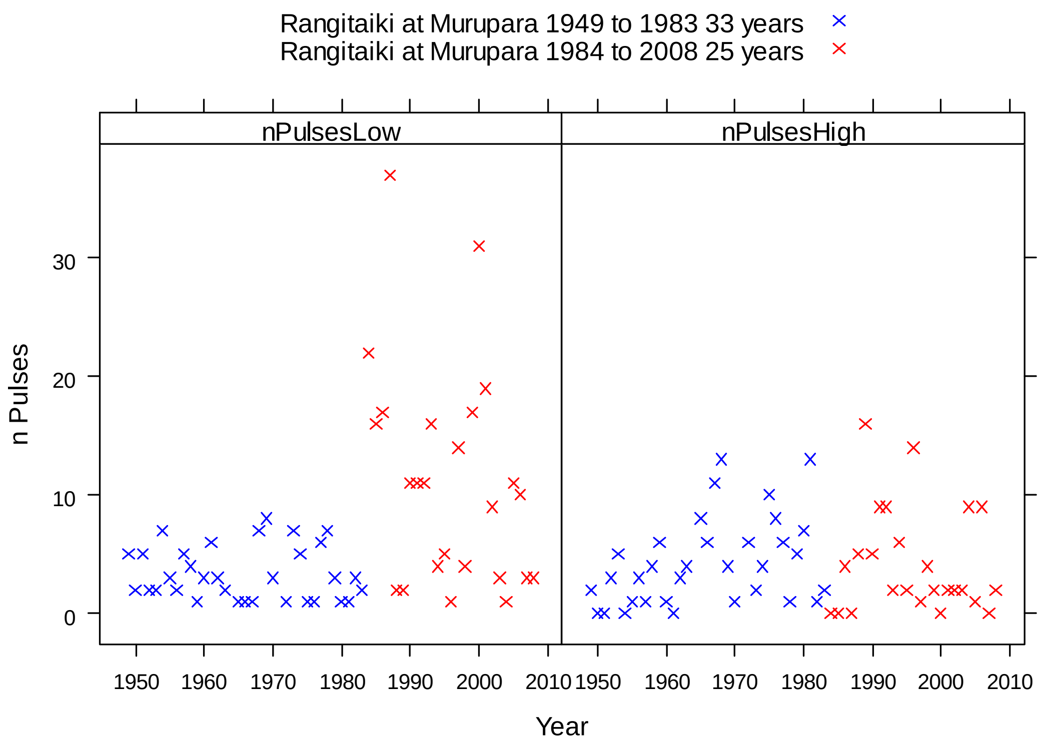


Figure 3—14: Number of low pulse and high pulse events during pre and post-scheme periods for the Rangitaiki at Murupara.

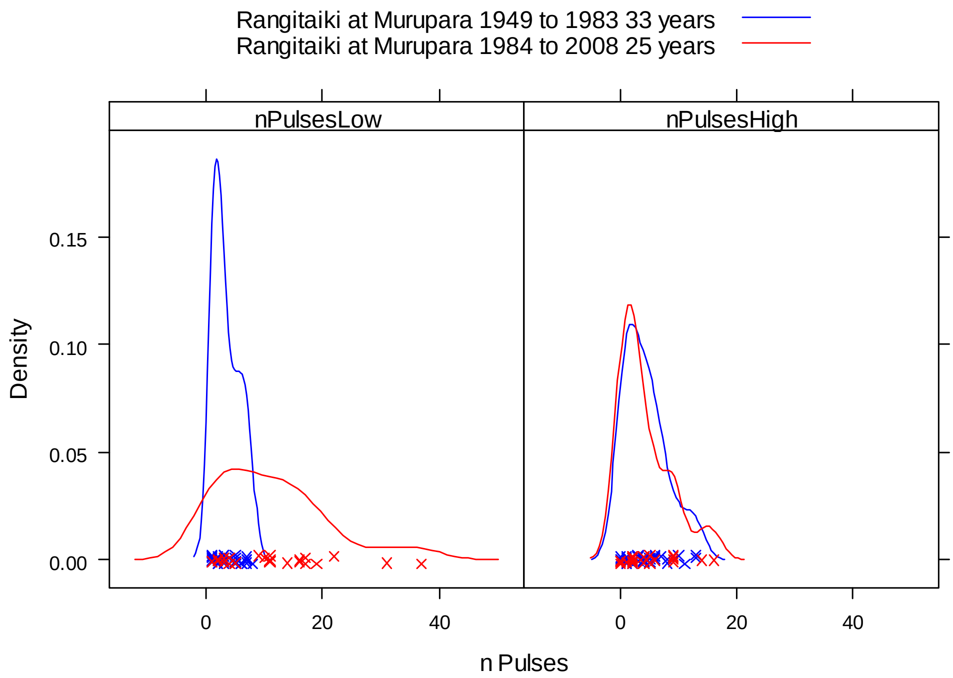


Figure 3—15: Distribution of the number of low pulse and high pulse events during pre and post-scheme periods for the Rangitaiki at Murupara.

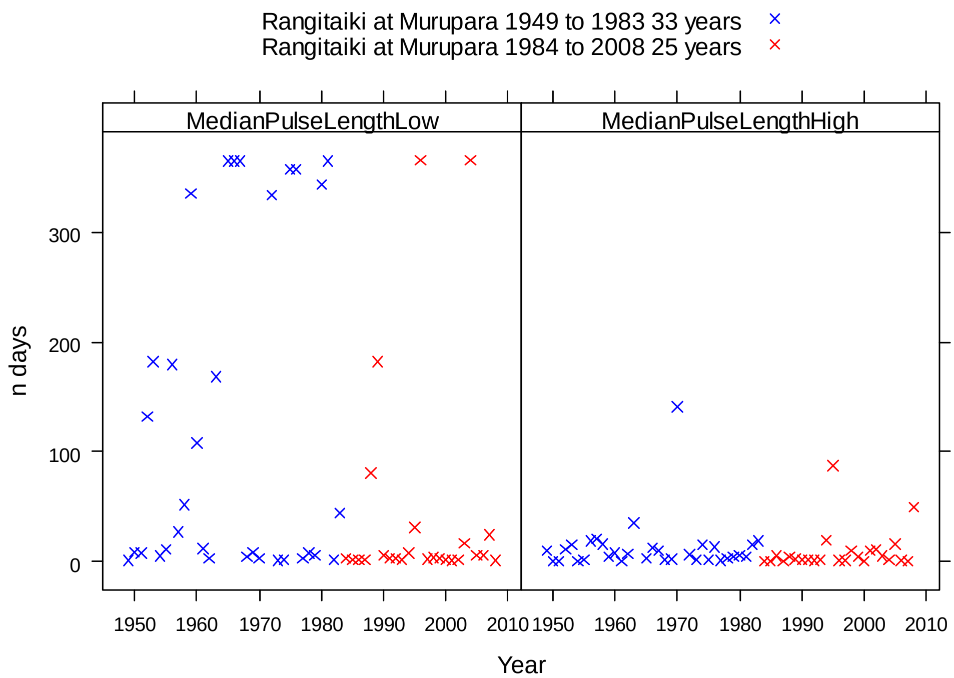


Figure 3—16: Median duration of low pulse and high pulse events during pre and post-scheme periods for the Rangitaiki at Murupara.

Rate and frequency of flow changes

The number of days on which flows are dropping (or constant) is strongly linked to the number of days on which flows are rising. This is because the sum of these two parameters for any given year should total the number days of for which there are daily records in that year. Therefore only the number of days on which flows are rising (nPos) is discussed here. Results from linear regressions with time showed that there was a statistically significant positive trend between nPos and year during the pre-scheme period (Table 3—5). There was not a significant temporal trend in nPos during the post-scheme period (Table 3—6). ANOVA results showed that there was a highly significant increase in nPos when pre- and post-scheme periods were compared (Table 3—7). This was confirmed by the HAFs (Table 3—8) and visual inspection of the data (Figure 3—17 and Figure 3—18).

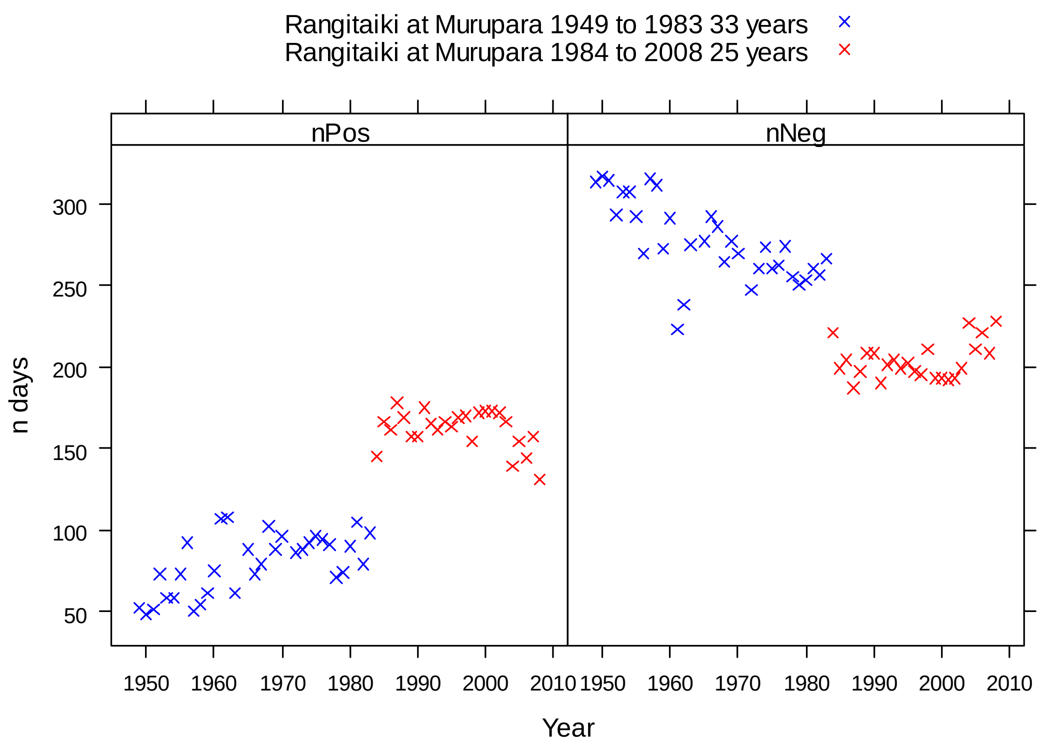


Figure 3—17: Number of days during which flow was falling and rising during pre and post-scheme periods for the Rangitaiki at Murupara.

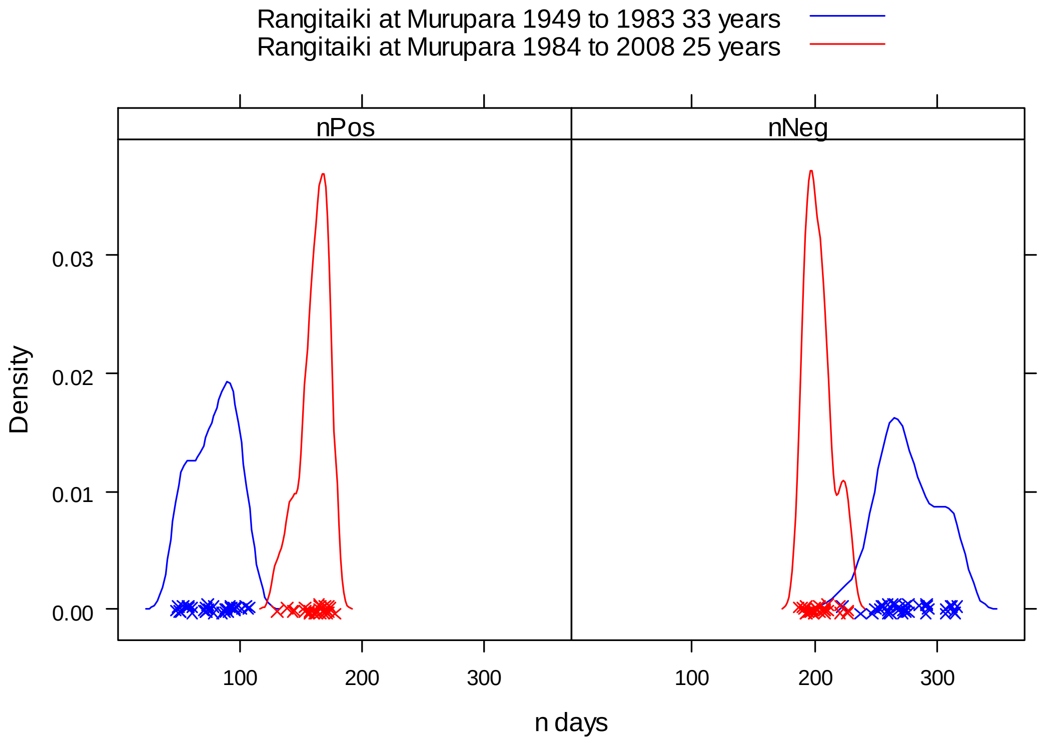


Figure 3—18: Distribution of the number of days during which flow was falling and rising during pre and post-scheme periods for the Rangitaiki at Murupara.

The median of all positive differences between consecutive days (medianPos) is a metric of the rate of change of flow during the rising limb of all hydrographs throughout the year. The median of all negative differences between consecutive days (medianNeg) is a metric of the rate of change of flow during recession limbs of all hydrographs throughout the year. A statistically significant ($p < 0.05$) negative linear trend with time was found for medianPos for the post-scheme period (Table 3—6). Statistically significant linear trends with time were found for medianNeg for both the pre-scheme (negative trend) and post-scheme (positive trend) periods (Table 3—5 and Table 3—6). Visual inspection of the annual time series shows that these trends were not consistent through these periods. ANOVA results showed that the means of medianNeg, but not medianPos, were significantly different (Table 3—7). This result corresponds well with kernel density distributions (Figure 3—20) and HAFs for these parameters (Table 3—8), which suggest that medianNeg during the post-scheme period was likely to be considerably greater than for during the pre-scheme period. In fact the majority of medianNeg values during the post-scheme period fell outside the range of that observed during the entire pre-scheme period.

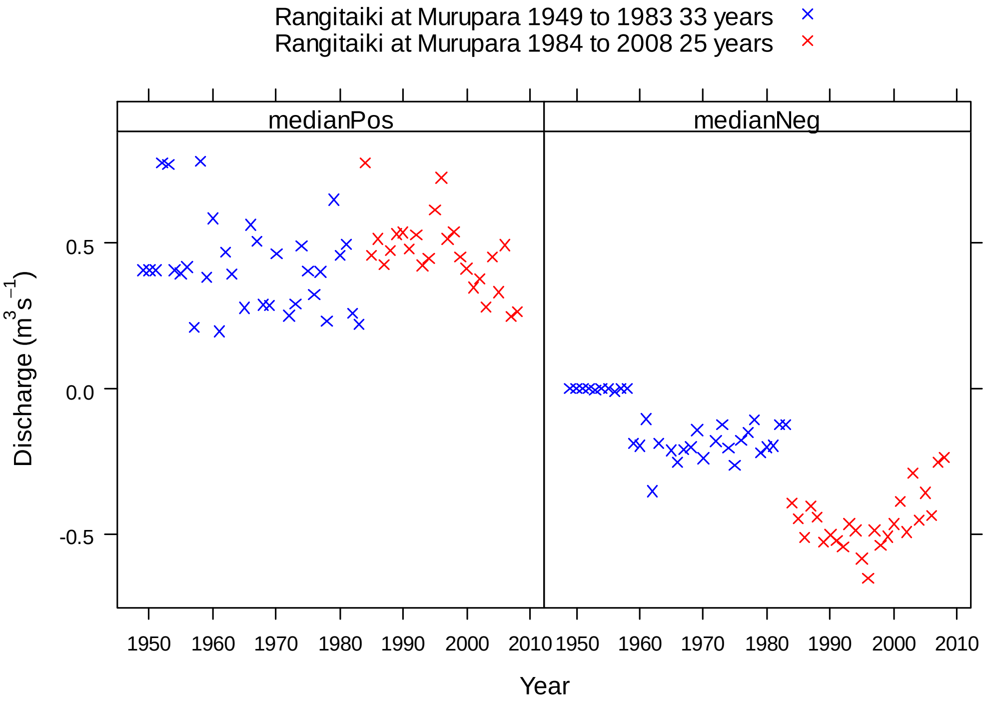


Figure 3—19: Median of all positive and negative differences between consecutive days during pre and post-scheme periods for the Rangitaiki at Murupara.

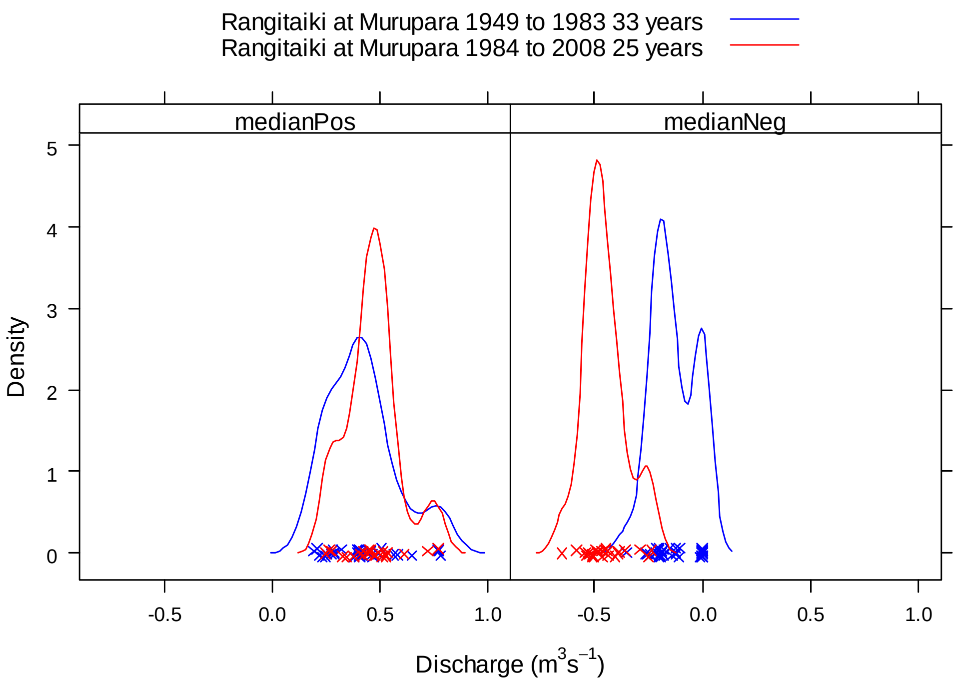


Figure 3—20: Distribution of the median of all positive and negative differences between consecutive days during pre and post-scheme periods for the Rangitaiki at Murupara.

Statistically significant ($p < 0.05$) linear trends in time were found for the number of hydrologic reversals during both the pre-scheme (positive trend) and post-scheme periods (negative trend) (Table 3—5 and Table 3—6). ANOVA results showed that the means of the number of reversals, were significantly different (Table 3—7) when the two periods were compared. Kernel density distributions (Figure 3—22) and HAFs (Table 3—8) also confirmed that there was no overlap in the distribution of the number of reversals from the pre and post-scheme periods.

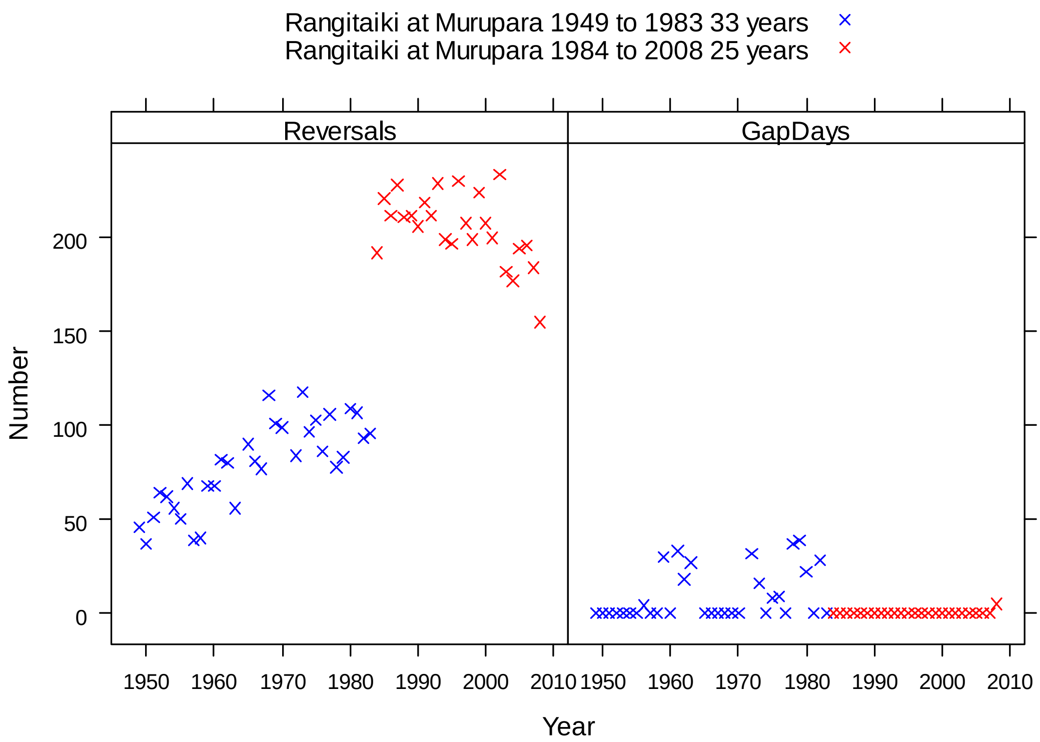


Figure 3—21: Number of hydrologic reversals and the number of days on which no flow data were recorded during pre and post-scheme periods for the Rangitaiki at Murupara.

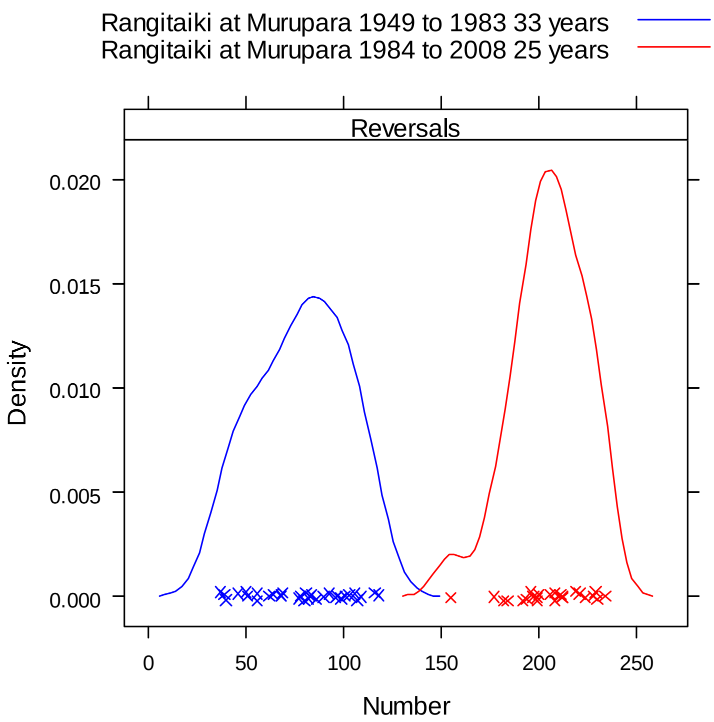


Figure 3—22: Distribution of the number of hydrologic reversals during pre and post-scheme periods for the Rangitaiki at Murupara.

3.2.5 Whirinaki results

No alternative flow scenarios or periods of contrasting river management were available for the Whirinaki at Galatea. We therefore conducted analysis of the historical data only. Thirty four IHA parameters were calculated for each year of the historical record. The annual time-series for each of the parameters was assessed for the presence of temporal trend. The presence of statistically significant trends in time within each time-series was assessed by applying linear regressions against year of record. Parameters with p-values less than 0.05 for the slope in this relationship were deemed to have statistically significant trends in time. The presence of temporal trends could suggest an alteration in the hydrological cycle, such as that which might be driven by climate change, or change in landuse/abstraction practices within the catchment.

Daily flow records

Visual inspection of the mean daily flow record for the Whirinaki at Galatea shows a flow regime that is relatively flashy, with high flow events occurring throughout the calendar year (Figure 3—23). Seasonal patterns are also evident with lower flows more likely to occur in late summer and early autumn. These patterns are reflected in the flow duration curves for the site (Figure 3—24).

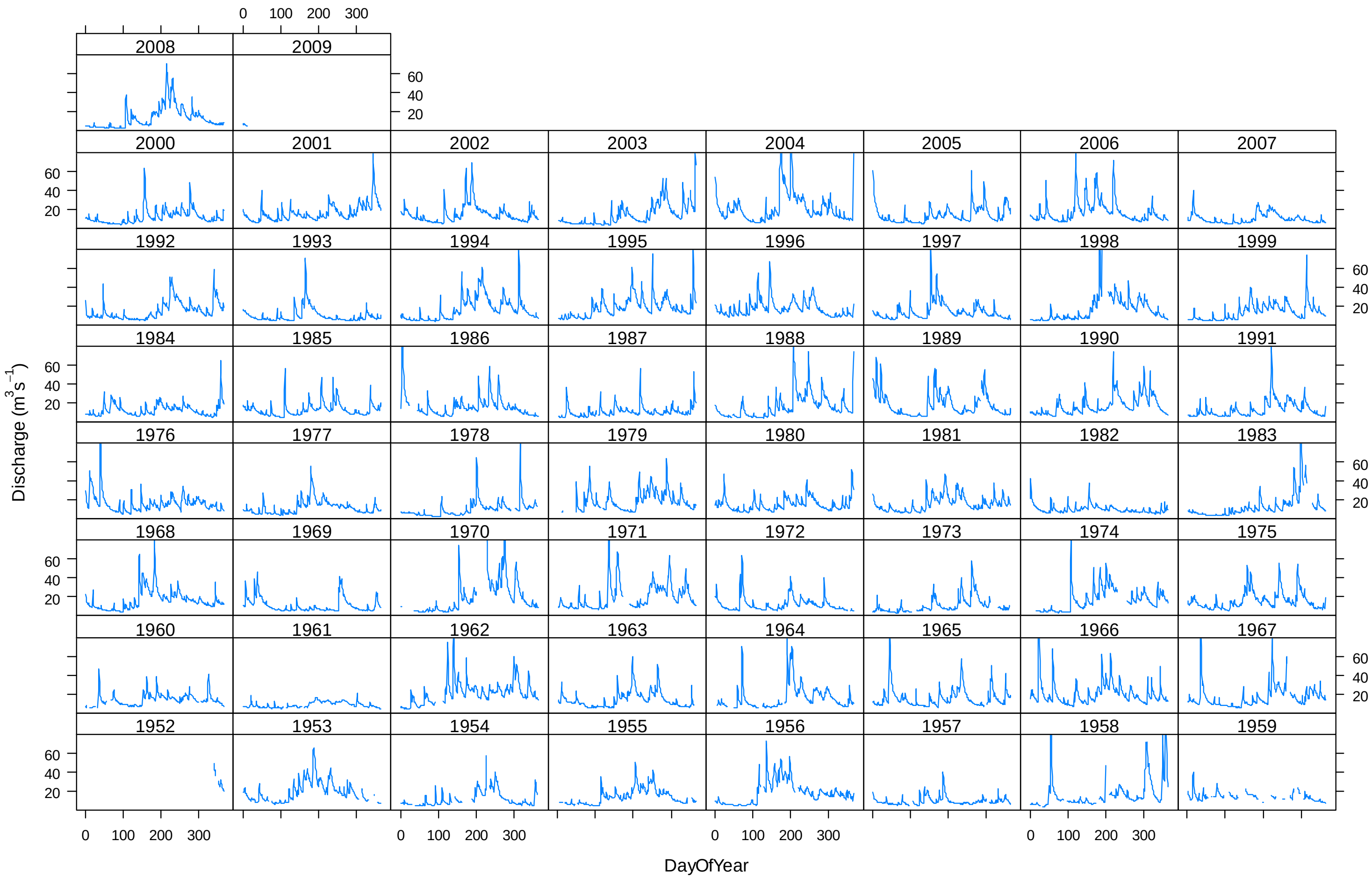


Figure 3—23: Recorded mean daily flows for the Whirinaki at Galatea. Note y-axis stops at 80 $m^3 s^{-1}$.

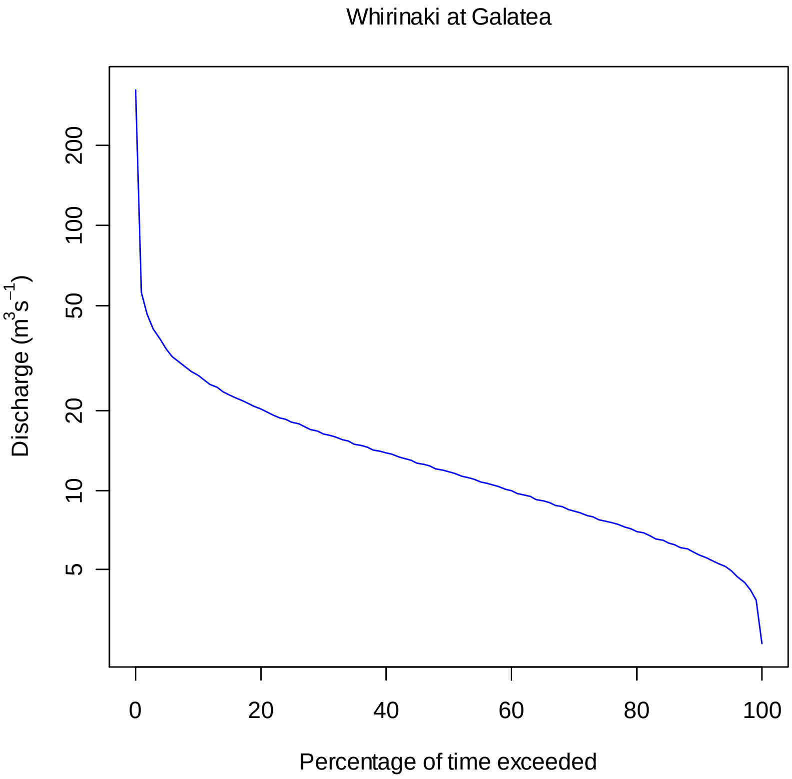


Figure 3—24: Flow duration curve for all mean daily flows for the Whirinaki at Galatea.

Prior to calculation of the IHA parameters, four years of data were removed from the analysis because they each contained more than 50 days of missing data. These four missing years were 1954, 1959, 1970 and 1979. This left 52 years of data for which IHA parameters were calculated. IHA parameters were calculated for each year from mean daily flows. Linear models were applied to test for the presence of consistent temporal trends in each IHA parameter (Table 3—9). The time-series for each of the IHA parameters are given below (Figure 3—25 to Figure 3—34).

Table 3—9: Results from linear regression between each IHA parameter and year during the period 1953–2008 for the Whirinaki at Galatea.

Group	Parameter	Estimate	Standard error	t value	p value	p < 0.05
Seasonal						
	MedianJan	0.026	0.047	0.549	0.586	FALSE
	MedianFeb	-0.033	0.039	-0.838	0.406	FALSE
	MedianMar	-0.046	0.030	-1.519	0.135	FALSE
	MedianApr	0.016	0.029	0.545	0.588	FALSE
	MedianMay	-0.066	0.044	-1.478	0.146	FALSE
	MedianJun	-0.033	0.069	-0.482	0.632	FALSE
	MedianJul	-0.025	0.073	-0.338	0.737	FALSE
	MedianAug	0.051	0.064	0.796	0.430	FALSE
	MedianSep	-0.055	0.045	-1.222	0.228	FALSE
	MedianOct	0.046	0.056	0.815	0.419	FALSE
	MedianNov	-0.021	0.055	-0.391	0.698	FALSE
	MedianDec	-0.003	0.048	-0.064	0.949	FALSE
Extremes						
	Mean1DayFlowMins	-0.003	0.009	-0.286	0.776	FALSE
	Mean3DayFlowMins	-0.004	0.010	-0.371	0.712	FALSE
	Mean7DayFlowMins	-0.006	0.010	-0.578	0.566	FALSE
	Mean30DayFlowMins	-0.009	0.012	-0.718	0.476	FALSE
	Mean90DayFlowMins	-0.009	0.018	-0.510	0.612	FALSE
	Mean1DayFlowMaxs	0.094	0.466	0.201	0.841	FALSE
	Mean3DayFlowMaxs	0.194	0.297	0.652	0.518	FALSE
	Mean7DayFlowMaxs	0.133	0.182	0.729	0.469	FALSE
	Mean30DayFlowMaxs	0.104	0.097	1.069	0.290	FALSE
	Mean90DayFlowMaxs	0.001	0.051	0.013	0.990	FALSE
	BFI	0.000	0.001	-0.355	0.724	FALSE
Timing						
	JulianMin	0.413	0.510	0.809	0.422	FALSE
	JulianMax	**1.840**	**0.902**	**2.041**	**0.047**	**TRUE**
Pulses						
	nPulsesLow	0.046	0.035	1.321	0.192	FALSE
	MedianPulseLengthLow	-0.274	0.247	-1.110	0.272	FALSE
	nPulsesHigh	0.032	0.034	0.932	0.356	FALSE
	MedianPulseLengthHigh	-0.018	0.023	-0.788	0.434	FALSE
Flow changes						
	nPos	-0.066	0.080	-0.825	0.413	FALSE
	medianPos	0.006	0.005	1.026	0.310	FALSE
	nNeg	**0.567**	**0.111**	**5.128**	**0.000**	**TRUE**
	medianNeg	0.000	0.002	-0.045	0.964	FALSE
	Reversals	**0.256**	**0.082**	**3.140**	**0.003**	**TRUE**

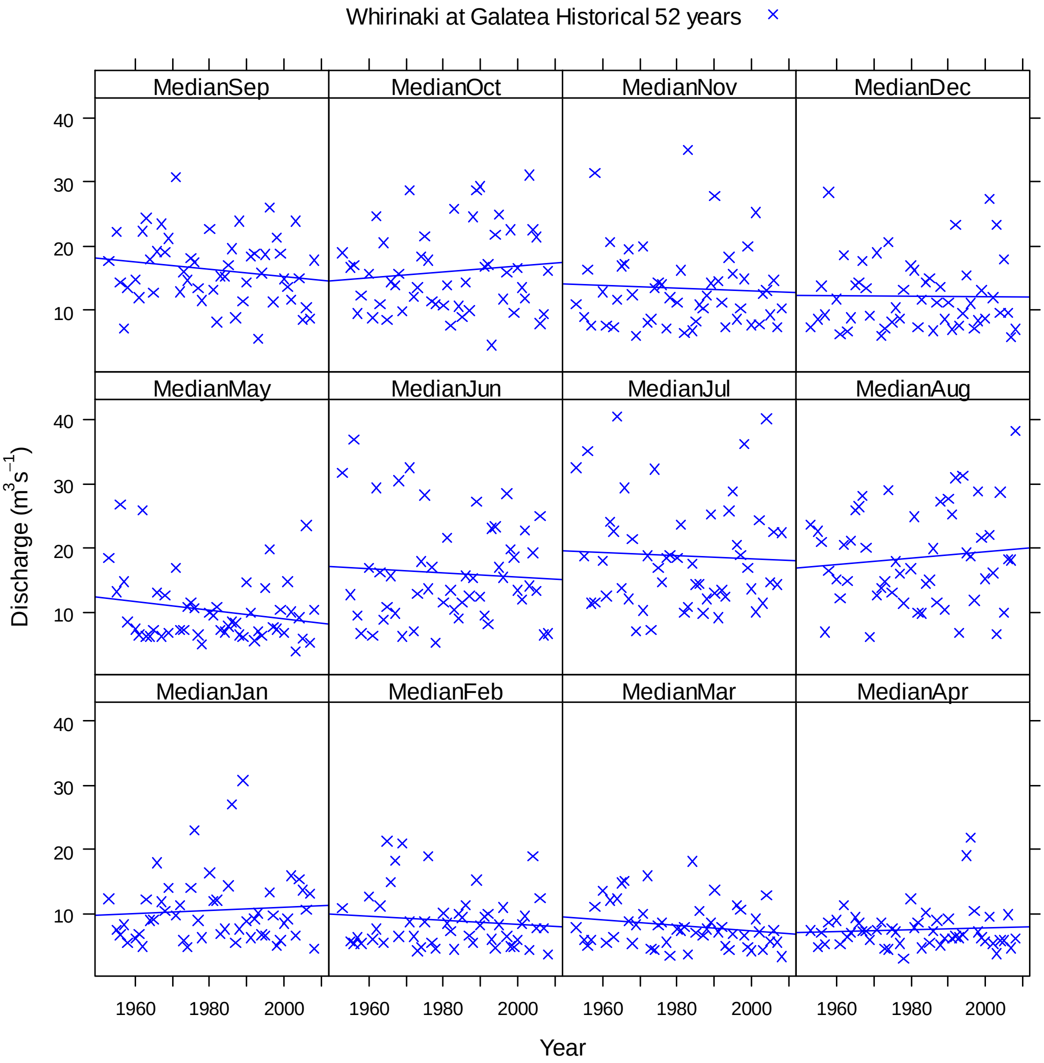


Figure 3—25: Time-series of monthly median flows for the Whirinaki at Galatea.

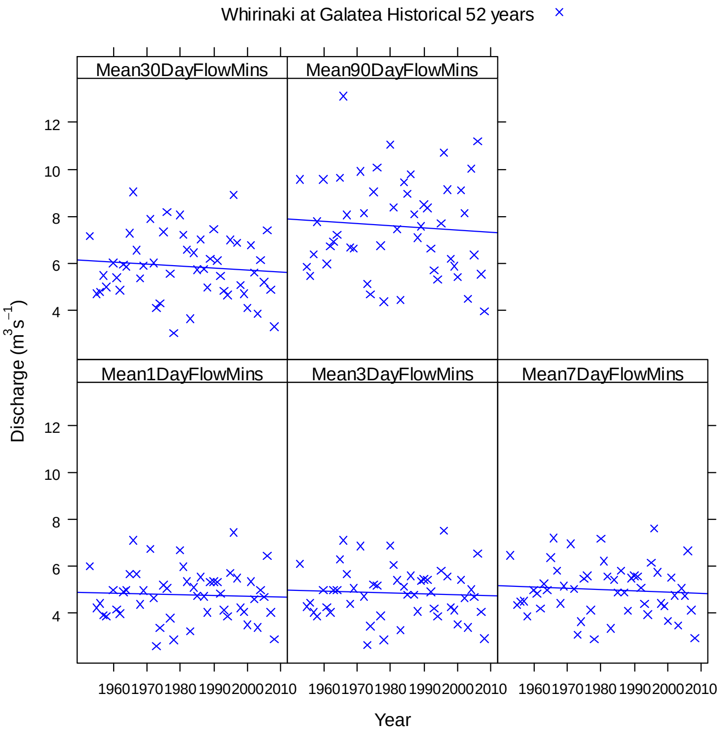


Figure 3—26: Time-series of low flow parameters for the Whirinaki at Galatea.

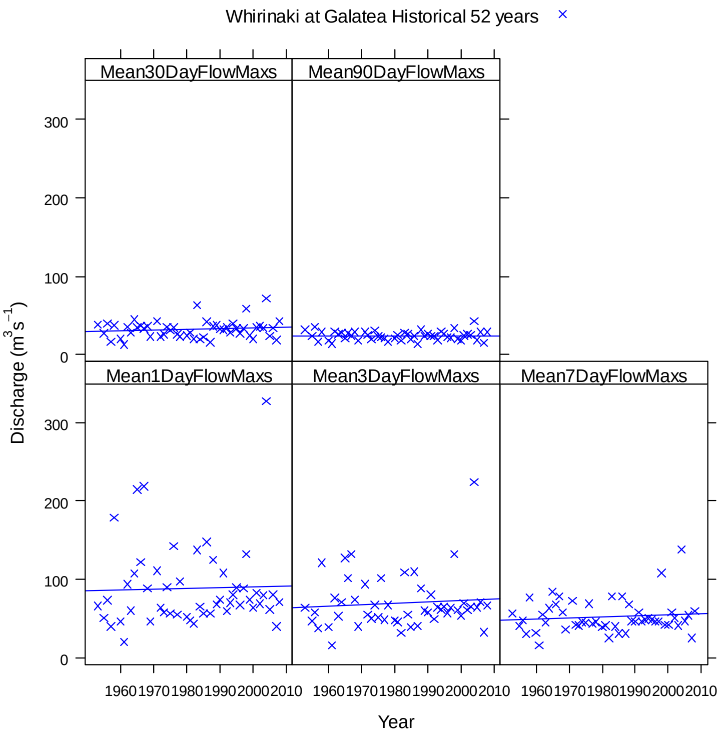


Figure 3—27: Time-series of high flow parameters for the Whirinaki at Galatea.

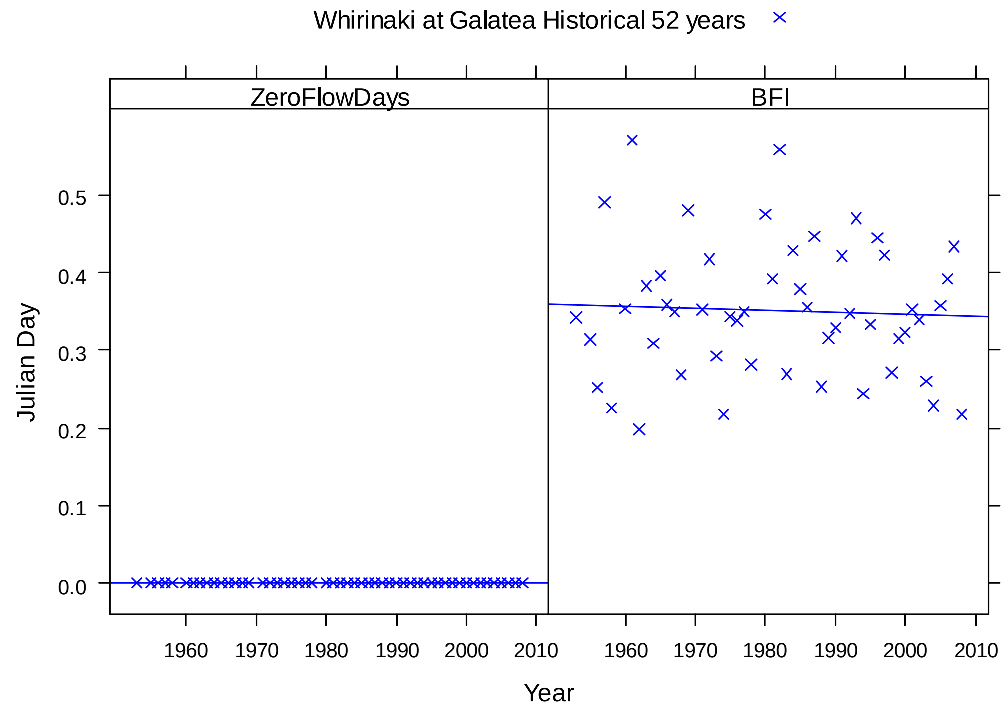


Figure 3—28: Time-series of zero flow days and Base flow index for the Whirinaki at Galatea.

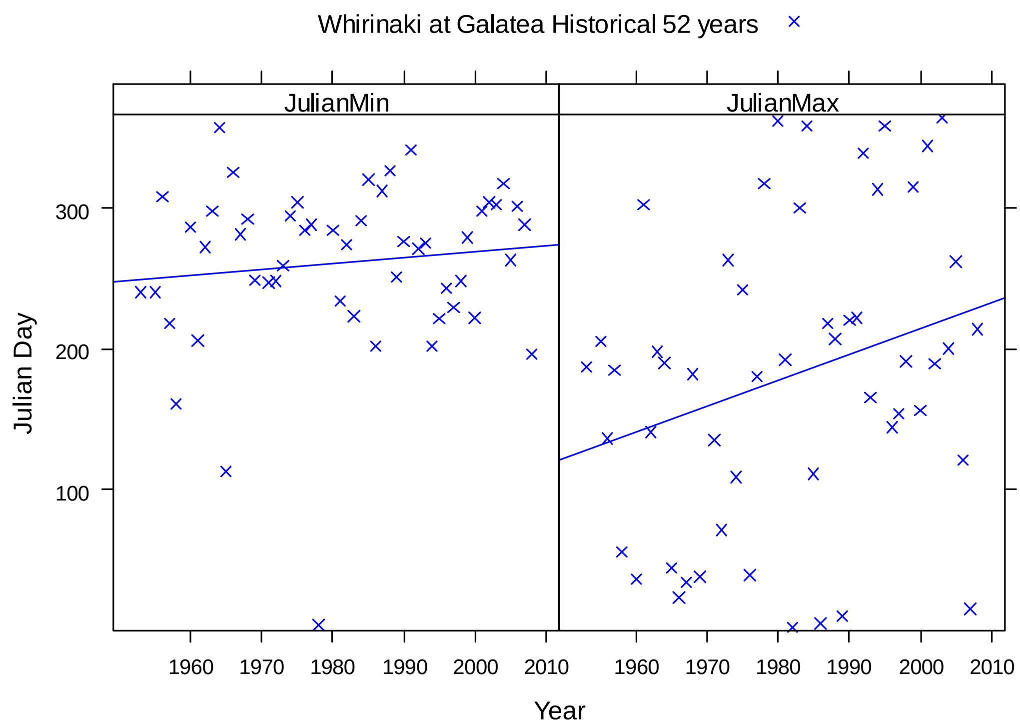


Figure 3—29: Julian days of flow minima and maxima for the Whirinaki at Galatea.

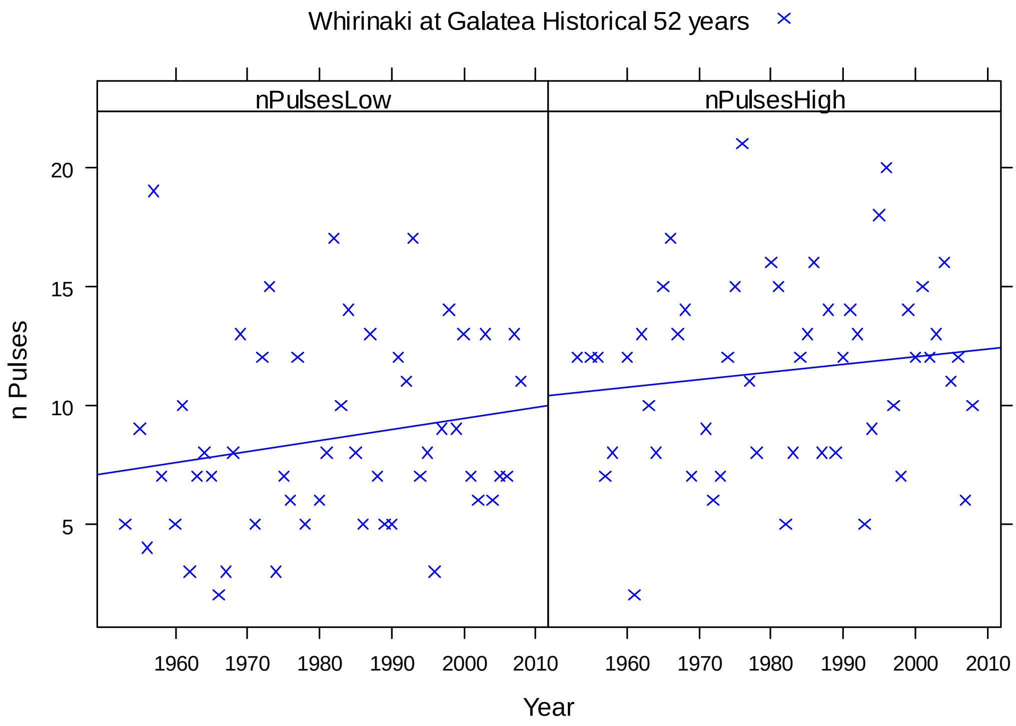


Figure 3—30: Number of low pulse and high pulse events for the Whirinaki at Galatea.

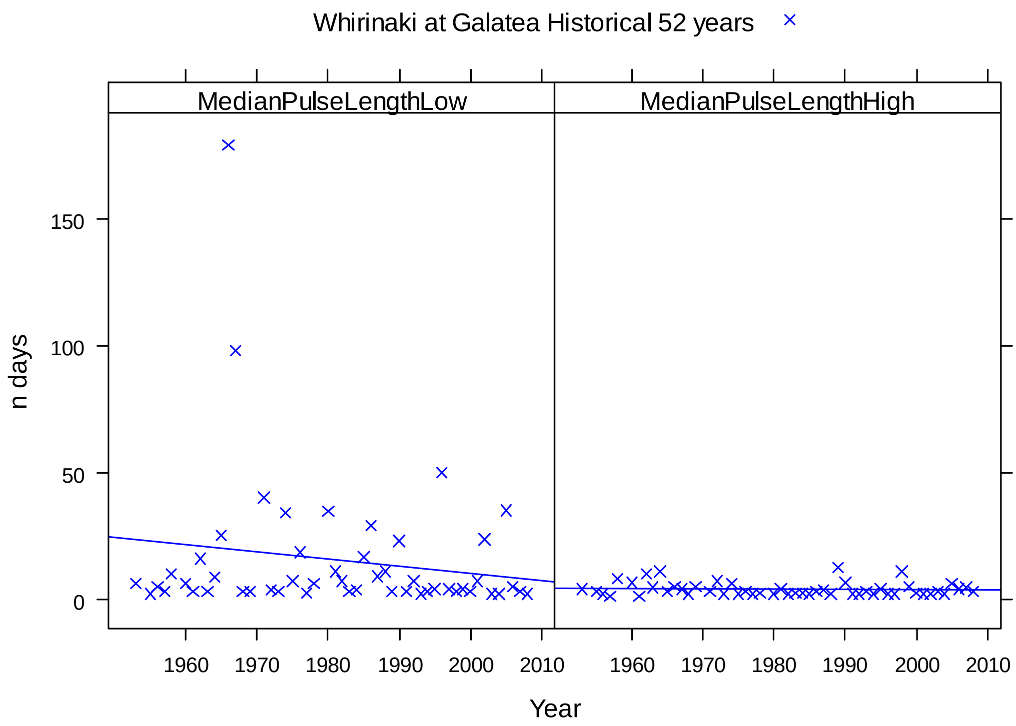


Figure 3—31: Median duration of low pulse and high pulse events for the Whirinaki at Galatea.

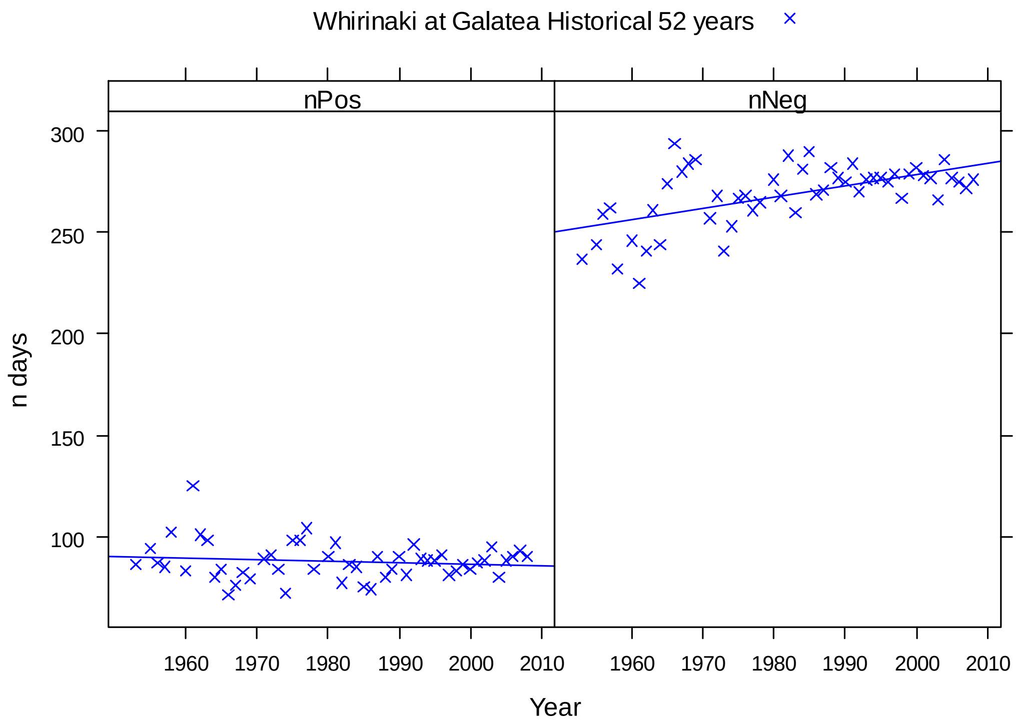


Figure 3—32: Number of days during which flow was falling and rising for the Whirinaki at Galatea.

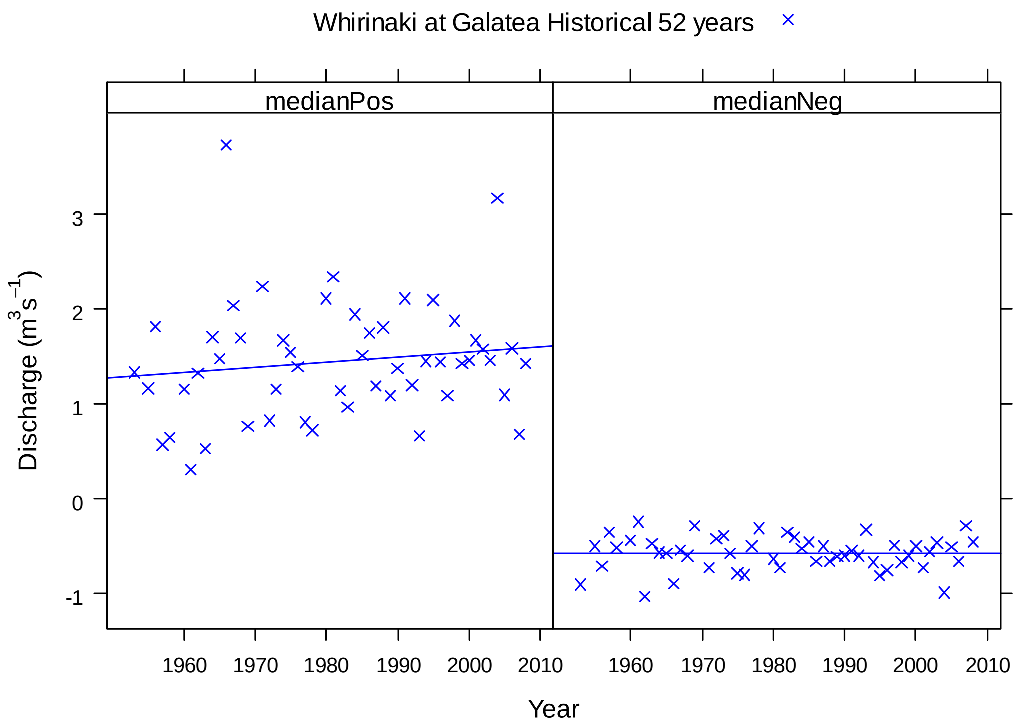


Figure 3—33: Median of all positive and negative differences between consecutive days for the Whirinaki at Galatea.

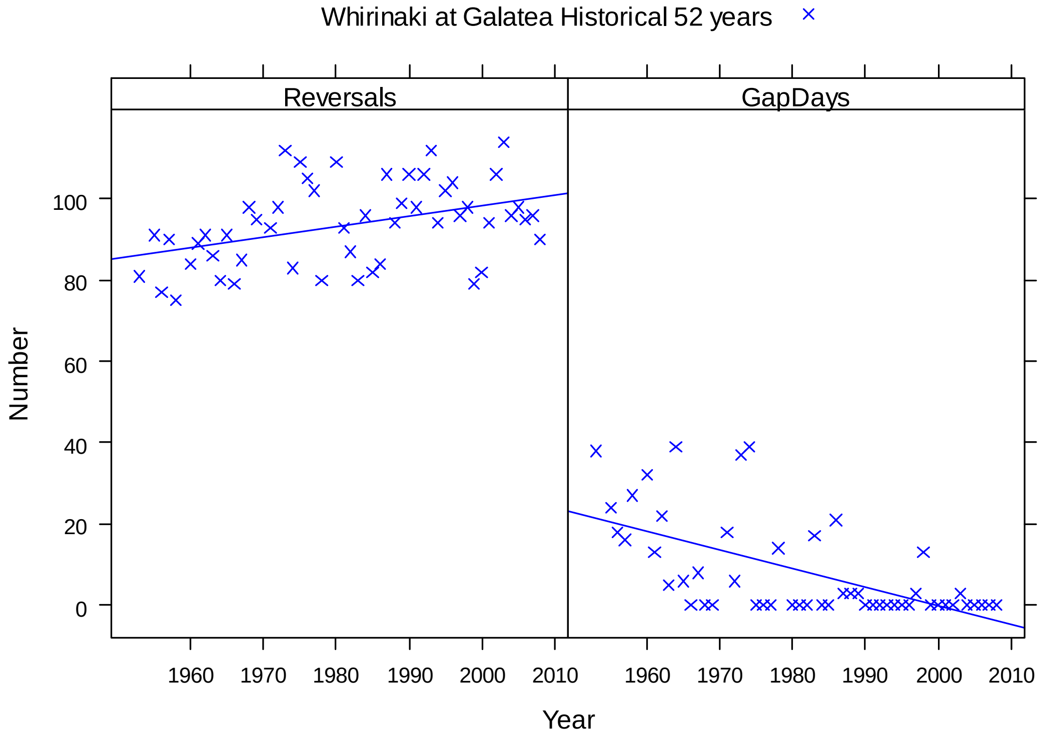


Figure 3—34: Number of hydrologic reversals and the number of days on which no flow data were recorded for the Whirinaki at Galatea.

Discussion

For this analysis we assumed that there were no errors in the mean daily flow records and that these data were collected using consistent methods throughout the period of the record. This assumption may not be correct as gauging methods and instrumentation may have changed during the observation period.

It was assumed that medians, rather than means, could be used as metrics of central tendency for the within month daily flows; the duration of both high and low pulses; and both the positive and negative differences between daily values. Further research could be undertaken to test the impacts of these assumptions.

We used mean daily data to apply the RVA. Mean daily data were used following the method outlined by The Nature Conservancy (2007) and to ensure consistency over the entire flow record. The same methods could have been employed using flow data of higher temporal resolution.

When employing the RVA we did not consider any physical hydrological mechanisms. For the Rangitaiki at Murupara we made comparisons between the hydrological conditions during two time-periods to distinguish the impacts of the Wheao Power Scheme. The period 1949–1983 was used to represent the pre-scheme period. The period 1984–2008 was used to represent the post-scheme period. Interpretation of the differences in hydrological conditions between the two periods must be made within the context of climatic and landuse conditions throughout the entire period of the hydrological record. Interpreting differences in hydrological conditions between these two periods as being solely the result of the Wheao Power Scheme, assumes that climatic and landuse conditions were constant. Analysis of climatic data, such as rainfall records, from within the catchments and changes in landuse are required to test the validity of this assumption. An alternative approach to assessing the impact of the scheme could be to undertaken simulations of the naturalised and managed flow regimes using a physically-based hydrological model.

Results for the Rangitaiki at Murupara showed that, whilst some aspects of the flow regime remained within the range of natural variability, some aspects have been significantly altered following commissioning of the Wheao Power Scheme. Given the range of natural variability, when comparing pre- and post-impact periods the following features were identified:

- there was no change in high flows;
- there was a reduction in very low flow extremes at short intervals;
- there was an increase in the number and a decrease in the duration of low pulses;
- there was an increase in the number of days during which flow was rising and subsequently a decrease in the number of days during which flow was falling;
- there was a decrease in the magnitude of change in flow for days during which flow was falling;
- there was a significant increase in the number of hydrologic reversals.

The identified changes (an increase in the frequency of short flushing flows), are consistent with what would be expected downstream of a power scheme like the Wheao scheme. It is a reflection of the artificial fluctuations induced by the generation demands. Unfortunately, the implications of these kinds of changes in hydrological regime for different instream values are largely unknown and further research is required.

No alternative scenarios were available for comparison in the Whirinaki River and so the Indicators of Hydrologic Alteration (Richter et al. 1996) variables were used to investigate long-term trends in hydrological conditions. There were no statistically significant ($p < 0.05$) linear trends over the recorded periods for any of the monthly medians, flow extreme parameters or parameters representing the behaviour of high and low pulses. Visual inspection of the data supports this finding, with no consistent patterns, such as reduction in low flows being evident. Some sequential patterns are apparent, which could be linked to long-term climate patterns such as the Interdecadal Pacific Oscillation (IPO). For example, there may be cyclical patterns within the Median flows for the month of April and the 7 day mean annual low flow.

A statistically significant trend was observed in the number of days on which flow was falling (nNeg) (Figure 3—32). According to this linear regression the number of days on which flow was falling increased at a rate of around half a day per year on average over the entire flow record. There was also a tendency for an increase in the number of hydrologic reversals (Figure 3—34). This suggests that the flow regime could be becoming flashier through time: with more frequent short rises in flow and longer periods of flow attenuation. However, the lack of significant trends in related hydrological parameters such as the number and duration of low pulses means that the process causing these patterns is difficult to interpret.

Overall the results suggest there have not been significant alterations to the flow regime of the Whirinaki River at Galatea during the period for which data are available.

Although determination of the IHAs and application of the RVA can yield a great deal of information to quantify the hydrological impacts on the natural flow regime, there are no rules that can be applied to indicate how much alteration should be recommended to sustain ecological values such as native species. It is important to note that the authors of the technique have recently published information on how these methods can be employed within an adaptive management framework (Richter et al. 2003, Richter et al. 2006). It is only within this type of framework that relationships between IHA parameters and ecosystem values or functions can be established.

3.3 Key issues

The water resources of the upper Rangitaiki River catchment have undergone significant development. The primary impacts have been through the diversion and damming for hydro-electric power schemes, but greater demand for water for irrigation in the Galatea Plains is increasing pressure on water resources in this area of the catchment. Alteration of the hydrological regime in terms of the magnitude, frequency, duration, timing and rate of change of high and low flows can have an impact on aquatic ecology and other values. However, current understanding of the links between changes in different parts of the flow regime and the nature and magnitude of the ecological response is still relatively poor. The above analysis has necessarily been restricted to a limited number of sites due to the availability of and access to suitable data. The following discussion considers these results in the context of the wider catchment and focuses on three main issues: flow diversion, flow regulation and water abstraction.

3.3.1 Flow diversion

The diversion of flow will have an impact on both the contributing and receiving rivers. The reduction of water in the contributing river will lead to reduced habitat availability, whilst increased flow in the receiving river may alter community composition by changing habitat conditions. The combination of different types of water may also impact on water quality and ecosystem dynamics. The diversion of water from one river to another may also have cultural implications.

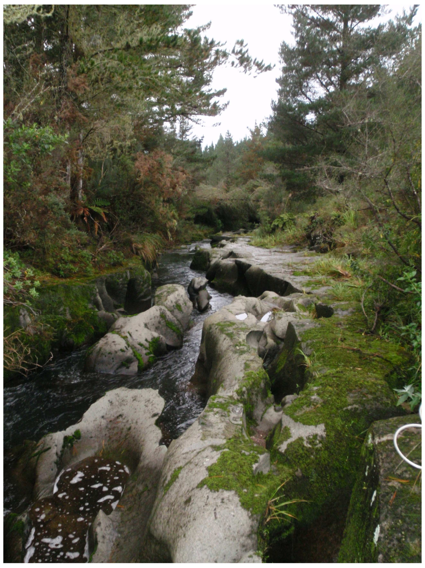
Both the Wheao and Aniwhenua power schemes involve the diversion of water from its natural course. Figure 3—35 shows some of the different components of the Wheao Power Scheme. The Wheao Dam (Figure 3—35a) was constructed to divert water from the Wheao River, into the Flaxy Lake system and subsequently through the Wheao Powerhouse and back into the Wheao River. At the time of our site visit there was no flow in the Wheao River in the reach immediately downstream of the dam (Figure 3—35b). This represents a 100% loss of habitat for aquatic species in this part of the river and would seriously degrade any cultural or recreational values associated with this reach of the river. A significant volume of water is also diverted from the Rangitaiki River to the Wheao via the Rangitaiki Canal (Figure 3—35d). This has resulted in a significant change in the habitat of the river downstream (Figure 3—35e). A minimum flow of 0.5 $m^3 s^{-1}$ in the Rangitaiki River downstream of the diversion is required by the Whaeo Power Scheme consent, but we were unable to find the reports which cited the justification for this figure. It is likely that the flow regime of the Rangitaiki River will now be more stable and experience a greater duration of low flows due to the diversion, which will have an associated impact on instream values.

a. Wheao Dam

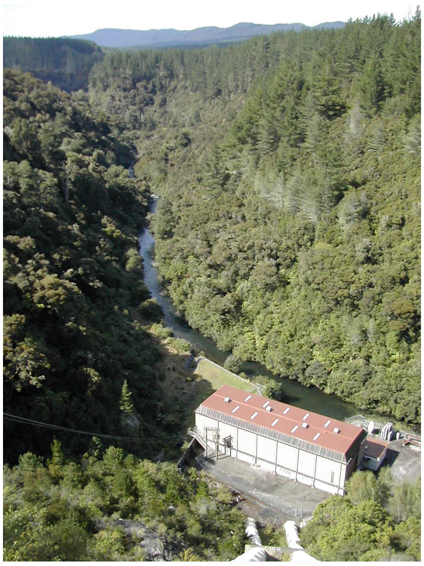
b. No flow downstream of Wheao Dam

c. Rangitaiki River diversion

d. Rangitaiki Canal



e. Rangitaiki River downstream of diversion



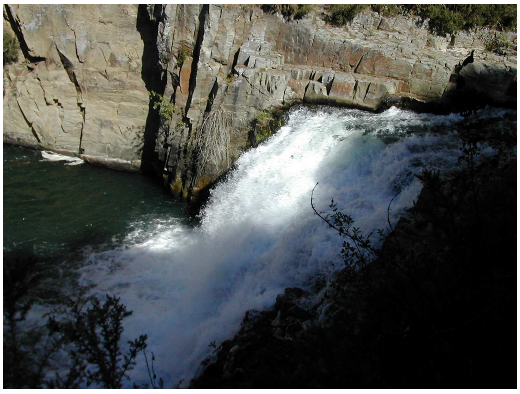
f. Wheao Powerhouse

Figure 3—35: Different components of the Wheao Power Scheme.

The Wheao River downstream of the powerhouse now receives a considerably larger flow due to transfer of water from the Rangitaiki River. This is likely to impact on the geomorphology, water quality, ecology and recreational values of the river. There are rules governing minimum permissible flows in the consents for the Wheao scheme.

In the case of the Aniwhenua Scheme, flow is diverted from Lake Aniwhenua down a canal to the Aniwhenua Powerhouse, where the water is returned to the Rangitaiki River downstream of Aniwhenua (Aniwaniwa) Falls (Figure 3—36). This means that a reach of approximately 2 km of the Rangitaiki is by-passed by the majority of flow, with only a minimum flow of 2.5 $m^3 s^{-1}$ required at Aniwhenua (Aniwaniwa) Falls. Figure 3—36c shows the channel of the Rangitaiki River upstream of Aniwhenua (Aniwaniwa) Falls and illustrates the significant reduction in wetted width, and thus potential aquatic habitat, which is caused by the diversion of water through the Aniwhenua power scheme.

a. Aniwhenua Dam



b. Aniwhenua (Aniwaniwa) Falls

c. Rangitaiki River upstream of Aniwhenua (Aniwaniwa) Falls

d. Rangitaiki River downstream of Aniwhenua powerhouse

Figure 3—36: Features of the Aniwhenua Power Scheme.

3.3.2 Flow regulation

The regulation of flows, for example through hydro-electric developments, results in a modification of the natural flow regime which can have impacts on instream values including aquatic ecology, recreational activities and may be inconsistent with cultural principles. Techniques to evaluate the changes in flow regime caused by flow regulation, e.g., RVA, are becoming increasingly well established and more widely utilised for making decisions regarding water allocation. It was illustrated above that the development of the Wheao Power Scheme has changed the flow regime of the river, with an increase in the number of small flushing flows and a higher rate of decline as flow recedes identified at a daily time-step. These patterns are determined by the daily generation requirements of the scheme. Knowledge regarding the ecological significance of these changes is poorly developed, but flow changes at this scale could potentially be linked to local scale habitat choices and feeding behaviour. It should also be noted that the hydrological analysis was carried out at a daily time step (i.e., using the average flow for the whole day). At the sub-daily time scale (i.e., from hour to hour) the operation of the Wheao Power Scheme results in artificial fluctuations in flow of typically 3–5 $m^3 s^{-1}$ over a day, with the transition from minimum to maximum flow typically taking place over about a six hour period. This is estimated to be approximately equivalent to a 150 mm variation in river level at Murupara, giving a ramping rate of approximately 25 mm hr^{-1}. High ramping rates can cause stranding of aquatic fauna, but the relatively deep, uniform shape of the Rangitaiki River channel means the risk of this happening is relatively low compared to shallower braided rivers. These sub-daily flow fluctuations will however impact on micro habitat conditions within the stream and thus could affect the behaviour of fish and their habitat choices throughout the day.

Because the Wheao Scheme is essentially a run of the river scheme, with limited storage capacity, the impacts on the flow regime are more restricted. The Aniwhenua and Matahina schemes are likely to have a more significant impact on the downstream flow regime due to the greater storage capacity available in the lakes. This allows greater manipulation of generation capacity, and hence flows, to match demand requirements. Aniwhenua, for example, follows a typical twin peaking regime whereby generation (and hence discharge) is highest in the morning and in the evening, and lowest at night, reflecting the pattern of demand for electricity. This results in a daily range in flows of approximately 25 $m^3 s^{-1}$ and an estimated difference between minimum and maximum water levels of approximately 300 mm. These changes typically occur over a period of 2–3 hours giving an approximate ramping rate of 100–150 mm hr^{-1}. It is important that this ramping rate (rate at which flows are increased or decreased) is carefully controlled, e.g., through resource consent conditions, because high ramping rates can result in stranding of aquatic organisms and also present potential hazards for recreational users of the river. Whilst there is now considerable evidence to show that flow regulation, particularly downstream of dams, has a negative impact on aquatic communities (Bain et al. 1988, Milhous 1982, Petts 1984, Swales 1989), the exact mechanisms are still relatively poorly understood.

3.3.3 Abstraction

Abstraction of water generally impacts only on low flows. Typically, the magnitude of low flow conditions is reduced and the duration of the flow event is increased. This can place pressure on aquatic communities by altering habitats and increasing competition between individuals. If low flows persist, increases in siltation, impaired water quality and higher temperatures may also occur.

Irrigation demand on the Galatea Plains has significantly increased with the intensification of dairy farming. The Galatea Plains provide well-drained alluvial soils that dry out quickly in summer. Surface and groundwater resources on the plains are approaching or exceeding the limits set by EBOP and thus pressure on water resources is high. Figure 3—37 shows the location of currently consented water abstractions in the upper Rangitaiki catchment. The majority of the takes are surface water abstractions for irrigation purposes. The maximum daily groundwater take is 32,615 m^3 d^{-1} and the maximum daily take from surface water is 77,645 m^3 d^{-1}. In the Whirinaki River, the current maximum consented surface water take is 16,618 m^3 d^{-1} compared to a median flow rate in the river of 1,010,880 m^3 d^{-1}. The maximum direct take consented for the Rangitaiki River upstream of Aniwhenua Dam is 31,245 m^3 d^{-1} compared to a median flow in the river of c.3,456,000 m^3 d^{-1}. However, the Rangitaiki River would be indirectly subject to the cumulative effect of all abstractions from the catchment. The impacts of abstraction are potentially greater on the two smaller tributaries draining the Galatea Plains, where maximum consented surface water abstraction totals 25,678 m^3 d^{-1}. Lack of information regarding flows in these streams limits our ability to assess the potential magnitude of the impact of abstraction in these tributaries.

Since 1990 consents granted have included conditions requiring reporting of the quantity of water taken and in 2001, conditions were introduced to allow for review of consents to alter management practices to prevent adverse impacts on the environment[8]. In addition to consented takes, surface water takes of up to 15 m^3 d^{-1} per property are also permitted under the Regional Land and Water Plan (EBOP 2009). Such takes are subject to the conditions that the rate of abstraction shall not exceed 2.5 L s^{-1} or 10% of the estimated five year low flow at the point of abstraction (whichever is lesser), and that total abstraction of all users does not exceed the IMFR (EBOP 2009).

[8] Anya Lambert (EBOP), personal communication

Instream minimum flow requirements are used by EBOP as a tool to protect instream values from over exploitation. The aim is to ensure that a suitable flow is maintained to prevent unacceptable impacts on instream values. Work to establish IMFRs has been carried out for the Rangitaiki River and the Whirinaki River (Wilding 2004 & 2006). Whilst analysis of flows in the Whirinaki River indicated no long term downward trends in low flows, it should be noted that the gauging station is located at the foothills of the Ikawhenua Ranges and thus will not include the effects of any abstraction that may take place on the plains, downstream of this site. Wilding (2004), however, noted that based on assessment of protecting instream habitat for fish, no water is available for allocation from the Whirinaki River.

The Galatea-Murupara Irrigation Society have been investigating potential sources of water for irrigating farms on the Galatea Plains (Aqualinc 2004, Aqualinc 2006a, Aqualinc 2006b, Aqualinc 2006c, Aqualinc 2006d). The preferred option was for a gravity fed irrigation scheme with an intake located on the Rangitaiki River upstream of Murupara (Aqualinc 2006a). The estimated maximum required take for that scheme was 5.3 $m^3\ s^{-1}$ (Aqualinc 2006c). However, since this proposal, the IMFR based on fish habitat availability for the reach where the proposed take is to be located has been determined at 10.5 $m^3\ s^{-1}$, which would leave an allocable flow of only 2.5 $m^3\ s^{-1}$ and thus render the scheme unfeasible. It is understood that a new proposal is under development in association with Trust Power, but details of this scheme are currently not available.

Demand for water in the other streams draining the Galatea Plains is also high, but only limited information is available on flows in these streams. Currently, no IMFR has been determined for these streams and thus the default protection value of 90% of Q_5 is applicable.

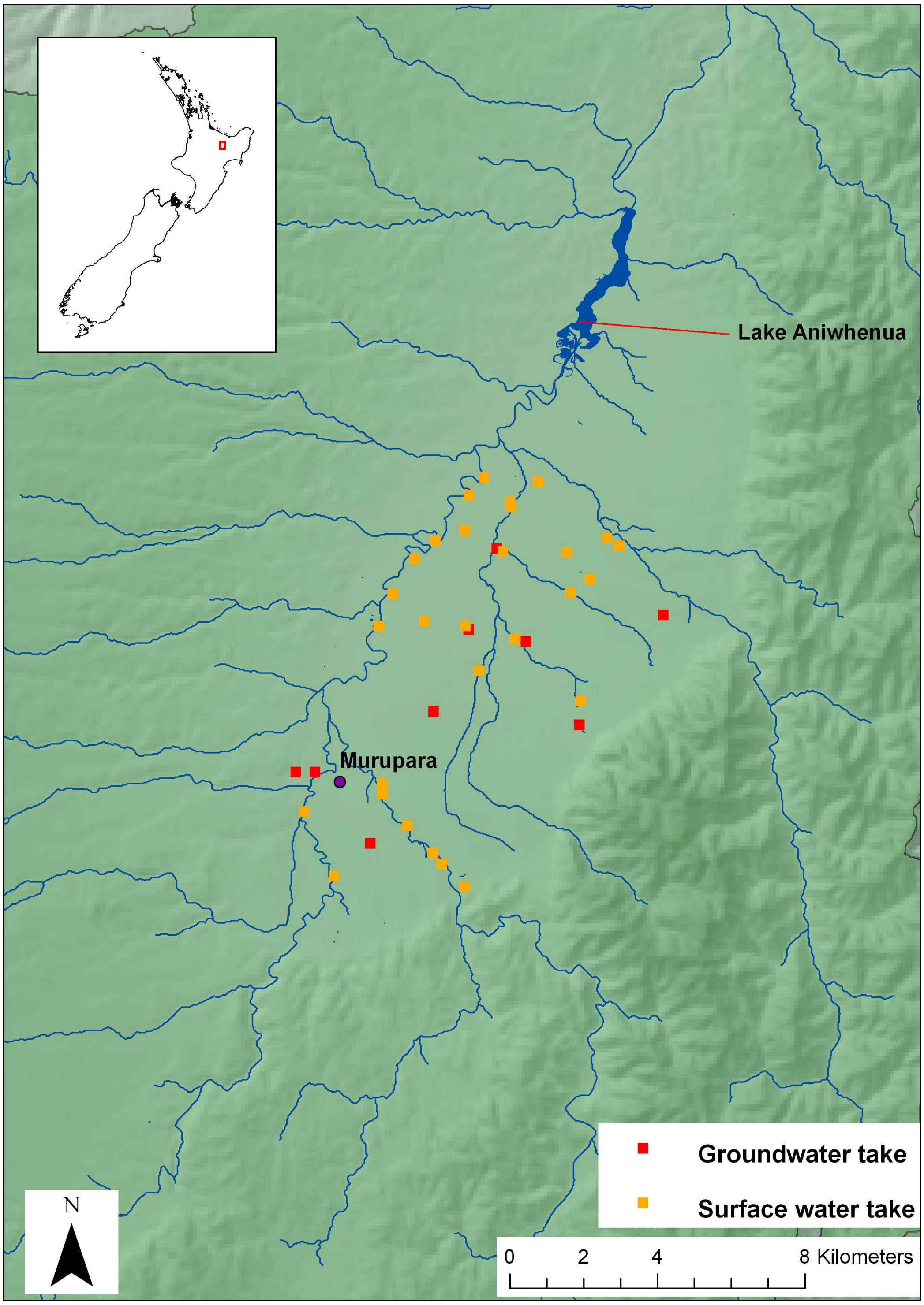


Figure 3—37: Location of current consented groundwater and surface water abstractions in the upper Rangitaiki catchment (data supplied by EBOP).

3.4 Knowledge gaps

- Understanding of the relationships between different components of the flow regime and instream values is limited.
    - In order to determine what degree of alteration in the flow regime is acceptable, it is necessary to identify the mechanisms which link changes in flow to ecological responses, e.g., downstream migration of eels.
- IMFRs for the Rangitaiki River and Whirinaki River are incomplete and not available for the other streams draining the Galatea Plains.
    - Until IMFRs reflecting all values (e.g., those of Ngati Manawa and of recreational water users), are determined, there is a risk that water will be over allocated, resulting in unacceptable impacts on instream values.
- The impacts of the diversion of the Rangitaiki River for the Wheao Power Scheme are unclear.
    - Trust Power state on their website[9] that extensive trout monitoring in the Wheao River indicates that the scheme has had no negative impact on the trout populations. At the time of writing it has not been possible to obtain copies of these reports. It is also not clear if the monitoring extended to the Rangitaiki River downstream of the diversion or whether impacts on other aquatic flora and fauna have been considered.

3.5 Conclusions and recommendations

Overall, the flow regime of the Rangitaiki River has been significantly impacted by the hydro-electric developments on the river. However, it is unclear how these alterations in flow regime may impact on the ecology of the river due to the lack of knowledge of the linkages between flow and ecological responses. The impacts of flow regime changes on other instream values, e.g., cultural and recreational, have not been assessed. The increasing demand for water to support the intensification of dairying in the Galatea Plains has the potential to significantly increase pressure on the Rangitaiki River itself, as well as on many of the tributaries. The extent of the impact in the tributary streams is unclear and needs to be determined.

[9] http://www.trustpower.co.nz/index.php?section=113

4. Groundwater and hydrogeology

4.1 Groundwater

Gil Zemansky, GNS Science (GNS), Wairakei

This chapter assesses groundwater resources of the upper Rangitaiki River catchment that lies within the Ngati Manawa rohe. The assessment is done in two sections:

a. Technical assessment of groundwater

   - Assessment of geology relevant to groundwater resources.
   - Assessment of groundwater levels and flow directions.
   - Assessment of current groundwater quality.
   - Assessment of current groundwater takes.
   - Assessment of ground-surface water relationships.
   - Identification of factors potentially impacting groundwater resources.

b. Assessment/review of groundwater regulatory system

   - Assessment of current groundwater quality standards.
   - Review of local government regulatory system.
   - Review of national government regulatory system.

The upper Rangitaiki River catchment, which is the subject of the present assessment, is shown coloured orange and yellow in Figure 4—1. Within this upper catchment are eight subcatchments (Figure 4—1). Seven were identified in a GIS file provided by EBOP. The additional subcatchment, shaded yellow in Figure 4—1, was defined by GNS from surface topography and drainage features shown on the topographic map. Surface area of subcatchments and GIS attribute numbers are listed in Table 4—1

Table 4—1: Subcatchments of the Upper Rangitaiki River[1].

ID #	Subcatchment name	Main stream in subcatchment[2]	Area[3]	
			km²	Hectares
–	NE Corner	None (direct to Rangitaiki River)	55	5,504
0	Horomanga	Horomanga River	201	20,063
1	Whirinaki	Whirinaki River	519	51,894
2	Pouarua	Rangitaiki River main stem	237	23,721
3	Otamatea	Otamatea River	114	11,379
4	Kaingaroa	Rangitaiki River main stem (fed by small streams to west)	704	70,352
5	Wheao	Wheao River	242	24,158
6	Mangatiti	Mangatiti Stream	205	20,532
Total			**2,276**	**227,603**

Notes:

Subcatchments identified from EBOP shape file on Version 9.2 of ArcMap geographical information system (GIS), with exception of northeast (NE) corner.

1 Area of "NE corner" estimated by small streams and topography in GIS.

With exception of NE corner, identification numbers and names of area as listed in EBOP GIS attribute table for subcatchments involved.

2 Main stream in subcatchment as identified from review of topographic map (Figure 2).

3 Areas as calculated by GIS for subcatchments involved and listed in EBOP GIS attribute table.

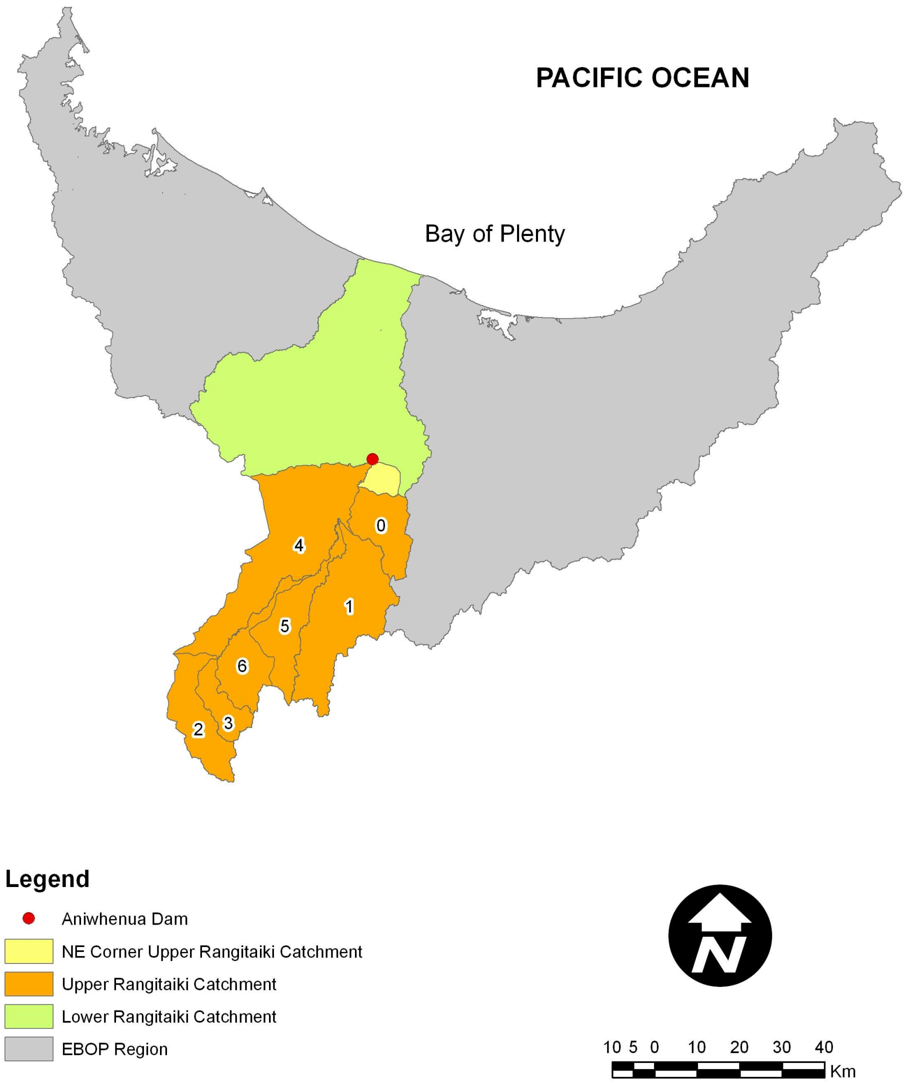


Figure 4—1: Location of Rangitaiki River and upper catchment within the Bay of Plenty Region.

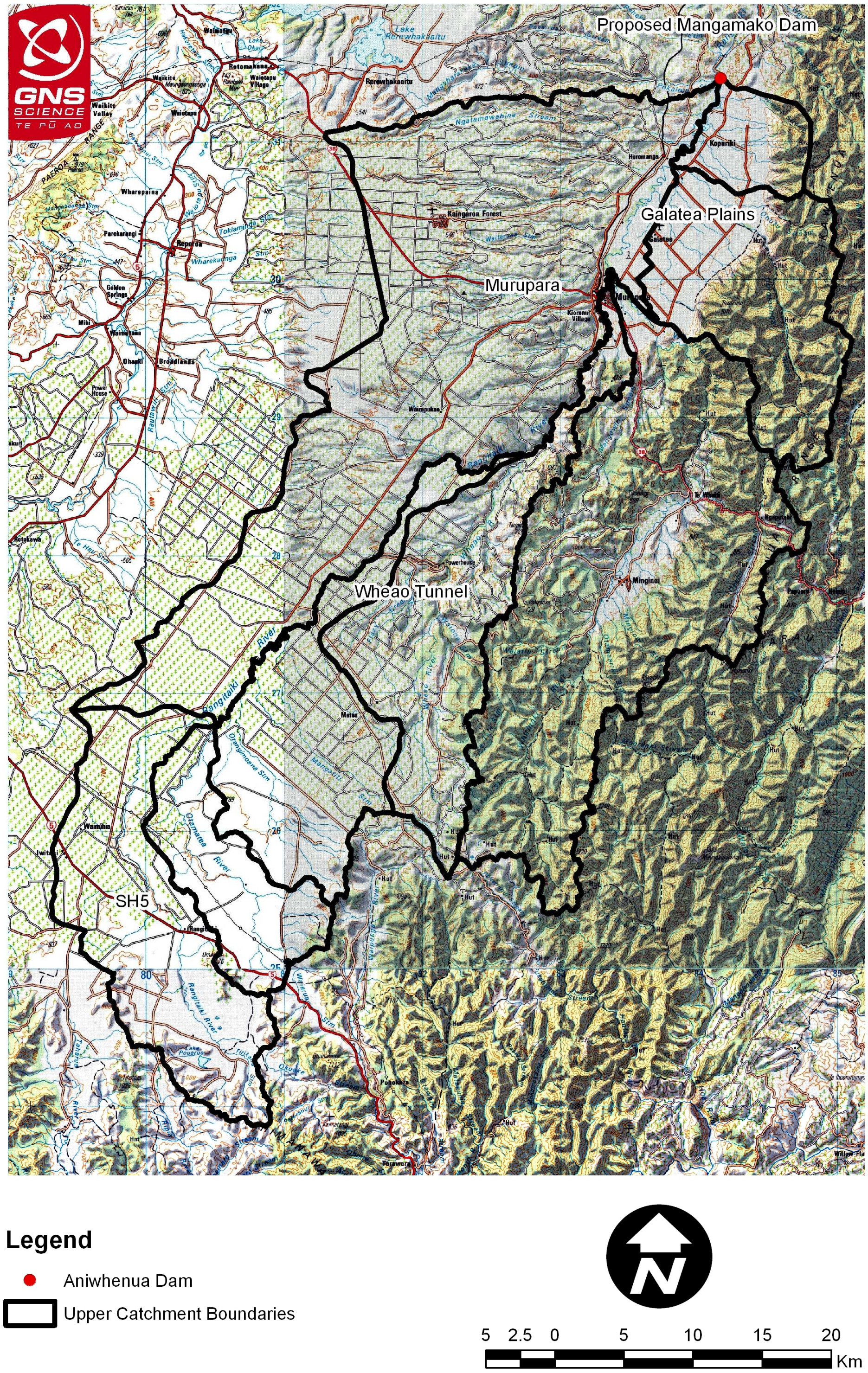


Figure 4—2: Subcatchments within the Lake Aniwhenua catchment.

4.1.1 Technical assessment of groundwater

Geology

The geology of New Zealand is a consequence of its modern day position on the tectonic boundary of the Indian-Australian and Pacific plates. The collision of these plates causes the thin-dense Pacific plate to subduct underneath the thicker but less-dense Indian-Australian plate (carrying the North Island). This subduction forms the Hikurangi Trough off the east coast of the North Island. Associated with this subduction are faults, running from the south tip of the North Island in a north-northeasterly direction to the Bay of Plenty, and volcanic activity occurring within the Taupo Volcanic Zone (TVZ), extending along the fault system from Mt. Ruapehu in the south to White Island in the Bay of Plenty (GNS, 2009 and University of Waikato, 2009).

The geology of the upper Rangitaiki River catchment consists of:

- A superficial cover of Holocene age pyroclastic materials (largely pumice and ash, deposited less than 10,000 years ago), overlying.

- Pleistocene age ignimbrite sheets (poorly sorted pumice and ash deposits from pyroclastic flows, deposited 1.6 million years ago to 10,000 years ago), which unconformably overlie.

- Mesozoic age greywacke basement rock (deposited about 248 to 65 million years ago).

The order of ignimbrites by age (from youngest to oldest) is Kaingaroa, Rangitaiki, and Te Whaiti. There are also surface or near surface deposits of Matahina ignimbrite material in northern areas of the upper catchment. Matahina ignimbrite was deposited in the time period between deposition of the Rangitaiki and Kaingaroa materials. The upper Rangitaiki River flows largely over the Kaingaroa Plateau, bounded on the east by the uplifted greywacke rocks of the Ikawhenua Range mountains (on the west side of Te Urewera National Park) and on the west by the Kaingaroa fault on the east side of the TVZ.

There are a series of faults running the length of the catchment (see Hancock & Aust 1979, Stagpoole 1994, Williams 1979). The series of faults from west to east are: the Wheao, Rangitaiki, Te Whaiti, and Waiohau (Figure 4—1).

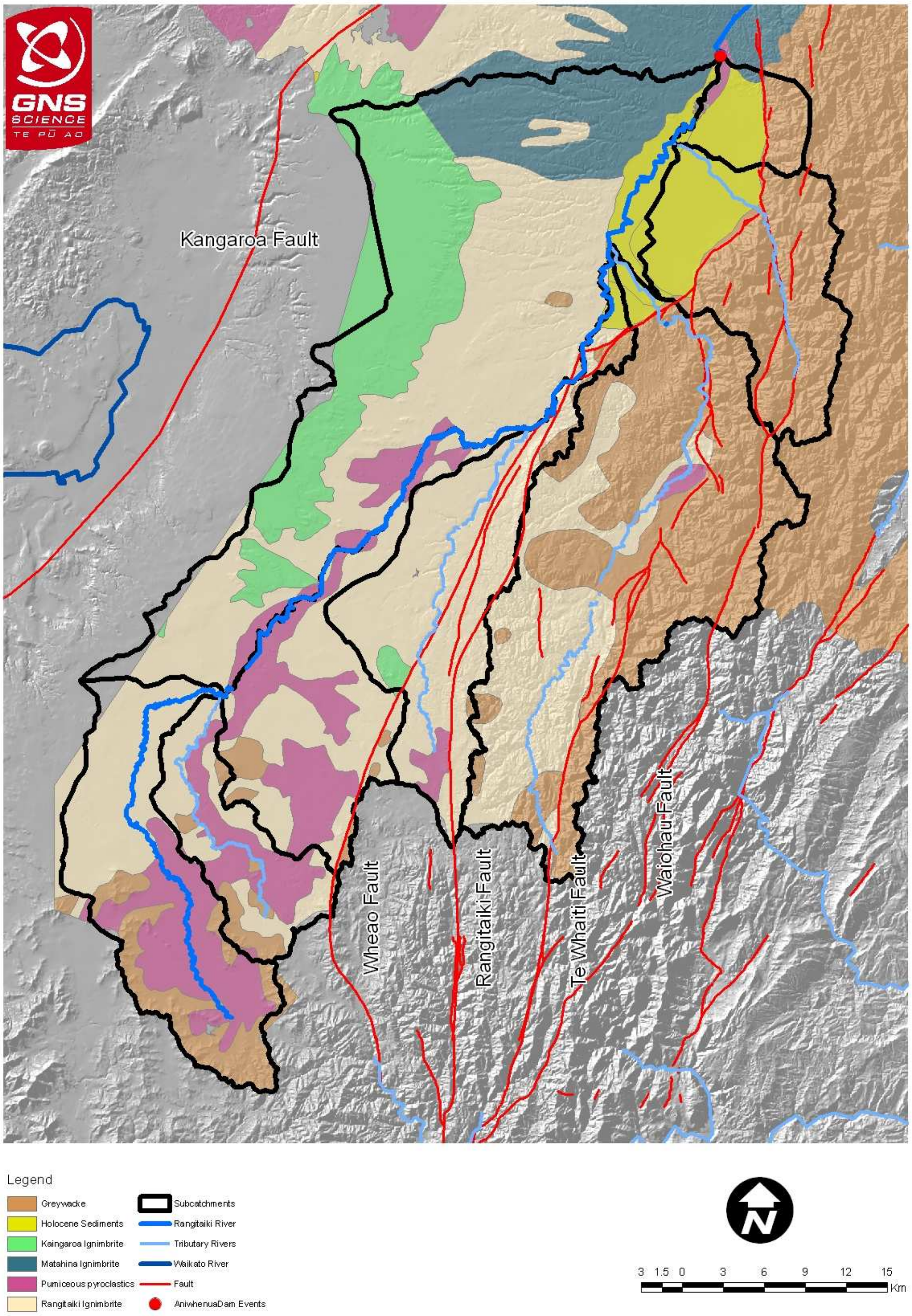


Figure 4—3: Surface geology of the upper Rangitaiki River catchment (Reproduced from GNS 2009).

Previous geophysical studies within the rohe

There have been several geophysical studies of the geology of portions of the upper Rangitaiki River catchment. These have largely been conducted in conjunction with proposals for hydro power development and have been concentrated in the vicinity of the Galatea Plains. These studies have provided information on subsurface geology provides geologic cross-sections in the following areas:

- Wheao River to Flaxy Creek tunnel (Hancock & Aust 1979).
- Lower Galatea Plains (Toulmin 2006).
- Central Galatea Plains (Williams 1979).
- Aniwhenua Dam site (Hochstein 1976).
- Proposed Mangamako Dam site (Williams 1979).

These studies included application of gravity, resistivity, and seismic methods. In general, they appear to have produced consistent representations of subsurface geology in the upper Rangitaiki River catchment. Copies of representative cross-sections from these reports are presented in Appendix 13.1 (Figure 13—1 through Figure 13—6 and Tables 13—1 through to 13—6).

Soils and surface geology

Information regarding soils in the upper Rangitaiki River catchment is only available for the Galatea Plains. This information indicates that the predominant soil type consists of freely draining light pumice materials of sand size (Rajanayaka & Rout 2004).

General surface geology for the EBOP region as a whole has been documented by Meilhac (2009). The upper Rangitaiki River catchment generally consists of ignimbrites in the west (Kaingaroa) and central (Rangitaiki) portions of the catchment and greywacke to the east Figure 4—3. All of these surface features are oriented south-southwest to north-northeast. In addition, there are small areas of pumaceous pyroclastic material scattered over southern parts of the catchment and exposed pockets of greywacke, and Holocene sediments over the Galatea Plains. Some Matahina Ignimbrite is present on the north end of the catchment. A more detailed description if this surface geology for the Galatea Plains is presented in Williams 1979 (see Appendix 13.1, Figure 13—7).

Well log/boring data

Well logs records are available from EBOP, the literature, and archives of the New Zealand Geological Survey (NZGS), maintained by GNS. These records show:

1. EBOP database – This has 68 well records from the upper Rangitaiki River catchment Figure 4—4.) The wells are all within the Galatea Plains with the exception of two wells near SH5. They are predominantly shallow wells with minimum, median, and maximum depths of about 5.2 m, 24 m, and 108 m, respectively (see Appendix 13.1, Table 13—1). Materials at the bottom of most of the wells were sand and gravel (46 of 68 wells (68%)). The remaining wells usually ended in other materials (e.g., silt), but generally sand and gravel were also reported above total depth.

2. Literature – Two reports were found in the literature providing boring log data. These were White (1983) and Hancock & Aust (1979). Figure 1 of White (1983) presents boring log geologic data for 38 locations in the Galatea Plains. These data are generally consistent with the EBOP database and show greywacke gravel as the predominant material at depth overlain by a thin surface layer of less permeable pumice and sand. Hancock & Aust (1979) provide "drill hole" logs and pictures of cores for 12 locations associated with the Wheao tunnel. For these drill holes, although many end in "soft pumaceous ignimbrite" or "lenticulite" at depths of about 50 m, the predominant overlying material appears to be Rangitaiki Ignimbrite. The deepest drill hole (132 m) ends in greywacke gravels.

3. Eighty-four core logs were found in the archives of the NZGS identified as "Murupara Core Logs" for the "Upper Rangitaiki Hydro Scheme" (NZGS, 1957–1986). These cannot be reviewed at this time as there is no diagram showing their locations and only a partial listing of coordinates. Depths for these core logs are variable and generally less than 100 m. Reported materials appear to be consistent with those in the EBOP database and literature noted above.

Raajanayaka & Rout (2004) summarised the available information for the Galatea Plains as follows:

0–20 m	Pumice sand with small amounts of silt and gravel.
20–70 m	Greywacke gravel which may extend to >120 m in places.

70–1,000 m	Ignimbrite deposits.
>1,000 m	Greywacke basement rock.

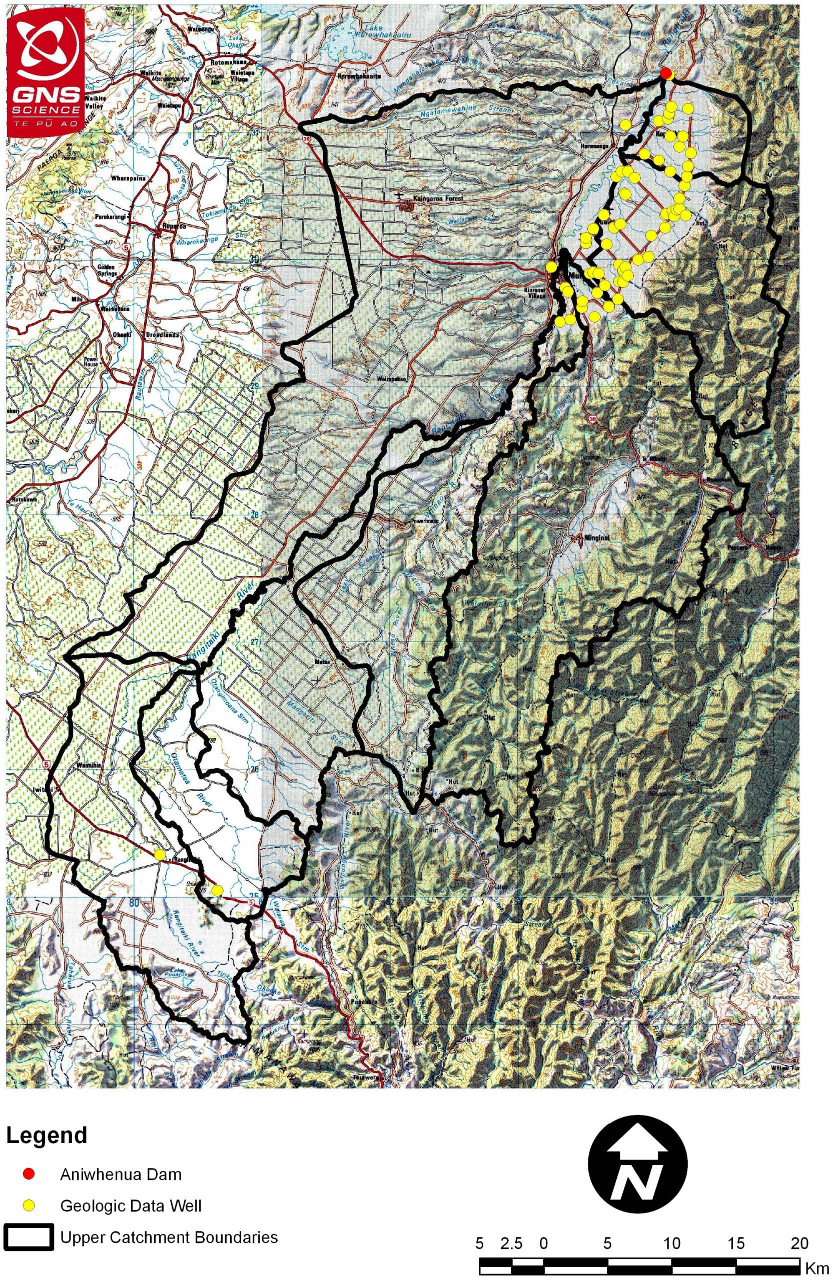


Figure 4—4: Location of wells for which geological data are available from EBOP.

4.1.2 Hydrogeology

Aquifer characterization

Aquifer physical properties are important factors when assessing groundwater resources. These include qualitative and quantitative information on the materials involved and their hydraulic properties. Qualitative information on aquifer materials is largely included under geology and most pertinently with regard to well log/boring data.

There is very little quantitative information on aquifer materials and their hydraulic properties within the upper Rangitaiki River catchment. The shallow pyroclastic materials may act to some degree as either granular porous media or fractured rock while the sand and gravel erosion products from greywacke infilling parts of the basins, such as under the Galatea Plains, would function as porous media; however, no information on such descriptors as particle size distribution, dry bulk density, or porosity appears to exist for these materials.

Available quantitative information on aquifer hydraulic properties consists of results from one pump test carried out in a well on the Galatea Plains. Groundwater was reported to be within an unconfined aquifer comprising sandy gravels, with water levels at the pump test site within a depth range of 8 to 9 m and having a maximum depth of about 30 m. It was concluded from the test results that this aquifer had a transmissivity of 1,400 m^2/day, a hydraulic conductivity of 96 m/day, a storage coefficient of 0.2 and a specific capacity of 13 L/s (Carryer & Associates Ltd., 1997). Such a hydraulic conductivity value would be characteristic of clean sand or the lower end of the range for gravel (Freeze and Cherry, 1979) and, therefore, is consistent with the sandy gravels reportedly involved.

Discussion of the potential yield of wells on the Galatea Plains indicates yields may be characteristically in the range of 0.3 to 2.5 L/s but occasionally as high as 5 L/s for shallow wells with depths in the range of 10 to 40 m. However, yields as high as 20 L/s have been achieved for deeper wells in the 60 to 80 m range (presumably within greywacke gravels). Reportedly, the reason for such low yields in a gravel formation is that the size of the gravel is small and the greywacke gravel has a high silt content that limits its permeability (Gordon 2001). Deeper wells within ignimbrite material may be capable of producing higher yields exceeding 50 L/s; however, there are questions regarding the quality of water available from them (Rajanayaka & Rout 2004). Ignimbrites may have a range of hydraulic properties and function either as porous media (e.g., sand and gravel size material) or fractured rock aquifers.

Groundwater levels

Available groundwater level information includes data reported at the time of drilling in the EBOP wells database and data from EBOP's Natural Environment Regional Monitoring Network (NERMN) program. All but two of the 88 wells in the database are within the Galatea Plains (Figure 4—5). The data for these wells indicates that the wells and water levels tend to be shallow (see Appendix 13.1, Table 13—2). Median well depth and water level depths were 21 and 5.1 m, respectively. The maximum depth for any of these wells is 108 m and the deepest water level reported was 52 m.

Water levels are monitored quarterly at two NERMN wells by EBOP. Both these wells (No. 1319 and 2913) are located within the Galatea Plains (Figure 4—6). The data for these wells span the period 1991 to present but with a three-year gap from late 1998 through late 2001. Water level in these two wells have varied considerably over time but are characteristically shallow, with median depths of 7.57 and 10.93 m, respectively (Figure 4—7). Part of the variation may have arisen because some measurements occurred while the installed well pump was in operation, while for other measurements the pump was off. Statistics provided in Appendix 13.1 (Table 13—1) show that this is a likely factor for well No. 2913 because minimum, median, and mean water level depths are all substantially greater when the pump was in operation than when it was not. This is not the case for well No. 1319. An anomalous and unexplained result is the exceptionally high water level (low depth) reported for well No. 1319 on 2 February 2006.

The linear line of best fit for the data indicate no statistically significant trends over time for either well (Figure 4—7). This suggests that ground water levels in the Galatea Plains have remained relatively constant since 1991.

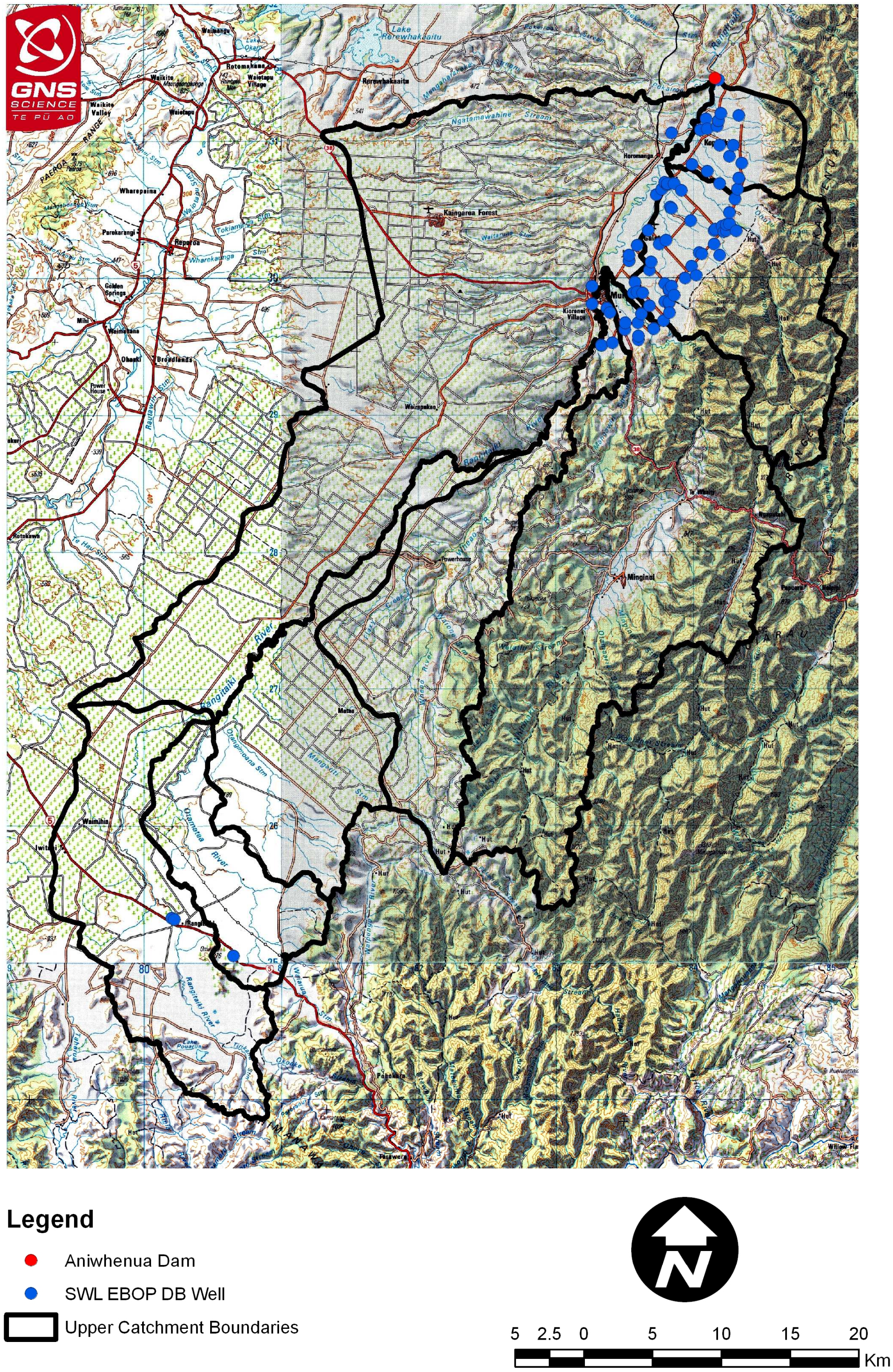


Figure 4—5: Location of wells for which groundwater level data are available.

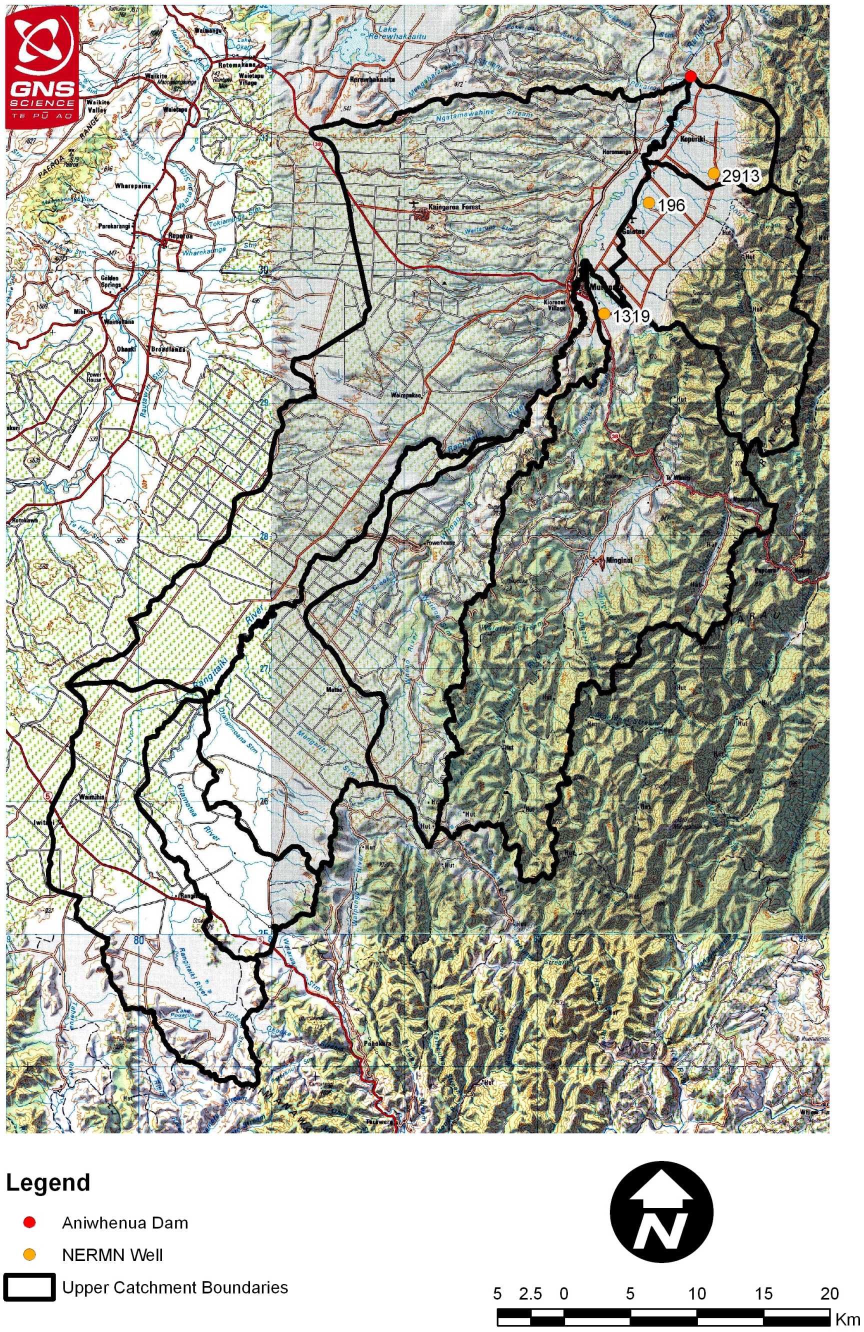


Figure 4—6: Location of wells used in the EBOP monitoring network.

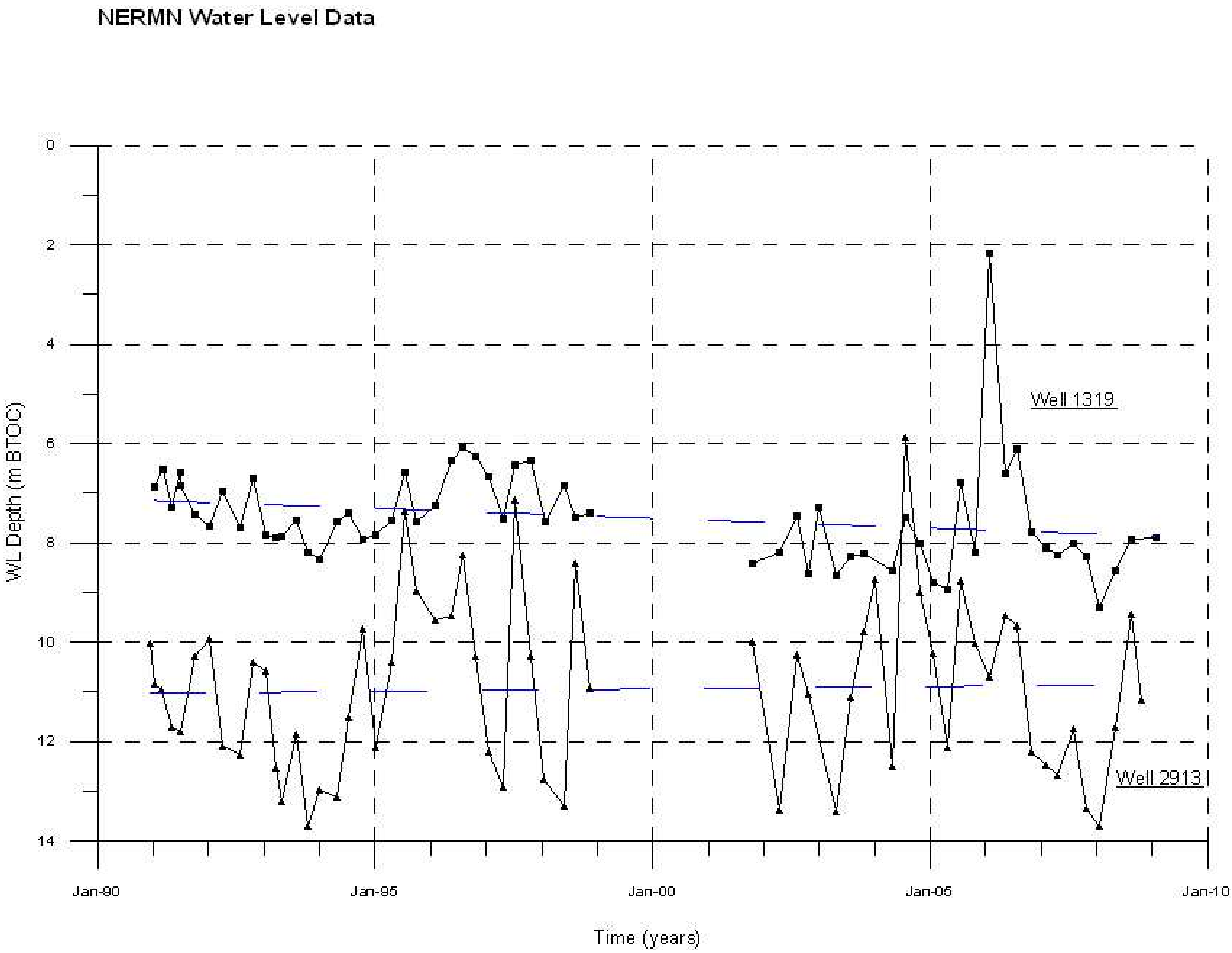


Figure 4—7: Water levels from two reference wells in the Galatea Plains. Blue dashed lines are the linear best line fit for each data set (data from EBOP routine monitoring programme).

Groundwater flow directions

It is possible to estimate the direction of groundwater flow when there is a sufficient density of wells for which groundwater level measurements are available in an area, based on a common datum. This is accomplished by contouring the data and taking into account other relevant factors (e.g., hydrologic features such as lakes and streams which may influence water levels). That is not possible for the upper Rangitaiki River catchment as measurements are only available from two wells.

However, since groundwater in the upper Rangitaiki River catchment appears to be shallow in nature and the direction of groundwater flow in shallow aquifers tends to be a subdued reflection of surface topography, it is possible to estimate the direction of groundwater flow based on surface topography. When that is the case, as it is here, the direction of groundwater flow will generally be perpendicular to topographical contours and consistent with the direction of surface water runoff. Figure 4—8 and Figure 4—9 present contours produced by GIS based on the digital terrain model (DTM) for the major portion of the upper Rangitaiki River catchment to the south of the Galatea Plains and for the Galatea Plains, respectively.

Figure 4—8 indicates that groundwater in the major portion of the upper Rangitaiki River catchment likely flows toward the Rangitaiki River from each side (mainly from the west and east) and that the river is an influent stream (i.e., the river receives groundwater flow from the surrounding catchment). Figure 4—9 indicates that groundwater under the Galatea Plains also flows toward the Rangitaiki River. The direction of flow east of Murupara in the southern part of the Galatea Plains is likely to be to the north or north-northwest before turning more westward toward the river. The direction of flow in the northern part of the Galatea Plains is likely to be west-northwest, directly toward the river and Lake Aniwhenua.

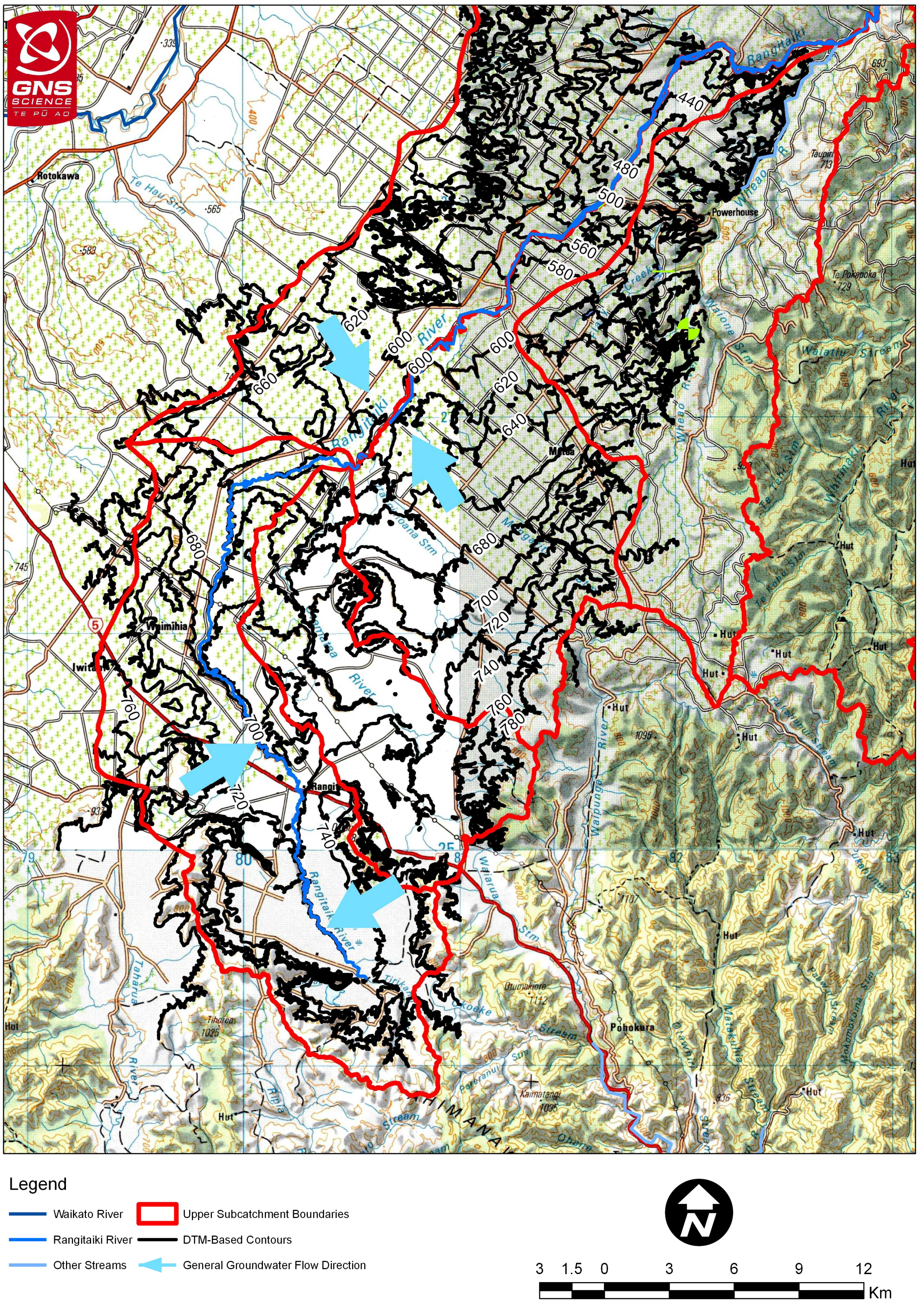


Figure 4—8: Direction of groundwater flows in the upper Rangitaiki River catchment inferred from DTM contours.

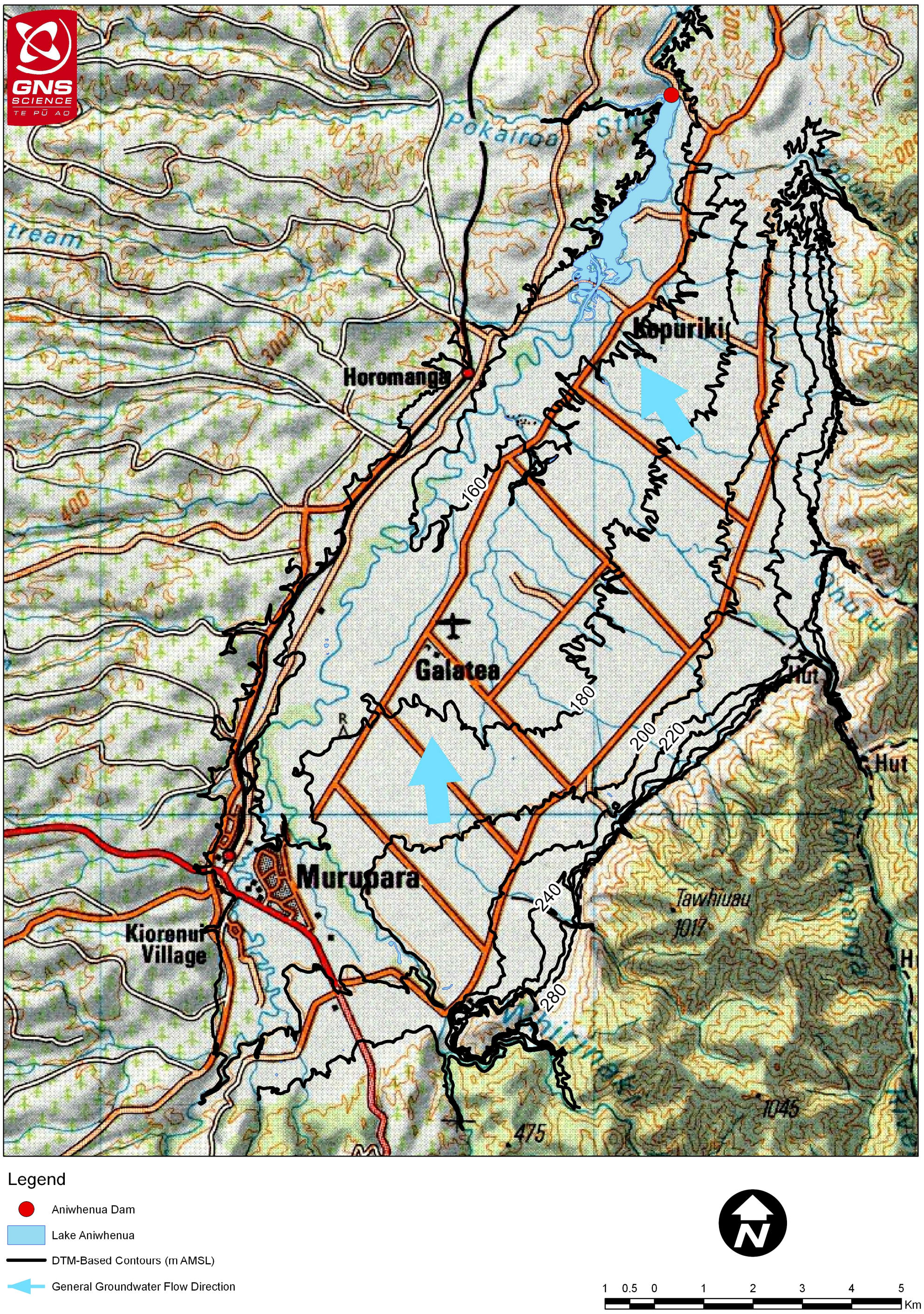


Figure 4—9: Direction of groundwater flows in the Galatea Plains inferred from DTM contours.

Groundwater quality

Available groundwater quality data consists of data from EBOP's NERMN program for three wells in the Galatea Plains (wells No. 196, 1319, and 2913). The locations of these three wells is shown in Figure 4—6.

Groundwater samples taken as part of the NERMN program are analysed for a wide range of variables listed in Appendix 13.1 (Table 13—3). Of the 46 variables, most are elements. Many of these typically occur only at relatively low levels in natural waters (e.g., antimony, cadmium, chromium, lead, tin, and vanadium) and that appears to be the case for data from these three wells. Therefore, results for these variables were not included in the present assessment, which was restricted to the variables listed in Appendix 13.1 (Table 13—4 to Table 13—6). In addition, as there was no apparent difference between results reported for reactive silica and silica, these data were included as "silica". It should also be noted that, for the range of pH values measured, total alkalinity would be the same as bicarbonate alkalinity. To obtain a comparative bicarbonate alkalinity concentration, however, it is necessary to convert the reported values to equivalent calcium carbonate units.

The concentrations of major ions indicate that the groundwater from all wells may be described as "sodium-calcium-magnesium-bicarbonate" type (Table 4—2, Figure 4—10). Sample results cluster reasonably well, indicating the water for all samples from all three wells is similar. There were no indications of trend in groundwater quality over time.

In general, these data indicate reasonably good quality water. Concentrations of most variables are low and consistent with use for drinking and other purposes. Iron appears to be the main exception to this general "fitness for use". Reported iron concentrations in well No. 196 are substantially higher than for the other two wells; in addition they greatly exceed the New Zealand Drinking Water Guideline Value (GV) of 0.2 mg/L (Ministry of Health 2005). The guideline value was established for aesthetic reasons and exceedance does not pose a health risk to consumers. However, at the concentrations measured (all greater than 3 mg/L), the taste of the iron would probably be objectionable to most consumers and staining of laundry and plumbing fixtures very noticeable.

Iron concentrations measured in well No. 1319 also exceed the GV, but not by as much (all less than 1 mg/L) and the water would probably be considered acceptable by some people. Apart for one record, reported iron concentrations for well No. 2913 were substantially less than the GV.

Table 4—2: Summary of groundwater quality derived from EBOP NERM monitoring data.

Well No.	Sample date	Water type[1]	Ion balance[2] (%)
196	09-Jun-03	Na-Ca-Mg-HCO_3	- 0.05
	06-Apr-04	Na-Ca-Mg-HCO_3	7.42
	31-Mar-05	Na-Ca-Mg-HCO_3	5.69
	27-Feb-06	Na-Ca-Mg-HCO_3	1.21
	06-Mar-07	Na-Ca-Mg	N/A[3]
	04-Mar-08	Na-Ca-Mg-HCO_3	4.24
1319	9-Jun-03	Na-Ca-Mg-HCO_3	4.96
	6-Apr-04	Na-Ca-Mg-HCO_3	10.32
	31-Mar-05	Na-Ca-Mg-HCO_3	8.10
	27-Feb-06	Na-Ca-Mg-HCO_3	9.36
	6-Mar-07	Na-Ca-Mg	- 1.85
	4-Mar-08	Na-Ca-Mg-HCO_3	8.83
2913	06-Apr-04	Na-Ca-Mg-HCO_3	8.62
	31-Mar-05	Na-Ca-Mg-HCO_3	7.73
	27-Feb-06	Na-Ca-Mg-HCO_3	8.53
	26-Mar-07	Na-Ca-Mg-Cl	N/A[3]
	06-Mar-08	Na-HCO_3-Cl	7.74

Notes:

1. Water type as determined by Version 5 of AquaChem
2. Ion balance determined as difference between sum of cations and sum of anions (sum of cations minus sum of anions) divided by total of sum of cations and sum of anions (sum of cations plus sum of anions) multiplied by 100%.
3. Alkalinity result not reported for this sample. Therefore, ion balance not calculated

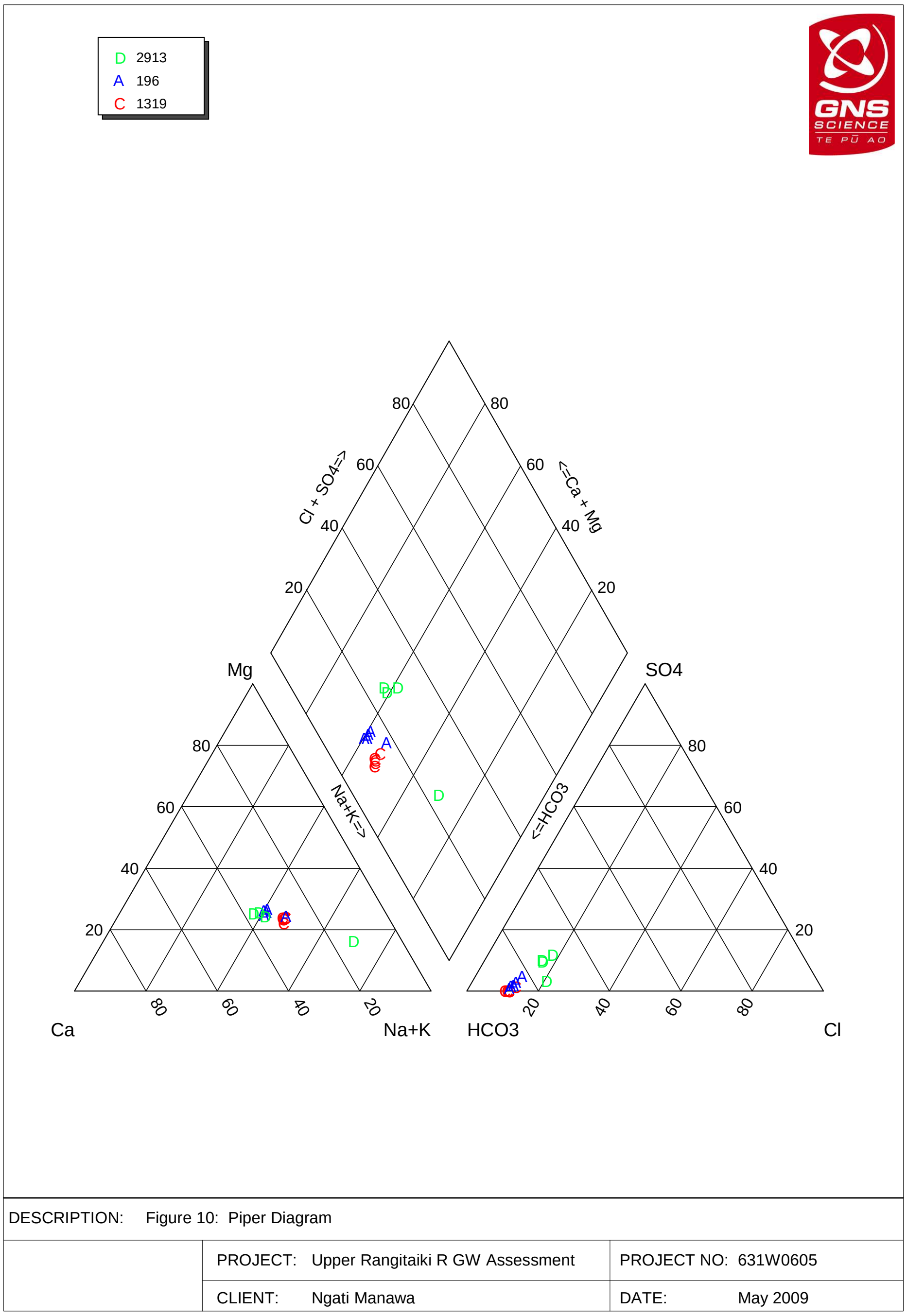


Figure 4—10: Classification of groundwater based on principal ion concentrations using Piper diagram.

The only other noteworthy issue related to groundwater quality concerns the concentration of nitrogen compounds. Reported values for ammonia-nitrogen and combined nitrite/nitrate-nitrogen (nitrite is normally a transient species of nitrogen such that the combined value of nitrite and nitrate present can normally be safely assumed to be predominantly nitrate) were all relatively low (i.e., less than 1 mg/L as nitrogen) and near or less than their respective GVs for ammonia (two of these exist at 0.3 and 1.5 mg/L) and maximum acceptable value (MAV) for nitrate (11.3 mg/L) (Ministry of Health 2005). Although the lower GV for ammonia was exceeded in several instances (wells No. 196 and 1319), this would only be of concern for a chlorinated water supply and is not, in any case, a mandatory standard.

Although concentrations are generally low, there is considerable variation in ammonia and nitrate concentrations over time. In view of land use in the area, this may indicate sporadic inputs of nitrogen into the groundwater system from agricultural operations. It is possible that groundwater quality is responding to rainfall events, periods of elevated groundwater level or periods when inputs of nitrogen are increased. To identify the cause of the fluctuations in dissolved nitrogen concentrations, it would be necessary to undertake more intensive sampling over time, and assess factors such as groundwater levels and antecedent rainfall.

While water quality data are limited to three wells on the Galatea Plains; these data are probably indicative of general water quality in the upper Rangitaiki River catchment. Given the geology (Section 4.1.1) and land use (Section 2.1.4), it may be expected that groundwater elsewhere in the catchment would be similar in terms of water type and major ion ratios. However, groundwater quality is susceptible to contamination by local sources (e.g., nitrates from agricultural operations) - where these exist, impacts may occur. It should also be considered that two of these wells are located on the upgradient side of the Galatea Plains and, therefore, samples from them are not monitoring possible groundwater contamination from agricultural operations downgradient of these wells. Additional monitoring wells on the downgradient side of the Galatea Plains prior to groundwater reaching the Rangitaiki River would be necessary to accomplish that purpose."

4.2 Groundwater takes/allocation

4.2.1 Current allocations

Data on current groundwater takes/allocations was obtained in electronic format from EBOP. Eleven consents have been granted by EBOP allocating the use of groundwater in the upper Rangitaiki River catchment. Selected information regarding these wells and the conditions of the consents are summarised in Table 4—3; their locations are shown in Figure 4—11. As can be seen from this Figure, ten of eleven consents are for wells in the Galatea Plains. The eleventh is for a school water supply (well No. 4904), located near the settlement of Rangitaiki on SH5.

In most cases, the purpose of the use is for irrigation (eight of 11 consents). There is one consent for each of the following: dust abatement, municipal water supply and school water supply. Using the consent value from the maximum day column and, where there is no such value, the highest of the consent values from the maximum rate or maximum irrigation columns in m^3/day from Table 4—3 (i.e., the maximum rate of abstraction for well No. 10452), the combined total for these allocations would be 39,635 m^3/day (0.459 $m^3 s^{-1}$ or 459 L/sec). This calculated total uses maximum consented rates of abstraction and it is likely that actual usage would be less than the total of maximum abstraction rates.

Table 4—3: Summary of groundwater consent data for the upper Rangitaiki River catchment (from EBOP Consent records).

Consent No.	Use	Allocation				Well No.	NZMG	
		Max rate[2]		Max day[3]	Max Irr[4]			
		L/sec	m³/day	m³/day	m³/day		Easting	Northing
60626	Irrigation	20	1,728		1,728	184	2840200	6300600
20907	Dust abatement	2.5	216	150		204	2832510	6299326
20114	Municipal water supply	76	6,566	4,100		4725	2832740	6298255
22051	Irrigation	2.3	199		203	4878	2834530	6297387
22172	School water supply	0.14	12	4		4904	2802183	6253233
61915	Irrigation	100	8,640		6,120	10452	2837200	6303200
62484	Irrigation				5,184	-	2836243	6300966
62485	Irrigation				9,500	-	2838746	6302866
64844	Irrigation	13.3	1,149	766		-	2842470	6303590
63234	Irrigation				5,040	-	2837960	6305380
62321	Irrigation				4,320	-	2843488	6311324
Total		214.24		5,020	32,095			

Notes:

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2 Maximum allocation rate in L/s from EBOP data max rate and in m³/day calculated from L/sec assuming continuous 24 hour pumping.

3 Maximum allocation rate/day in m³/day.

4 Maximum allocation rate/day in m³/day for irrigation purposes

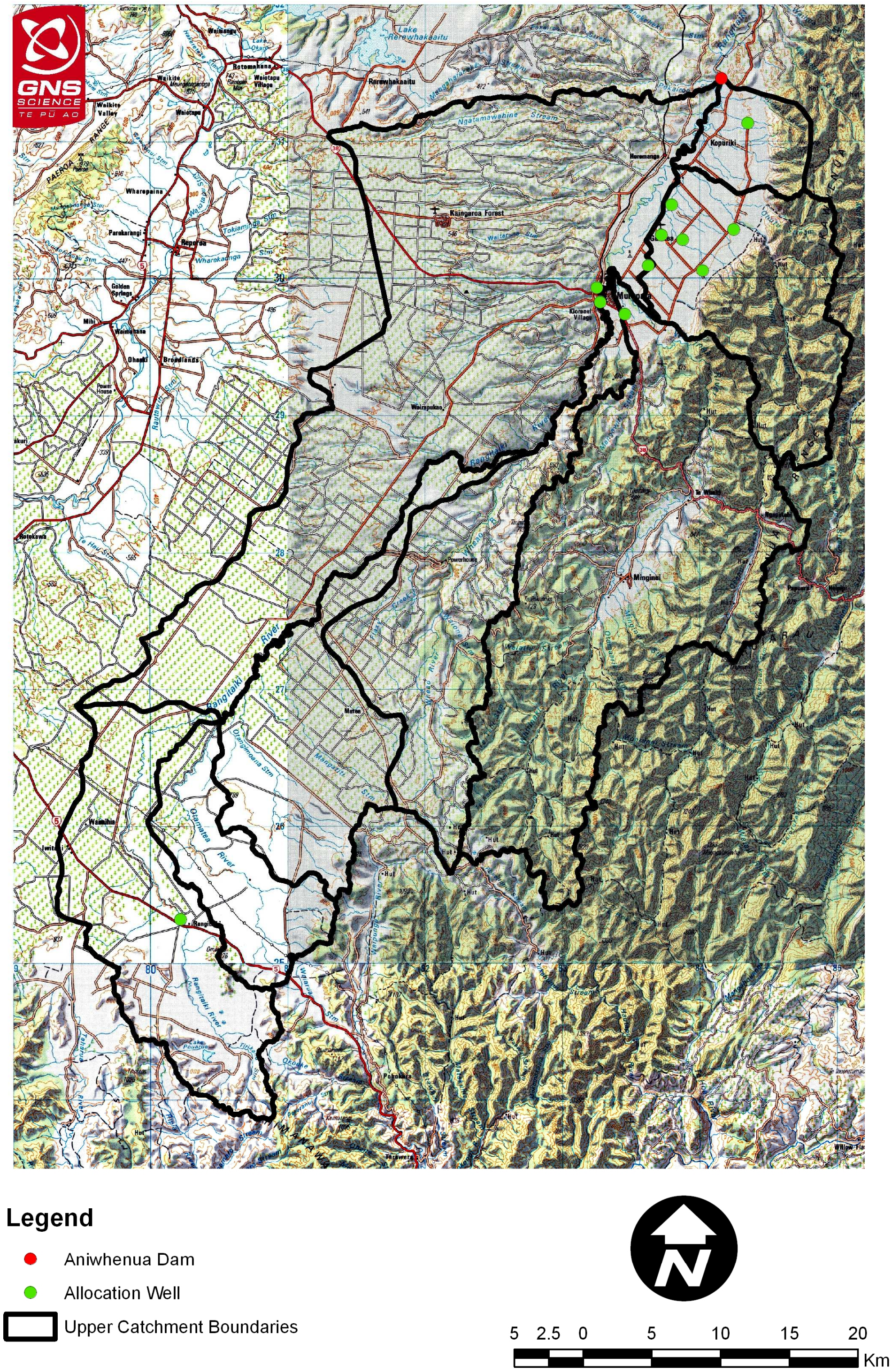


Figure 4—11: Location of consented groundwater abstractions in the upper Rangitaiki River catchment.

Consented takes represent only a portion of total groundwater takes and there are many wells in the upper Rangitaiki River catchment for which a consent is not required. For example, the use of groundwater with a temperature of less than 30 $^{\circ}$C (i.e., not geothermal), is permitted without a consent for *"an individual's reasonable domestic needs"* and the *"reasonable needs of an individual's animals for drinking water"* so long as *"the quantity of water does not exceed 35 m^3/day per property"* (EBOP 2009). If 77 of the 88 wells listed in the EBOP wells database for the upper Rangitaiki River catchment (i.e., 88 minus the 11 with consents), were being pumped at this rate, the total rate of abstraction for them would be 2,695 m^3/day. When added to the combined total of maximum allocations, this would increase to the rate of abstraction to 42,330 m^3/day. There may also be unrecorded and/or illegal wells taking water for irrigation or other purposes.

4.2.2 Potential capacity/demand

Current groundwater use in the Galatea Plains area appears to be relatively minor compared to known surface water flows. Maximum rate of abstraction is of the order of 0.5 m^3 s^{-1}, whereas the median discharge for the Rangitaiki River at Murupara is 20.6 m^3 s^{-1} and 11.7 m^3 s^{-1} for the Whirinaki River, However, the nature and potential of the available resource is poorly characterised and additional data, analysis and information is required to provide a reasonable estimate of the sustainable yield of this groundwater resource. Even less information is available regarding the groundwater resources elsewhere in the upper Rangitaiki River catchment.

Development of groundwater resources in the upper Rangitaiki River basin has been proposed as one possible source of additional water supply for dairy operations on the Galatea Plains, should surface water options *"prove not to be feasible"*. However, when making this proposal it was acknowledged *"that current knowledge about the groundwater resource is poor"* (Rajanayaka & Rout 2004).

4.3 Assessment of groundwater-surface water interaction

Little information exists to allow assessment of groundwater-surface water interactions in the upper Rangitaiki River catchment. As noted in Section 4.1.2 of this report, the limited information regarding groundwater levels and flow directions indicates that groundwater occurs at shallow depths and is generally influent to surface streams (i.e., groundwater flows towards rather from the Rangitaiki River and its tributaries). This is based largely on what was indicated by surface topography from the DTM, rather than from the more reliable method of contouring groundwater level data to produce a potentiometric surface. The groundwater level data required to undertake this task does not exist.

Specific concern has been raised with regard to some streams draining the Galatea Plains that they may become seasonally dry. When highly permeable materials are involved, the groundwater table is close to or at a marginally lower elevation than the streambed, and streamflows are low, surface water leaving the stream (i.e., a losing stream) and entering groundwater can exceed stream flow and result in this phenomena. Appropriate field studies would be necessary to investigate this situation.

General hydrological principles also indicate that water may flow from surface streams into groundwater when stream stages are temporarily elevated during storm water events. Accurately measured surface and groundwater levels are required to determine the frequency and duration of such conditions.

4.4 Factors potentially impacting groundwater resources

Changes in the hydrologic system that add sources of water (e.g., recharge basins or reservoirs impounded behind dams) or take away water (e.g., new wells) will impact groundwater resources. For relatively "natural" or system-wide changes (e.g., climate change), potential general trends can be considered (e.g., it might be hypothesised that if an area like the upper Rangitaiki River catchment became drier due to climate oscillations that available groundwater quantities might be similarly reduced and groundwater quality also impacted). However, there are no research results currently available on the impact of climate on groundwater resources. Therefore, such impacts are highly speculative and such human-caused (anthropogenic) impacts can only be evaluated in the context of the planning stages of projects.

There are a number of anthropogenic activities that may impact groundwater resources. There are cautions regarding some of these in EBOP's Regional Water and Land Plan. For example, precautions are specified in that plan regarding the application of fertiliser to land in order to avoid leaching of nutrients to groundwater and to the effect that farm dumps, offal holes, silage pits and stacks, and composting operations *"shall not be located within… 50 m of any groundwater bore"* and that large bark and wood waste disposal sites "*shall not be located within… one (1) Km horizontal distance from any groundwater bore*". Additionally, offal holes "*shall not be located within… an area where the highest groundwater level is less than two (2) m below the base of the offal hole"* (EBOP 2009).

Land use within a catchment is very relevant[10]. Land use information from 1996 and 2001 imagery was obtained from Landcare Research in the form of GIS files with LCDB1 and LCDB2 data. The boundaries for the polygons from the Landcare Research GIS files do not precisely overlie the GIS catchment boundaries, but are similar. Of the 2,192 GIS polygons present in the file, there are 103 in the Hawke's Bay Region and 56 in the Waikato Region. For the purposes of this report, only the 2,053 polygons in the Environment Bay of Plenty Region were considered. Land use areas for the various land use classes present in the upper Rangitaiki River catchment are shown in Table 4—4 for each year using the name for LCDB2 (i.e., year 2001). Change in land use classes between the 1996 and 2001 is indicated in the "Delta" column of that table. For 17 of the 27 classes, there was no change at all. For six classes there was only minor (i.e., about 10 percent or less) change up or down and for three classes the change was more substantial. One class in 2001 (i.e., afforestation) had not been used in 1996. Land use classes are grouped by category for year 2001 data on the right-hand side of Table 4—4. The most substantial changes were with regard to different classes within the overall category of "Forest." The increase in harvested and open canopy pine forest is balanced by the decrease in closed canopy pine forest. Therefore, it is evident that these data do not indicate any substantial change in land use categories between 1996 and 2001. As can be seen in Figure 4—12, the predominant land use in the catchment is "Forest" at 78% with "Cropland" next at 16.9% and other vegetation at 4.5%. The "Structures" category (i.e., human-built structures such as roads and buildings) is relatively very small at 0.4%. Most of the cropland is concentrated in the Galatea Plains and the southern part of the catchment. There is also some in the Whirinaki River valley near the settlement of Minginui.

Updated land use data are expected in 2010, once imagery recorded in 2008 has been processed. Available information indicates that substantial changes have taken place in at least one part of the catchment since 2001. Observation from State Highway 5 indicates that considerable land area has been converted to cattle and/or dairy farm use. This may impact on surface and groundwater by increasing nitrogen inputs into the system near the headwaters of the catchment.

The main anthropogenic land uses that have occurred in the upper Rangitaiki River catchment are clearly forestry and cropland. Cropland, from the standpoint of potential impact in this case, means grasslands used for pasture such as is the case for dairy operations. Forestry operations pose a risk of sedimentation for surface waters but are generally considered relatively benign with respect to groundwater. Dairy operations can be a substantial source of nutrient contamination for groundwaters.

[10] For a fuller description of land use and land cover please refer to Section 2.2

Table 4—4: Summary of land use data[1].

#	LCDB1 - 1996 Class	No. Poly-gons[2]	Area (ha)[3]	LCDB2 - 2001 Class	Name	No. Poly-gons[2]	Area (ha)[3]	Delta[4-8]	Major 2001 classes Use Categ.	Area (ha)[3]	Percent of total
1	1	17	237	1	Built-up area	17	237	NC[5]			
2	2	5	56	2	Urban parkland/open space	5	56	NC			
3	3	8	38	3	Surface mine	8	38	NC			
4	5	67	680	5	Transport infrastructure	74	682	M-Up	Struture s	1,013	0.4
5	11	8	58	11	River and lakeshore gravel and rock	8	58	NC			
6	12	12	17	12	Landslide	12	17	NC			
7	20	12	211	20	Lake and pond	12	211	NC			
8	21	19	177	21	River	19	177	NC	Water-related	462	0.2
9	30	13	1,470	30	Short - rotation cropland	13	1,470	NC			
10	32	3	12	32	Orchard and other perennial crops	3	12	NC			
11	40	216	33,374	40	High producing exotic grassland	202	33,334	M-Down			
12	41	21	3,280	41	Low producing grassland	31	3,327	M-Down	Crop land	38,143	16.9
13	45	26	510	45	Herbaceous freshwater vegetation	26	510	NC			
14	51	19	281	51	Gorse and broom	21	291	M-Up			
15	52	167	5,376	52	Manuka and/or kanuka	167	5,387	M-Up			
16	53	1	4	53	Matagouri	1	4	NC			
17	54	175	2,989	54	Broadleaved indigenous hardwoods	175	2,989	NC			
18	56	6	102	56	Mixed exotic scrubland	6	102	NC			
19	57	2	7	57	Grey scrub	2	7	NC			
20	61	197	804	61	Major shelter belts	197	804	NC	Other veg.	10,095	4.5
21	63	N/A	N/A	63	Afforestation	15	46	N/A			
22	64	165	18,802	64	Forest harvested	198	23,691	S-Up			
23	65	131	18,634	65	Pine forest - open canopy	271	33,944	S-Up			
24	66	581	75,667	66	Pine forest - closed canopy	385	55,163	S-Down			
25	67	42	2,522	67	Other exotic forest	45	2,752	M-Up			
26	68	42	287	68	Deciduous hardwood	42	287	NC			
27	69	78	59,862	69	Indigenous forest	78	59,862	NC	Forest	175,744	78.0
Total		2,033	225,458			2,033	225,458			225,458	100

Notes

1 Data from LCDB1 and LCDB2 based on interpretation of 1996 and 2001 imagery, respectively, provided in the form of GIS files by Landcare Research (Fraser, 2009).
2 "# Polygons" is number of GIS polygons listed in the attribute table.
3 Area is combined total for all polygons
4 "Delta" column indicates difference between area in 2001 imagery compared to area in 1996 imagery.
5 "NC" means no change.
6 "Up" means increased and "Down" means decreased, over time.
7 "M" in front of "Up" or "Down" means change was minor (~10% or less).
8 "S" in front of "Up" or "Down" means change was apparently substantial.

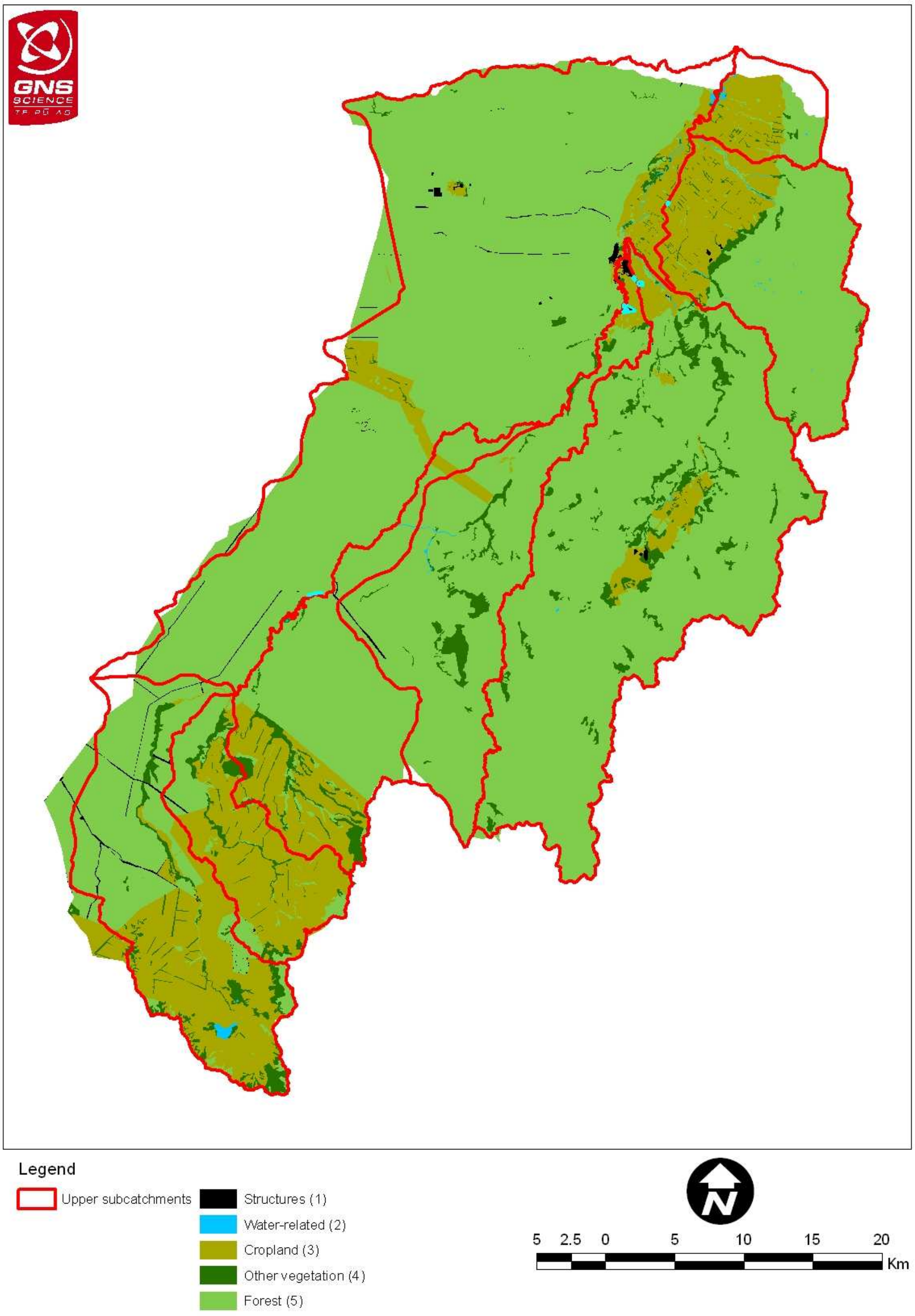


Figure 4—12: Summary of general land use categories.

4.5 Groundwater regulatory system

4.5.1 Groundwater quality standards

No specific groundwater quality standards apply to the upper Rangitaiki River catchment or anywhere within the Bay of Plenty Region. However, the Drinking Water Standards for New Zealand 2005 are frequently used as guidelines when evaluating groundwater quality. There are a number of microbiological assessment categories and guidelines values in these standards covering microbiological, chemical, and radiological variables (Ministry of Health 2005).

4.5.2 Local/Regional government regulation

With respect to local/regional government regulation, the upper Rangitaiki River catchment is within the boundaries of the Whakatane District Council (WDC) and EBOP. The WDC has no responsibilities with regard to the regulation of groundwater; however, it does operate a water supply facility at Murupara. Reportedly, this facility was developed in the early 1960s and at one time included two wells. These were deepened in 1984 to achieve a collective capacity of 70 L/sec (Whakatane District Council 2009). Only one of these wells (well No. 4275) currently has a consent to take water at a maximum rate of 76 L/sec.

EBOP has substantial regulatory responsibilities with regard to groundwater. These are primarily exercised through EBOP's Regional Water and Land Plan (EBOP 2009). The EBOP Regional Water and Land Plan was adopted to implement provisions of the Resource Management Act of 1991 to promote the sustainable management of natural and physical resources without adverse effects on the environment. The current version of the EBOP Regional Water and Land Plan became operative on 1 December 2008 (EBOP 2009).

The EBOP Regional Water and Land Plan recognises that the "major causes" of adverse effects on groundwater quality are "inappropriate water and land use activities in the recharge areas of aquifer systems" and "Poor groundwater bore and well construction and maintenance." There are various requirements in this plan that apply to groundwater (e.g., those mentioned in Section 2.5 above with regard to citing of certain facilities like farm dumps which could potential contaminate groundwater). However, the major provisions with regard to groundwater are found in Rule Numbers 38, 39, 40, and 43 pertinent to the installation of bores and the taking and using of groundwater. Portions of the EBOP Regional Water and Land Plan relevant to groundwater were amended by Plan Change 8 effective 28 April 2009. These affected Rule Numbers 39 and 40 (EBOP 2009).

Relevant Rules associated with groundwater include:

Rule 38: Permitted – Take and Use of Groundwater

"The take and use of groundwater with a temperature less than 30°C, where the quantity of water does not exceed 35 m^3/day per property, is a permitted activity.

Rule 39: Permitted – Use, Maintenance or Decommissioning of a Hole, Bore, Well or Water Infiltration Gallery

Provides that "to use, maintain or decommission a hole, bore, well or water infiltration gallery" is a permitted activity subject to conditions designed to prevent "infiltration of contaminants" and the "uncontrolled discharge or leakage of water to the surface." Further, use, maintenance, and decommissioning is to be carried out in accordance with EBOP standards.

Rule 40: Permitted – Drilling

Drilling that does not intercept a water table or aquifer is permitted but does not confer a right to take and use water and does not authorise modification or disturbance of archaeological or registered waahi tapu sites.

Rule 40A: Controlled Drilling

Drilling that does intercept a water table or aquifer that is not for the purposed of constructing a bore is controlled and EBOP reserves its control over various matters including the location and depth of drilling.

Rule 40B: Restricted Discretionary – Installation, Alteration or Reconstruction of a Bore, Well or Infiltration Gallery

Drilling or other disturbance of land for the purpose of constructing a bore is restricted discretionary and EBOP restricts its discretion to various matters including location and depth and the amount of water taken and used for aquifer testing.

Rule 43: Discretionary – Take and Use of Water

The take and use of groundwater not otherwise permitted and not a controlled activity or prohibited is a discretionary activity. This rule specifies, but does not limit, the EBOP objectives, policy, and methods applied under this plan to assess resource consent applications.

Chapter 5 of the EBOP Regional Water and Land Plan contains details about water quantity and allocation for both surface and groundwater and Chapter 11 addresses information to be submitted with resource consent applications. Among other considerations are that the volume and rate of abstraction of groundwater may not *"Permanently or unsustainably lower water levels or decrease ground water quality in aquifer systems"* or *"linked"* surface water bodies.

4.5.3 National Regulation

There are four items of national or potential national regulations concerning groundwater. These are:

(1) Requirements under the Resource Management Act of 1991: These are dealt with by EBOP under its Regional Water and Land Plan discussed in Section 3.2.

(2) National Environmental Standards for Sources of Human Drinking Water (Resource Management Regulations, 2007): These regulations provide an explicit legislative requirement for regional councils to consider the effects of activities on sources of human drinking water for communities during council decision-making processes. Implementation of Drinking Water Standards for New Zealand 2005 by the Ministry of Health is integral to this regulation.

(3) Proposed MfE National Environmental Standard on Ecological Flows and Water Levels (MfE 2008). With respect to groundwater, this proposed national standard defines the levels of potential risk for changes in level as being low, medium, or high depending on the level of use (less than 10%, between 11 and 25%, or greater than 26%, respectively). Depending on this potential and the low, medium, or high value and relative significance of the resource, methods to use in assessing and setting water level requirements are given.

With respect to groundwater, this proposed national standard gives *"proposed interim limits"* for groundwater allocation in the case of Regions that have not adopted limits through *"the regional plan process"*. Proposed interim limits include allocation limits for:

a) shallow, coastal aquifers the larger of either 15% of the "average annual recharge" or existing allocations less allocations that lapse for one reason or another; or

b) all other aquifers, 35% of the “average annual recharge” or existing allocations less allocations that lapse for one reason or another (MfE, 2008).

(4) Proposed National Policy Statement for Freshwater Management (MfE 2009). This proposed policy statement would cover nine different objectives aimed at such general matters as “improving the quality of fresh water,” controlling the degradation of fresh water, promoting sustainable and efficient use of fresh water, and ensuring that iwi and hapu are involved in the management of freshwater resources.

4.6 Conclusions

1. Data are sufficient to generally describe catchment geology with reasonable confidence.

2. There are only minimal hydrogeologic data available; however, with broad assumptions, they may be used to generally describe the catchment. No information was found regarding springs in the catchment.

3. Current consented groundwater allocation is small compared to surface water flows but it is not clear all historical take are included in the current database.

4. There is an established regional regulatory system under the Resource Management Act (RMA) relevant to groundwater. Potentially applicable national policies are under development.

5. Additional information and site-specific research is necessary to better define catchment hydrogeology, groundwater-surface water relationships, and long-term sustainable groundwater yield. This is particularly important in relatively small subcatchments such as the Galatea Plains.

6. Land use in the upper Rangitaiki River catchment is predominantly related to forestry. However, there are two areas that have been substantially modified for non-forestry agricultural operations. These are: (a) the Galatea Plains; and (b) the extreme upper or southernmost part of the catchment on both sides of SH5. There are no data by which to assess groundwater in the latter area (either with respect to quantity or quality). The limited available data for the Galatea Plains do not indicate that substantial adverse impacts have occurred yet. However, the available information does indicate that a potential exists for both. As most of the few wells that are monitored are in upgradient parts of the Galatea Plains, the current groundwater monitoring network is not well-suited to detect anthropogenic changes. It is axiomatic in such work that efforts to remediate groundwater once it has been

degraded are invariably expensive and take substantial time. Therefore, it is a superior approach to regulate in a way that prevents degradation before it occurs.

4.7 Recommendations

1. Additional information is needed to better assess and regulate groundwater resources in the catchment. The main initial priority of work to generate such information should be the Galatea Plains and the extreme upper or southernmost part of the catchment where there are current and substantial non-forestry agricultural operations and the potential for intensification. Due to the existence of a number of wells in the Galatea Plains, relevant information may be more readily developed there.

2. Hydrogeological investigation in the Galatea Plains could include:

   - Select wells for water level measurements.
   - Survey well reference point and ground elevations.
   - Synoptically measure water levels in selected wells and observed associated surface stream conditions.
   - Calculate and contour groundwater elevations to produce a potentiometric surface.
   - Infer groundwater flow directions and relationships with surface streams from the potentiometric surface.
   - Select a geographic spread of wells in the Galatea Plains for water quality sampling. Include wells along potential groundwater flow paths and downgradient of agricultural operations.
   - Take and analyse groundwater samples from wells for chemical constituents (both general water quality such as major ions and potential contaminant variables such as nutrients).
   - Evaluate water quality data.
   - Solicitation of local knowledge about the locations of springs within the catchment.
   - Survey to visit and confirm spring locations and document coordinates and elevations using handheld GPS units.
   - Sampling of selected springs for chemical constituents.
   - Measurement of flows of selected springs.

- Select wells in the Galatea Plains for hydraulic testing to obtain representative geographic coverage of the area.
- Test selected wells to determine aquifer properties and well yield.
- Identify surface streams that reportedly lose flow to groundwater and go dry as they flow across the Galatea Plains.
- Conduct site-specific work to define groundwater-surface water relationships for these streams.
- Conduct exploratory survey of groundwater conditions in the extreme upper or southernmost part of the catchment.
- Obtain detailed site-specific information on land use and nutrient applications.
- Measure water levels in two wells known to exist and obtain and analyse samples from them for selected chemical constituents.
- Determine whether other wells not included in EBOP database exist.
- Plan and undertake additional groundwater assessment activities designed to obtain representative information about groundwater conditions in this part of the catchment. This may require the drilling of boreholes and installation of monitoring wells with subsequent water level measurements, water quality sampling, and hydraulic testing.

3. Conduct a desktop assessment of the effects of land use on groundwater and associated surface water quality for a range of potential future land use options.

5. Surface water quality

Neale Hudson, NIWA

NIWA was contracted to conduct a comprehensive assessment of chemical, physical and microbiological data available for the Rangitaiki River catchment upstream of Lake Aniwhenua. The outcomes of this assessment would contribute to identifying the current "state of the aquatic environment" in the Rangitaiki River catchment within the rohe of Ngati Manawa. Indicator variables were to be used, with emphasis given to nutrients, organisms indicating faecal contamination, and biodegradable organic material. The process would define the visual clarity of water within the catchment, as well as biological integrity and stream "health".

Relevant data and information regarding the state of the Rangitaiki River was derived primarily from two sources

- the National River Water Quality Network (NRWQN) database; and
- data held by EBOP.

Originally we did not anticipate undertaking any field assessments or collecting or analysing any additional samples. After a preliminary review of the available data, we decided to include a single longitudinal survey to provide additional information regarding trends in water quality.

This assessment of water quality data therefore makes extensive use of data derived from "state of environment" monitoring programmes, as well as specific data derived from a one-off longitudinal survey.

Data for a number of chemical (e.g., nutrient, and dissolved oxygen concentrations) and physical (temperature and visual clarity) variables have been summarised in tabular (as summary statistics) and graphical format (time-series, trend and box plots). Particular attention was given to determining overall trends in the selected variables over time, as well as identifying possible inflection points – periods of time or specific events that indicated variation in rates of change.

The results of the assessment were also used to a limited extent by other components of this project, partially to contribute to the interpretation of fish, periphyton, macrophyte and macroinvertebrate populations.

5.1 Materials and methods

5.1.1 Assessment of data derived from routine monitoring programmes

Substantial water quality data are held by EBOP and NIWA.

The data held by EBOP has been derived principally from long-term "state of environment" monitoring programmes. Samples have been collected from a number of sites upstream of Aniwhenua Dam since July 1985. The site codes, descriptions and locations are listed in Table 5—1, along with the start and end dates of the data holdings.

The location of routine water quality monitoring stations is indicated in Figure 5—1. The availability of data for specific variables is summarised in Appendix 13.2.

Table 5—1: Monitoring sites along the Rangitaiki and Whirinaki Rivers within the Ngati Manawa rohe and extent of data.

Site	Catchment, agency[1]	Description	Grid reference		Number of data	Holdings	
			Easting	Northing		Start date	End date
RO3	R, N	Rangitaiki at Murupara	2832905	6298355	239	15/02/1989	10/12/2008[2]
BOP110015	R, E	Old Bridge at Murupara	2832700	6298300	260	18/07/1985	12/03/2009[2]
BOP110016	R, E	Inlet to Aniwhenua Canal	2841600	6314600	92	9/12/1985	11/03/2009[2]
BOP110017	R, E	Waiohou Bridge	2845600	6329100	67	18/07/1985	13/10/1998
BOP110081	R, E	Kopuriki (Rabbit Bridge)	2840100	6310700	29	18/07/1985	2/04/1996
BOP110104	R, E	At SH 5 Bridge	2802460	6252820	20	26/03/1999	15/06/2005
BOP110011	R, E	Otamatea River at Lochinver Dam	2807000	6256070	19	7/07/1999	15/06/2005
BOP110103	R, E	Otamatea River at Farm Bridge (Wastelands)	2808200	6252270	23	26/03/1999	15/06/2005
BOP110110	R, E	Otamatea River at Culvert under Dairy Race	2809120	6249940	20	7/07/1999	15/06/2005
BOP160107	R, E	Above Murupara - Raft exit	2832800	6297100	28	7/01/1992	21/01/2004
BOP210113	R, E	u/s of Horomanga Confluence	2838100	6308200	12	23/03/1995	2/04/1996
BOP210114	R, E	d/s of Whirinaki Confluence	2833300	6301800	12	23/03/1995	2/04/1996
RO4	W, N	Whirinaki at Galatea	2837043	6295952	239	15/02/1989	10/12/2008[2]
BOP110014	W, E	Galatea Bridge	2837000	6295900	261	8/07/1985	12/03/2009[2]
BOP210285	W, E	Ohu Camp Track	2834460	6278570	1	16/01/2008	16/01/2008
BOP210286	W, E	River Road Water Supply	2833510	6277830	1	16/01/2008	16/01/2008
BOP210287	W, E	Mangamate Camping Reserve	2834790	6280180	1	16/01/2008	16/01/2008

Notes:

[1] R = Rangitaiki River and tributaries, excluding Whirinaki River; W = Whirinaki River and tributaries; N = NIWA, E = EBOP.

[2] Ongoing routine monitoring location.

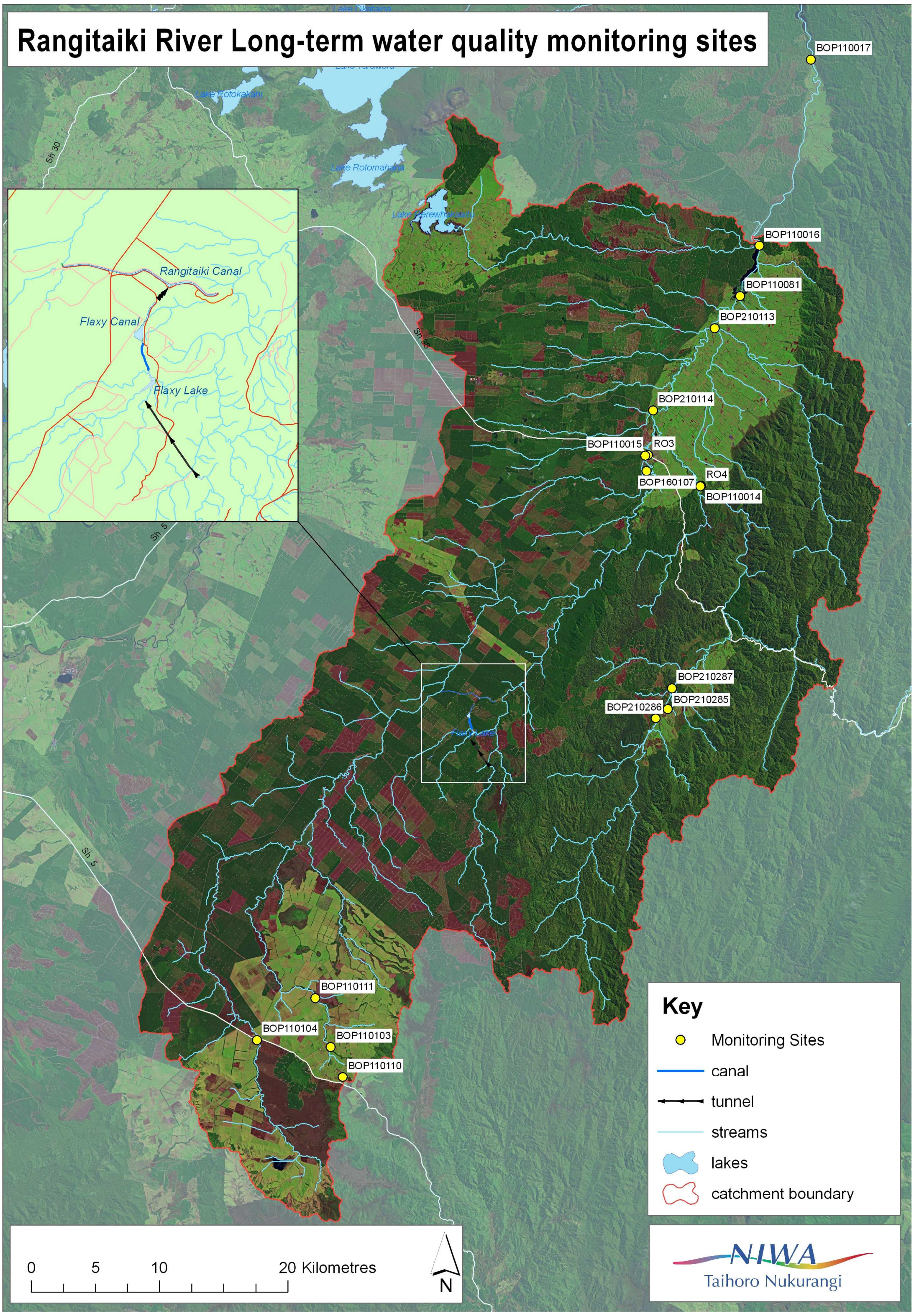


Figure 5—1: Location of routine monitoring locations, Rangitaiki and Whirinaki River catchments.

The data held by NIWA is part of the NRWQN. This monitoring programme was established in 1989, with the principal objective being to indicate water quality state and trend. To this end, the monitoring programme has been deliberately operated largely unchanged since its establishment. Samples are collected at monthly intervals, and have been analysed in the same laboratory for a consistent suite of variables over the entire monitoring period. Comprehensive quality assurance procedures are applied to the entire process, from field activities through analysis to storage of the data.

The data held by EBOP is also of high quality, and provides generally consistent information to that derived from the NRWQN data.

5.1.2 Water quality assessment – longitudinal survey

A water quality survey was conducted along the Rangitaiki River and selected tributaries in the reach upstream of the Aniwhenua diversion canal. This survey fulfilled a number of objectives:

- it familiarised the team with the river under current conditions;
- it identified sources of contaminants along the reaches surveyed;
- it allowed the collection of specific data for determination of additional, non-routine variables (e.g., light penetration).

The survey was undertaken 28 and 29 April 2009 under base flow conditions. Table 5—2 identifies the variables that were measured in the field during this survey. Water quality samples were collected at the locations where field measurements were made. Table 5—3 identifies the analyses to which these samples were subjected. The sites used for the survey are listed in Table 5—4 and shown in Figure 5—2.

Table 5—2: Variables measured during longitudinal survey.

Variable	Description	Details
Visual clarity	Visual clarity by black disk measurement (m)	Direct measurement of underwater visibility.
DO concentration	Dissolved oxygen concentration by probe (mg/L or % saturation)	Direct measurement of dissolved oxygen concentration.
Temperature	Water temperature (°C) measured using DO probe	Direct measurement of water temperature.
EC	Specific Electrical conductivity measured using EC probe	Assessment of concentrations of dissolved ionic species ("salts").
K_d (euphotic depth)	Pair of photoreceptors deployed at different fixed depths within water column. Attenuation coefficient calculated.	Allows estimation of euphotic depth (~1% incident light).

Table 5—3: Analytical tests applied to samples collected during longitudinal survey.

Variable	Details	Comment
Absorbance at 270, 340, 440 and 740 nm	Determined on filtered sample using laboratory spectrophotometer equipped with 40 mm pathlength cuvette	Absorbance values used to calculate absorption coefficients at 340 nm (g_{340})and 440 nm (g_{440}); latter is surrogate for coloured dissolved organic matter (CDOM)
Dissolved reactive phosphate (DRP), total phosphorus (TP), nitrate-N, ammoniacal-N and total nitrogen (TN)	DRP, nitrate-N and ammoniacal-N determined using autoanalyser; TP and TN determined using autoanalyser following digestion	Results used to describe nutrient status of river water.
Dissolved organic carbon (DOC) and total organic carbon (TOC)	Determined using dedicated analyser	Results used to assess organic content of surface waters.

Table 5—4: Sample sites used during longitudinal survey.

Code	Sample site description	Grid reference	
		Easting	Northing
W1	Rangitaiki u/s diversion	2816520	6279850
W1A	Flaxy Dam	2819320	6276700
W2	Wheao River d/s powerhouse	2821580	6279500
W3	Rangitaiki d/s diversion	2818860	6283800
W4	Rangitaiki River d/s Wheao River confluence	2827340	6287300
W6	Rangitaiki River near proposed diversion	2832500	6294670
W7	Whirinaki River at Troutbeck Road	2836950	6295990
W8	Rangitaiki River d/s Murupara	2833200	6301580
W9	Rangitaiki River at Rabbit Bridge	2840050	6310760
W10	Rangitaiki At Aniwhenua diversion canal	2841545	6314715
W11	Horomanga River u/s Rangitaiki River confluence	2838210	6308070
W12	Omahuru Stream u/s Rangitaiki River confluence	2837190	6305680
W13	Rangitaiki River near Galatea	2837070	6307380
W14	Rangitaiki River at Rabbit Bridge	2840022	6310772
W15	Wheo River at upper dam	2821550	6279370
W16	Bore water at Roy farm		

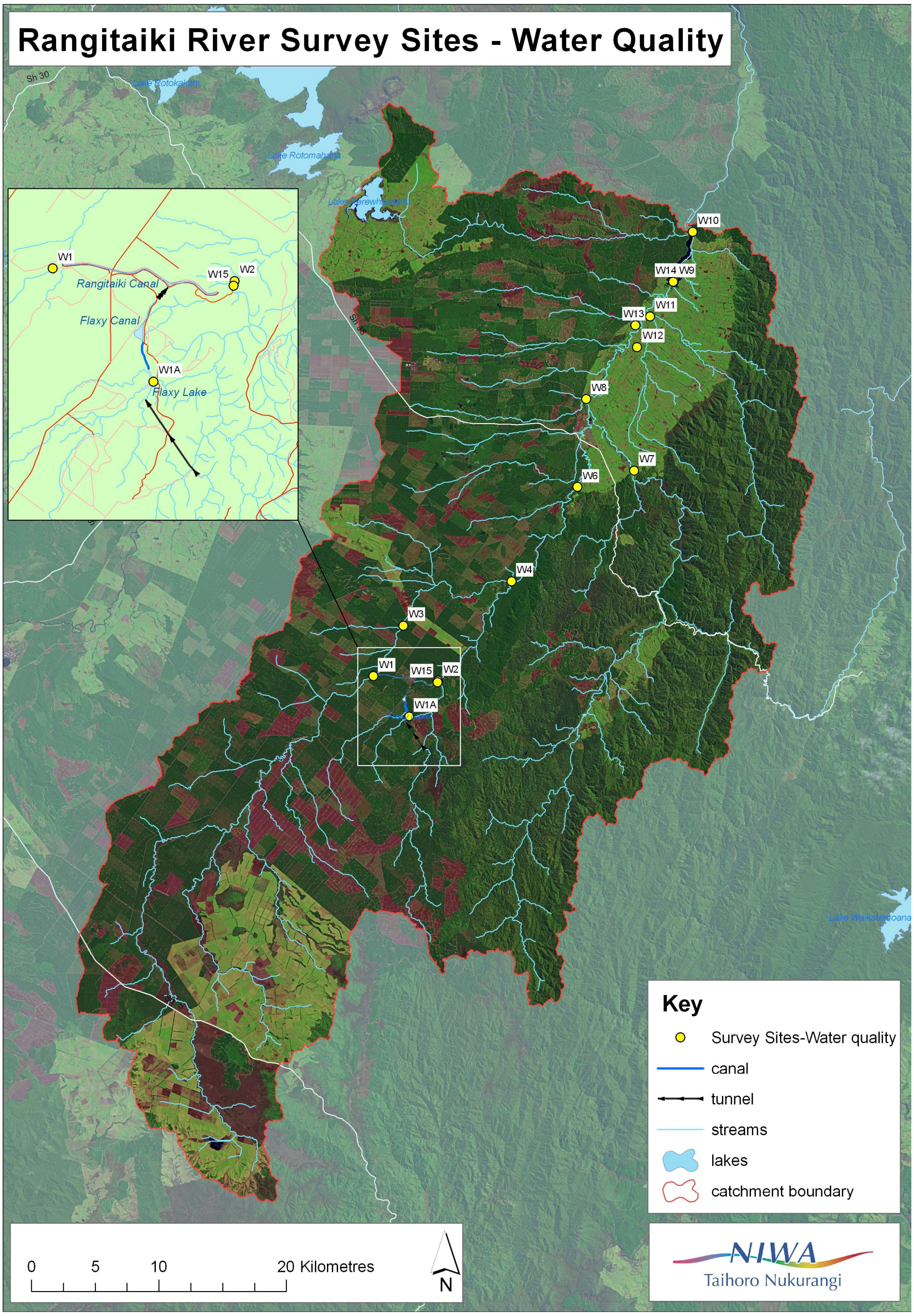


Figure 5—2: Location of sites used for longitudinal survey of 28–29 April 2009, Rangitaiki and Whirinaki River catchments.

Assessment of light attenuation

In addition to measurement of "conventional" water quality variables, the light climate in the Rangitaiki River was also assessed by measuring light attenuation through the water column. Two LiCor photosynthetically available radiation (PAR) sensors were mounted on a custom-built stand that allowed the sensors to be deployed at fixed depth below the water surface, and at user-selected separation distance. Following deployment, the sensors were left in position for a period of at least 10 minutes. During this time, incident light levels were measured continuously by each sensor. A logger calculated and stored an average value at one-minute intervals. These one-minute average values were used to calculate the light attenuation coefficient (K_d) using Equation 5–1:

$$K_d = \frac{\ln\left[E_z / E_{z+\Delta z}\right]}{\Delta z}$$ Equation 5–1

Where E_z and $E_{z+\Delta z}$ are the PAR values at the two depths at which the sensors were submerged, and Δz is the separation distance between the two sensors.

The euphotic depth (z_{eu}), an index of plant growth limitation by light is defined as the depth to which 1% of the incident light occurs. It may be reasonably approximated using Equation 5–2:

$$z_{eu} \approx \frac{4.6}{K_d}$$ Equation 5–2

Munsell colour and hue

Colour was determined during one of the surveys using the Munsell colour system. The appearance of the water (viewed horizontally using the black disk viewer) was matched with Munsell colour standards following Davies-Colley et al. (2003).

"Continuous" dissolved oxygen measurement

Three water quality sonde devices were deployed at three different locations along the Rangitaiki River between Murapara and Rabbit Bridge. These compact devices contain a number of sensors that measure specific water quality variables. The data derived from the sensors is stored on a built-in logger. The three sondes deployed measured water temperature, water level, dissolved oxygen concentration, electrical conductivity and pH. Data were collected at 15 minute intervals over a period of about 43 hours.

Data analysis techniques

A range of exploratory techniques were used to analyse the data.

Box and whisker plots were prepared to display temporal or spatial trends. These plots provide a convenient way to represent the distribution of a dataset visually. The series of boxes show the distribution of data for each water quality variable (e.g., concentration) as a function of another variable (e.g., time or sampling location). In these assessments, this was done on the basis of sample site (providing an indication of spatial variability), as well as over time (by comparing data for discrete time periods). The boxes contain the middle 50% of the data. The '*' symbols within each plot indicate results 1.5 times larger or smaller than the 75th or 25th percentile respectively, while the 'O' symbols indicate values 3 times larger or smaller than the 75th or 25th percentile respectively.

Scatter graphs (X-Y graphs) allow trends in variables over time and space to be assessed visually. When trend over space was being assessed, data were plotted as a function of river length. This allowed identification of river reaches where changes in water quality took place.

For selected variables at some sites, formal assessment of trend of variable (value, concentration) over time was undertaken. The seasonal Kendall test was applied. This is a non-parametric test that accounts for seasonality by calculating the Mann-Kendall test on each of *m* seasons separately, and then combines the results. The Sen slope is the median annual slope of all possible pairs of values in each season (Seasonal Kendall Slope Estimator, SKSE). It is expressed as change in the variable per year. The SKSE is often normalised by dividing by the median value of the variable for the entire data set, to indicate the relative magnitude of the change (RSKSE). A large positive or negative RSKSE value implies a large change per year. The magnitude of the change is described in this report as "meaningful" if it is both statistically significant ($p < 0.05$) *and* the magnitude of the change is greater than 1%/year. The software package "Time Trends"[11] was used to undertake these assessments, as well as generate graphs to allow visual display of the data and associated trend lines.

Summary statistics were prepared for selected variables using Systat for Windows v12. Where necessary, data files from various sources were combined using the MERGE facility of Systat; in these circumstances, data files were combined using "sample date" as a field common to both files.

[11] Version 1.10, 2008. Developed by NIWA and Ian Jowett for Northland Regional Council on behalf of the Foundation for Research, Science and Technology through the Envirolink fund.

5.2 Results and discussion

5.2.1 Hydrology at time of sample collection

The hydrology of the Rangitaiki and Whirinaki Rivers is discussed in detail in Section 3. The discussion that follows relates to river discharge at the time of sampling. It is expanded later to include describing relationships between river discharge and the concentrations of selected variables.

Both the NRWQN and EBOP database includes the river discharge at the time of sampling. Statistics for these discharge values are included in the Appendices. The flow duration curve for the two sample points are shown in Figure 5—3, while the time-series of discharge at time of sampling is shown in Figure 5—4. The influence of the control structures on the discharge values in the Rangitaiki River is immediately apparent:

- The Rangitaiki River had a higher average flow at time of sampling (about 21.3 $m^3 s^{-1}$) than the Whirinaki River (14.8 $m^3 s^{-1}$).
- The discharge at the time of sampling in the Rangitaiki River is likely to fall within a narrow range of values, determined principally by the operation of the hydro-scheme in the upper catchment.
- Related to this, the Rangitaiki River at Murupara is less subject to extreme flow events than the Whirinaki River – the 95th percentile discharge value is about 32 $m^3 s^{-1}$, compared with 38 $m^3 s^{-1}$ for the Whirinaki River (despite the larger average discharge for the Rangitaiki River).

These factors may be expected to influence the range of values or concentrations of water quality variables, as well as the frequency and duration of transient events.

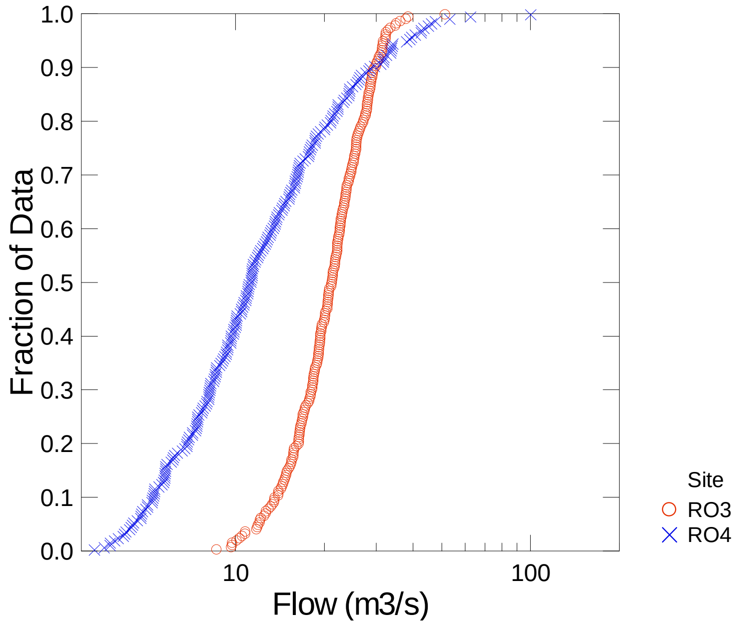


Figure 5—3: Flow duration curve for Rangitaiki (RO3) and Whirinaki (RO4) rivers, using flow data at the time of sampling. Note log scale used for x axis.

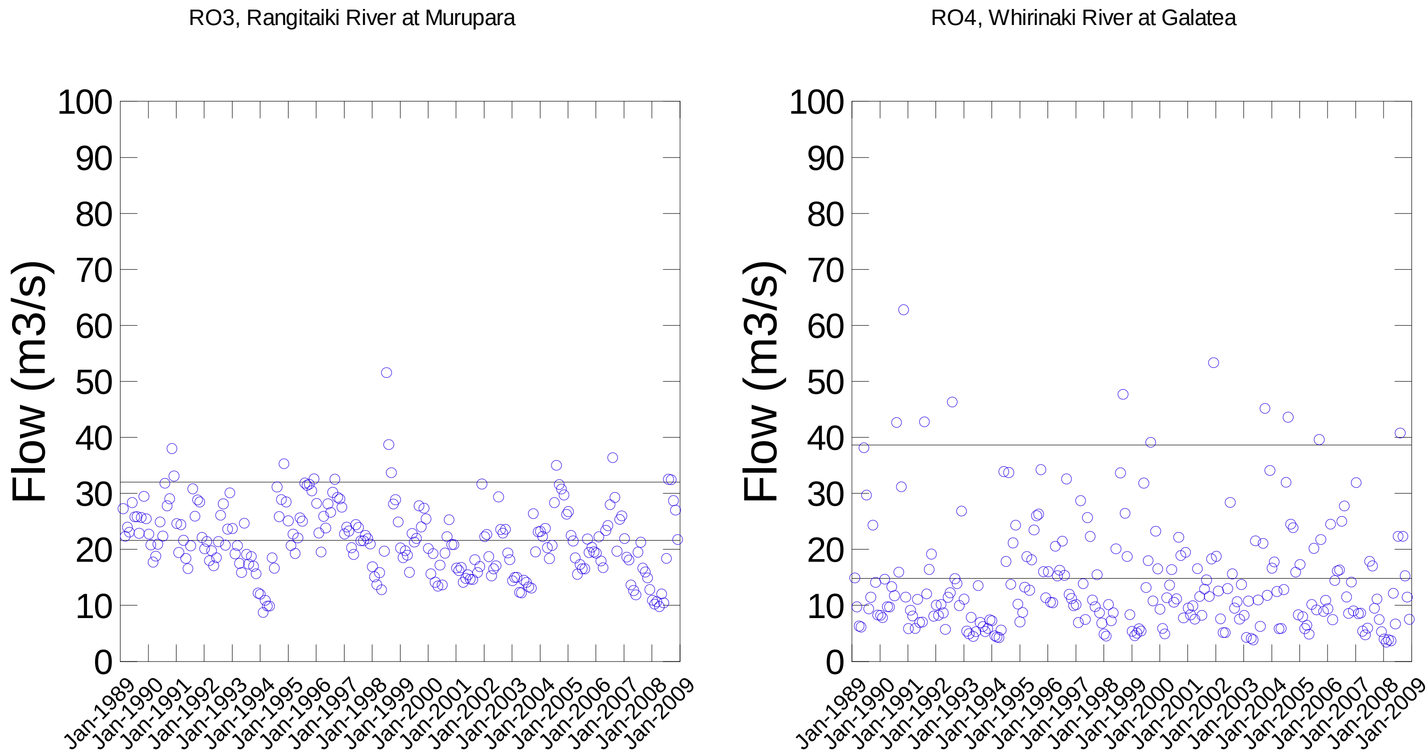


Figure 5—4: Time-series of discharge at time of sampling. The lower horizontal line is the average flow and the upper horizontal line is the 95th percentile value.

5.2.2 Spatial and temporal trends in water quality

While water quality samples have been collected from a number of locations within the Ngati Manawa rohe, these have not always been collected concurrently from multiple sampling locations. The time series data for a range of variables at all sample points are provided in the Appendix 13.2 No data exists for some variables at some sampling locations, while others are well represented. The data allows general conclusions to be reached.

Physical variables and dissolved oxygen

A wide range of temperatures occur in surface water across the mid-upper Rangitaiki River catchment, as indicated in Appendix 13.2. Monthly maxima occur in February annually.

The solubility of dissolved oxygen decreases as water temperature increases. Accordingly, dissolved oxygen concentrations are highest in winter. Dissolved oxygen concentrations are generally at or above 100% saturation for the Rangitaiki and Whirinaki Rivers upstream of Murupara at the time of sampling. While less data are available downstream, it appears that at times concentrations lower than about 8 mg/L may be measured. Richardson & Dean (1997) reviewed the literature to determine the likely responses of freshwater fish to dissolved oxygen concentrations. They concluded that concentrations greater than about 6 mg/L provided adequate protection to rainbow trout. The limited data available regarding the impact of low dissolved oxygen on the health of native fish indicated that some native fish species appeared more tolerant to low dissolved oxygen concentrations than species such as trout.

Data derived from both the NRWQN and EBOP monitoring programmes provides values for *daylight hours only*, because samples are collected mainly between 10:00 and 15:00. Minimum dissolved oxygen concentrations are typically observed at dawn – concentrations reflect the depletion of dissolved oxygen in response to biochemical demand and respiration by plants. To assess dissolved oxygen dynamics in the Rangitaiki River, three sondes were deployed. These measured concentrations at 15 minute intervals over a period of about 43 hours. The sondes were deployed at points P13, W8 and W9 (RO3, downstream of the Whirinaki River confluence and Rabbit Bridge respectively). The two upstream devices functioned correctly, but unfortunately the device deployed at Rabbit Bridge malfunctioned. Dissolved oxygen concentrations are shown in Figure 5—5. A similar diurnal trend is evident at both sites, with periods of minimum and maximum percent saturation dissolved oxygen concentrations coinciding closely, and no consistent difference in concentrations between the two sites.

On average, the percent saturation dissolved oxygen concentration at the downstream site is about 0.3% lower than the upstream site.

The long-term summary statistics for sites RO3 and RO4 indicate that average percent saturation dissolved oxygen concentrations at RO3 are 1.6% lower than at RO4 (104.7 vs. 103.1). The median values differ by 1.8%. This indicates that the observed difference and values measured during this survey are reasonably typical. The downstream monitoring point is about 1.2 km downstream of the Murupara wastewater treatment pond outfall. While it is likely that the effluent is fully mixed with the river after this distance, the oxygen demand represented by the wastewater may not be fully exerted, i.e., lower percent saturation values may occur further downstream of the discharge. Additional surveys would be required to test this hypothesis. This relatively small wastewater discharge seems unlikely to depress dissolved oxygen concentrations in the receiving water significantly.

Overall, we conclude from the available data that dissolved oxygen concentrations in the Rangitaiki River upstream of Aniwhenua Canal are adequate to sustain native fish and a viable trout fishery.

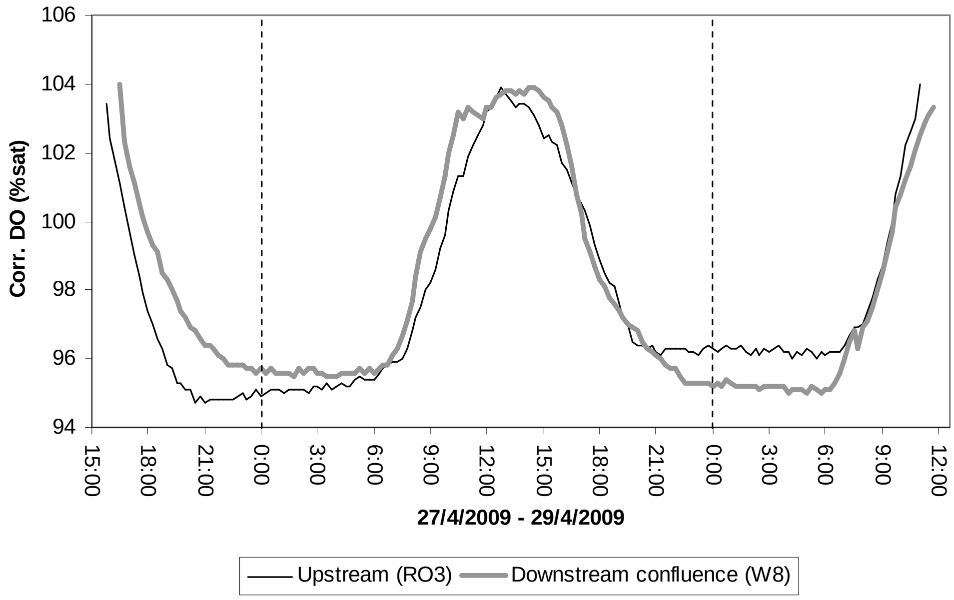


Figure 5—5: Measured dissolved oxygen concentrations, Rangitaiki River. Stippled lines define a 24 hour diurnal period.

Electrical conductivity provides a measure of the total concentration of dissolved ionic (electrically charged) species. This includes species such as chloride, sodium, magnesium and calcium. Some forms of nutrients (e.g., DRP or nitrate-N) also contribute to electrical conductivity. Weak seasonality is evident within the catchment, with highest conductivities observed in autumn, prior to dilution of dissolved materials by early winter rainfall (refer to Appendix 13.2).

There is a strong relationship between electrical conductivity and discharge (Figure 5—6). In addition to showing the relationship between discharge and concentration of dissolved ions, this Figure also highlights the impact of regulated flow on water quality. Data for RO4 (Whirinaki River) and BOP110016 indicate that the relationship extends over a wide range of concentration and discharge values. In the regulated catchment (RO3), there is less correlation between discharge and conductivity. The impact of flow regulation on relationships between discharge and concentration extends to other water quality variables as well. These are discussed further in the subsequent Sections.

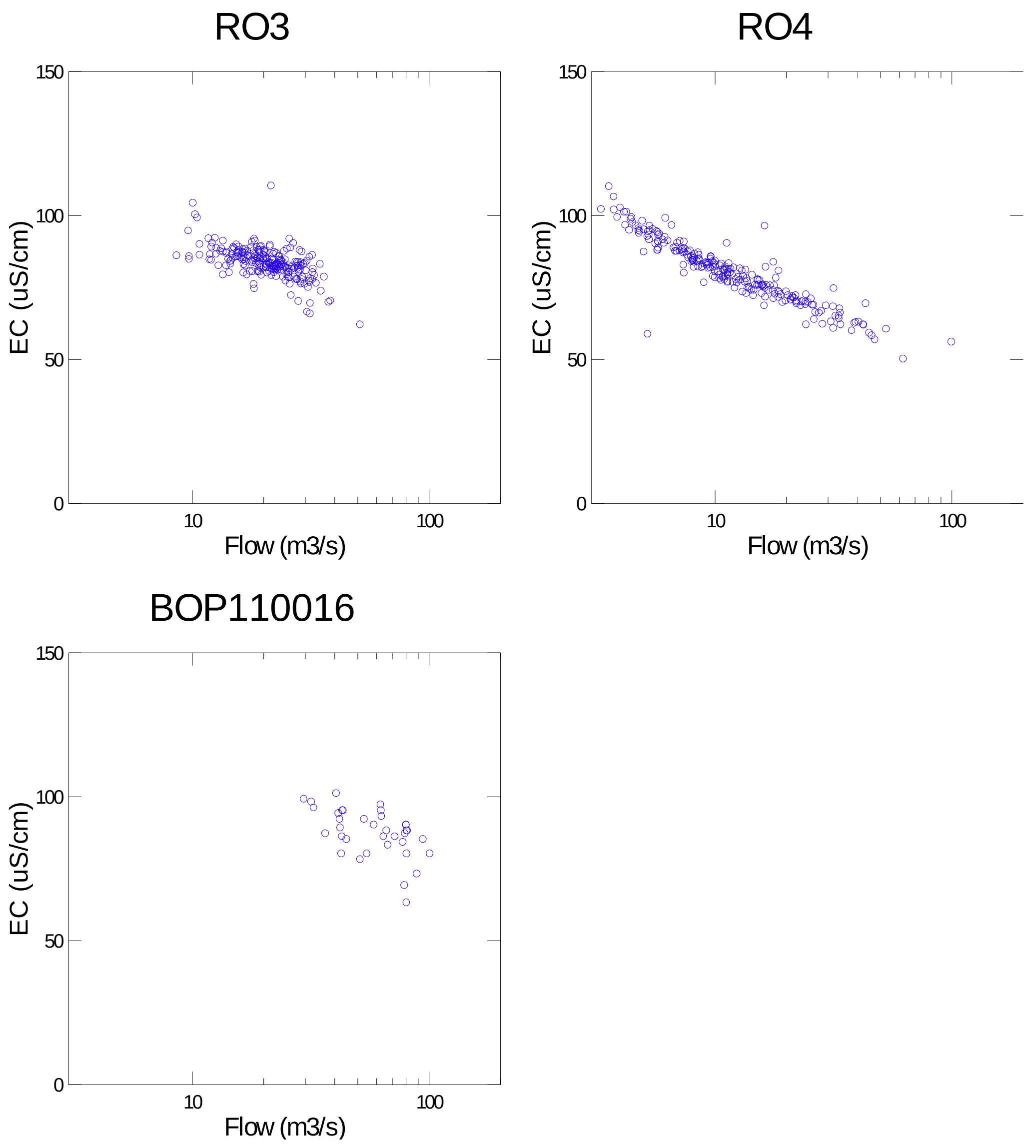


Figure 5—6: Relationship between electrical conductivity and discharge, Rangitaiki River (RO3 regulated), Aniwhenua Canal (BOP110016) and Whirinaki River (RO4 unregulated) (note log scale on x axis).

Trend testing indicated a significant decrease in the percent saturation dissolved oxygen concentrations at RO3 and RO4, but the magnitude of the trend was not meaningful for either site. A statistically significant increase in electrical conductivity was detected for RO3, but the magnitude of the trend was not "meaningful" (RSKSE=0.32).

Visual clarity and optical properties

Visual clarity appears generally lower in the Whirinaki River than the Rangitaiki River upstream of Murupara. There also appear to be extended periods of higher clarity in the Rangitaiki River, notably in the late summer/autumn period. This is probably related to the regulation of flows in the Rangitaiki River upstream of Murupara and the influence of less turbid groundwater, which is a significant component of the baseflow. Maintenance of a higher than natural baseflow, will remove more material from the channel than might occur under natural baseflow conditions. Attenuation of peak or flood discharge will limit the mobilisation of material within the channel. This is observed as higher visual clarity and less turbid, less coloured water.

Visual clarity in both the Rangitaiki and Whirinaki Rivers may be regarded as "reasonably average" in a national context. RO4 ranks 31/77 sites, while RO3 ranks 27/77 sites, rating 60 % and 65 % respectively when the ranking is normalised (Figure 5—7).

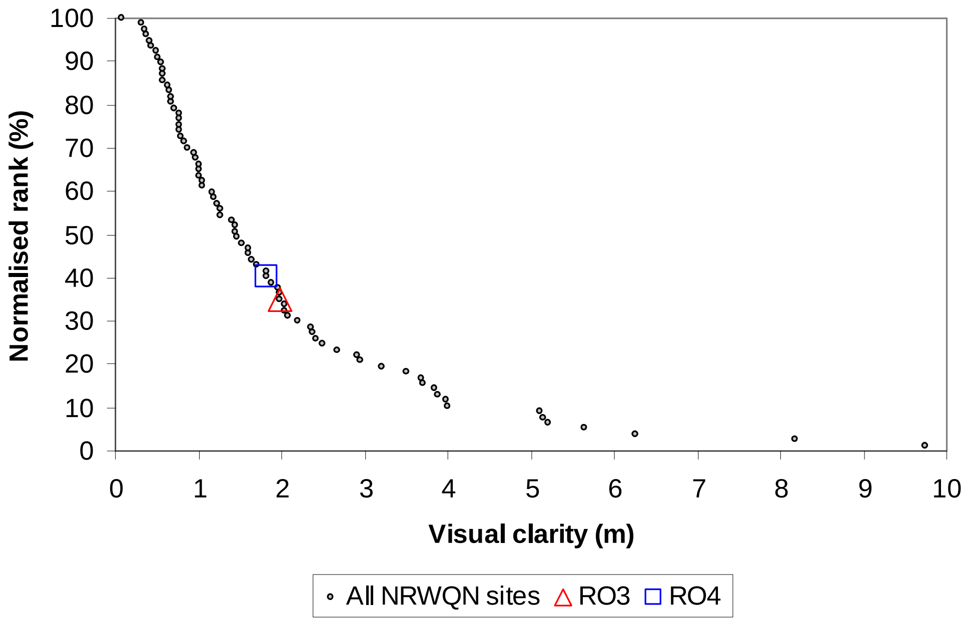


Figure 5—7: Comparison of visual clarity in the Rangitaiki River (RO3) and Whirinaki River (RO4) with results for other rivers in New Zealand. Data derived from NRWQN results, 1989–2008.

CDOM, as indicated by absorption coefficient values (g_{340} and g_{440}) are generally lower at RO3 than RO4. CDOM can impart a hue shift from the blue of optically pure water towards yellow.

Limited data for the Aniwhenua Canal site (BOP110016) indicates higher CDOM concentrations than for the RO3 site. This suggests that coloured material enters the river (or is generated within the river channel) downstream of Murupara.

Turbidity data generally support conclusions regarding visual clarity, to which it is inversely related. While the Whirinaki and Rangitaiki Rivers are generally not turbid, on occasions high turbidity values are measured. A greater number of these events are apparent for the Whirinaki River (RO4) than the Rangitaiki River (RO3) (refer to Appendix 13.2). At the Aniwhenua Canal, river water generally has low turbidity.

Statistical testing indicated a meaningful decrease in visual clarity (RSKSE=-1.51) and a meaningful increase in g_{340} and g_{440} for RO3 over time (RSKSE=1.16 and 2.48 respectively). The "weight of evidence" provided by trend in these variables indicates a decrease in visual clarity and optical properties in water within the Rangitaiki River catchment. A significant but not meaningful increase in g_{440} was indicated for the Whirinaki River upstream of Murupara.

A strong relationship exists between discharge and visual clarity, as shown in Figure 5—8. Note the generally lower clarity in the Whirinaki River (RO4) and the narrow range of discharge values for the RO3 site relative to RO4. The average black disk visibility in the Aniwhenua Canal (1.9 m) is marginally shorter than that in the Rangitaiki River upstream of Murupara (2.05 m).

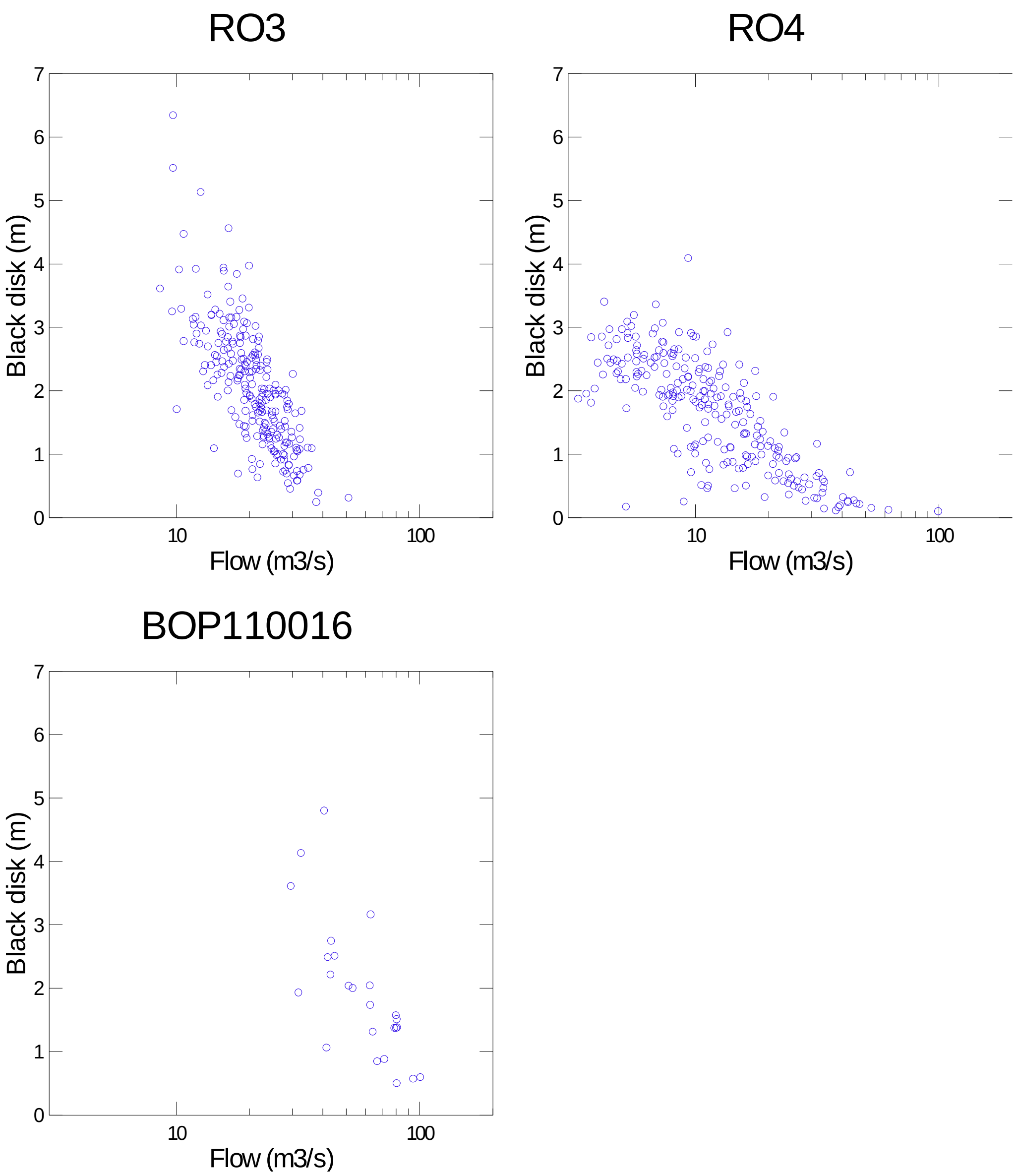


Figure 5—8: Relationship between visual clarity and discharge, Rangitaiki River (RO3), Aniwhenua Canal (BOP110016) and Whirinaki River (RO4) (note log scale for x axis only).

There is a strong seasonal variation in clarity for the Rangitaiki River upstream of Murupara; it is less obvious for the Whirinaki River (summarised in Figure 5—9). For site RO3, visual clarity is greatest in March to May annually (when conditions are driest and runoff reduced), and lowest in August and September annually, in response to seasonal rain. Insufficient data exists to assess the seasonal variability in visual clarity between Aniwhenua canal and Murupara.

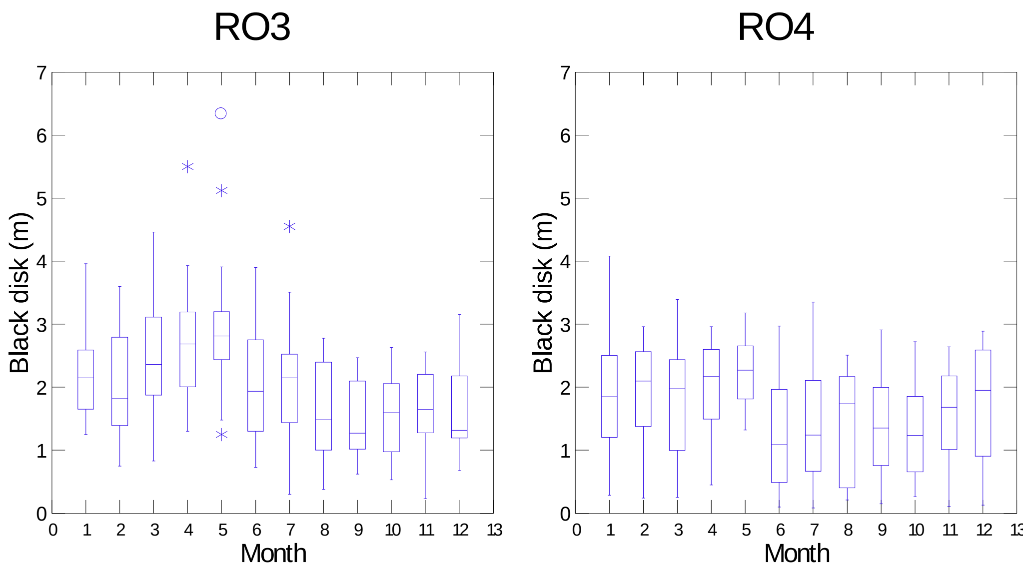


Figure 5—9: Seasonal trend in visual clarity, Rangitaiki (RO3) and Whirinaki (RO4) rivers upstream of Murupara. Data are for the period 1989–2008.

Suspended solids concentrations

Data from the EBOP dataset indicates relatively high suspended solids concentrations in the Rangitaiki River at SH5 (most results greater than 5 g/m^3). Around Murupara, the concentrations are slightly higher in the Whirinaki River than the Rangitaiki River. At both sites there is a difference between the average concentration and the median concentration, indicating a skewed distribution. This arises from a limited number of "extreme" events, during which much greater suspended solids concentrations occur. As anticipated, much lower values occur in the Aniwhenua Canal, following deposition of material derived from the upper catchment in Aniwhenua Dam. This is evident at Rabbit Bridge, where deposition of suspended material has raised the bed of the river.

A strong positive relationship exists between discharge and suspended solids concentrations at all locations sampled, indicated in Figure 5—10.

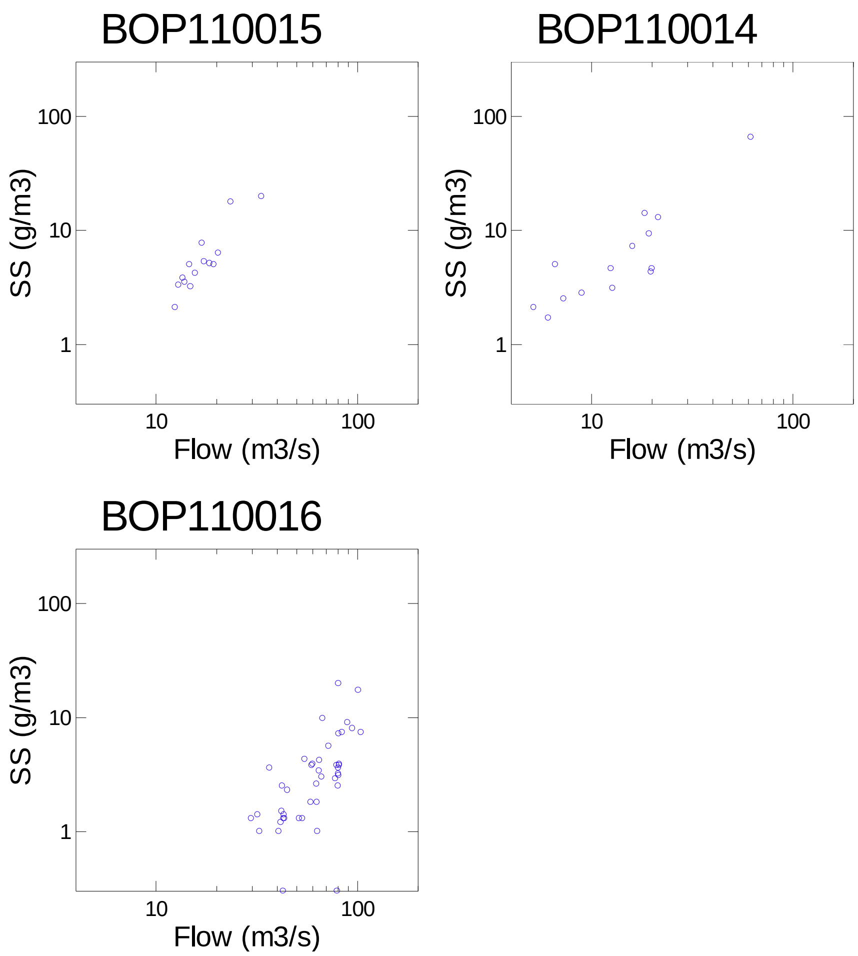


Figure 5—10: Relationship between suspended solids concentration and discharge, Rangitaiki (BOP11015 and BOP11016) and Whirinaki (BOP110014) catchments (note log–log scale).

Determination of suspended solids concentrations is costly and is the reason it ha been omitted from the NRWQN. Suspended solids concentrations may be correlated with turbidity or visual clarity. Although a large number of data are available for these variables, the suspended solids data were collected by EBOP and most of the turbidity and clarity data was collected by NIWA. The timing of these collection events rarely coincides, so that fewer than 30 pairs of results (across a number of sites) exist for turbidity and suspended solids concentration, or suspended solids and visual clarity. In general however, negative relationship between clarity and suspended solids concentration, and positive relationship between turbidity and suspended solids concentration is demonstrated (refer to Appendix 13.2).

Nutrient concentrations

Average concentrations of DRP and ammoniacal-N are similar in the Whirinaki and Rangitaiki Rivers upstream of Murupara, while concentrations of both variables are considerable greater in Aniwhenua Canal. While it is not possible to identify specifically where the additional nutrient enters the catchment, the limited data indicate that higher concentrations occur not far downstream of Murupara itself, particularly for DRP. It is likely that the discharge from the Murupara oxidation pond, plus inputs from agriculture downstream of Murupara contribute to the DRP concentrations.

Nitrate concentrations in the Rangitaiki River at Murupara are considerably greater than in the Whirinaki River. The low concentrations in the Whirinaki River should be anticipated – it drains a forested catchment, with lower input from groundwater than the Rangitaiki River catchment. For example, the mean concentrations at RO3 and RO4 are 608 and 119 mg/m^3 respectively. A simple dilution model (of the form shown in Equation 5–3) predicts that after mixing, and ignoring any other nutrient input or assimilation, the average nitrate-N concentration downstream of Murupara should be about 230 mg/m^3.

$$c_{Rd/s} = \frac{Q_{Ru/s} + Q_{Wu/s}}{\left[\frac{Q_{Ru/s}}{c_{Ru/s}}\right] + \left[\frac{Q_{Wu/s}}{c_{Wu/s}}\right]} \qquad \text{Equation 5–3}$$

Where:
c and Q refer to concentration and discharge respectively,
$_R$ and $_W$ refer to Rangitaiki River and Whirinaki River respectively, and
$_{u/s}$ and $_{d/s}$ refer to upstream and downstream of the mixing zone respectively

Average nitrate concentrations measured at the Aniwhenua Canal are about 380 mg/m^3, indicating that considerable input of nitrogen occurs downstream of Murupara, as well as phosphorus. Once again, it is likely that the discharge from the Murupara oxidation pond, plus inputs from agriculture in tributaries and groundwater draining the Galatea Plains, are responsible for this increase.

Similar trends exist for total P and total N as for DRP and nitrate-N respectively:

- The Rangitaiki River has considerably higher concentrations of total N than the Whirinaki River, and most of the N is in the nitrate form (89%), whereas in the Whirinaki about 55% of total nitrogen is in nitrate-N form.
- TP concentrations are similar in both catchments, although DRP constitutes over two-thirds of TP in the Rangitaiki River catchment (69%), whereas in the Whirinaki River it is closer to half (54%).

- The 95th percentile values for TP in the Rangitaiki River and Whirinaki River are 43 and 84 mg/m^3 respectively – this implies that much of the input of phosphorus to the Whirinaki River is associated with storm events and mobilisation of particulate material.

There is a strong positive correlation between concentrations of DRP, nitrate-N, TP and TN and discharge in the Whirinaki River, but low or no correlation in the Rangitaiki River. Examples are shown in Figure 5—11 and Figure 5—12. Correlation between water quality variables and discharge is also less defined for the Aniwhenua Canal site. Typically, nutrient concentrations in the Rangitaiki River at Lake Aniwhenua appear to be consistently elevated, increasing further in response to storm events in the Whirinaki River catchment.

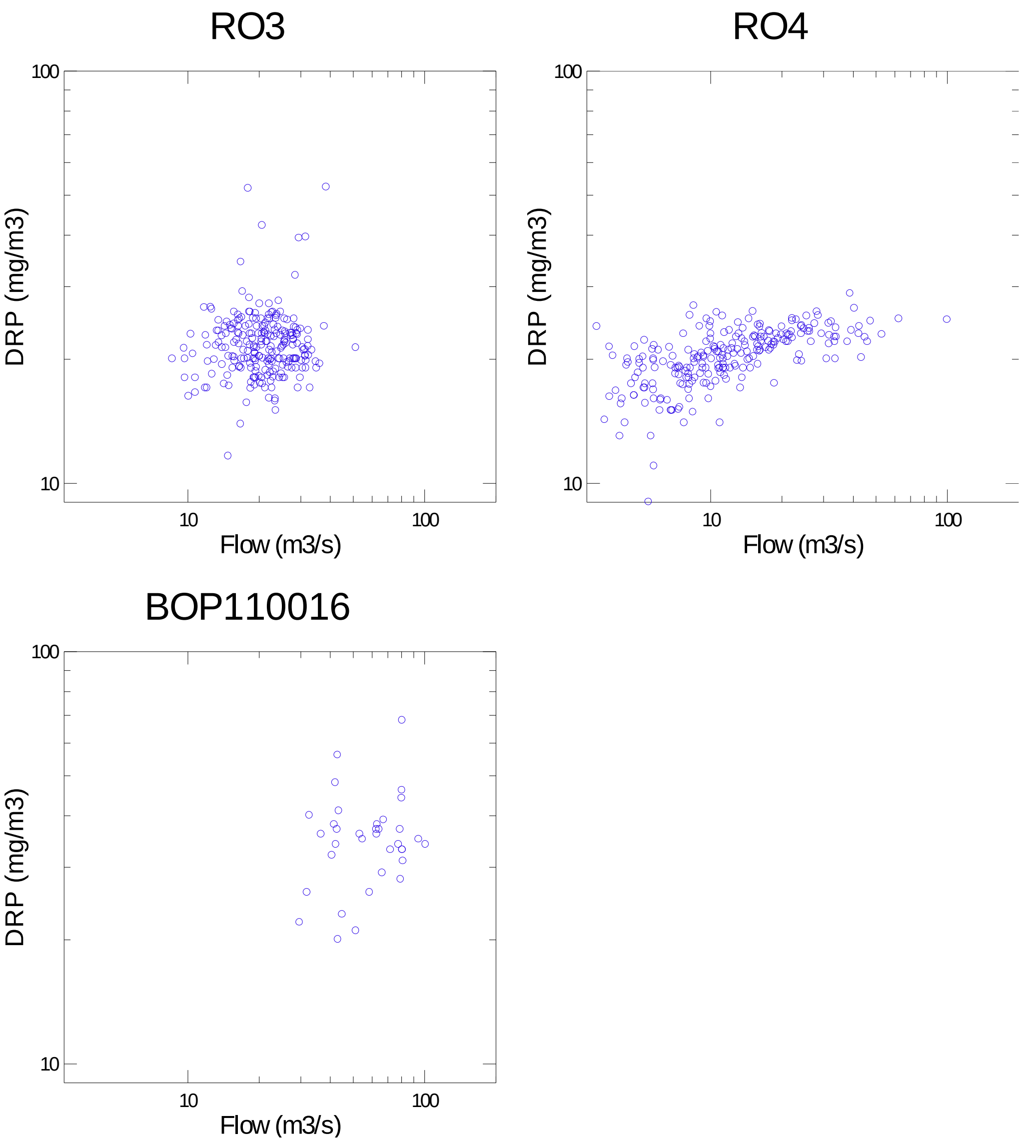


Figure 5—11: Relationship between DRP concentration and discharge in the Rangitaiki River (RO3), Whirinaki River (RO4) and Aniwhenua Canal (BOP110016) (note log-log scale).

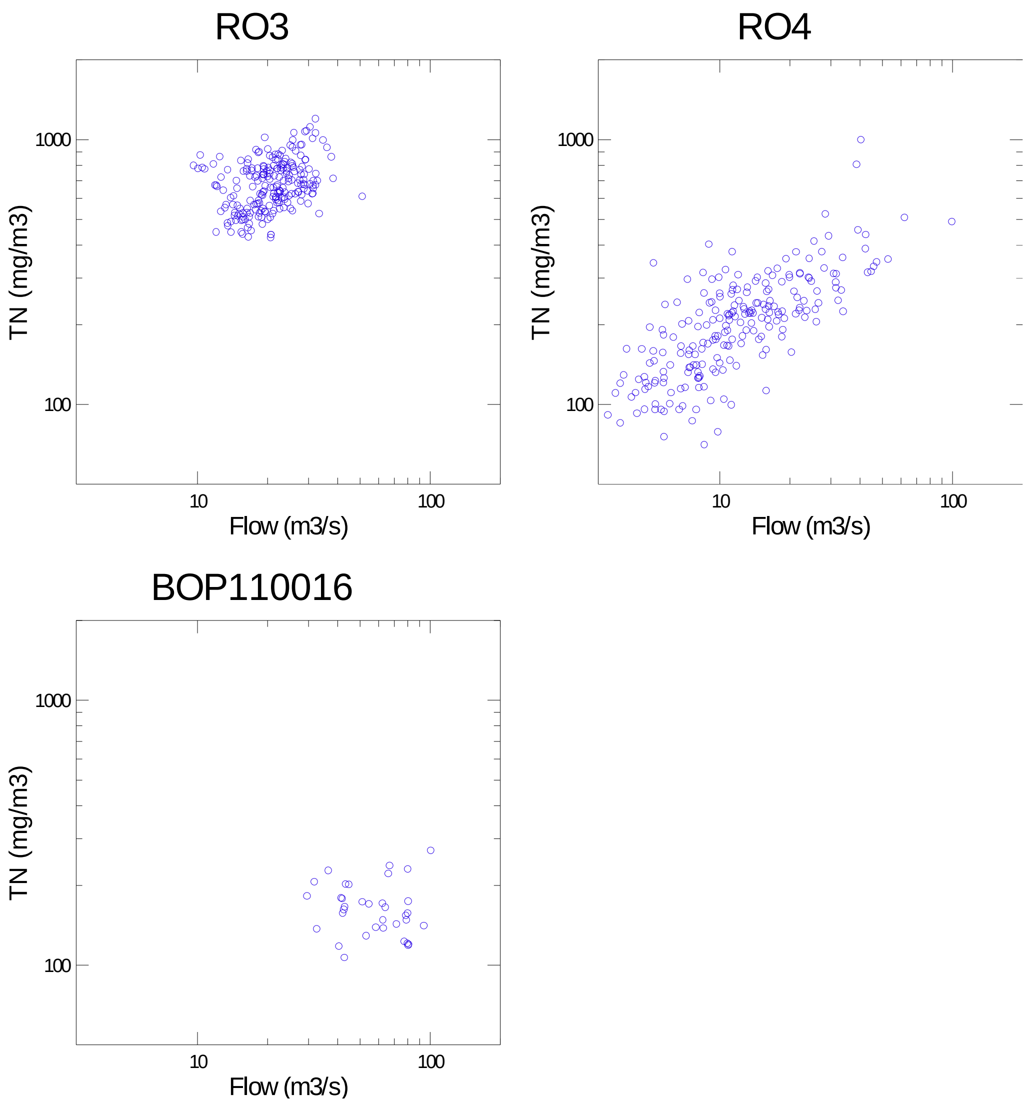


Figure 5—12: Relationship between TN concentration and discharge, in the Rangitaiki River (RO3), Whirinaki River (RO4) and Aniwhenua Canal (BOP110016) (note log–log scale).

Statistical trend testing of NRWQN data for the period 1989–2008 indicated a meaningful increase in nitrate-N and total-N at RO3 (RSKSE=1.83 and 2.09 respectively), and a meaningful increase in total-N at RO4 (RSKSE=1.55); a statistically significant (but not meaningful) increase in nitrate-N was indicated for RO4 (RSKSE=0.69). Statistically significant (but not meaningful) increases in DRP and TP were detected for RO4 (RSKSE=0.29 and 0.76 respectively).

No significant trends in nutrient concentrations were detected downstream at the Aniwhenua Canal. Insufficient data exists to perform trend tests at any of the other sites downstream of Murupara.

The relationship between concentration and flow was also explored as the flux of nutrient. Flux is the product of concentration and flow, as defined in Equation 5–4:

$$Flux = Q \times c \qquad \text{Equation 5–4}$$

Where $Flux$ is the instantaneous load (say g/s), Q is the discharge ($m^3\ s^{-1}$) and c is concentration (g/m^3).

The relationship between concentration and flux of nitrate-N for the Rangitaiki River (RO3) and the Whirinaki River upstream of Murupara (RO4) is shown in Figure 5—13 and Figure 5—14. While the trend of increasing nitrate-N concentrations at RO3 is reasonably distinct in Figure 5—13, the increase in nitrate-N flux is less obvious. These Figures highlight the importance of considering both *concentration and flow* when assessing water quality. The impact of extreme events on the flux of nutrients mobilised within the catchments are particularly evident for the Whirinaki River (RO4) in Figure 5—15.

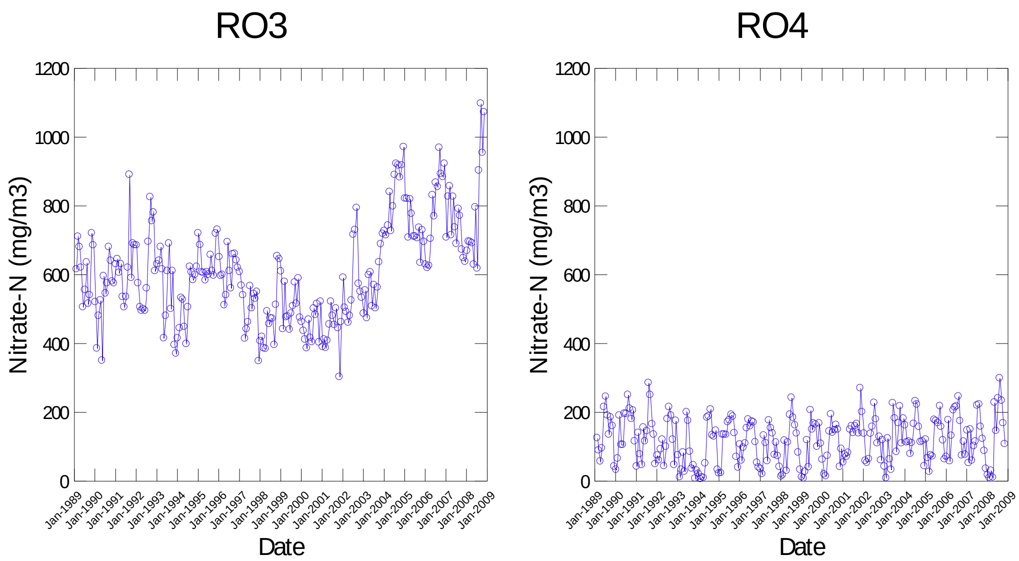


Figure 5—13: Nitrate-N concentrations in Rangitaiki (RO3) and Whirinaki (RO4) rivers upstream of Murupara.

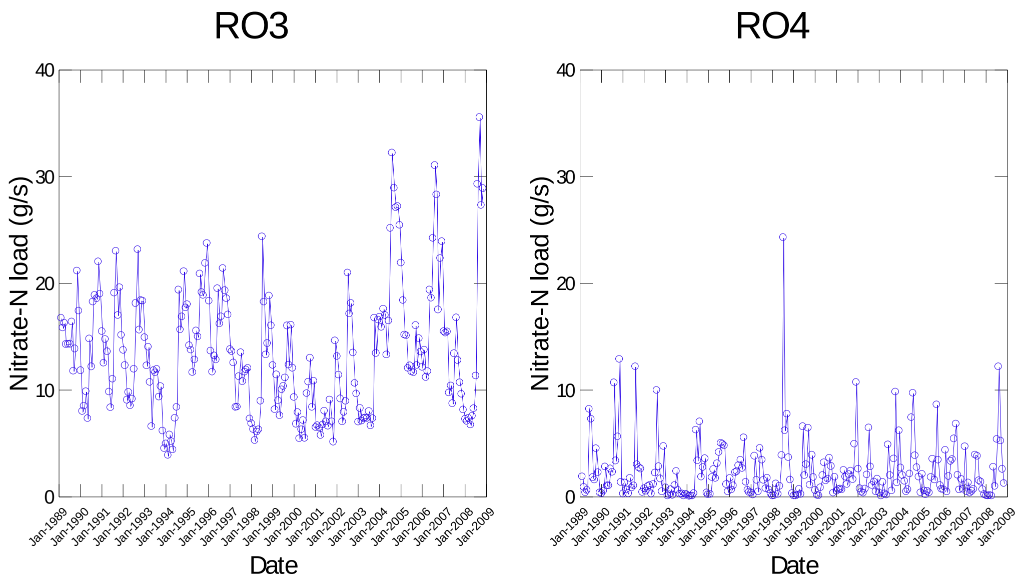


Figure 5—14: Nitrate-N flux in the Rangitaiki(RO3) and Whirinaki (RO4) rivers upstream of Murupara.

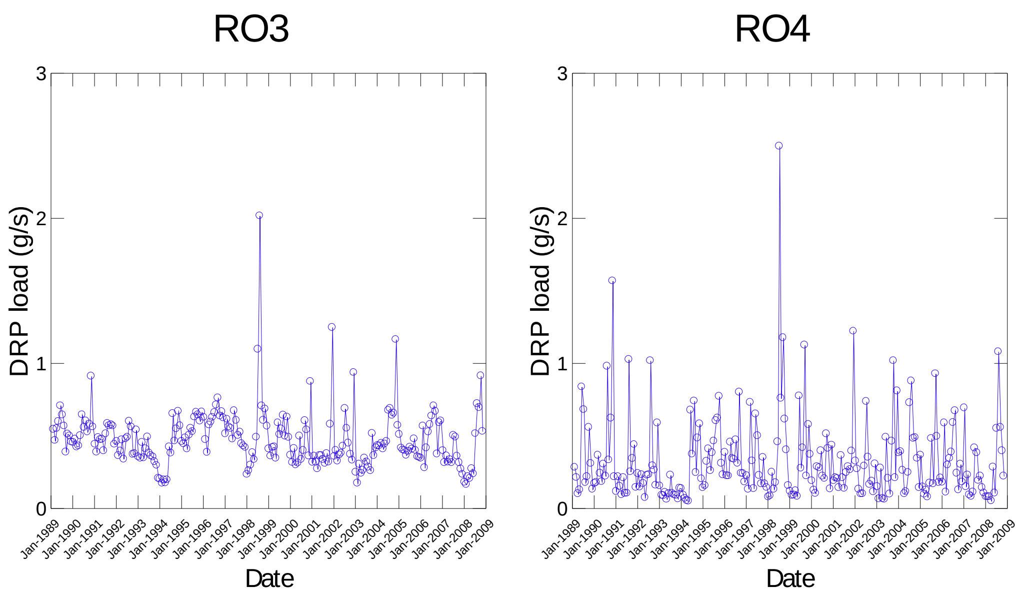


Figure 5—15: Time-series of DRP flux in Rangitaiki (RO3) and Whirinaki (RO4) rivers upstream of Murupara.

Soluble nutrient concentrations are compared with those for the other 75 sites that comprise the NRWQN in Figure 5—16. The elevated nutrient concentrations in the Rangitaiki River upstream of Murupara are confirmed – soluble inorganic nitrogen concentrations (SIN – nitrate-N plus ammoniacal-N) ranked 70/77 sites (91%, when normalised), while DRP concentrations also ranked 70/77 (91%). The latter ranking was shared by the Whirinaki River site for DRP concentrations, but the SIN concentrations ranked 53% (41/77) for the Whirinaki River site.

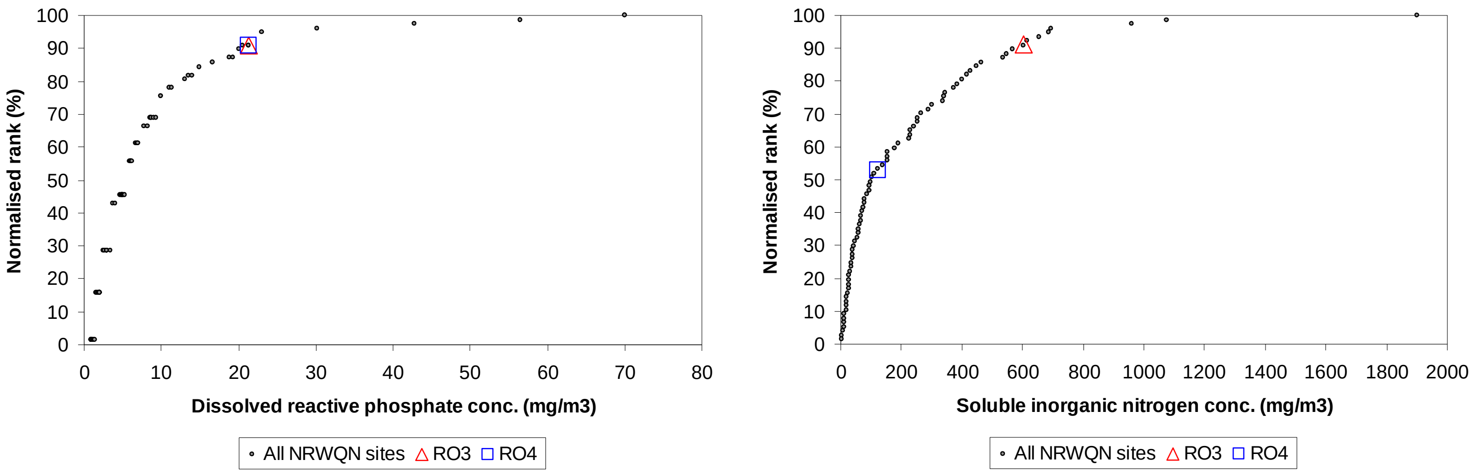


Figure 5—16: Comparison of soluble nutrient concentrations with those in other rivers in NZ. Data derived from NRWQN results, 1989-2008. (RO3 = Rangitaiki River and RO4 = Whirinaki River.)

These concentrations may be anticipated to have ecological significance in terms of the growth and potential proliferation of aquatic plants (algae and macrophytes). Using data from the NRWQN, Davies-Colley (2000) identified "trigger levels", or concentrations of water quality variables at which management action may be anticipated. These were subsequently incorporated in the ANZECC guidelines (ANZECC & ARMCANZ, 2000). These actions could be in the form of policy or regulation, aimed at reducing or avoiding environmental impact. Trigger concentrations were based on the 80^{th} percentile values for sites, grouped on the basis of altitude, similarities in land uses or geology. Values for DRP and nitrate-N for "Upland sites (>150 m), non-glacial or lake-fed" were 9.0 mg/m^3 and 167 mg/m^3 respectively. These values are considerably exceeded at both RO3 and RO4, showing that the Rangitaiki River system is appreciably nutrient enriched.

Proliferation of aquatic plants, including nuisance growths of periphyton and blue-green algae, may occur if the habitat within the river channel is suitable. Suitable habitat is determined by stable substrate, adequate light and moderate water velocity. The results of a periphyton and macrophyte survey are summarised in Section 6 and Section 7 respectively.

Comparison of nutrient concentrations with results from other catchments

The generally elevated nutrient concentrations in the Rangitaiki River catchment are of interest and possibly a cause for concern. We showed in the previous section that soluble phosphorus and nitrogen concentrations are amongst the highest in New Zealand. The issue of land use change and impact on water quality have been widely recognised in New Zealand, e.g., Ballantine & Davies-Colley (2009) and MfE (2005).

It has also been noted that land use changes in catchments with similar characteristics to that of the upper Rangitaiki River has impacted on surface water quality. For example, intensive dairying commenced in the adjacent Taharua River catchment (Hawke's Bay Region) during the 1990s. This catchment adjoins the Rangitaiki River to the south and west. Geology, climate and land use is likely to be very similar to that in the upper Rangitaiki River. Currently the nitrate-N concentrations range from 1,300 – 2,800 mg/m^3 annually. In addition, ongoing monitoring indicates that nitrate-N concentrations have increased by more than 6%/year[12].

The relationship between land use and nutrient concentrations has been extensively studied in the Rotorua lake catchments. In a predominantly pumice catchment with moderately intense landuse, such as that of the Ngongotaha Stream, nitrate-N concentrations are between 1,000 and 2,000 mg/m^3, while DRP concentrations average about 50 mg/m^3 annually. In the Hamurana Stream, where the most intensive landuse is confined to the upper reaches of the catchment, nitrate-N concentrations range from 500 to 600 mg/m^3. In relatively unmodified catchments, such as the Purangi Stream, nitrate-N concentrations are about 100-200 mg/m^3, similar to those in the Whirinaki River[13]. This information derived from other catchments in the Region with similar soils and land uses indicates that nitrogen is readily lost from agricultural catchments as nitrate, once a lag period has passed. Typically this is relatively short, in a range from years to decades.

Limited water quality data are available for streams in the upper Rangitaiki River catchment. Selected data are summarised as dot plots (each dot representing the annual mean value) in Figure 5—17 and Figure 5—18, and as box and whisker plots in Figure 5—19 and Figure 5—20. Data for TKN and TP provided little extra insight over and above the soluble nutrient species, and are not shown.

These Figures indicate:

[12] Draft "Esk and Mohaka Catchments Surface Water Quality and Ecology State of the Environment Report", Brett Stansfield, Hawke's Bay Regional Council, pers. comm.. June 2009.
[13] Pers. comm. Dr Kit Rutherford, NIWA Hamilton, June 2009.

- a general decrease in concentration in a downstream direction along the Otamatea River
- a general increase in concentration between 1999–2001 vs. 2004–2005 at all sites.

In Table 5—5, discharge and concentration and flux data are compared for selected soluble nutrients. The comparison is between the Otamatea Stream at Lochinver Dam and the Rangitaiki River at Murupara. The ratio of these selected metrics are also shown. These data indicate that while the flow in the Otamatea Stream is only about 1/15th (7%) that of the Rangitaiki River at Murupara, the DRP and nitrate-N flux is about 11% and 17% respectively. This indicates that the intensively farmed upper Rangitaiki River catchment appears to contribute a disproportionate amount of nutrient to the Rangitaiki River, relative to the remainder of the upper catchment.

Consideration of typical nutrient export rates from forested catchments supports this conclusion. For example, research undertaken in the Rotorua lakes catchments indicates that forested catchments export about 4 kg N/ha/year[14]. Assuming a water yield of 1000 mm/year and ignoring any other inputs or attenuation, the concentration of nitrate-N in streams draining forested catchments would be about 400 mg/m^3.

For the period 2004–2005, average nitrate-N concentrations in the Rangitaiki River at Murupara were about twice this value - 790 mg/m^3 (Table 5—5). To achieve these values from purely forested catchments, the nitrate-N export factor would need to be twice that typical for other catchments. In the Otamatea Stream, during this period, nitrate-N concentrations were almost 2.5 times greater (almost 2,000 mg/m^3). Taking into account the leaky pumiceous soils in the upper catchment (leading to significant transport of material in groundwater), and the elevated concentration of nitrate-N observed in surface water, it is apparent that the intensively farmed upper catchment may contribute a considerable proportion of the dissolved nitrogen load.

[14] Dr Kit Rutherford, pers. comm. NIWA Hamilton, June 2009

Table 5—5: Comparison of discharge, concentration and flux data for Otatea Stream (BOP110111) and Rangitaiki River at Murupara(RO3), 2004–2005.

Variable	Site		Ratio, RO3/BOP110111
	BOP110111	RO3	
Discharge (m^3/s)	1.47	21.6	14.7
DRP conc. (mg/m^3)	31	21.7	0.7
NNN conc. (mg/m^3)	1916	787	0.4
DRP flux (g/s)	0.05	0.45	9.0
NNN flux (g/s)	2.85	17	6.0

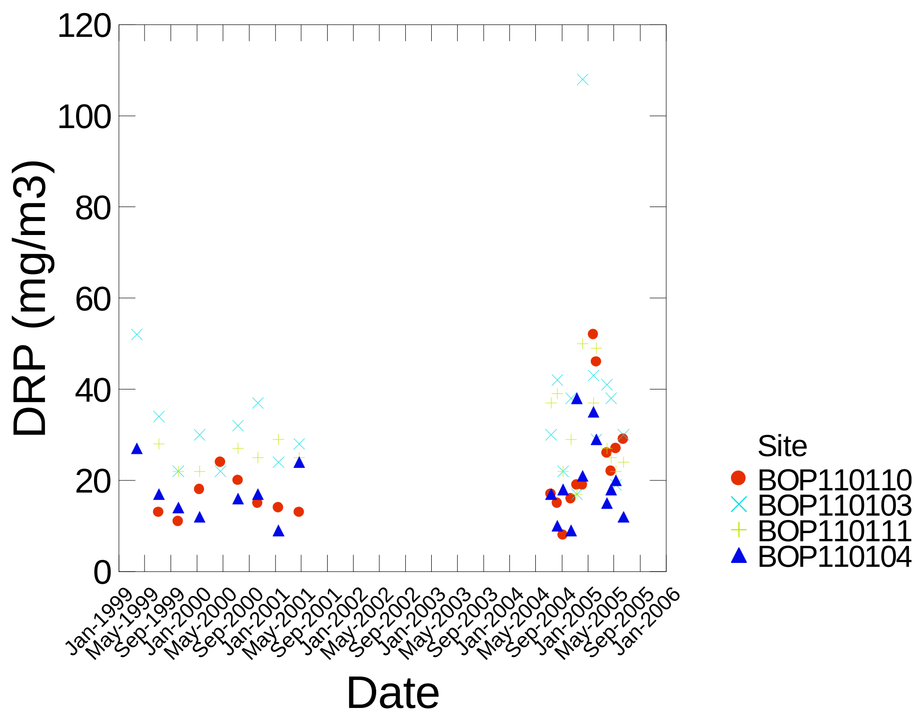


Figure 5—17: Comparison of DRP concentrations over time for sites in upper Rangitaiki River. Data derived from EBOP results, 1999–2005. (See Figure 5—1 for location of sites.)

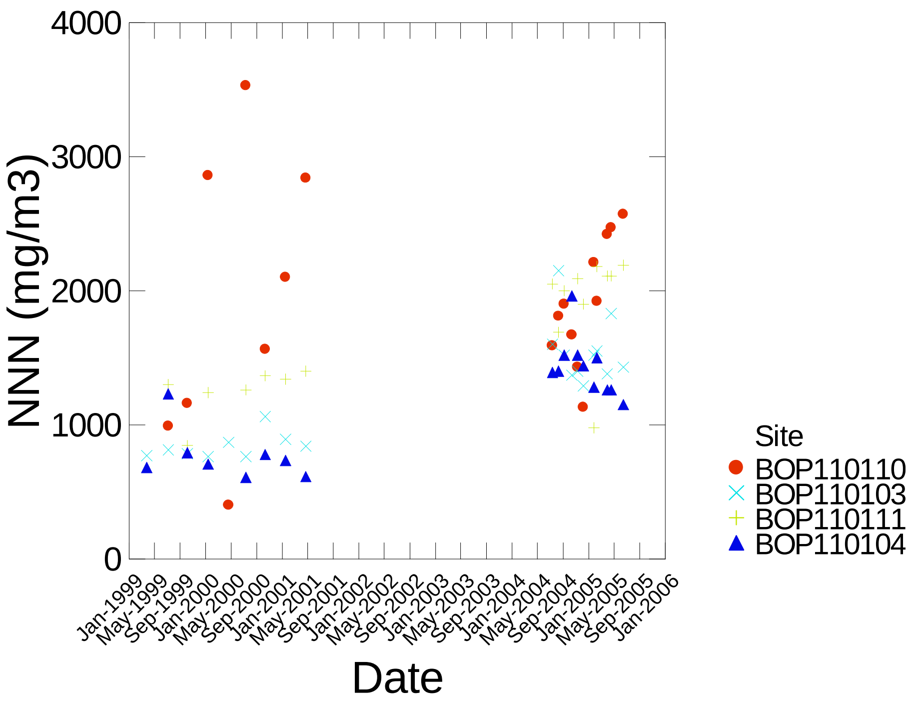


Figure 5—18: Comparison of nitrate-N concentrations over time for sites in upper Rangitaiki River. Data derived from EBOP results, 1999–2005. (See Figure 5—1 for location of sites.)

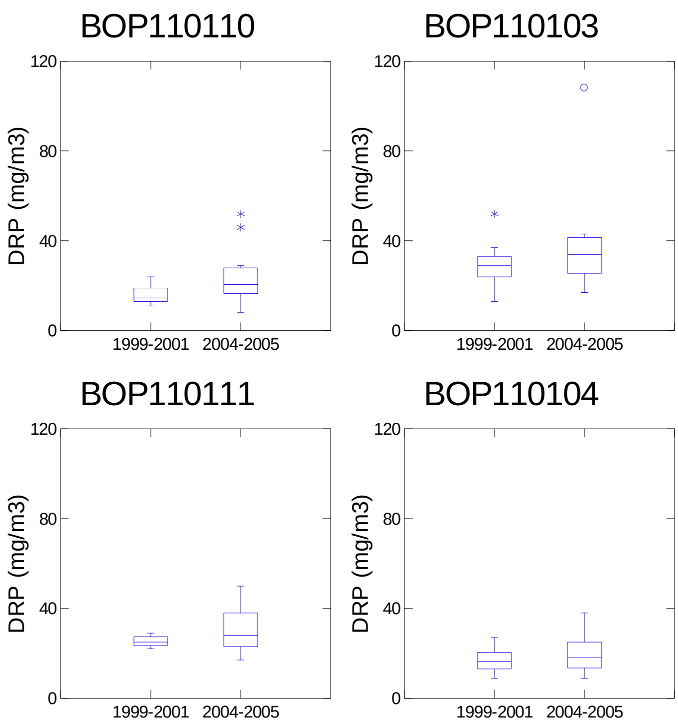


Figure 5—19: Comparison of DRP concentrations between monitoring periods for sites in upper Rangitaiki River. Data derived from EBOP results, 1999–2005. (See Figure 5—1 for location of sites.)

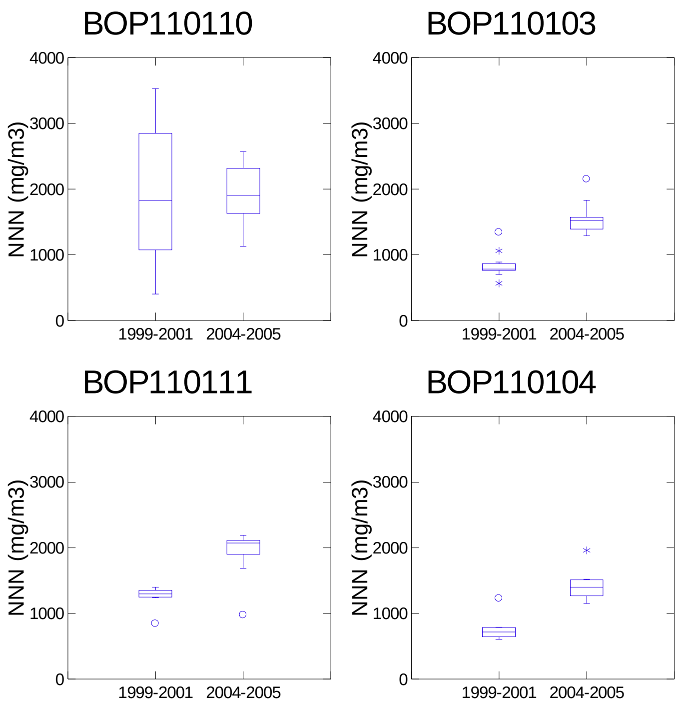


Figure 5—20: Comparison of nitrate-N concentrations between monitoring periods for sites in upper Rangitaiki River. Data derived from EBOP results, 1999–2005. (See Figure 5—1 for location of sites.)

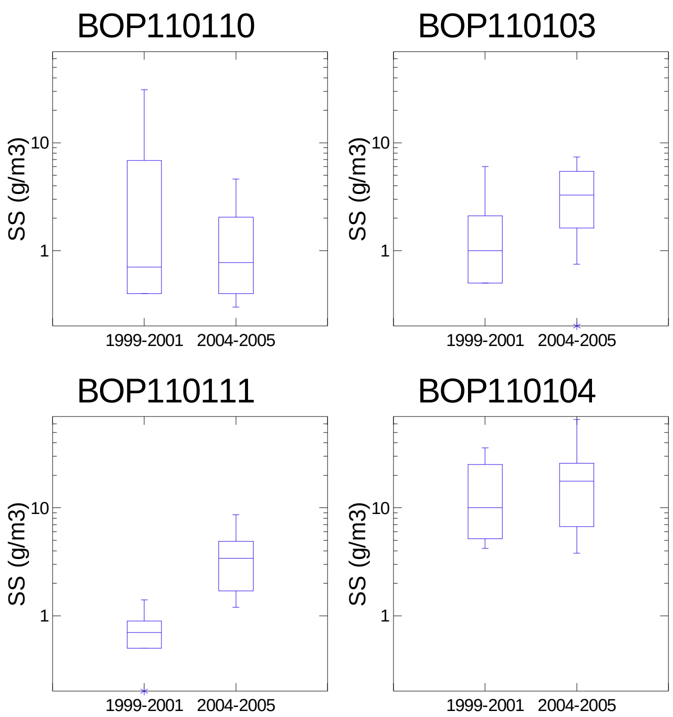


Figure 5—21: Comparison of suspended solids concentrations between monitoring periods for sites in upper Rangitaiki River. Data derived from EBOP results, 1999–2005. Note log scale used for y axis. (See Figure 5—1 for location of sites.)

The data summarised in the box and whisker plots (Figure 5—19 and Figure 5—20) should cause concern to all resource users and managers. While the dot plots indicated the distribution of data into two discrete monitoring periods (1999–2001 and 2004–2005), the box plots allow comparison of concentrations between these two periods. It is clear that concentrations of soluble nutrients have increased considerably between the two monitoring periods. This trend is consistent across all sites in the upper Rangitaiki River catchment. Figure 5—21 indicates that concentrations of suspended solids have also increased considerably over this period.

While discharge data is not available to calculate loads, or determine whether river flows were significantly different between the two monitoring periods, consideration of the rainfall record indicates that rainfall was reasonably consistent over the two periods. Mean monthly rainfall at the Aniwhenua site differed by about 4% between the two periods, while the mean monthly rainfall measured at Taupo differed by 6%. Therefore it appears unlikely that a difference in flow could be responsible for increasing median nutrient concentrations by more than 50%.

With the data available, it was not possible to relate nitrate concentrations in the Rangitaiki River at Murupara to the increase in nitrate concentrations in the Rangitaiki River at SH5 or the Otamatea River. However, this possibility should not be ignored. Discussions with EBOP staff indicate that there is the potential for nutrient applied in the Hawke's Bay region to actually travel in the groundwater toward the Rangitaiki River[15]. Targeted investigation will be required to establish whether this transfer of nutrient between surface water catchments is possible.

The periphyton survey (Section 6) indicated that habitat (current velocity, mobile substrate and light climate) primarily determines periphyton population composition and abundance. The survey also revealed that where habitat was suitable, excessive biological growth was possible. Attached cyanobacteria (*Phormidium* spp) are currently a cause for concern in the reach upstream of Lake Aniwhenua. Continued nutrient enrichment may therefore lead to additional water quality problems associated with free-floating cyanobacteria in the hydro lakes and lower river.

Microbiological indicator species

Faecal microbiological monitoring has been consistent since about 2001 (EBOP) and 2005 (NRWQN). Indicators of faecal contamination are higher in the Whirinaki River than in the Rangitaiki River at Murupara. For example, the EBOP dataset indicates:

[15] Rob Donald, EBOP, pers. comm. Telephone conversation, 17/06/2009.

- Median and average *E. coli* concentrations are 40 and 96 MPN/100 mL and 16 and 39 MPN/100 mL (Whirinaki River and Rangitaiki River respectively).
- Median and average enterococci concentrations are 14 and 50 MPN/100 mL and 8 and 17 MPN/100 mL (Whirinaki River and Rangitaiki River respectively).
- The NRWQN data set indicates that median and average *E. coli* concentrations are 42 and 95 MPN/100 mL, vs. 20 and 64 MPN/100 mL (Whirinaki River and Rangitaiki River respectively).

The EBOP data set indicates that the concentrations of these faecal indicator bacteria in the Aniwhenua Canal are similar to those in the Rangitaiki River upstream of Murupara – 17 and 58 MPN/100 mL (*E. coli*) and 8 and 26 MPN/100 mL (enterococci) respectively. Between these two points, however, there is a discharge of treated wastewater, as well as a range of agricultural land uses and inputs from tributaries crossing the Galatea Plains. Some attenuation of indicator organism numbers is likely as the Rangitaiki River traverses Lake Aniwhenua. Spatial comparison of concentrations of a faecal indicator organism is provided in Figure 5—22.

Little can be said regarding the input of microbial indicator species for the Murupara oxidation pond – the resource consent has no condition requiring monitoring of the discharge or impact on the receiving environment[16]. Loading rates and receiving water concentrations could be estimated in future using published concentration values for representative oxidation ponds.

[16] E-mail response from Stephen Park, Senior Environmental Scientist, EBOP, 13/05/2009.

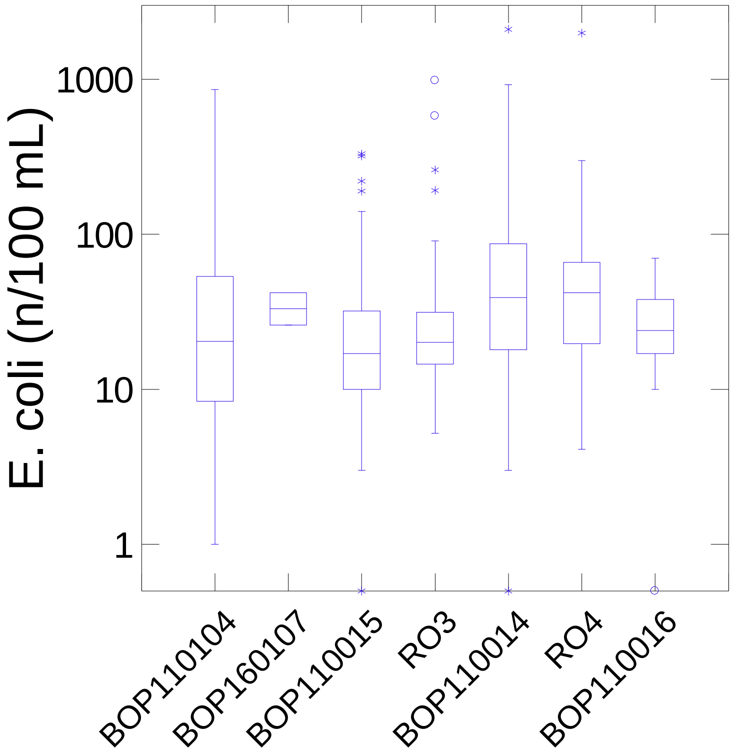


Figure 5—22: Comparison of concentrations of faecal indicator organisms upstream of Aniwhenua Dam, 2003-2009. (See Figure 5—1 for location of sites.)

There is no discernible relationship between discharge and *E. coli* numbers in the Rangitaiki River upstream of Murupara (adjusted $R^2 = 0.00$), but there is indication of a weak positive relationship between these variables in the Whirinaki River and in the Rangitaiki River in the Aniwhenua Canal (adjusted $R^2 = 0.23$ and 0.21 respectively) (Figure 5—23). Increased export of faecal bacteria from the Whirinaki River and tributaries downstream of Murupara appears likely during rainfall events.

Use of surface water within the rohe is probably limited to irrigation, stock watering and recreation. Guidance regarding the microbiological quality of water is provided by the Ministry for the Environment/Ministry of Health (2003). These guidelines identify a number of factors that should be considered when assessing the microbiological quality of fresh waters, including:

- sampling frequency;
- the time of sampling;
- selection of indicator organism; and
- presence of risk factors within the catchment.

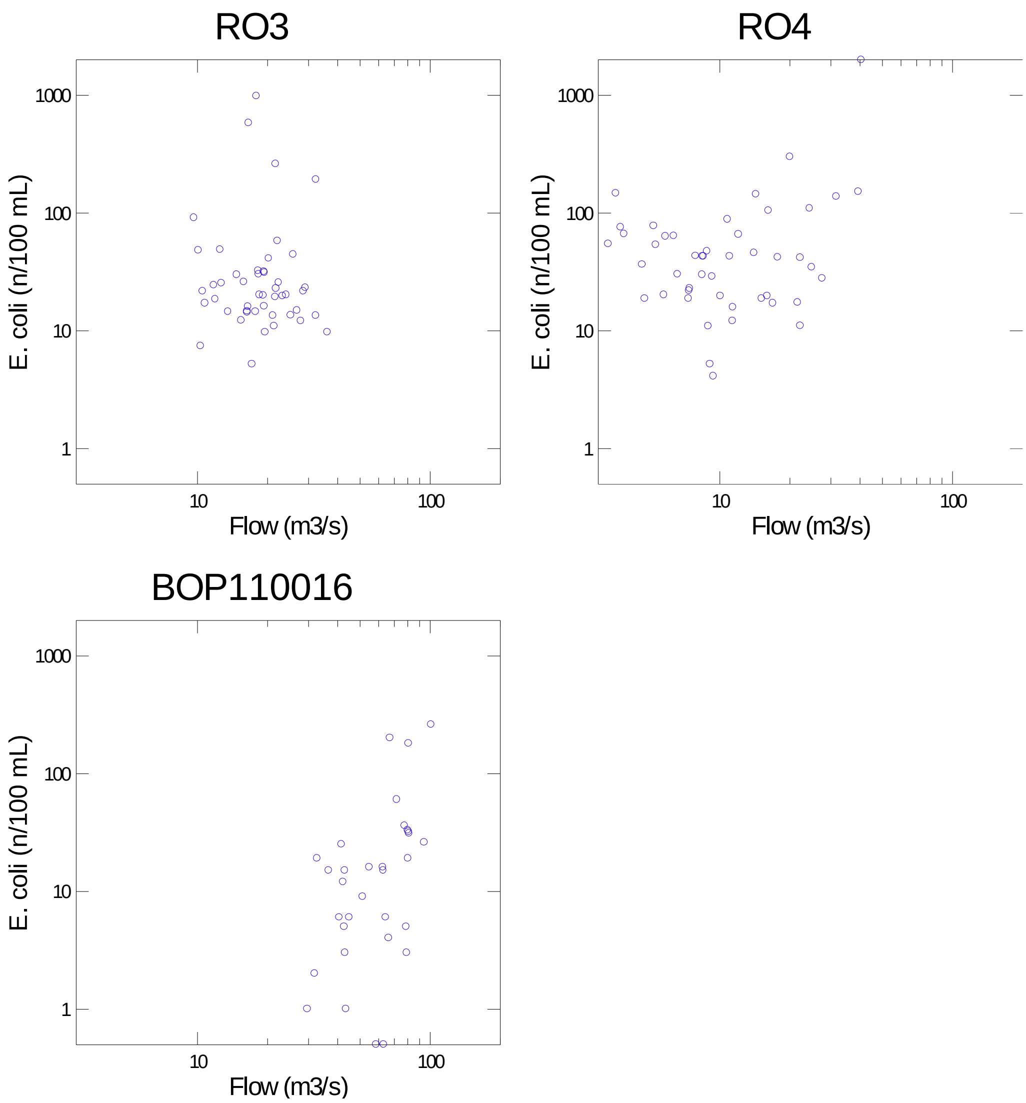


Figure 5—23: Relationship between *E. coli* concentration (MPN/100 mL) and discharge, Rangitaiki River (RO3) and Whirinaki River (RO4) and Aniwhenua Canal (BOP110016) (note log–log scale).

Known risk factors within the catchment include a discharge of treated wastewater. When grading the resource, it is also recommended that 100 data points are available for a five-year period, although the grading may be made with as few as 20 results. Grading takes place according to two criteria:

- a microbiological assessment category (MAC), using statistics ideally based on five years' data; and
- sanitary inspection category (SIC), which identifies vulnerability to contamination, based on the outcomes of a sanitary inspection.

These criteria are combined to provide a "Suitability for recreation grade for freshwater sites".

The *E. coli* concentration data for the Rangitaiki River upstream of Aniwhenua Dam are summarised in Table 5—6. Sites where the 95%ile value exceeds 130 MPN/100 mL have been highlighted. This does not imply unsuitability for contact recreation. It indicates that a threshold value has been exceeded. In some circumstances the MoH/MfE process indicates follow-up surveys should be conducted (MfE/MoH 2003).

It should be noted, however, that for two sites where a reasonable amount of data exist, the "D" MAC threshold of 550 MPN/100 mL is exceeded.

At BOP110104, where only four results exist for the preceding five-year period, the 95th %ile is 860 MPN/100 mL.

Site BOP110015 is the same as NRWQN site RO3. If the data from the two sources are combined and the 95th%ile re-calculated, it decreases to 246 MPN/100 mL (n=106), a "B" MAC category.

Applying this process to BOP110014 and RO4, the recalculated 95thile is 221 MPN/100 mL (n=108), which also falls within the "B" MAC category.

These limited data indicate that in relatively unimpacted reaches of the upper Rangitaiki River catchment (at SH5, well upstream of Murupara), elevated concentrations of faecal indicator organisms may occur. In the vicinity (but still upstream) of Murupara, a reasonably extensive dataset indicates that indicator organism concentrations are generally lower (average of about 78 MPN/100 mL).

These concentrations are relatively low compared with the neighbouring Tarawera River catchment, where the 95thile *E. coli* at the Awakaponga site (RO2 in the NRWQN) is 1330 MPN/100 mL (n=43). The latter site is downstream of Kawerau town, where treated wastewater is discharged to highly permeable soils along the river margin. Quite intensive pastoral farming occurs upstream of Awakaponga as well.

While the concentrations of indicator organisms at the outflow of Aniwhenua Dam are quite low (following attenuation by sedimentation and sunlight), little is known about concentrations immediately downstream of Murupara and along the river in the reach adjacent to the Galatea Plains. Other water quality variables indicate input of nutrient in the streams draining the Galatea Plains – it is possible that faecal indicator concentrations may also be elevated in these streams relative to the Rangitaiki River.

Table 5—6: *E. coli* concentration data for the Rangitaiki River catchment upstream of Aniwhenua Canal, 2004–2009. Greyed cells indicate 95th percentile values exceed 130 MPN/100 mL MfE/MoH guideline.

Statistic	*E. coli* concentrations (MPN/100 mL) by sample site, summer samples only (December – March), 2004–2009 inclusive.						
	BOP110104	BOP160107	BOP110015	RO3	BOP110014	RO4	BOP110016
N of Cases	4	2	18	15	19	15	4
Median	51.5	34	25	22.8	52	43.1	17
Arithmetic Mean	245.2	34	46.8	90.6	117.6	55.0	16.1
Standard Error of Arithmetic Mean	205.1	8	12.5	63.6	46.9	9.5	6.7
Standard Deviation	410.2	11.314	53.0	246.5	204.7	36.8	13.4
95.00%ile	860	42	184	749.7	609.5	130.3	30
99.00%ile	860	42	220	980.4	920	137.4	30

Five-day biochemical oxygen demand (BOD_5)

BOD_5 is a measure of the concentration of readily biodegradable organic material in a water body. The oxygen demand created by consistently elevated BOD_5 concentrations may cause depletion of dissolved oxygen within a water body, causing ecological damage. Collection of samples for the determination of BOD_5 by the NRWQN ceased in 2002.

Spatial comparison of BOD_5 concentrations is provided in Figure 5—24. This was done for the entire data set, as well as for the period since 2003. Concentrations are generally low. The earlier data gave some indication of an increase in BOD_5 in the reach between Murupara and Aniwhenua Canal, but this assessment cannot be made using the limited recent data. The generally low BOD_5 values are consistent with the observed near-saturation dissolved oxygen concentrations.

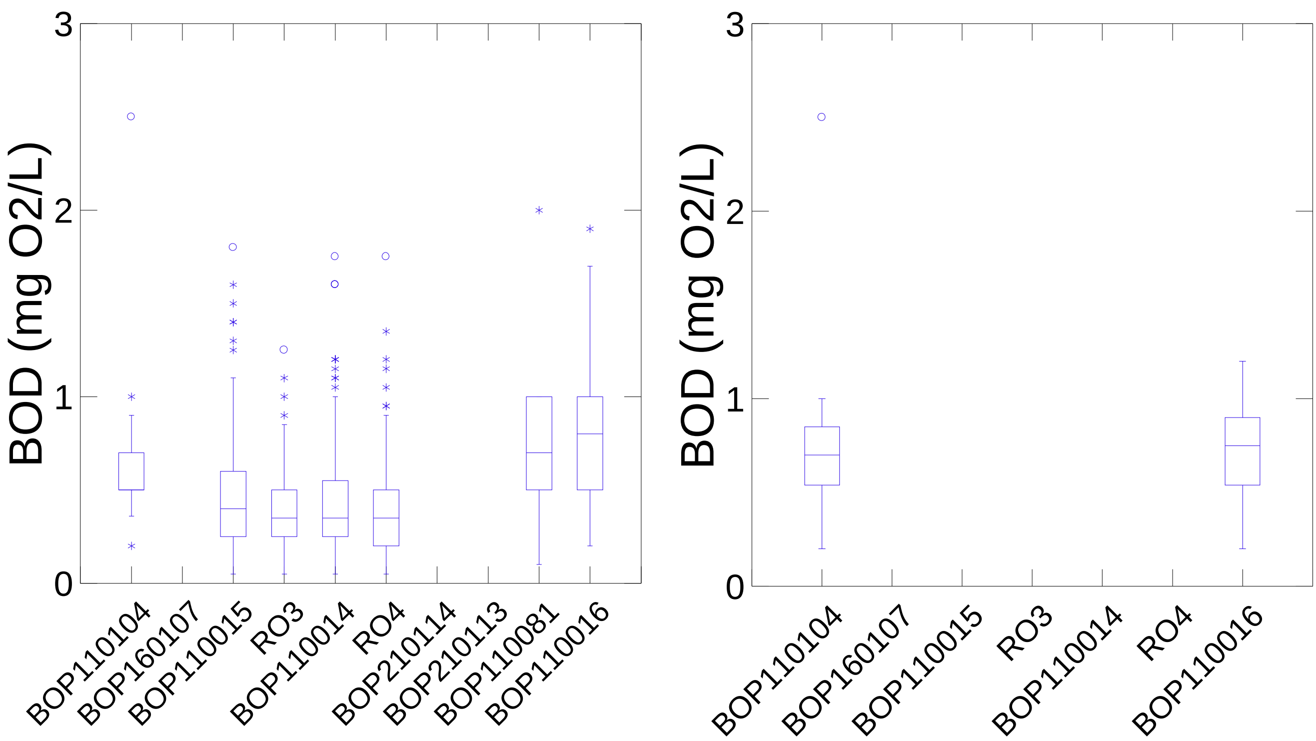


Figure 5—24: Comparison of concentrations of BOD_5 upstream of Aniwhenua Dam – entire record (LEFT) and post-2003 (RIGHT). (See Figure 5—1 for location of sites.)

Trend testing of available data indicated a meaningful decrease in BOD_5 concentrations at RO3 over the period 1989 to 2002 (RSKSE=-2.86), and a meaningful but not statistically significant decrease at RO4 (P=0.08) over the same period. No reason can be offered for this trend at present. In other catchments, decrease in BOD_5 concentrations over time have been related to reduction in the organic loads discharged from point pollution sources, e.g., by improved treatment of industrial and municipal wastes, or discharging dairy shed effluent to land rather than water. No point source discharges have been identified in the Rangitaiki River catchment upstream of Murupara, so changes in waste management cannot be offered as explanation.

5.2.3 Results of longitudinal survey, April 2009

While the available data provides a good picture of the long-term trends in water quality, and detailed information at a number of key points, spatial trends are not well-defined. The results of the longitudinal survey provide a picture of spatial trends in water quality across the Ngati Manawa rohe. The available results for the water quality survey are summarised in Figure 5—25 through Figure 5—29 for the Rangitaiki River mainstem, and Figure 5—30 through Figure 5—33 for tributaries to the Rangitaiki River in the reach from Murupara to Rabbit Bridge.

Trends along the Rangitaiki River mainstem:

- Temperature increased in a downstream direction.
- Electrical conductivity increased in a downstream direction, with obvious impact by the diversion (conductivity temporarily increased downstream of the diversion, and reduced when the diverted water rejoins the main stem).
- Visual clarity decreased in a downstream direction, with particular impact downstream of Murupara (primarily due to inflow of water with low clarity from Whirinaki River catchment).
- Munsell colour number decreased in a downstream direction, indicating a shift from blue-hue to blue-green hue (consistent with increase in g_{440} and algal growth).
- g_{340} and g_{440} both increased in a downstream direction, with a step change increase downstream of Murupara.
- Euphotic depth decreased in a downstream direction. While only two results were obtained – this is consistent with increase in g_{440}, reduction in visual clarity and indicates higher concentration of light-absorbing or attenuating material within Aniwhenua Canal.
- DRP concentrations increase steadily along the Rangitaiki River downstream of the Wheao scheme, particularly in the reach downstream of Murupara – considerable nutrient appears to be input from the surface and groundwater draining the Galatea Plains.
- Elevated nitrate-N was observed in the catchment upstream of the Wheao scheme, which appears to be steadily diluted by other tributaries – this appears to confirm that the nitrogen enters the Rangitaiki River in the headwater reaches.
- These results do not permit a distinction between input from forested or intensively farmed catchments – additional, targeted investigation is required to achieve this information.

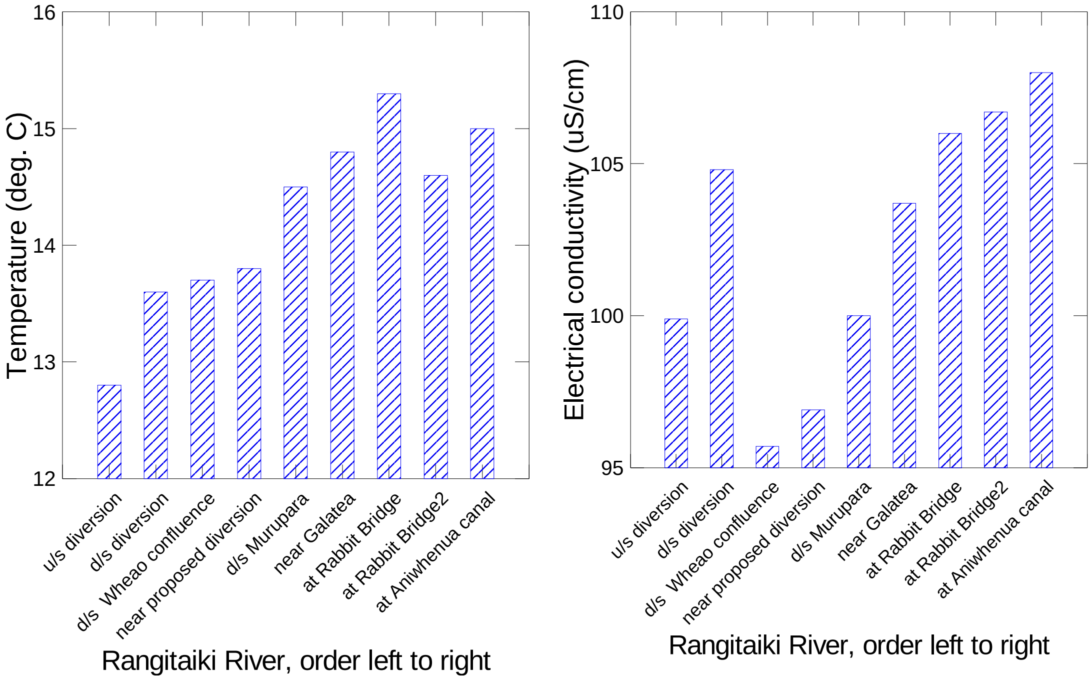


Figure 5—25: Trend in water temperature and electrical conductivity, Rangitaiki River mainstem.

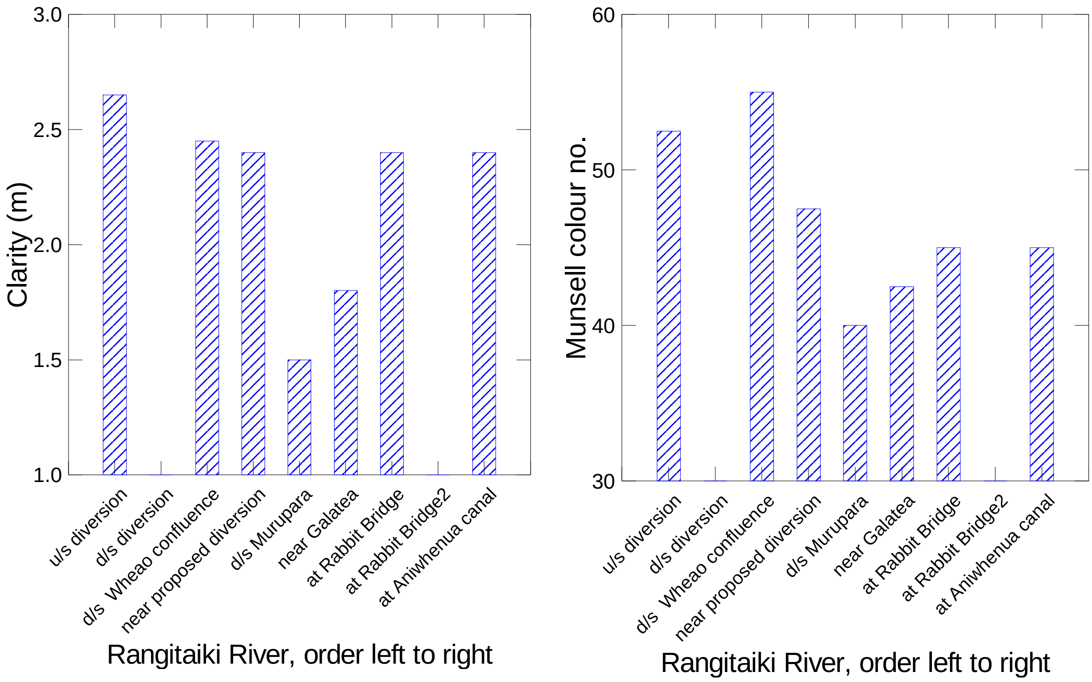


Figure 5—26: Trend in visual clarity and Munsell colour number, Rangitaiki River mainstem.

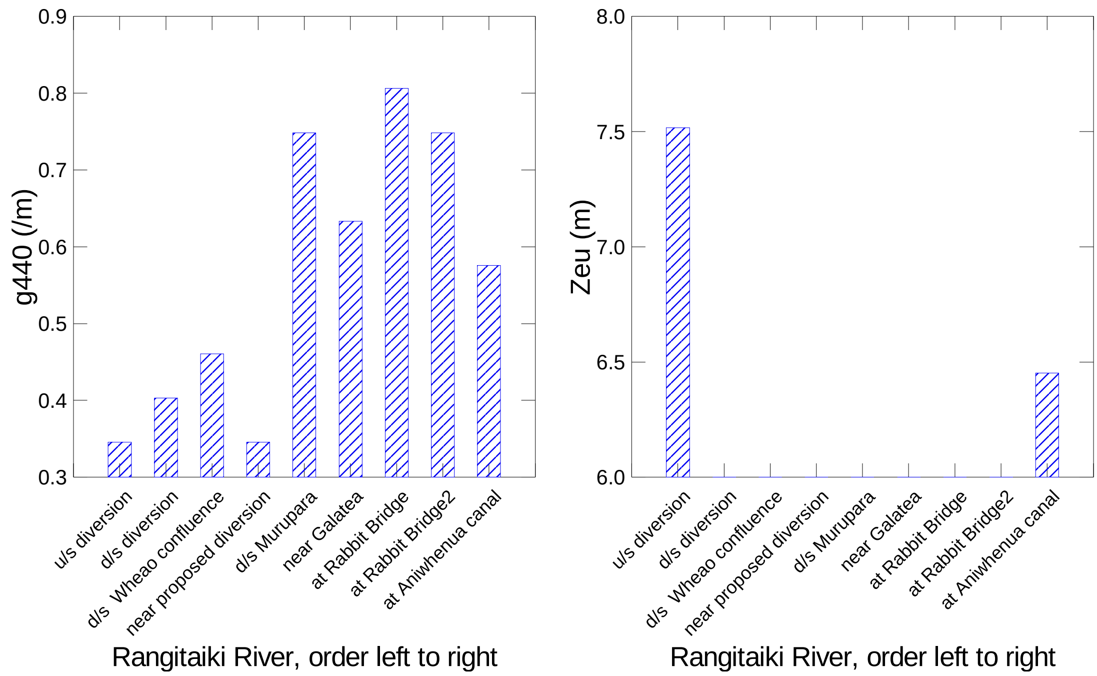


Figure 5—27: Trend in absorption coefficient values (440 nm) and comparison of euphotic depth, Rangitaiki River mainstem.

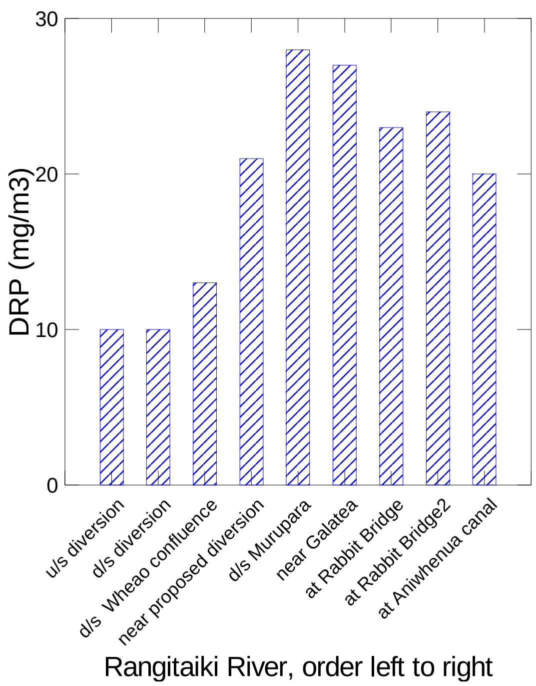


Figure 5—28: Trend in DRP concentrations, Rangitaiki River mainstem.

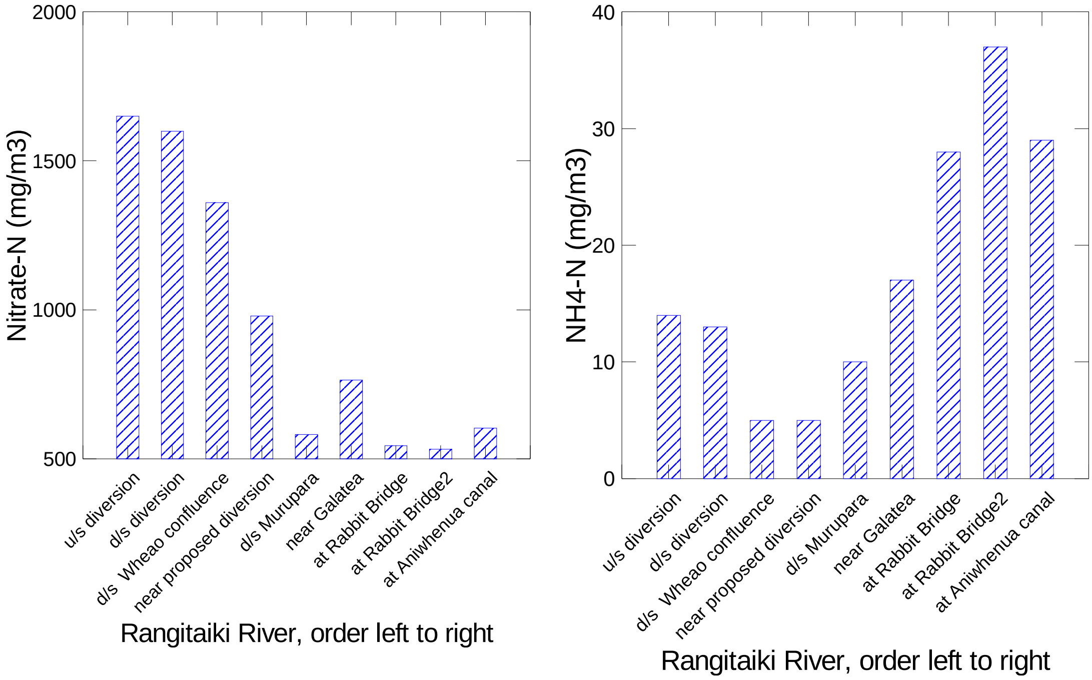


Figure 5—29: Trend in concentrations of soluble nitrogen, Rangitaiki River mainstem.

Trends in tributaries to Rangitaiki River over the reach between confluence with the Wheao River and Rabbit Bridge:

- Temperature increased in a downstream direction.
- Considerably greater concentration of dissolved salts occurs in the two tributaries draining the Galatea Plains (Horomanga River and Omahuru Stream) than in the Rangitaiki or Whirinaki Rivers.
- Generally high clarity in all tributaries where measurements were made, with exception of the Whirinaki River.
- Decrease in Munsell colour number from blue to blue-green down the catchment.
- Pronounced decrease in g_{340} and g_{440} along the Wheao River, indicating a decrease in the concentration of material imparting yellow colouration to the water.
- Relatively high concentrations of "yellow substance" (indicated by g_{440}) in the Whirinaki River and Omahuru Stream in part responsible for the increase in g_{440} in the Rangitaiki River mainstem downstream of Murupara.
- Relatively high concentrations of ammoniacal-N in the Wheao River at Flaxy Dam, which is diluted by water from the upper Rangitaiki River downstream of the powerhouse.
- Very high concentrations of nitrate-N and DRP in the Omahuru Stream.

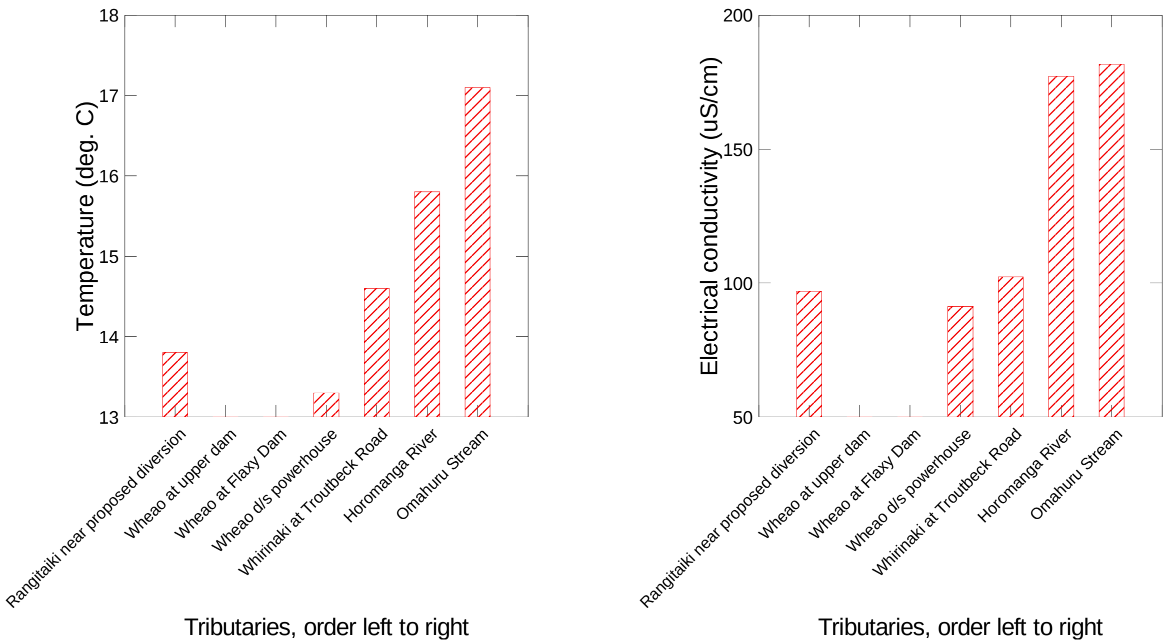


Figure 5—30: Trend in concentrations of selected physical variables, tributaries to Rangitaiki River.

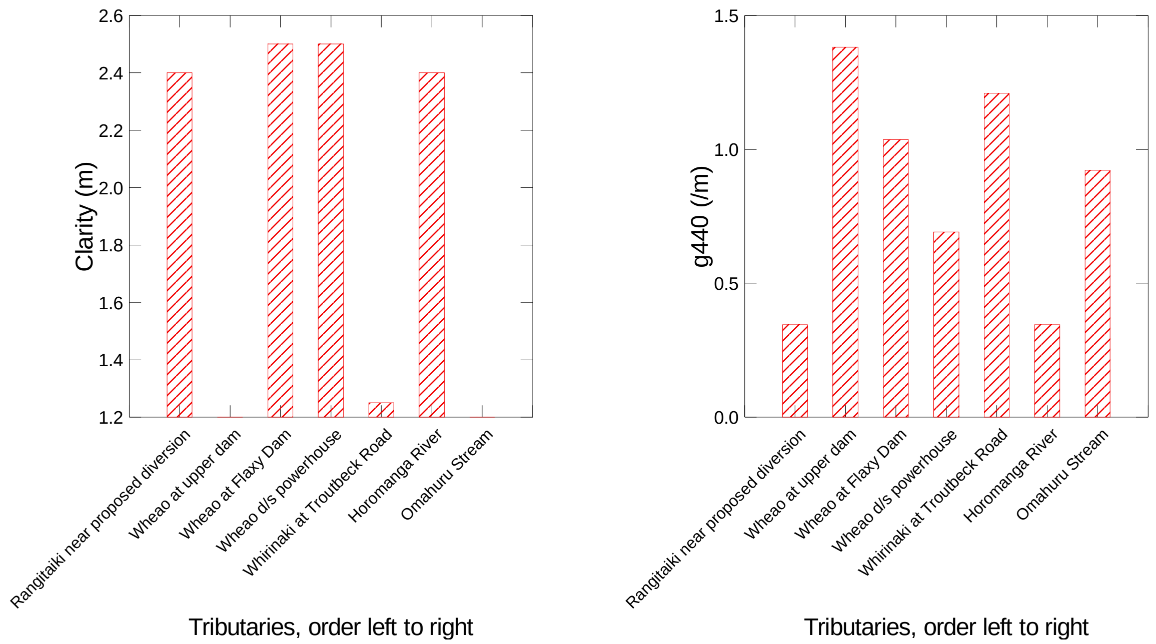


Figure 5—31: Trend in clarity and absorption coefficient, tributaries to Rangitaiki River.

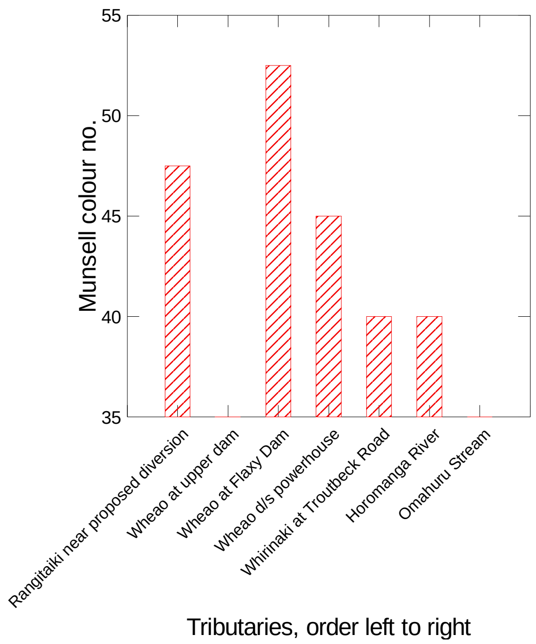


Figure 5—32: Trend in Munsell colour number, tributaries to Rangitaiki River.

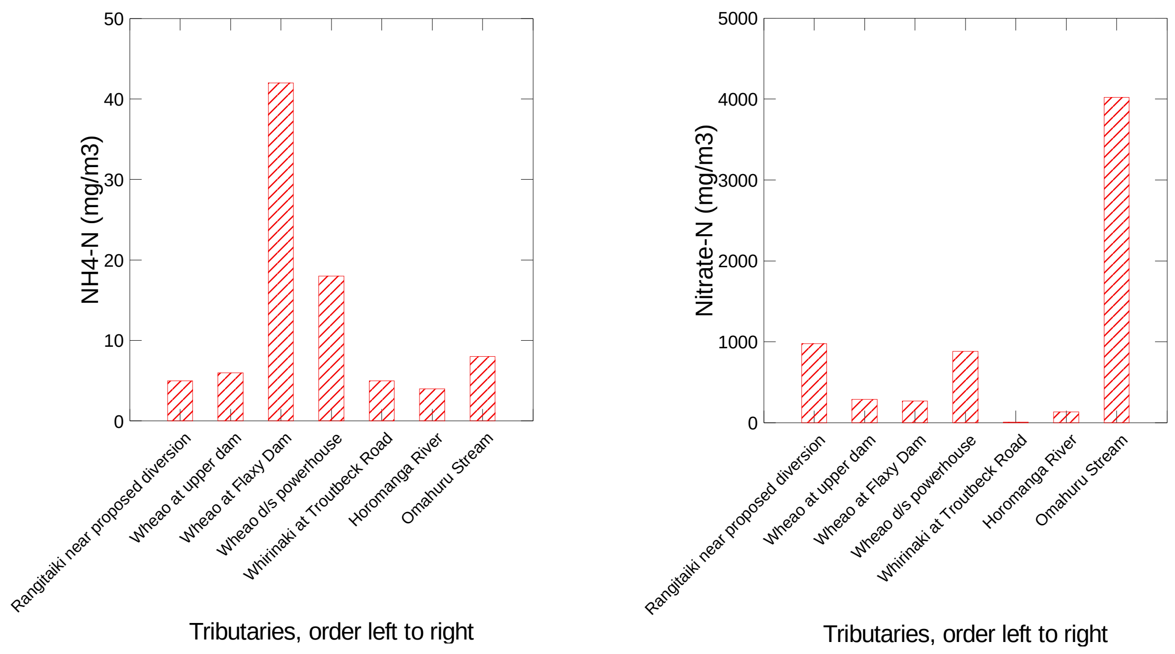


Figure 5—33: Trend in concentrations of soluble nitrogen, tributaries of Rangitaiki River.

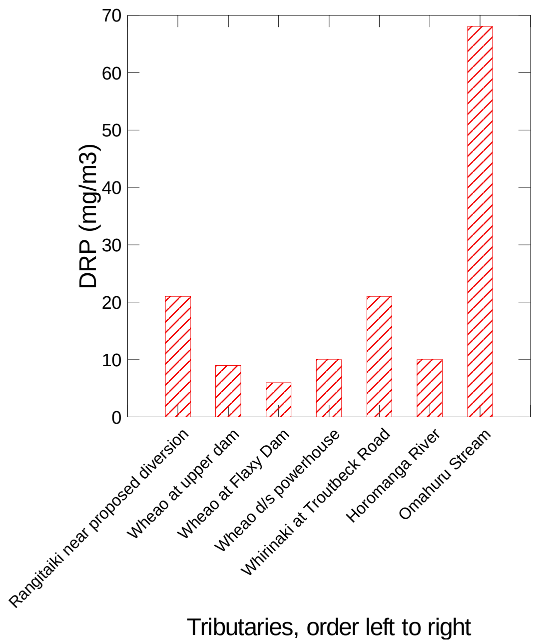


Figure 5—34: Trend in concentrations of DRP, tributaries of Rangitaiki River.

Spatial survey - conclusions

Comparison of the results of the longitudinal survey with long-term monitoring data indicate that these one-sample survey results are probably quite typical for the catchment under late summer, low-flow conditions. For example, comparing the results for the “Rangitaiki near proposed diversion site” with those of RO3 for April annually, the values for visual clarity are similar to the long-term average (2.4 m vs. 2.7 m), g_{440} is slightly lower (0.42 /m vs. 0.47 /m), and nutrient concentrations are quite similar to long-term average values. Considerable coloured material arises in the Wheao and Whirinaki River catchments, which shifts hue (toward green) downstream of Murupara and may contribute to reduced clarity.

The Wheao and Whirinaki Rivers appear to be the source of much of the DRP in the Lake Aniwhenua catchment. The Upper Rangitaiki River appears to be the source of most of the nitrogen in the Lake Aniwhenua catchment. There appears to be conversion of the nitrogen from nitrate-N to ammoniacal-N form in the reach between Murupara and Rabbit Bridge. This is likely to occur during microbially-mediated nitrification-denitrification process.

While the Omahuru Stream appears to have elevated concentrations of DRP and nitrate-N, the flux of material derived from this stream is probably quite low relative to the load present in the Rangitaiki River. Discharge data was not available to quantify the flux in this stream. It does indicate however, that current land use practices could continue to input nutrients and potentially, faecal pollution, into the Rangitaiki River.

5.3 Regulatory context and guideline values

A number of water quality guidelines have been established (ANZECC & ARMCANZ 2000, MfE/MoH 2003, MfE 1994). These guidelines are applicable to catchments across a range of situations, landscapes, climate types etc.

These guideline values should also be considered in association with the classifications of various rivers and catchments in the Bay of Plenty Regional Water and Land Plan (EBOP 2008)[17]. The rivers, stream and catchments to which the relevant classifications apply are identified in a series of "Water quality classification maps"[18] associated with the Regional Plan. Schedule 1 of the Plan identifies Aquatic ecosystem areas, as well as lists of species present within these catchments. Selected classifications relevant to the Ngati Manawa rohe are identified in Table 5—7.

Table 5—7: Areas of the Bay of Plenty region within the Ngati Manawa rohe that have been classified in the Bay of Plenty Regional Water and Land Plan.

Schedule	Catchment and river	Classification
1 A	Rangitaiki River and tributaries, including Horomanga River	Habitat and migratory pathway for indigenous fish species
1 B	Rangitaiki River and tributaries, including Horomanga River, Whirinaki River	Habitat of threatened indigenous flora and fauna
1 D	Rangitaiki River and tributaries, including Lake Aniwhenua, Horomanga River, Whirinaki River, Wheao River, Lake Flaxy	Important habitat of trout

Schedule 9 of the Plan defines the criteria for a series of standards, including narrative and numeric values. Extensive use is made of the (ANZECC & ARMCANZ 2000).

Much of the Rangitaiki River upstream of the Aniwhenua Canal has been classified for "Natural State", "Aquatic Ecosystem (Bay of Plenty)" and "Bay of Plenty Regional Baseline" purposes.

[17], http://www.envbop.govt.nz/Publications/Details-about-the-Regional-Water-and-Land-Plan.asp
[18] http://www.envbop.govt.nz/Publications/Details-about-the-Regional-Water-and-Land-Plan.asp

While none of the catchment has been explicitly classified for “Contact Recreation” purposes, contact recreation may still take place, and these guidelines may still apply.

Colour and clarity guidelines

In addition to the Bay of Plenty Regional Water and Land Plan, two related guidelines are applicable to the New Zealand context – “Guidelines for the management of water colour and clarity” (MfE 1994) and the ANZECC guidelines (ANZECC & ARMCANZ 2000). The latter were primarily derived from the MfE guidelines, which will be used for this discussion. The MfE Guidelines were also developed to quantify the narrative Standards contained within the RMA 1991.

The five separate guidelines identified in the MfE guidelines (MfE 1994) are listed in Table 5—8, together with relevant data for the Rangitaiki River catchment upstream of the Aniwhenua Canal. Classifications are made in terms of the Third Schedule of the RMA 1991. Class A refers to waters managed for aesthetic purposes.

Conspicuous change in visual clarity

Visual clarity within the Rangitaiki River catchment is generally good, with slightly lower clarity in the Whirinaki River. The results of the single longitudinal survey indicates that the Whirinaki River may impair visual clarity downstream of its confluence with the Rangitaiki River. Downstream of the confluence, however, the Rangitaiki River still complied with the guideline for “other” waters.

Conspicuous change in colour

Based on the results of a single longitudinal survey, water in the Rangitaiki River catchment generally appears to be green, tending toward blue-green in the upper catchment. The Whirinaki River appears to be the dominant cause of hue shift around Murupara. Downstream of the confluence, however, the Rangitaiki still complied with the guideline for “other” waters.

Reflectance

Reflectance was not measured in the single survey, but a change causing exceedance of the guideline (i.e., >50% change), will probably be very infrequent.

Visual clarity - contact recreation

The visual clarity of water within the Rangitaiki River catchment generally exceeds the 1.6 m guideline. This guideline value generally provides some protection to swimmers, and generally satisfies aesthetic requirements. Based on the results of a single survey, the Whirinaki River may impair visibility in the main stem of the Rangitaiki River on occasions.

Protection against significant adverse effects on aquatic life

Conclusions drawn from the limited light penetration data available are limited (two measurements conducted during a single survey, under late summer, autumn flow conditions). However, light attenuation at Aniwhenua Canal does not appear to indicate adverse ecological impact. The macrophyte and periphyton survey (Sections 6 and 7) indicated that light penetration is not an issue along any of the surveyed reaches in the rohe.

Overall, colour and clarity upstream of the Aniwhenua Canal appears generally good although subject to seasonal trends. The macrophyte survey documented prolific growth of aquatic plants wherever habitat was suitable, i.e., light limitation was not an issue.

The trend indicated by the long-term monitoring data is of slight deterioration in visual clarity and colour. Future monitoring should have regard for the changes in land use in the upper catchment, and possible impact on optical properties.

Table 5—8: Comparison with guidelines for colour and clarity (MfE 1994).

Guideline	Criterion	Rangitaiki River value	Comment
Conspicuous change in visual clarity	Class A – Change in visual clarity <20%	<15% variation in upper catchment	Based on single survey
	Other waters - Change in visual clarity 33-50% (site dependent)	Up to 37% change downstream of Whirinaki River confluence	Based on single survey; improves further downstream of confluence
Conspicuous change in colour	Class A – Change in visual hue <5 points on Munsell scale	<10 units variation in river upstream Murupara	Colour hue generally >45 units (green).
	Other waters - Change in visual hue <10 points on Munsell scale	<10 units variation in reach downstream Murupara	Colour hue generally >40 units (green to green-yellow). Largest change observed downstream of Murupara, probably due to Whirinaki River, improves downstream of confluence.
Conspicuous change in colour	Reflectance of water should not be changed by more than 50%	Not measured	Not measured, but unlikely that a change of this magnitude could occur
Contact recreation requirements	Horizontal sighting range of 200 mm black disk should exceed 1.6 m	Typically >1.6 m	Lower clarity observed in Whirinaki River than Rangitaiki River
Protection against significant adverse effects on aquatic life	Waters deeper than ½ euphotic depth, change in euphotic depth <10%	Not applicable	Not applicable
	Waters shallower than ½ euphotic depth, change in euphotic depth <20%	15%	Based on single survey, two points.

Nutrient concentration guidelines

Guideline "trigger" values applicable to the New Zealand context are provided in the ANZECC guidelines (ANZECC & ARMCANZ 2000). The values contained in the latter were primarily derived from work undertaken at NIWA, using data derived from the NRWQN. Two ecosystem types were identified – upland and lowland, with the lowland ecosystems defined as those occurring in rivers with < 150 m altitudes. Trigger values identified for "slightly disturbed" lowland ecosystems are listed in Table 5—9, along with average values for selected monitoring points in the Rangitaiki River catchment.

Table 5—9: Comparison with trigger values for nutrients (ANZECC & ARMCANZ 2000).

Nutrient	Concentration (mg/m^3)		Comment
	Trigger value	Average values	
DRP	10	21.9	Rangitaiki River upstream of Murupara
		20.4	Whirinaki River upstream of Murupara
		33	Aniwhenua Canal
TP	33	32.3	Rangitaiki River upstream of Murupara
		38.1	Whirinaki River upstream of Murupara
		43	Aniwhenua Canal
Oxidised N (Nitrate-N plus nitrite-N)	444	608.5	Rangitaiki River upstream of Murupara
		119.4	Whirinaki River upstream of Murupara
		387	Aniwhenua Canal
Ammoniacal-N	21	6.5	Rangitaiki River upstream of Murupara
		5.3	Whirinaki River upstream of Murupara
		26	Aniwhenua Canal
Total N	614	685	Rangitaiki River upstream of Murupara
		218	Whirinaki River upstream of Murupara
		165	Aniwhenua Canal

Phosphorus concentrations generally exceed the ANZECC trigger values. Total-N and nitrate-N trigger values are exceeded in most of the Rangitaiki River mainstem. Processes within Lake Aniwhenua convert some of the oxidised nitrogen into ammoniacal form, leading to exceedance of the ammoniacal-N trigger value in the Aniwhenua Canal.

The generally high nutrient concentrations imply that plant growth is unlikely to be limited by nutrient availability. The results of the periphyton survey (Section 6) indicated that where habitat and substrate was suitable, considerable algal growth was possible. In these cases, the guideline values for biomass conducive to a trout habitat were exceeded. While these observations were derived from a single survey, the sites selected were representative of much of the catchment. The survey was undertaken in the late summer/autumn period, when growth was unlikely to be at a maximum. During mid-summer, with higher temperatures and light availability, periphyton biomass could potentially be higher in those areas where substrate and habitat are favourable.

The survey did not include unattached algal species. It would be useful to survey the cyanobacterial ("blue-green" algae) population and numbers, as well the concentrations of cyanotoxins, in Lake Aniwhenua during peak growing season.

Overall, however, the relatively elevated nutrient concentrations do not appear to give rise to nuisance growth conditions within the Ngati Manawa rohe. Future monitoring should have regard for ongoing development and land use change in the upper catchment, which has the potential to alter conditions upstream of Aniwhenua Canal.

Compliance with microbiological guidelines

Both the Ministry for the Environment and Ministry of Health (MfE & MoH 2003) and the Bay of Plenty Regional Water and Land Plan (EBOP 2008) recommend relevant guideline values. Results are compared with the MfE & MoH guidelines in Table 5—11, and with the EBOP guidelines in Table 5—10.

Table 5—10: Classification of sampling sites using measured concentrations (2004–2009) and values for faecal indicator bacteria (MfE & MoH 2003).

Variable	Rangitaiki River concentration (MPN/100 mL	Microbiological assessment category	Location
95th percentile *E. coli* concentration	860	D	Rangitaiki River at SH5
	308	C	Rangitaiki River upstream of Murupara
	174	B	Whirinaki River upstream of Murupara
	69	A	Aniwhenua Canal

Table 5—11 indicates that during the summer period, the probability of faecal indicator bacteria concentrations exceeding 126 MPN/100 mL are reasonably high. It must be noted however that the frequency of detecting indicator organisms above a guideline concentration does not equal risk of infection.

Two points should be noted:

- for some the SH5 site, limited data are available; and
- the exceedance of a microbiological guideline does not necessarily mean that people exposed to the water will get sick – the risk of such sickness is however increased.

Table 5—11: Comparison of measured concentrations (2004–2009) with guideline value for single sample faecal indicator bacteria concentrations (EBOP 2008). Results for samples collected during summer bathing period only (November to March).

Variable	Guideline concentration (MPN/100 mL)	Agency	Number exceeding guideline concentration	Percent exceedance	Comment
Single sample *E. coli* concentration	126	EBOP	1/6	17	Rangitaiki River at SH5
		NIWA	4/47	9	Rangitaiki River upstream of Murupara
		EBOP	8/29	27	
		NIWA	6/47	13	Whirinaki River upstream of Murupara
		EBOP	4/28	14	
		EBOP	0	0	Aniwhenua Canal

5.4 Overall conclusions regarding water quality

Considerable data exists for selected points in the reach of the Rangitaiki River and major tributaries near the mid-point of the Ngati Manawa rohe. River flow in the upper Rangitaiki River is highly regulated. This influences both the flows, concentrations and loads of water quality variables in the reach of river upstream of Murupara.

Many water quality variables are strongly influenced by the flow in the rivers, with strong positive and negative correlations between flow and concentration, indicating mobilisation (possible increases in concentrations and loads), or dilution of contaminants, respectively.

The upper Rangitaiki River is probably less subject to extreme rainfall events than the Whirinaki River. Much of its baseflow comes from groundwater derived from the pumiceous upper catchment. In addition, the regulated nature of the Rangitaiki River is likely to reduce the impact of storm events, and attenuate pollutants mobilised during these events. Accordingly, clarity is slightly higher in the Rangitaiki River than the Whirinaki River, and suspended solids concentrations are slightly lower. Water in the Whirinaki River catchment appears to have higher coloured dissolved organic matter (CDOM) generally than that of the Rangitaiki River.

Concentrations of DRP and ammonia are similar in the Rangitaiki and Whirinaki Rivers upstream of Murupara. Concentrations of nitrate-N and total-N are considerably (and consistently) higher in the Rangitaiki River than the Whirinaki River.

Trend analysis indicates that concentrations of N and P in both the Rangitaiki and Whirinaki are tending to increase. This is likely due to changes in land use in these catchments, and in particular, intensification in land use in the upper Rangitaiki River catchment.

The limited data available indicates that water discharged from the intensively farmed upper Rangitaiki River catchment has considerably higher concentrations of dissolved and particulate bound nutrients than the mainstem (Rangitaiki and Whirinaki Rivers) at Murupara. The intensively farmed upper catchment appears to contribute a disproportionate amount of nutrient to the catchment than the forested areas. This conclusion is supported by measurements and trends over time in the adjoining Mohaka River catchment (Hawke's Bay Region), where soils, climate and land use is similar.

In the preceding two-year period, three consents have been granted to "discharge untreated dairy effluent to pasture irrigation and sludge to land" in the upper Rangitaiki River catchment near SH5. The limited data available indicates a sharp increase in the concentration of nutrients in the Otamatea River catchment, where these new consents are located. These data cover two periods that precede the granting of recent consents. Further increase in sediment, nutrient and faecal contaminants should therefore be anticipated.

Concentrations of indicator organisms, particularly *E. coli*, are typically well-below threshold guideline concentrations upstream of Murupara, but subject to large increases during transient events. No surface water resource should be considered safe for consumption without treatment. The water generally poses low risk to contact recreational users, i.e., there is a generally low risk of becoming sick following swimming.

The water quality observed during the longitudinal survey were typical of late summer, low flow conditions. The survey indicated a general slight deterioration in water quality down the river. Rivers and streams draining the Galatea Plains had extremely high nutrient concentrations, indicating impact from current land use.

While nutrient concentrations generally exceed guideline values, nuisance periphyton growths are not observed because habitat and substrate are unfavourable. Where conditions were conducive to periphyton development, however, quite extensive growth was observed. In addition, extensive cyanobacterial mats occurred in many places. The relationship between these mats and nutrient concentrations in the Rangitaiki River are currently not known. The periphyton survey did not include any sites along the Whirinaki River, so we are unable to assess the significance of differences in dissolved nutrient concentrations and the development of *Phormidium* mats between these two catchments.

Future water quality issues are likely to be related to increases in nutrient and sediment concentrations and loads. Routine monitoring data indicates that concentrations of nutrients and suspended materials have increased considerably in the upper Rangitaiki River since 1999. The headwaters appear to be at ongoing risk of further nutrient and sediment loading because of land use change and intensification. This trend is consistent with what has already occurred in the Rotorua lakes catchments, as well as what is currently being observed across the catchment divide in the Hawke's Bay region. The spatial water quality survey indicated that groundwater draining from the Galatea Plains contains high nutrient concentrations. Intensification of land use on the Galatea Plains will probably increase these concentrations further – the soil layer is thin and the geology very leaky – additional nutrient is likely to rapidly enter the shallow groundwater and the Rangitaiki River upstream of Lake Aniwhenua.

5.5 Recommendations

Based on the available water quality record it is recommended that:

- Additional water quality data be collected for the Otamatea River, upper Rangitaiki River and nearby catchments. The resulting data would indicate whether the apparent increase in nutrient and suspended solids concentrations is a real trend or an artefact arising from a climatic cycle.

- Measurement of discharge in the rivers at the time of sampling would allow the flux of nutrients and suspended solids to be calculated.

- Consideration could also be given to the application of land use - water quality models. Model output could be used to assess whether the observed water quality trends are consistent with the land use change that has occurred. Application of these models could also be used to predict the potential consequences of current and likely future land use changes.

6. Periphyton

Donna Sutherland, NIWA

Periphyton is a complex matrix of algae and heterotrophic microbes (such as bacteria and fungi) attached to submerged substrata in almost all aquatic ecosystems. It serves as an important food source for invertebrates and some fish, and it can be an important sorber of contaminants. Periphyton is also an important indicator of water quality; responses of this community to pollutants can be measured at a variety of times scales representing physiological to community-level changes. The main controllers of periphyton growth in a river are water chemistry, flow regime, and substrate type.

Little is known about the periphyton community composition and biomass in the Wheao and Rangitaiki Rivers. Environment Bay of Plenty does not monitor periphyton in these rivers but does include the Rangitaiki River in their visual surveys for *Phormidium* mats in the local region (Matt Bloxham, Environment Bay of Plenty pers. comm.). *Phormidium* is a filamentous cyanobacteria, or blue-green alga, comprising of numerous morphotypes with many transient forms. Cyanobacteria are known to produce cyanotoxins, ranging from hepatotoxins (toxins that attack the liver), dermatotoxins (toxins that irritate the skin) to neurotoxins (toxins that attack the brain and nervous system). In 2005, *Phormidium autumnale* mats in five rivers in the Wellington region were shown to be producing neurotoxic cyanotoxins. These neurotoxic cyanotoxins were associated with at least five dog deaths after they had come in contact with water from an affected river (Wood et al. 2007). EBOP continues to monitor for the presence of these mats due to the potential toxic nature of these cyanobacteria.

In November 2007, the Medical Officer of Health issued a health warning advising against any recreational use of the Rangitaiki River from State Highway 30 at Te Teko to the river mouth at Thornton. This included paddling, swimming, fishing or any recreational activity that might involve contact with the mats. Health warnings have not been issued since but regular monitoring has been conducted to detect when ‘blooms’ of mats occur. Currently, there is no guideline for an ‘acceptable level’ of phormidium mats before health warnings are issued. However, monitoring guidelines are being established by EBOP.

6.1 Methods

Field sampling

Twelve sites were visited on the Wheao and Rangitaiki Rivers on 28 & 29 April 2009. The locations of the sites were recorded by GPS and are listed in Table 6—1. The location of the survey sites is shown in Figure 6—1. At each site, visual estimate of percent cover of periphyton was made using the rapid assessment method 2 (RAM-2) as described in Biggs & Kilroy (2000). In addition to visual assessment, algal samples were collected from cobbles and macrophytes at each site, for species determination. To assess biomass at sites where sufficient cobble substrate occurred, three stones were collected randomly in each of three water depths (0.2, 0.35 and 0.5 m). A quantitative sample was collected from the top of each stone by brushing / scraping periphyton from a defined area (9.6 cm^2). Samples were collected into containers and returned to the laboratory for chlorophyll *a* analysis. The Biggs & Kilroy (2000) methods are part of the stream periphyton monitoring manual adopted as standard methodology by MfE.

Table 6—1: Sites visited on the Wheao and Rangitaiki Rivers.

Site description	Easting	Northing
1. Wheao Dam	2820453	6274214
2. Flaxy Lake canal	2819281	6276858
3. Rangitaiki River upstream of canal intake	2816660	6279900
4. Rangitaiki Canal	2817566	6279948
5. Wheao River above Rangitaiki Powerhouse	2821542	6279321
6. Wheao River below Rangitaiki Powerhouse	2821550	6279446
7. Rangitaiki River above Wheao River confluence	2827341	6287279
8. Rangitaiki River downstream of Wheao River junction	2828767	6288298
9. Rangitaiki River near proposed diversion.	2832040	6294171
10. Rangitaiki River upstream of SH 38	2832725	6298325
11. Rangitaiki River downstream of Murupara	2833466	6301866
12. Rangitaiki River at Rabbit Bridge	2840011	6310785

Laboratory analyses

Subsamples were examined under an inverted microscope at magnifications up to 400x to identify common algal taxa present. Relative abundance of each common taxon was assessed on a scale where 1 = rare, 2 = rare – occasional, 3 = occasional, 4 = occasional – common, 5 = common, 6 = common – abundant, 7 = abundant, 8 = dominant. (Biggs & Kilroy 2000). Chlorophyll *a* samples were extracted in 90% acetone at 4^{o}C, in the dark, for 24 hours. Samples were then centrifuged at 3000 rpm for 10 minutes and the absorbance of the supernatant read on a Shimadzu UV-2550 spectrophotometer before and after acidification (Marker et al. 1980). Chlorophyll *a* concentrations were estimated using calibration standards prepared with purified Chlorophyll *a* (Sigma chemicals). Chlorophyll *a* values were normalised to give concentration per m^2 of river bed.

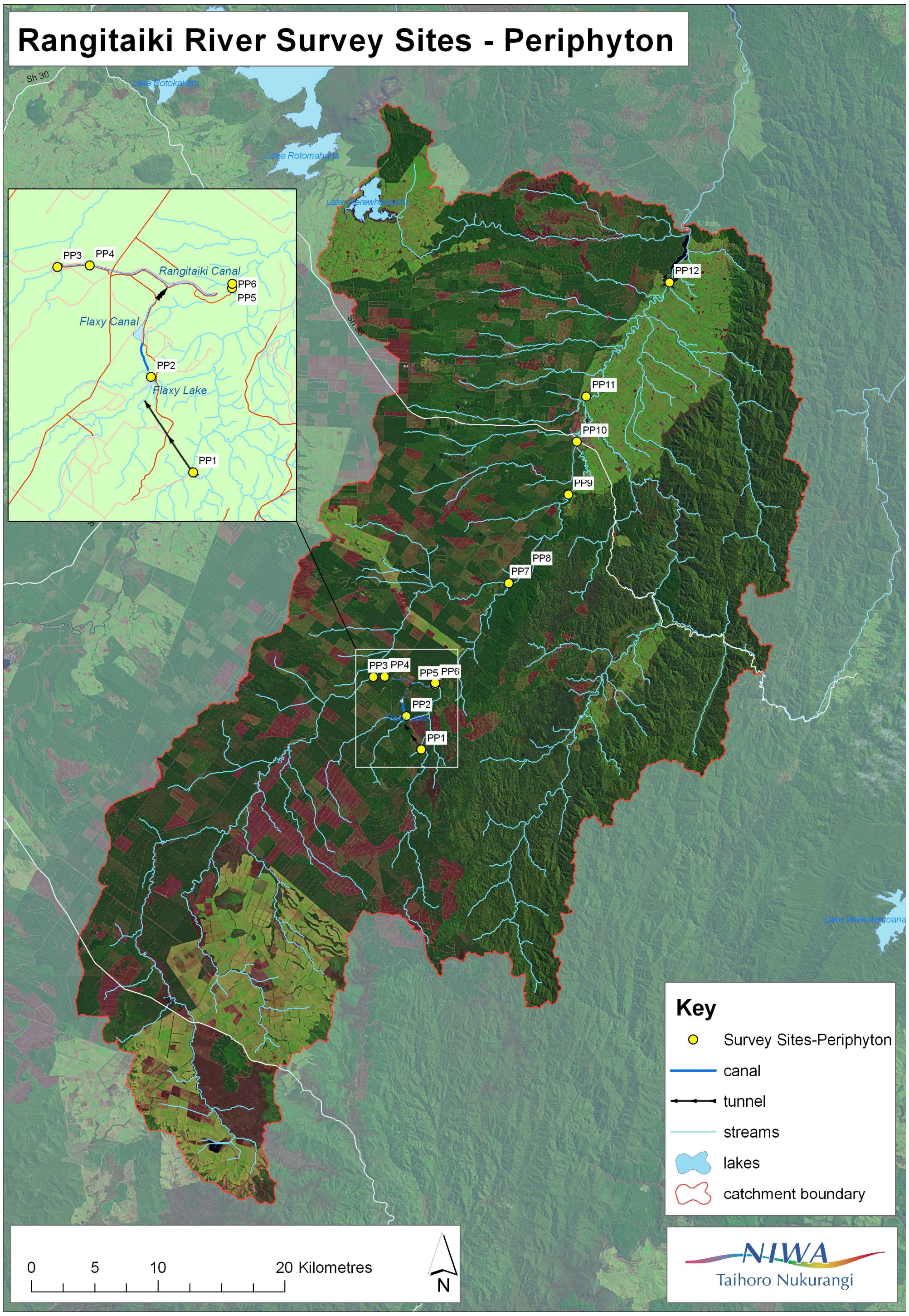


Figure 6—1: Location of periphyton survey points.

6.2 Results

Site 1 Wheao Dam

Substrate suitable for periphyton development was limited above the Whaeo Dam. Much of the area was comprised of muddy substrate, which, coupled with shading from overhanging vegetation was not conducive to periphyton development (Figure 6—2). The occasional submerged log provided limited solid substrate for periphyton to develop. Below the Wheao Dam suitable substrate for periphyton growth existed in the form of cobbles and boulders but there was no residual flow to allow periphyton to establish (Figure 6—3).

Figure 6—2: Upper Wheao River above the Wheao Dam. Submerged logs provide little solid substrate for periphyton to colonise.

Figure 6—3: Upper Wheao River below the Wheao Dam. Suitable solid substrate in the form of boulders is present but the absence of residual flow means that periphyton are unable to develop.

Site 2 Flaxy Lake and Canal

From the Wheao Dam water is diverted to Flaxy Lake. The muddy lake margin did not provide a suitable substrate for periphyton development (Figure 6—4). Limited epipelic algae (algae growing on fine mud surfaces) were present on the bare substrate approximately 0.5m below the existing water surface. The lake supports a mostly indigenous plant community (see Section 7), which is covered in a heavy epiphyte growth (Figure 6—5). This community was comprised mainly of diatoms and was dominated by *Aulacoseira granulata*, *Cocconeis placentula* and *Rhoicosphenia curvata* (Table 6—2). In areas of higher flows, such is in the centre of the canal, epiphyte development was restricted.

Table 6—2: Common epiphyte taxa in Flaxy Lake.

Dominant species	Score
Diatoms	
Aulacoseira granulate	7
Cocconeis placentula	8
Cymbella tumida	3
Fragilaria capuncina	3
Fragilaria vaucheriae	5
Gomphonema sp.	3
Rhoicosphenia curvata	7
Synedra ulna	4

Figure 6—4: Muddy substrate along the margins of Flaxy Lake and Canal.

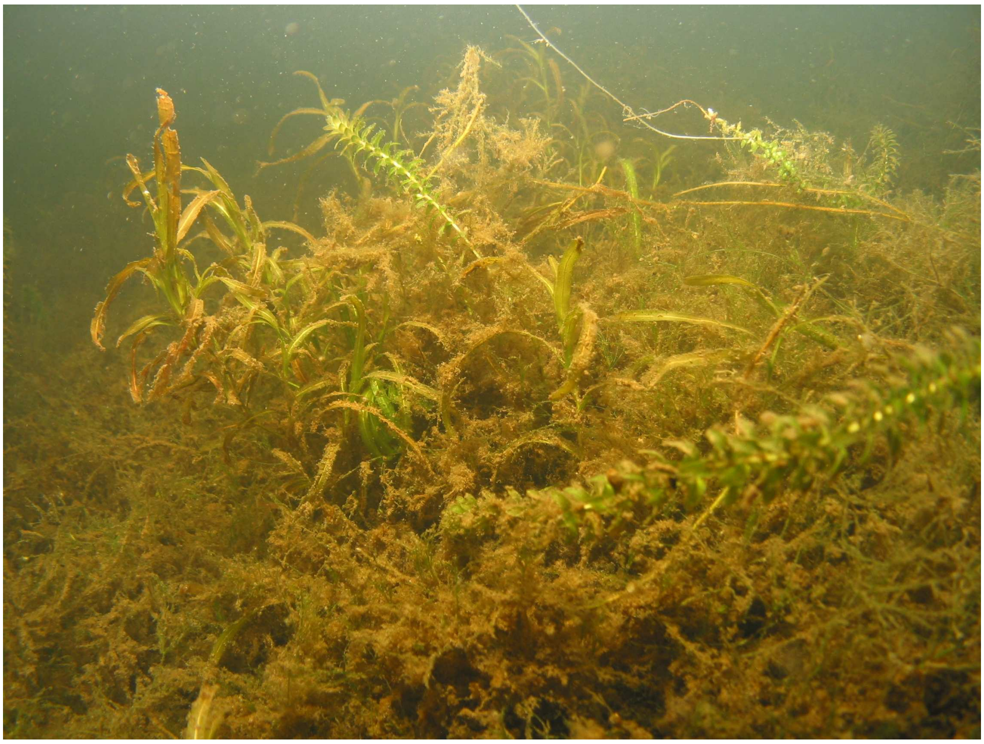


Figure 6—5: Heavy epiphyte development covering the macrophytes in Flaxy Lake.

Site 3 Rangitaiki River upstream of canal intake

Upstream of the Rangitaiki Canal intake there was little periphyton development in the river. High water velocities in riffles prevented periphyton establishing on the boulder substrate. In crevices and on the downstream-facing surface of the boulders, the cyanobacterium *Nostoc* sp. formed colonial balls. However, total cover was less than 5%. In areas of back flows and low flows epipelic algae colonised < 10% of available substrate.

Site 4 Rangitaiki Canal

In the Rangitaiki Canal (Figure 6—6), algae covered the macrophytes and cobbles along the margins, where flow was reduced, while the central channel was relatively clear of algal growth. Percent cover ranged from 0, in the middle of the canal, to 60% 2-3 m from the edge (Figure 6—7). The algal community was dominated by the diatom *Melosira varians* and the macroalga, *Ulva intestinalis* (Table 6—3).

Table 6—3: Common algae present in the Rangitaiki Canal.

Dominant species	Score
Macroalgae	
Ulva intestinalis	5
Diatoms	
Cymbella tumida	3
Gomphoneis minuta var. *cassieae*	4
Gomphonema sp.	3
Melosira varians	8
Synedra ulna	6

Figure 6—6: Location of the sampling site in the Rangitaiki Canal.

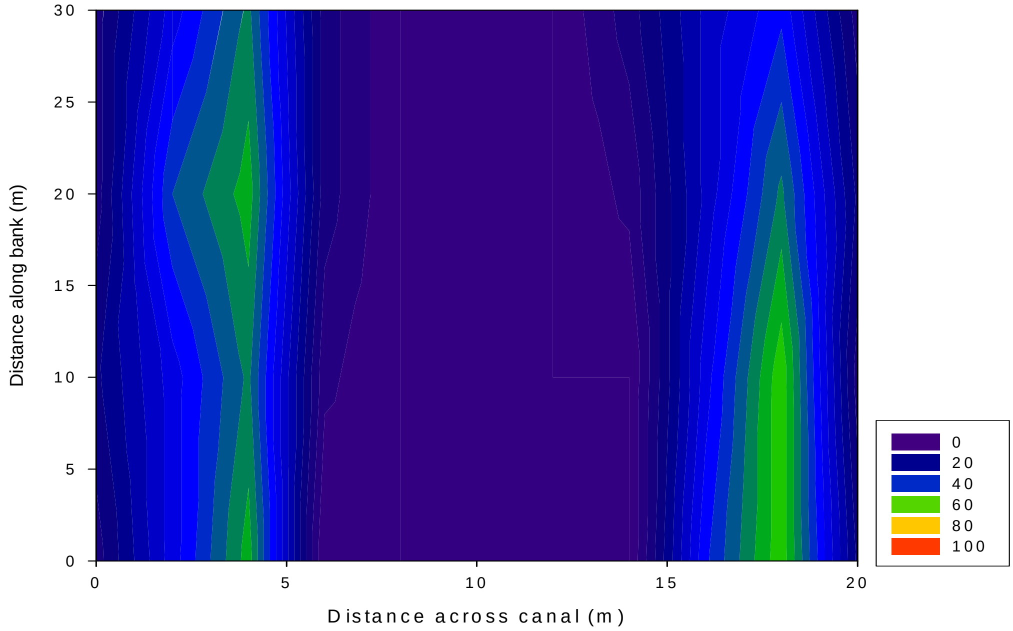


Figure 6—7: Contour plot showing percent cover of periphyton in the Rangitaiki Canal.

Site 5 Wheao River above Rangitaiki Powerhouse

Habitat at this site was unsuitable for significant periphyton development (Figure 6—8). Shallow fast flowing water, coupled with overhanging vegetation, prevented periphyton from forming, with the exception of *Nostoc* sp. balls growing in crevices. Total percent cover of *Nostoc* sp. was < 5%.

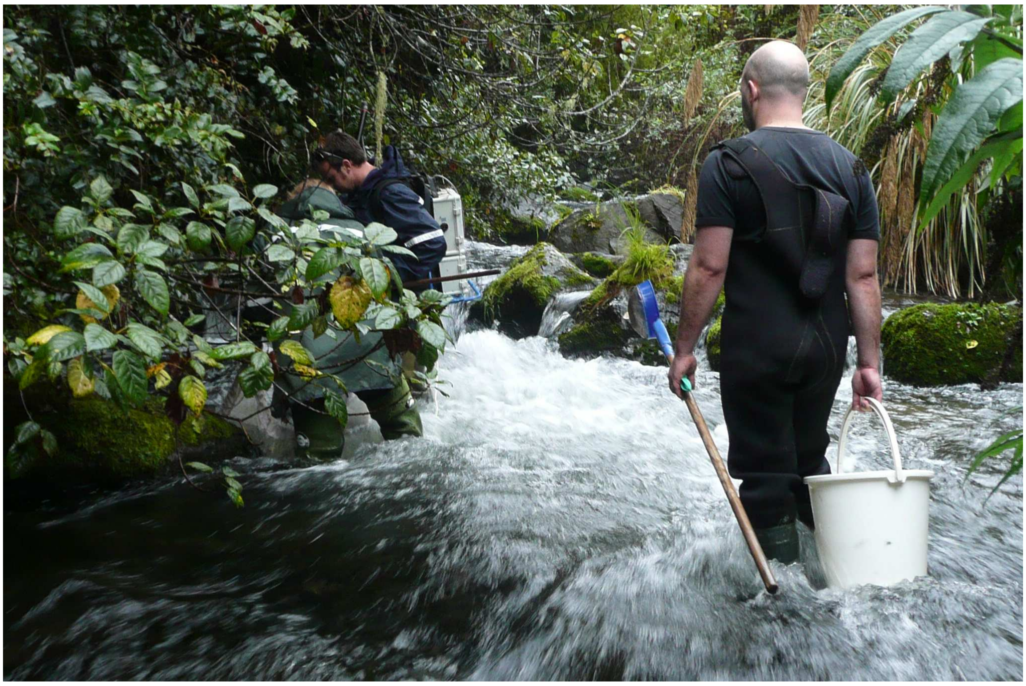


Figure 6—8: Habitat in the Wheao River upstream of the Rangitaiki Powerhouse**.**

Site 6 Wheao River below Rangitaiki powerhouse

Approximately half of the stream supported periphyton on cobble and rock substrate, with percent cover reaching up to 90% within the first 4 m from the true left bank. High water velocity prevented periphyton developing on the true right of the river (Figure 6—9 & Figure 6—10). Diatoms comprised the majority of the community, with *Gomphoneis minuta* var. *cassieae, Melosira varians,* and *Fragilaria vaucheriae* dominating the community (Table 6—4). Cyanobacterial mats were present along the margins. These were comprised mainly of species of *Phormidium* with *Phormidium* aff. *autumnale* dominant. Chlorophyll *a* biomass exceeded the current 200 mg /m^2 periphyton biomass guidelines for trout habitat and angling values (Biggs 2000). Samples from all three depths examined exceeded this value, with a mean value for all depths of 294 mg/m^2 (Figure 6—11).

Figure 6—9: Wheao River just below the Rangitaiki Powerhouse.

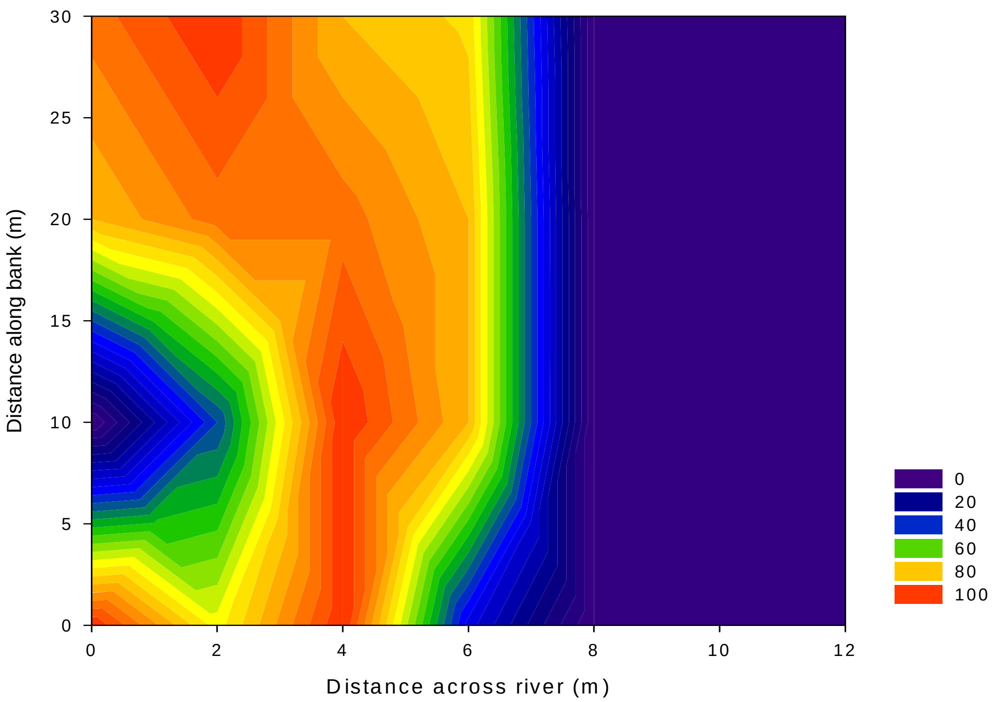


Figure 6—10: Percent cover of periphyton in the Wheao River below the Rangitaiki Powerhouse.

Table 6—4: Common algal taxa present in the Wheao River below the Rangitikei Powerhouse.

Species	Score
Diatoms	
Cymbella tumida	4
Fragilaria vaucheriae	7
Fragilaria capucina	6
Gomphoneis minuta var. *cassieae*	8
Mastogloia elliptica	6
Melosira varians	7
Cyanobacteria	
Phormidium aff *retzii*	3
Phormidium aff. *autumnale*	5
Lyngbya aff. *martensiana*	3

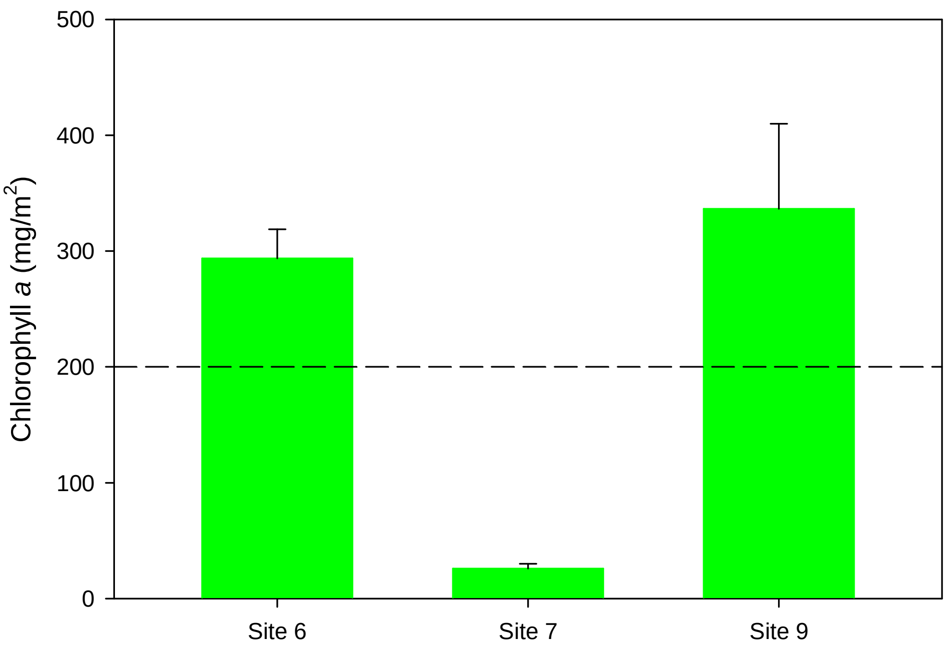


Figure 6—11: Mean chlorophyll a measured in the Wheao River (Site 6) and in the Rangitaiki River (Sites 7 and 9). The horizontal line shows the current guidelines for maximum desirable periphyton biomass for trout habitat and angling (chlorophyll *a*, 200 mg/m^2).

Site 7 Rangitaiki River above Wheao River confluence

At this site a combination of cobble substrate and low flows provided ideal habitat for periphyton development (Figure 6—12). Up to 70% of the river bed was colonised by macroscopic growths of periphyton (Figure 6—13). The filamentous green alga, *Oedogonium* sp., and the chain forming diatom *Melosira varians,* were the dominant species (Table 6—5). Chlorophyll *a* biomass was low at this site with a mean value of 26 mg/m^2 across the river bed (Figure 6—11).

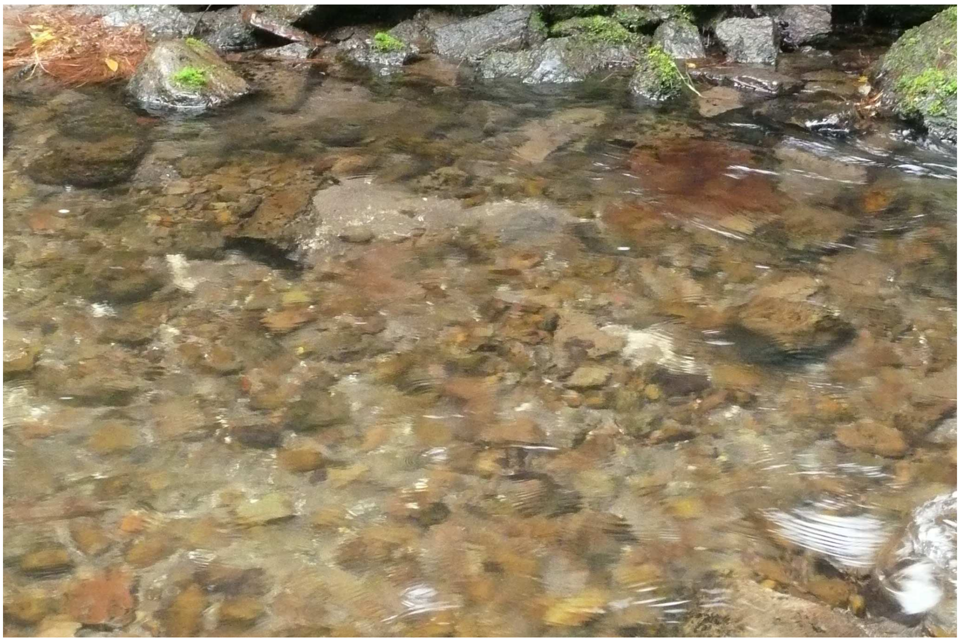


Figure 6—12: Cobble substrate in the Rangitaiki River upstream of the Whaeo River confluence.

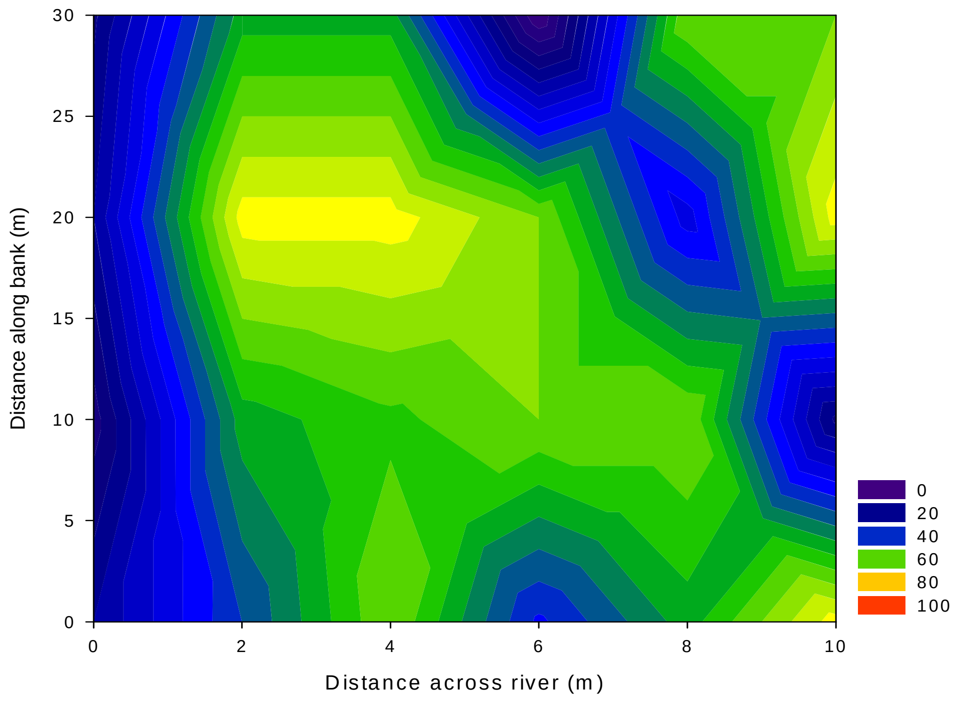


Figure 6—13: Percent cover of periphyton in the Rangitaiki River above the Wheao confluence.

Table 6—5: Common algae taxa in the Rangitaiki River above the Wheao confluence.

Species	Score
Diatoms	
Gomphoneis minuta var. *cassieae*	3
Mastogloia elliptica	4
Melosira varians	7
Rhoicosphenia curvata	4
Synedra ulna	4
Cyanobacteria	
Phormidium aff. *autumnale*	5
Nostoc sp.	3
Filamentous green algae	
Oedogonium sp.	8
Cladophora sp.	4
Tribonema sp.	3

Site 8 Rangitaiki R. downstream of Wheao R. junction

In riffle areas bedrock dominated the substrate. Periphyton was confined to the margins along the true left bank where water velocity was sufficiently low to allow growth (Figure 6—14). The algal community was dominated by the filamentous green alga, *Vaucheria* sp. and the chain forming diatom *Melosira varians* (Table 6—6). In areas of slower flow (run) thick silt deposits limited periphyton development.

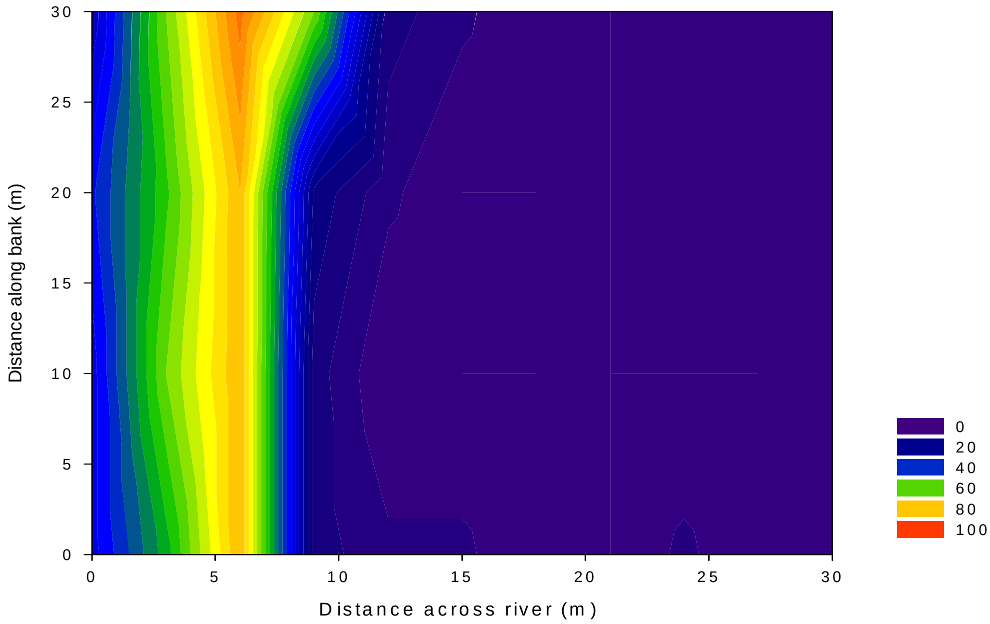


Figure 6—14: Percent cover of periphyton in riffles in the Rangitaiki River downstream of the Wheao confluence.

Table 6—6: Common algae taxa in the Rangitaiki River below the Wheao confluence.

Species		Score
Diatoms		
	Cocconeis placentula	6
	Gomphoneis minuta var. *cassieae*	5
	Mastogloia elliptica	5
	Melosira varians	8
	Rhoicosphenia curvata	4
	Synedra ulna	6
Cyanobacteria		
	Oscillatoria sp.	3
	Nostoc sp.	4
Filamentous green algae		
	Spirogyra sp.	4
	Tribonema sp.	3
	Vaucheria sp.	8

Site 9 Rangitaiki River near proposed diversion

Mobile pumice sands in the faster flowing waters prevented algal growth thus restricting periphyton development to the margins of the river bed where there was stable substrate and slower flows. Percent cover reached a maximum of 90% and an average cover of 65% (Figure 6—15). Epiphytic growth on the macrophytes was dominated by diatoms, particularly *M. varians* (Figure 6—16, Table 6—7), while cyanobacteria mats, dominated by *P. autumnale*, grew over cobbles along the margins of the river (Figure 6—17). Biomass, measured by chlorophyll *a*, was in excess of the guidelines with an average value of 336 mg/m^2 (range 198 – 449) across all depths sampled (Figure 6—11).

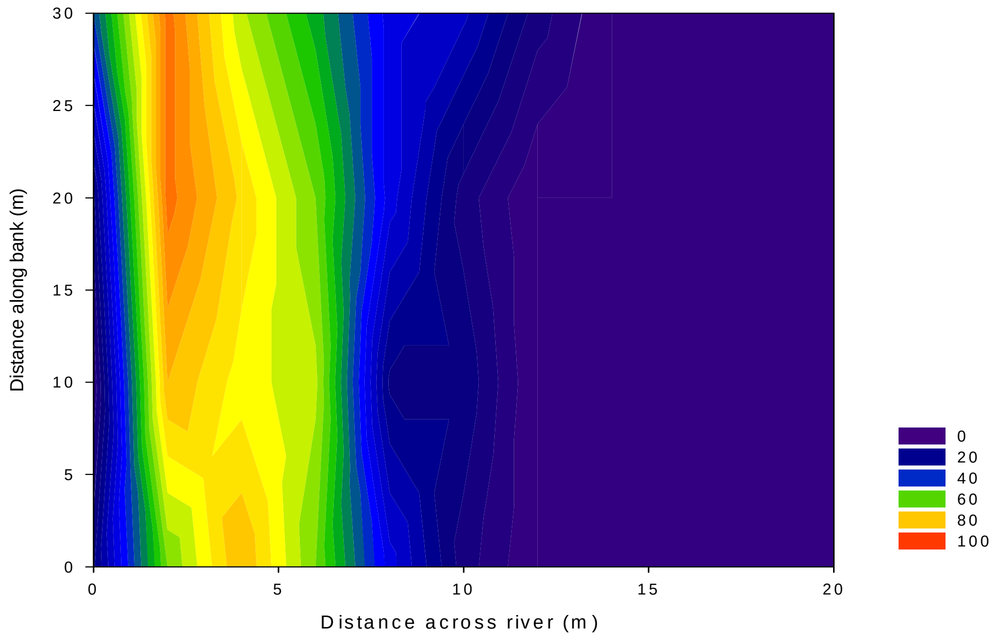


Figure 6—15: Percent cover of all periphyton in the Rangitaiki River just above proposed irrigation intake.

Figure 6—16: Epiphyte cover (brown growth) on the macrophytes.

Figure 6—17: Rangitaiki River just above the proposed irrigation diversion with dark felt-like mats *of Phormidium* aff. *autumnale* on the cobbles.

Table 6—7: Common algal taxa in the Rangitaiki River just above the proposed irrigation diversion.

Species	Score
Diatoms	
Cymbella tumida	3
Gomphoneis minuta var*. cassieae*	5
Gomphonema sp.	4
Mastogloia elliptica	6
Melosira varians	8
Synedra ulna	7
Cyanobacteria	
Leptolyngbya angustissima	3
Phormidium aff. *autumnale*	8

Site 10 Rangitaiki River just above the SH 38 Bridge and Site 11 downstream of Murupara

At both Site 10 and 11, periphyton development was restricted by the presence of silt in the slow flowing waters and mobile pumice in the high flowing waters. Epiphytes did not develop to levels that were visually obvious. Visual cover estimates were <5% at both reaches.

Site 12 Rangitaiki River at Rabbit Bridge

Visual estimates of percent cover were lower at the Rabbit Bridge site than at upstream sites. Maximum cover reached 35% and average cover was 15% across the entire reach (Figure 6—18). Epiphytes were most common form of algal growth due to the volume of macrophytes present at this site. In the central channel, where macrophytes was absent, felt-like cyanobacteria mats, dominated by *Phormidium* aff. *autumnale*, grew over the cobbled substrate (Figure 6—19). Diatoms comprised the epiphyte species, while cyanobacteria dominated the benthic community (Table 6—8).

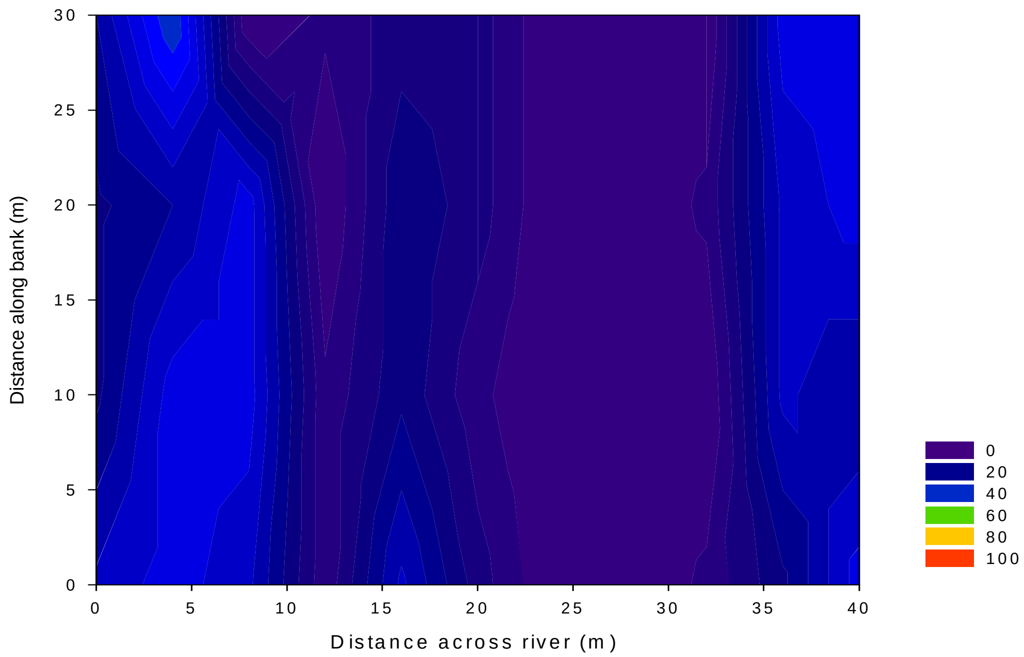


Figure 6—18: Percent cover estimate of periphyton at Rabbit Bridge.

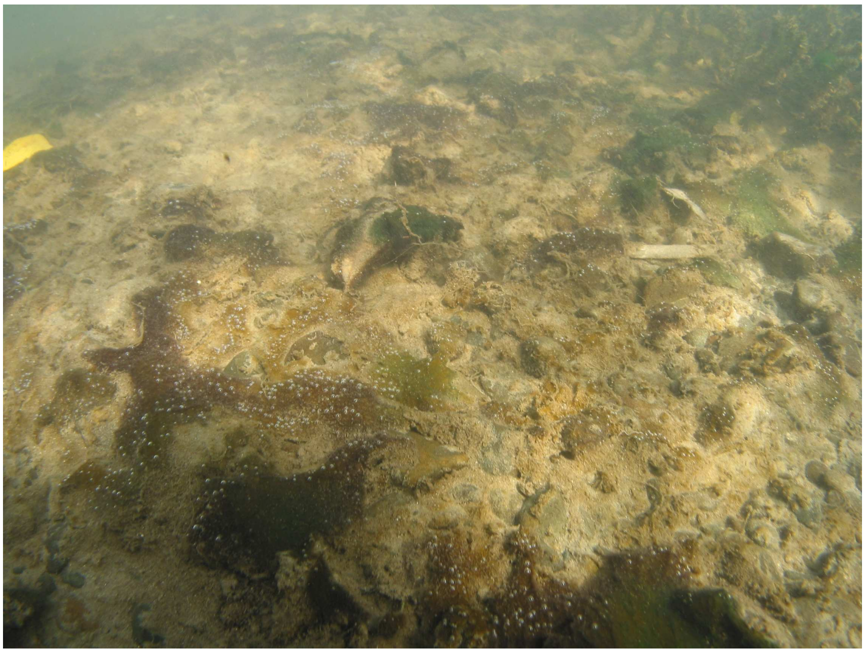


Figure 6—19: Cyanobacteria mats growing on cobbles in the central channel of the Rangitaiki River at Rabbit Bridge.

Table 6—8: Common algal taxa in the Rangitaiki River at Rabbit Bridge.

Species	Score
Diatoms	
Cymbella tumida	3
Fragilaria vaucheriae	8
Gomphoneis minuta var. *cassieae*	5
Mastogloia elliptica	5
Melosira varians	7
Rhoicosphenia curvata	4
Cyanobacteria	
Phormidium aff *retzii*	4
Phormidium aff. *autumnale*	8
Oscillatoria sp	3

6.3 Conclusions and Recommendations

Species diversity was low at all sites and there was little variability within and between sites. One possible reason for this low diversity is the late timing of the survey. Typically, periphyton diversity is reduced this late in the growth season to tolerant species. Greatest diversity would most likely occur in spring and early summer.

Low diversity may also indicate landuse pressures. However, to fully gauge this potential impact, temporal studies on both diversity and biomass would need to be conducted.

At two of the three sites where substrate did not restrict growth. periphyton, accumulated to levels in excess of the recommended guidelines for trout habitat and angling value (Biggs 2000). It is likely that biomass was even higher during the peak summer months, when low flows, warm temperatures and high light intensities would have favoured rapid growth of algae. Further spatial and temporal studies would be needed to confirm the extent of periphyton development through the Wheao and Rangitaiki Rivers.

Cyanobacterial mats were present in the river up to a total cover of 20%. This is consistent with records held by EBOP. The dominant cyanobacterium in the mats was a strain most resembling *Phormidium autumnale*. This is the same species implicated in the dog deaths in the rivers in the Wellington region (Woods et al. 2007). While it is not known whether the cyanobacterial mats in the Wheao and Rangitaiki Rivers produce toxins, given the occurrence of toxins in other New Zealand rivers it is very probable. Cyanobacteria typically produce toxins under periods of environmental stress and this varies between strains (Sutherland 1997). Even when the cyanobacteria are producing toxins a healthy mat may pose a low risk as the majority of cyanotoxins are produced intracellularly. However, when mats die or become detached from their substrate, cyanotoxins may be released into the water in a massive pulse.

Periphyton growth is stimulated by three main factors; nutrient concentrations, available light and stability of substrate. In an effort to reduce the periphyton biomass, efforts need to be made to manage these factors. By reducing nutrient concentrations, retaining and enhancing overhanging riparian vegetation (which shades the margins and reduces light), and providing flushing flows, biomass can be reduced to levels that will maintain river health and values.

In the lake environments, periphyton, and in particular Phormidium, is not thought to be problematic. Little substrate is available for the growth of benthic algae and light penetration to the bottom of the lake is considerably reduced by the dense macrophyte beds. Epiphytes are present but do not appear to develop to levels that would cause stress to the macrophytes. To date, there is no monitoring of phytoplankton (algae that floats in the water column) growth in the lakes. Blooms of phytoplankton (particularly cyanobacteria) occur when the water column stratifies, light levels are high and nutrient concentrations are not limiting. Summer-time monitoring would be needed to assess these lakes and better understand the potentials for phytoplankton bloom development water.

7. Macrophytes

Rohan Wells, NIWA

This section reports on the current status of macrophytes (larger aquatic plants excluding micro-algae) in the upper Rangitaiki River catchment. The creation of canals and lakes for the generation of hydro power have modified the habitat for macrophytes (submerged aquatic plants) markedly. Over the years these habitats have also been invaded by non-native weedy species that are characterised by excessive nuisance growths. Aquatic weeds can change the habitat markedly and impact on other aquatic life.

Information presented at the consent hearings for the creation of Lake Aniwhenua indicated that elodea (*Elodea canadensis*), curled pondweed (*Potamogeton crispus*), native pondweed (*Potamogeton ochreatus*) and water buttercup (*Ranunculus trichophyllus*) were present in the Rangitaiki River in the mid 1970s. Elodea was predicted to be the dominant plant in the proposed reservoir. Access problems were predicted for fishing and other recreational pursuits when the weeds egeria (*Egeria densa*) and hornwort (*Ceratophyllum demersum*) spread to the reservoir and it was submitted that these plants would need to be managed (Dr J. Clayton NIWA pers. comm. & NIWA unpubl. file records).

Subsequent to the formation of the Lake Aniwhenua, Clayton (then Aquatic Plant Section, MAF) conducted detailed macrophyte surveys in 1981, 1983 and 1984 (NIWA Lakes Database, *fbis.niwa.co.nz*). These surveys documented successional changes in establishment of extensive macrophyte beds in the lake with elodea becoming the dominant component as predicted with another oxygen weed (*Lagarosiphon major*), water buttercup, native pondweed, and curled pondweed also common (Table 7—1).

Aquatic weeds have invaded most of our aquatic ecosystems (De Winton et al. 2009). In the 1990’s, the water net alga (*Hydrodictyon reticulatum*) proliferated and regularly formed >10 ha thick floating mats in the reservoir (Wells et al. 1999) (Figure 7—2). Wells & Clayton (2001) documented the ecological consequences of the plant. An unexpected benefit was that it almost certainly produced a large number of exceptionally large trophy trout as the nets provided good habitat for invertebrates and goldfish. Several control options for control of water net were developed and used in Lake Aniwhenua including design and construction of a harvesting machine, use of barley straw bails, and copper (Wells 1994, Wells et al. 1994). More recently (date not known, but likely to be around 2000) hornwort and egeria have invaded the reservoir and now form extensive nuisance, surface-reaching growths displacing much of the pre-existing aquatic vegetation.

The Rangitaiki Canal and Flaxy lakes system was looked at in 1997 as the generator (then Rotorua Electricity) was experiencing problems with weed restricting flow rates through the system. Macrophyte composition was the same then as in the current survey. The use of blades and diggers in the canals to physically remove the sediment was not providing sufficient benefit, was risking disturbing the canal lining, and was impacting on trout numbers. NIWA developed a strategy, involving the use of diquat to control deeper growing elodea while leaving the margins, coupled with a periodic scouring high flow regime, that when trialled proved beneficial for both the fishery and power generation (Wells 1997, Wells 1998a, Wells 1998b, Wells et al. 1998, Wells & Taumoepeau 2001).

Figure 7—2: Water net on Lake Aniwhenua (LEFT), and water net being harvested (RIGHT).

Table 7—1: Lake Aniwhenua aquatic macrophytes recorded on 29 August 1984 (sourced from NIWA database) with depth range, maximum and average lengths, and maximum and average covers (see methods). + denotes non-native species.

Species	Depth range (m)	Height / length (m) Max / av.	%Profiles	Cover class Max / av.
Submerged species+				
+*Elodea canadensis*	0.3 - 4	1.5 / 1.0	100	6 / 4
Potamogeton ochreatus	0 – 5.5	3 / 1	93	6 / 1
+*Lagarosiphon major*	1 – 1+	3.0 / 1.0	73	6 / 1
Ranunculus trichophyllus	0.5 – 4.5	2 / 1	53	6 / 1
+*Potamogeton crispus*	0.5 – 4.0	2 / 1	67	2 / 1
Nitella cristata	0.5 - 6	0.5 / 0.3	33	5 / 1
Myriophyllum propinquum	0.5 – 0.5	0.3 / 0.2	7	5 / 1
Potamogeton cheesemanii	1.0 / 1.5	1 / 0.5	7	1 / 1
Floating species				
Azolla rubra	surface		20	2 / 2
Lemna minor	surface		13	2 / 2

7.1 Methods

A total of 17 sites within the upper Rangitaiki River catchment were surveyed on 28 and 29 April 2009 (Table 7—2). At each site SCUBA / snorkel divers investigated the aquatic vegetation (macrophytes) where present across the full width of the river or reservoir where possible. Maximum cover was determined in a series of 1 m^2 quadrat, and average cover was estimated for each species within the area surveyed. Cover was estimated using cover classes 1 = 1 – 5%; 2 = 6 – 25; 3 = 26 – 50%; 4 = 51 – 75%; 5 = 76 – 95%; 6 = 96 – 100%. Height or length of plants were measured and recorded as maximum and average heights for each species taller than 0.1 m. Photographs were taken of the marginal vegetation at each site and underwater photographs were taken where possible (dependent on flow and visibility). Sites 15 and 16 on Lake Aniwhenua was accessed by boat and sonar profiles recorded. Diving observations were also made at these sites to ground truth the profiles (Table 7—2). The location of the sites is shown in Figure 7—1.

Table 7—2: Sites surveyed on the Whaeo and Rangitaiki Rivers, 28–29 April 2009.

Site number	Site descriptions	Eastings	Northings
1	Wheao Dam	2820570	6274110
2	Flaxy Lake	2819320	6276700
3	Flaxy Canal	2819120	6277220
4	Flaxy Lake 2	2818970	6278040
5	Rangitaiki R. upstream of canal intake	2816660	6279900
6	Rangitaiki Canal	2817440	6279980
7	Rangitaiki R. upstream of Wheao R. confluence	2827348	6287288
8	Wheao R. upstream of Rangitaiki Powerhouse	2821550	6279370
9	Wheao R. downstream of Rangitaiki Powerhouse	2821580	6279500
10	Rangitaiki R. below junction with Wheao R.	2828880	6288620
11	Rangitaiki R. near proposed diversion	2832972	6295368
12	Rangitaiki R. SH38 Bridge	2832725	6298325
13	Rangitaiki R. downstream of Murupara	2833200	6301580
14	Rabbit Bridge and top end Lake Aniwhenua	2840022	6310772
15	Lake Aniwhenua upper half	2841305	6313428
16	Lake Aniwhenua near the dam	2841680	6314528
17	Aniwhenua Canal	2841555	6314792

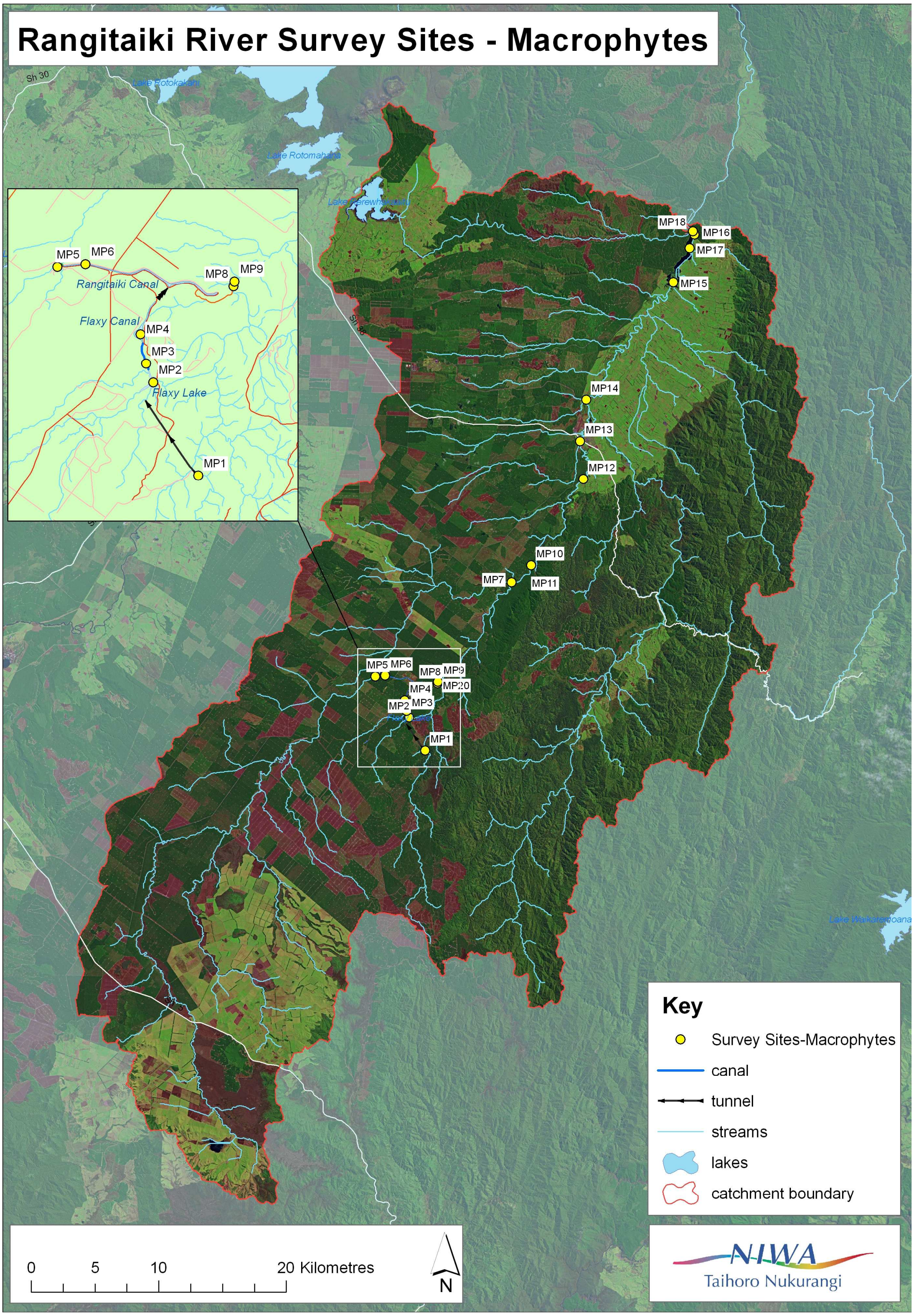


Figure 7—1: Location of macrophyte survey points.

7.2 Results and Discussion

Site 1 Wheao Dam

Current distribution:

No macrophytes were seen in the Wheao River near the Wheao Dam. The habitat was unfavourable for macrophytes with steep sides and overhanging vegetation above the dam (Figure 7—2). Below the dam there was no residual flow and consequently no macrophytes (Figure 7—3).

Historical distribution:

Fast flowing water would have restricted macrophyte growths to bryophytes (mosses and liverworts) on stable rock surfaces sheltered from abrasion by bed load.

Figure 7—2: Upper Wheao River above the Weao Dam.

Figure 7—3: Upper Wheao River below the Weao Dam.

Site 2 Flaxy Lake

Current distribution:

Water is diverted to Flaxy Lake (Figure 7—4) from the upper Wheao River. The lake was largely covered with macrophytes and they were mostly indigenous species, *Nitella cristata* and *Potamogeton ochreatus* (Figure 7—5) with some exotic oxygen weed, *Elodea canadensis* (Figure 7—6 and Table 7—3).

Table 7—3: Macrophytes recorded in Flaxy Lake, with their depth range, maximum and average lengths, and maximum and average covers (see methods for description of criteria). + denotes exotic species.

Species	Depth range (m)	Height / length (m) (Max / av.)	Cover class (Max / av.)
+*Elodea canadensis*	1.0 – 2.0	0.7 / 0.6	1 / 1
Lilaeopsis novae-zelandiae	Above water*		3 / 2
Glossostigma submersum	Above water		3 / 2
Potamogeton ochreatus	0.5 – 2.5	1.7 / 1.0	6 / 12
Nitella cristata	0.3 – 3.0+	0.4 / 0.3	6 / 5

*Water levels were low (estimate down about 1 m from maximum) at the time of the visit.

Historical distribution:

This lacustrine habitat would not have existed prior to the diversion.

Figure 7—4: Flaxy Lake with a low water level (estimate 1 m below maximum). Exposed low-growing turf plants visible in the foreground.

Figure 7—5: Stand of indigenous macrophytes from Flaxy Lake. *Nitella cristata* (foreground) and *Potamogeton ochreatus* (above).

Figure 7—6: Flaxy Lake *Elodea canadensis* (tall plant left).

Site 3 Flaxy Canal

Present distribution:

The tall-growing native macrophyte, *Potamogeton ochreatus* (Figure 7—8) was the most abundant plant, with the native charophyte *Nitella cristata* (Figure 7—9) also present in the canal (Table 7—3).

Historical distribution:

This canal is new habitat created by the diversion scheme.

Table 7—4: Macrophytes recorded in the Flaxy Canal, with their depth range, maximum and average lengths, and maximum and average covers (see methods).

Species	Depth range (m)	Height / length (m) Max / av.	Cover class Max / av.
Potamogeton ochreatus	0.5 – 2.5	2.2 / 1.7	6 / 5
Nitella cristata	0.5 – 2.5	0.5 / 0.4	5 / 2

Figure 7—7: Flaxy Canal joins the main body of Flaxy Lake to a second smaller open water body which, for the purpose of this study, is referred to a 'Flaxy Lake 2'.

Figure 7—8: *Potamogeton ochreatus* in the flowing water of Flaxy Canal.

Figure 7—9: Flaxy Canal with patches of *Nitella cristata*.

Site 4 ‘Flaxy Lake 2’

Present distribution:

The submerged vegetation in “Flaxy Lake 2” was similar to that of Flaxy Lake with *Potamogeton ochreatus* and *Nitella cristata* the dominant macrophyte and *Elodea canadensis* also common (Table 7—1).

Historical distribution:

This lake was formed by the diversion scheme, so provides a large shallow lacustrine aquatic habitat that would otherwise not be present. Water flows from this lake via a pipeline and through a small power house before entering the Rangitaiki Canal at about the mid point.

Table 7—5: Macrophytes recorded in 'Flaxy Lake 2', with their depth range, maximum and average lengths, and maximum and average covers (see methods).

Species	Depth range (m)	Height / length (m) Max / av.	Cover class Max / av.
+Elodea canadensis	0.1 – 1.5*	1.0 / 0.6	6 / 2
Potamogeton ochreatus	0.1 – 1.5	1.2 / 1.0	6 / 4
Nitella cristata	0.1 – 1.5	0.5 / 0.4	6 / 3

*Water levels were low (estimate down about 1 m) at the time of the visit.

Figure 7—10: **"**Flaxy Lake 2" with water level down about 1 m from maximum levels.

Site 5 Rangitaiki River above the Rangitaiki Canal intake

Figure 7—11: Rangitaiki River above the Rangitaiki Canal intake.

Present distribution:

No macrophytes were seen in the river above the intake. On previous occasions other parts of the river were accessed up to 5 km upstream and the river was swift flowing over a rocky substrate with no aquatic macrophytes present.

Historical distribution:

Habitat for macrophytes in this section of the river is not affected by the existing power scheme. High flows and rocky substrates restricted plants to bryophytes (mosses and liverworts).

Site 6 Rangitaiki Canal

Present distribution:

The Rangitaiki Canal is 4.2 km long, about 20 m wide and up to 3 m deep. It was dominated throughout its length by dense growth of oxygen weed elodea, *Elodea canadensis* (Figure 7—13). Other common species included curled pondweed, *Potamogeton crispus* and the native pondweed, *Potamogeton ochreatus* (Table 7—6). On previous visits some oxygen weed, *Lagarosiphon major* was recorded in the lower parts of the canal, and watercress (*Nasturtium offinale*) an exotic edible plant, was abundant on the margins of the upper part of the canal. Recent earth work has widened the canal immediately below the canal intake. Periodically weed control measures are known to been made to prevent flow restrictions in the canal.

Historical distribution:

This extensive aquatic habitat did not exist prior to construction of the power scheme.

Table 7—6: Macrophytes recorded in the Rangitaiki Canal, with their depth range, maximum and average lengths, and maximum and average covers (see methods). + denotes exotic species.

Species	Depth range (m)	Height / length (m) Max / av.	Cover class Max / av.
+*Elodea canadensis*	0 – 2.3	1.0 / 0.6	6 / 5
Potamogeton ochreatus	0 – 2.3	1.2 / 1.0	4 / 3
+*Potamogeton crispus*	0 – 2.3	0.8 / 0.4	3 / 2

Figure 7—12: The Rangitaiki Canal is about 4.2 km long and heavily vegetated.

Figure 7—13: High covers of elodea**, (***Elodea canadensis)* in the Rangitaiki Canal.

Site 7 Rangitaiki River upstream of the Wheao River confluence

The section of the Rangitaiki River downstream of the Rangitaiki Dam is maintained by residual flows (Figure 7—14). The diverted water re-joins the Rangitaiki River at the Wheao / Rangitaiki River junction. Site 7 was just upstream of the junction.

Present distribution:

The de-watered section of the Rangitaiki River had few macrophytes present and was shallow and fast flowing (Figure 7—15). Just above the confluence with the Wheao River, the Rangitaiki River was wider and slower flowing. Some small pockets of submerged macrophytes were present including (all introduced) elodea, *Elodea canadensis*, blue sweetgrass, *Glyceria declinata*, starwort *Callitriche stagnalis*, and American speedwell, (*Veronica Americana*), water forget-me-not (*Myosotis laxa*), water purslane (*Ludwigia palustris*), and watercress (*Nasturtium officinale*) (Figure 7—16). The only indigenous plant found was *Glossostigma elatinoides*, and some marginal wetland species including the native raupo (*Typha orientalis*) and the native lake club rush (*Schoenoplectus tabernaemontani*) (Figure 7—17).

Historical distribution:

Higher flows through the channel pre-diversion would have made the presence of macrophytes in this reach less likely.

Figure 7—14: Rangitaiki River below the Rangitaiki Canal intake with a residual flow. Compare with the river in **Figure 7—11** above the intake.

Figure 7—15: Rangitaiki River above the Wheao River confluence had few submerged macrophytes Introduced pampas grass (*Coraderia selloana*) was present along the river bank.

Figure 7—16: Macrophytes in the Rangitaiki River upstream of the Wheao River confluence. LEFT elodea top, blue sweetgrass (strap leaves mid left), American speedwell (glossy leaves centre foreground); RIGHT the indigenous turf plant *Glossostigma elatinoides* (small leaves right), and introduced water forget-me-not, water purslane and watercress (amongst the large leaved plants on the left).

Figure 7—17: LEFT lake club rush (*Schoenoplectus tabernaemontani*) (the rush growing from the waters edge), RIGHT raupo (*Typha orientalis*) (the tall plant leaning into the water) and pampas grass (*Cortedaria selloana*) (behind the raupo).

Site 8 Wheao River upstream of the Rangitaiki Canal powerhouse

This site had flows that entered the Wheao River downstream of the upper dam (i.e., minus the water diverted through Flaxy lakes). The river resembled a small stream with fast shallow water running over a rocky substrate (Figure 7—18).

Present distribution:

No macrophytes were seen but a thick layer of bryophytes (mosses and liverworts, mostly *Fissidens* covered many of the larger rocks. The steep gradient, rocky substrate and heavy shading did not favour macrophyte growth.

Historical distribution:

The Wheao River channel without the diversion would have been even less suitable for macrophyte growth.

Figure 7—18: Wheao River above the Rangitaiki Canal powerhouse.

Site 9 Wheao River downstream of the Rangitaiki Canal powerhouse

The Rangitaiki Canal carries about 12 (maximum 20+) m^3 s^{-1} of water to the Wheao River via the powerhouse.

Present distribution:

Apart from bryophytes (mosses and liverworts) there were no macrophytes seen in the Wheao River below the powerhouse (Figure 7—19). High flows in a narrow deep channel did not favour macrophytes.

Historical distribution:

The Wheao River channel with or without the extra water from the Rangitaiki River diversion was unsuitable for macrophyte growth, due to high flows and rocky substrates.

Figure 7—19: The Wheao River just below the powerhouse, with the Rangitaiki River diverted water including the upper Whaeo River diverted water.

Site 10 Rangitaiki River downstream of the Wheao River junction

The river channel at this site was much wider and gradient lower than further upstream so water velocity was lower.

Present distribution:

Patches of macrophytes were present (Figure 7—21) near the river margins particularly where the river was widest and fine sediment was present. Species present included the introduced water buttercup, (*Ranunculus trichophyllus*) and elodea (*Elodea canadensis*).

Historical distribution:

At this location the Rangitaiki River has its full complement of water and is probably little different from pre-diversion times, except possibly elodea may not have been present as it may have been introduced into the lakes along with trout.

Figure 7—20: Rangitaiki River below the Wheao River junction carries more water but was generally wider, shallower and slower flowing than at sites surveyed further upstream.

Figure 7—21: The Rangitaiki River below the junction with the Wheao River with occasional patches of the introduced macrophytes water buttercup (*Ranunculus trichophyllus*) and elodea (*Elodea canadensis*). Pampas grass (*Cortaderia selloana*), also an introduced plant, was present on the river banks.

Site 11 Rangitaiki River just upstream of the proposed irrigation diversion

Present distribution:

Patches of macrophytes were present along the edges of the main channel high flows (Figure 7—23). Water buttercup (*Ranunculus trichophyllus*), and curled pondweed (*Potamogeton crispus*) were the most common submerged plants (Figure 7—24 present at this site. Small patches of elodea (*Elodea canadensis*), and of the native low-growing *turf plant Lilaeopsis novae-zelandiae* (Figure 7—25) were also present (Table 7—7).

Expected effect of proposed abstraction:

This site is above the proposed diversion so would not be impacted by the proposal. However macrophytes would be expected to become more common downstream as a result of the abstraction because of resulting lower velocities in the river channel. Elodea (*Elodea canadensis*) in particular would likely become the dominant species.

Table 7—7: Macrophytes recorded in the Rangitaiki River just upstream of the proposed irrigation diversion, with their depth range, maximum and average lengths, and maximum and average covers (see methods). + denotes non-native species.

Species	Depth range (m)	Height / length (m) Max / av.	Cover class Max / av.
+*Ranunculus trichophyllus*	0.3 – 0.8	0.3 / 0.3	6 / 2
+*Potamogeton crispus*	0.4 – 0.7	0.25 / 0.2	2 / 1
+*Elodea canadensis*	0.3 – 0.4	1.0 / 0.6	1 / 1
Lilaeopsis novae-zelandiae	0 1– 0.15	1.2 / 1.0	2 / 1

Figure 7—22: Rangitaiki River just above the proposed irrigation diversion.

Figure 7—23: Rangitaiki River just above the proposed irrigation diversion with patches of macrophytes comprised of mostly *Ranunculus trichophyllus* and *Potamogeton crispus* in the foreground.

Figure 7—24: Rangitaiki River just above the proposed irrigation diversion with (non-natives *Ranunculus trichophyllus* (front left) and *Potamogeton crispus* (centre).

Figure 7—25: The indigenous macrophyte *Lilaeopsis novae-zelandiae* (with algae) in the Rangitaiki River just above the proposed irrigation diversion.

Site 12 Rangitaiki River upstream of SH38

Present distribution:

At this site, patches of exotic macrophytes were present on the edge of the main channel flow. On the margins there was some watercress (Figure 7—27) and submerged plants included elodea (Elodea canadensis), water buttercup (Ranunculus trichophyllus) (Figure 7—28) and curled pondweed (Potamogeton crispus) (Table 7—8). More extensive areas of fine sediment provided greater habitat for macrophytes than upriver**.**

Expected effect of proposed abstraction:

Less water resulting from abstraction would favour more abundant macrophyte growth.

Figure 7—26: Rangitaiki River at Murupara just above the SH38 bridge, dark patches on the left in the river were mostly the non-native oxygen weed elodea (*Elodea canadensis*).

Figure 7—27: Watercress (*Nasturtium officinale*) Rangitaiki River at Murupara just above the SH38 bridge, below the proposed diversion.

Figure 7—28: Water buttercup (*Ranunculus trichophyllus*) in the Rangitaiki River at Murupara just above the SH 38 bridge, below the proposed irrigation diversion.

Table 7—8: Macrophytes recorded in the Rangitaiki River just above SH38 near Murupara, with their depth range, maximum and average lengths, and maximum and average covers (see methods). + denotes non-native species.

Species	Depth range (m)	Height / length (m) Max / av.	Cover class Max / av.
+*Potamogeton crispus*	0.3 – 1.2	0.4 / 0.4	3 / 2
+*Ranunculus trichophyllus*	0.2 – 1.0	0.5 / 0.4	6 / 2
+*Elodea canadensis*	0.1 – 1.4	0.5 / 0.4	6 / 2

Site 13 Rangitaiki River downstream of Murupara

At this point the river flows across the alluvial plain of the Galatea Basin and has soft banks lined with willows, mostly crack willow (*Salix fragilis*) but also grey willow (*Salix cinerea*).

Present distribution:

Elodea was the dominant submerged plant (Table 7—9) growing on the sides of the river channel to 1.4 m water depth. Water buttercup (*Ranunculus trichophyllus*), and the native turf plants *Lilaeopsis novae-zelandiae, and Glossostigma submersum* were also present in shallow water.

Expected effect of proposed abstraction:

Lower water levels in the river and slower flows would favour an increase in macrophyte growth, although greater encroachment of crack willow into the river channel may increase shading and decrease macrophyte growth.

Figure 7—29: Site 13 Rangitaiki River between Murupara and Lake Aniwhenua with a soft margin and overhanging crack willow (*Salix fragilis*).

Table 7—9: Macrophytes recorded in the Rangitaiki River downstream of Murupara, with their depth range, maximum and average lengths, and maximum and average covers (see methods). + denotes non-native species.

Species	Depth range (m)	Height / length (m) Max / av.	Cover class Max / av.
+*Elodea canadensis*	0.1 – 1.4	0.3 / 0.2	6 / 3
+*Ranunculus trichophyllus*	0.2 – 1.0	0.3 / 0.2	2 / 1
Lilaeopsis novae-zelandiae	0.1 – 0.5		2 / 2
Glossostigma submersum	0.1 – 0.25		1 / 1

Site 14 Rangitaiki River at Rabbit Bridge, and top end of Lake Aniwhenua

The Rangitaiki River at Rabbit Bridge Figure 7—30 was wide and shallow (~0.6 m).

Present distribution:

The river bed was mostly armoured with rocks (Figure 7—31), but towards the margins elodea (*Elodea canadensis*) and water buttercup (*Ranunculus trichophyllus*) grew prolifically (Figure 7—32). Elodea was the dominant species forming beds up to a 10 m wide. Closer to the river bank, and protected from stronger flows curled pondweed (*Potamogeton crispus*), then egeria, (*Egeria densa*) and hornwort (*Ceratophyllum demersum*) dominated with some native pondweed (*Potamogeton ochreatus*) also present (Figure 7—33, Figure 7—34, Figure 7—35, Figure 7—36). These vegetated margins are periodically washed out with flood flows.

Figure 7—30: Rangitaiki River at Rabbit Bridge viewed downstream with large crack willow (*Salix fragilis*) and smaller grey willow (*Salix cinerea*) on the river margins.

Figure 7—31: Rangitaiki River channel with an armoured bed (left) and the most outward margin of the elodea (*Elodea canadensis*) beds (right).

Figure 7—32: Rangitaiki River with water buttercup (*Ranunculus trichophyllus*) growing in high flows.

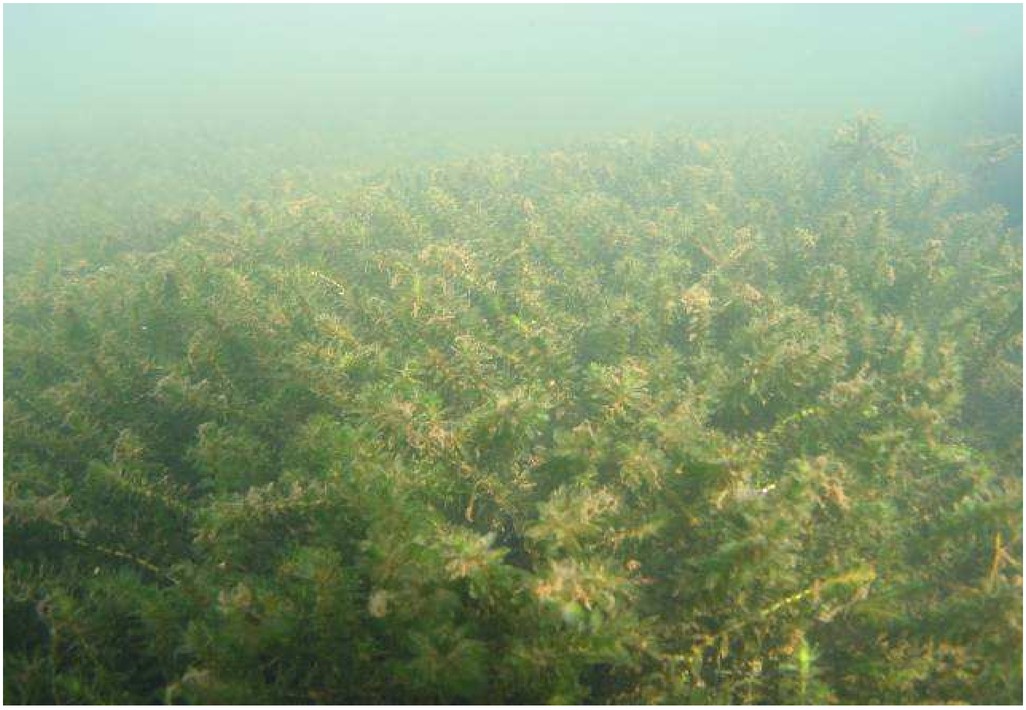


Figure 7—33: Elodea beds (*Elodea canadensis*) an exotic species dominated the silty margins of the Rangitaiki River at Rabbit Bridge.

Figure 7—34: The Rangitaiki River at Rabbit Bridge. Dense curled pondweed (*Potamogeton crispus*) an exotic species was common in low flow zones on the river bank side of the elodea beds.

Figure 7—35: The Rangitaiki River at Rabbit Bridge. Close to the river bank exotic species egeria (*Egeria densa*) and hornwort (*Ceratophyllum demersum*) were abundant.

Figure 7—36: The Rangitaiki River at Rabbit Bridge. Native pondweed **(***Potamogeton ochreatus*) was present in low flow areas of this reach.

Around Rabbit Bridge there were extensive (~100 ha) wetlands with crack willow (*Salix fragilis*) and raupo (*Typha orientalis*) the dominant species (Figure 7—37, Figure 7—38, Figure 7—39). Where sheltered and with little water movement, the non-native floating fern (*Azolla pinnata*) and native duckweed (*Lemna minor*) covered the water surface (Figure 7—38) shading out most of the submerged vegetation below. Crack willow stands had a diffuse understory of native karamu (*Coprosma robusta*) and swamp sedge (*Carex virgata*) (Figure 7—40). On drier ground exotic blackberry (*Rubus fruticosus*) was common (Figure 7—41). The river divided into a number of channels and supported thick beds of macrophytes with species composition dependent on current velocity. Species ordered with regard to flow tolerance from the most tolerant are: water buttercup, elodea, curled pondweed, egeria and then hornwort. Egeria was the dominant species in slow flowing water close to Lake Aniwhenua (Figure 7—42).

Expected effect of proposed abstraction

The floristic composition of this varied wetland is determined by water levels and water movements though the wetland. If water is diverted above this wetland and returned below, then this area will be affected greatly by reduced water flows, warmer temperatures and less oxygen. Macrophytes adapted to slow-flowing habitats will be favoured so hornwort would likely become the dominant species and be surface-reaching throughout most of the wetland. Hornwort tolerates well warmer nutrient rich water better than the other species currently present. Some egeria might also be present. Willows are likely to spread further with more sediment build up in the wetland without high flows in the channels to keep it mobile. This could reduce the amount of open water markedly over time.

Figure 7—37: Around Rabbit Bridge crack willow (*Salix fragilis*) background, and raupo (*Typha orientalis*) foreground, were the dominant species. Photo taken in summer 2008/09.

Figure 7—38: Upper section of the lake Aniwhenua with backwaters covered with floating *Azolla pinnata* and duck weed *Lemna minor.*

Figure 7—39: Upper section of the Lake Aniwhenua showing wetland with raupo (*Typha orientalis*) front left, and purei (*Carex secta)* and willow weed (*Persicaria decipiens*) middle ground.

Figure 7—40: Upper Lake Aniwhenua under a crack willow canopy was karamu, (*Coprosma robusta*) (foreground centre right) and the swamp sedge (*Carex virgata*) (foreground right). In the sheltered habitat duckweed (*Lemna minor*) covers the water surface indicating high nitrogen levels.

Figure 7—41: Blackberry (*Rubus fruticosus*) foreground was dominant on drier ground.

Figure 7—42: A fly fisher fishing a channel towards a surface-reaching bed of *Egeria densa* (white flowers). Photo taken in summer 2008/09.

Site 15 Upper Section of the Lake Aniwhenua

This lacustrine habitat was not present prior to construction of Aniwhenua Dam. The river and associated oxbows then (mid 1970's) supported elodea (*Elodea canadensis*), curled pondweed (*Potamogeton crispus*), native pondweed (*Potamogeton ochreatus*) and water buttercup (*Ranunculus trichophyllus*) (Dr J Clayton, NIWA pers. comm.).

Present distribution:

The reservoir had extensive areas of surface-reaching weed beds present (Figure 7—44). Egeria (*Egeria densa*) (Figure 7—46, and Figure 7—47) and hornwort (*Ceratophyllum demersum*) (Figure 7—48) were the dominant species and grew to nearly 5 m tall and to water depths of 5 m. (Table 7—10). About 90% of the lake area was vegetated with only the deeper parts of the old river channel without macrophytes (Figure 7—45). The depth limits of macrophytes appeared to be restricted by light as deeper sediments and slope appeared favourable for macrophytes (Figure 7—49).

Table 7—10: Macrophytes recorded at Site 15 in Lake Aniwhenua, with their depth range, maximum and average lengths, and maximum and average covers (see methods). + denotes non-native species.

Species	Depth range (m)	Height / length (m) Max / av.	Cover class Max / av.
+*Ceratophyllum demersum*	0.1 – 5.0	4.8 / 2.5	6 / 3
+*Egeria densa*	0.5 – 5.0	4.5 / 1.8	6 / 4
+*Potamogeton crispus*	1.5 – 4.3	2.4 / 1.2	5 / 2
Potamogeton ochreatus	0.1 – 5.6	2.2 / 0.3	2 / 1

Expected effect of proposed abstraction

Little change in the area of weed beds is expected in the lake but it is likely hornwort would become more abundant than egeria. Hornwort is the dominant plant by far in the Waikato hydro lakes where water temperatures are warmer flows are low and nutrient levels high.

Figure 7—43: Lake Aniwhenua with Site 15 mid-way up the lake off the point (right side of photo) with pine trees in the top of the picture.

Figure 7—44: Lake Aniwhenua near Site 15 highlighting the surface-reaching weed beds extending across the lake with the red-coloured floating water fern Azolla pinnata.

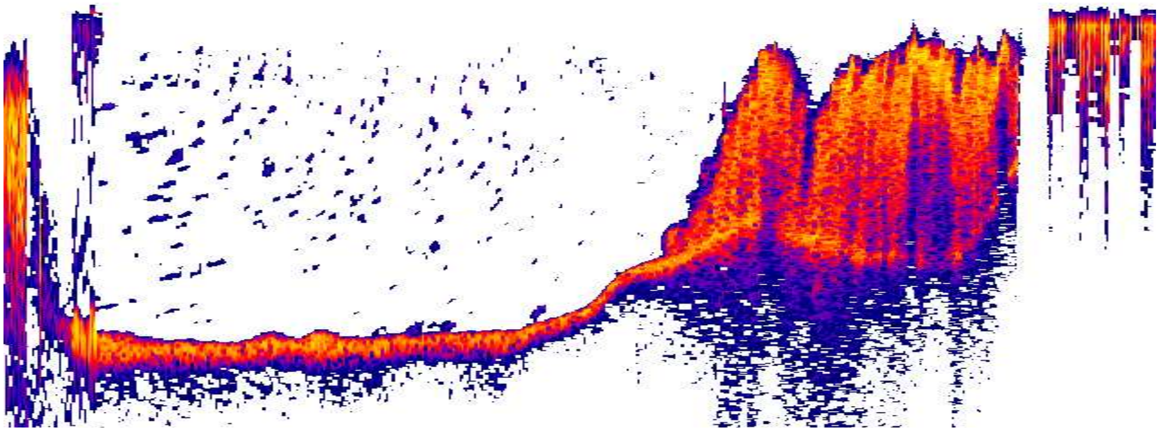


Figure 7—45: Site 15 sonar profile of weed beds in Lake Aniwhenua from west to east (right bank is right hand side of profile). The maximum depth was 8.3 m; the horizontal scale spans only about 125 m and was limited as we could not penetrate the surface-reaching weed beds with the boat. The central channel was bare sediment, and the tall weed beds far left and right sides (tall red yellow images) were up to 4.8 m tall.

Figure 7—46: Tall-growing exotic egeria (*Egeria densa*), growing to near the water surface from 5 m deep in Lake Aniwhenua at Site 15.

Figure 7—47: Tall-growing non-native oxygen weed, egeria **(***Egeria densa*), growing 4.5 m tall in the Lake Aniwhenua at Site 15.

Figure 7—48: The tall-growing exotic hornwort (*Ceratophyllum demersum*) growing 4.5 m tall in Lake Aniwhenua at Site 15.

Figure 7—49: The lake bed at 6 m water depth at Site 15 in Lake Aniwhenua.

Site 16 Lake Aniwhenua from the boat ramp near the dam.

Present distribution:

Hornwort and egeria were by far the dominant species as recorded for Site 15. They were surface-reaching near the lake shores (Figure 7—50) and grew right across the lake (Figure 7—51). Some curled pondweed (*Potamogeton crispus*) was also present (Table 7—11).

Figure 7—50: View of Lake Aniwhenua from the dam, with surface-reaching hornwort and egeria on the lake margins.

Table 7—11: Macrophytes recorded at Site 16 in Lake Aniwhenua, with their depth range, maximum and average lengths, and maximum and average covers (see methods). + denotes non-native species.

Species	Depth range (m)	Height / length (m) Max / av.	Cover class Max / av.
+*Ceratophyllum demersum*	0.1 – 4.2	2.5 / 1.5	6 / 4
+*Egeria densa*	0.5 – 4.2	2.5 / 1.5	6 / 4
+*Potamogeton crispus*	1.5 – 2	1.4 / 1.2	2 / 1

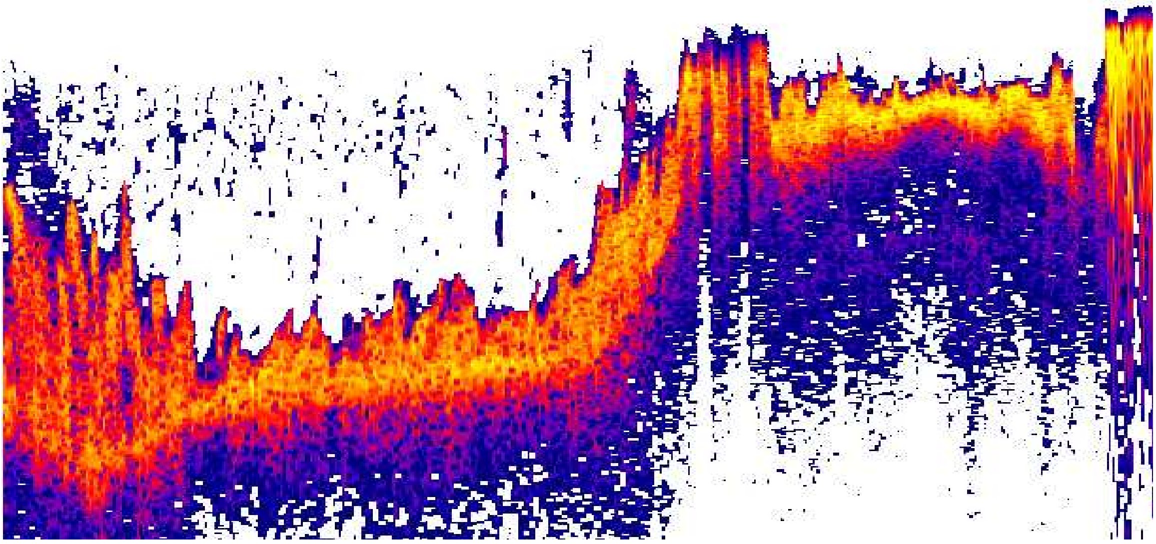


Figure 7—51: Sonar profile of Site 16, showing macrophytes (red yellow) right across Lake Aniwhenua from the west side towards the boat ramp in the east (right bank is right hand side of profile). The maximum depth was 4.2 m; the horizontal scale spans about 250 m.

Site 17, Aniwhenua Canal

Present distribution:

The Aniwhenua Canal walls were dominated by mosses mostly *Fissidens* spp. to about 2.5 m water depth, and had some exotic macrophytes including watercress (*Nasturtium officinale*), bead plant (*Nertera depressa*) and water forget-me-not (*Myosotis laxa*) growing submerged (Figure 7—52). The steep sides of the canal with limited amounts of sediment currently prevent greater macrophyte growth.

Expected effect of proposed abstraction:

Little change is expected in the canal unless flows reduce and sedimentation increases.

Figure 7—52: The Aniwhenua Canal walls were dominated by mosses mostly *Fissidens* spp. to about 2.5 m water depth, and had some exotic watercress (*Nasturtium officinale*) as seen in bright green mainly in the top 1 m of water.

7.3 Conclusions and Recommendations

The creation of canals and lakes for hydro power generation in the upper Rangitaiki River has modified the habitat for macrophytes markedly. Over the years these habitats have also been invaded by non-native species notably hornwort. These have changed the habitat markedly and have impacted not only the other aquatic life but also recreational and commercial users. Increasing water abstraction and nutrient levels are expected to favour more abundant macrophyte growth in the future, and plant control measures are advocated.

8. Macroinvertebrates

David Reid, NIWA

Invertebrates play very important roles in the processing of organic matter and the transfer of energy through aquatic ecosystems. In New Zealand the primary consumers of plant material in streams and rivers are almost exclusively invertebrates, particularly insects, molluscs, crustaceans and worms (Winterbourn 2004a). Few of New Zealand's indigenous freshwater fish fauna feed directly on algal or detrital food sources - most are dependent on the macroinvertebrate link in the food chain (Winterbourn 2004b). All of the fish within the upper Rangitaiki catchment feed on macroinvertebrates at some stage during their lives:

- tuna (longfin eel, *Anguilla australis* and shortfin eel, *A. dieffenbachii*) feed primarily on aquatic insects (particularly dipteran larvae, snails and crustaceans) when juveniles, increasing consumption of fish and terrestrial insects etc[19] as they grow;

- kokopu (*Galaxias* spp) feed on both terrestrial and aquatic invertebrates (particularly caddisflies and stoneflies) and koura;

- bullies (*Gobiomorphus* spp) feed on a wide variety of stream insects (including dipteran larvae, mayflies and caddisflies), snails and small crustaceans;

- the introduced trout species (both Rainbow trout, *Oncorhynchus mykiss*, and Brown trout, *Salmo trutta*) prey extensively on drifting invertebrates and emergent adult stages of aquatic insects drifting on the surface of the water, as well as terrestrial animals but also consume crustaceans and snails;

- goldfish (*Carassius auratus*) eat a wide variety of aquatic plants and detritus, as well as small aquatic insects, worm, snails and crustacean; and

- gambusia (*Gambusia affinis*) prey on a wide range of small aquatic and terrestrial insects and crustaceans (McDowall 2000).

[19] Particularly during flooding

In addition to their importance in aquatic food webs, macroinvertebrates are also regularly used to assess the condition of streams and rivers. They are suitable for this purpose because they are a diverse group that display a wide variety of responses to changes in habitat and environmental conditions (Boothroyd & Stark 2000, Winterbourn 2004b). Macroinvertebrate communities are sensitive to changes in water quality, temperature, flow regimes, riparian vegetation, sediment supply and concentration of pollutants that may be caused by damming and diversion of water, hydro-electric production, forestry and agriculture (Harding et al. 2004). The structure of macroinvertebrate communities can be compared to that in reference reaches (spatial comparisons) and/or monitored over time to establish current conditions and any trajectory of change. The loss of sensitive species, such as the “EPT taxa” (Ephemeroptera, Plecoptera and Trichoptera or mayflies, stoneflies and caddisflies) can be used to indicate deterioration in ecosystem condition. Biotic indices can also be used to simplify complex community level data. The Macroinvertebrate Community Index (MCI) combines taxa richness with the known pollution tolerance of each taxon present in the community, to provide a single score to assess the condition of a river or stream (Boothroyd & Stark 2000). When combined with densities of individuals of each taxon, a Quantitative Macroinvertebrate Community Index (QMCI) may be calculated.

A range of competing interests place multiple demands on the Rangitaiki River and its resources. Activities that are likely to impact on aquatic fauna within the Rangitaiki catchment include changes in landuse for hydro-electricity production, forestry and agriculture, as well as recreational activities. The earliest surveys conducted in the Rangitaiki River provide little detail regarding the composition of macroinvertebrate communities. Rather, they tend to describe broad patterns of invertebrate abundance in the drift with a focus on the value of these animals as a food source for trout (e.g., Donovan & Thompson 1976). In the early 1990s a report by the Environment Bay of Plenty Council (EBOP) provided more specific quantitative information about the macroinvertebrate community within the Rangitaiki River, at Murupara (Donald 1992). These results will be discussed more fully at the conclusion of this section of the present report. Monitoring of macroinvertebrate communities within the Rangitaiki River has continued at Murupara, as well as Te Teko, as a component of the NRWQN programme. This data was analysed to detect changes in macroinvertebrate community composition over time. An additional survey was conducted to describe the macroinvertebrate communities occurring in some of the upper reaches of the catchment.

8.1 Methods

As part of this study a desktop review of all available historic information pertaining to the macroinvertebrate fauna of the Rangitaiki River was conducted.

Macroinvertebrate databases for the middle (Murupara) and lower (Te Teko) reaches of the Rangitaiki River are available from surveys conducted for the National River Water Quality Network (NRWQN, collected within March to April of each year from 1990 to present, with data for the period up to 2007 entered into database) and EBOP (Murupara only, collected from 1992–2001). These reaches are defined as 'Impacted' within the NRWQN database. There is some agricultural activity in the vicinity and upstream of Murupara, whilst forestry occurs adjacent to most of the river upstream of this site. Te Teko is further downstream, with more influence from agricultural landuse. Both the NRWQN and EBOP databases contain quantitative information, obtained from full counts of invertebrate samples collected with Surber samplers (multiple samples, seven for NRWQN and five for EBOP, using a Surber sampler with a 0.1 m^2 collection area and 0.25 mm mesh). However, the two datasets differ in the level of taxonomic resolution, with more animals taken to species level in the NRWQN database. Further, the resolution of the NRWQN data has increased over time. As the principal objective of this report was to describe the present condition of the Rangitaiki River, the most comprehensive and up-to-date data, i.e., NRWQN data from 1999 to present, were used in most analyses. We anticipate that the EBOP data would support the outcomes of our assessment.

Non-metric multidimensional scaling, based on Bray-Curtis similarities of fourth-root transformed data, was used to display the similarities in community structure at the Murupara and Te Teko sites over time. Fourth-root transformation was applied prior to calculating similarity matrices to reduce the influence of a few highly abundant taxa on the results of these analyses (Clarke & Warwick 1994). The proportions of different taxa, grouped to order level, were also calculated to determine whether there were any differences in the composition of macroinvertebrates between the two sites or within each of the sites over time. The numbers of taxa, numbers of EPT taxa, MCI and QMCI at Murupara and Te Teko were also calculated from NRWQN data. The equations used to calculate the MCI and QMCI index values, and their interpretation (Table 8—1), are shown below. Finally, the relative abundances of all taxa identified at Murupara and Te Teko within the NRWQN database were tabulated.

The following equations, derived from Boothroyd & Stark (2000), were used to calculate MCI and QMCI:

$$MCI = \frac{20\Sigma a_i}{S} \text{ (ranges from 0 to 200)} \qquad \text{Equation 8–1}$$

$$QMCI = \frac{\Sigma(n_i a_i)}{N} \text{ (ranges from 0 to 10)} \qquad \text{Equation 8–2}$$

Where:

a_i = MCI tolerance score for the ith taxon, S = total number of taxa, n_i = number of individuals of the ith taxon and N = total number of individuals.

Table 8—1: Interpretation of MCI and QMCI indices (note: although these indices have been shown to be sensitive to various anthropogenic land uses they were originally developed to be used to assess organic pollution in stony streams).

Water quality status	MCI	QMCI
Clean water	>120	>6.00
Possible mild pollution	100-119	5.00-5.99
Probable moderate pollution	80-99	4.00-4.99
Probable severe pollution	<80	<4.00

To increase the spatial coverage of the macroinvertebrate data for this report, samples were collected from two upper reaches on both the Rangitaiki River (below the diversion and immediately above the confluence with the Wheao River) and Wheao River (above and below the power station), on 28 and 29 of April, 2009. Surber sampling was not practical in these reaches. Instead, a hand net (0.5 mm mesh) was used to collect invertebrate samples from all the river reaches surveyed. Each sample was collected from a total of 10 m of the reach, with all habitats occurring within the reach sampled in proportion to their occurrence within that reach. Divers also collected additional deep water samples by hand from the bottom of lakes and canals (Flaxy Lake, Rangitaiki Canal and Aniwhenua Canal). All macroinvertebrate samples were stored in 70% isopropyl alcohol for transportation to the laboratory. These samples were sorted semi-quantitatively, with subsamples taken until 100 animals had been identified (most often to genus level), and counted. The remainder of the sample was then transferred to a shallow plastic tray and any rare taxa which were not recorded from the subsample were also identified and counted. These data were used to calculate the proportions of different taxa (grouped to order level), numbers of taxa, numbers of EPT taxa, MCI and the most commonly occurring taxa at each site. QMCI values were not calculated for any of the sites, as the data obtained from hand net samples and partial counts was not quantitative. Furthermore, MCI values were not calculated for samples collected from lakes and canals as this index was developed for rivers and streams with stony substrates.

8.2 Results

Downstream sites (historical data)

Over the period for which directly comparable data is available (i.e., NRWQN data from 1999–2007), no defined directional change in the structures of macroinvertebrate communities in the middle and downstream sites on the Rangitaiki River was detected (Figure 8—1a). At Te Teko there was greater inter-annual variability than at Murupara, but the structure of the community sampled during the first survey, in 2000, was most similar to that of the last reported survey, in 2007. At Murupara the overall community structure has remained very similar from 2001 to 2007. EBOP data recorded prior to 2001 at Murupara confirmed that there was no defined trajectory of change in the macroinvertebrate community structure at this site through the 1990s (Figure 8—1b). However, as the EBOP records are not directly comparable to NRWQN data due to lower taxonomic resolution they were omitted from subsequent analyses.

There were substantial inter-annual fluctuations in the proportional representation of different macroinvertebrate taxa at Murupara and Te Teko. There were a number of occasions when a particular taxon was ‘very, very abundant’ in one year (> 500 individuals counted from samples collected from a site), but totally absent in the following year. The pattern observed at the order level (Figure 8—2), was due to these large fluctuations in the relative abundances of particular taxa between years. Diptera and/or Ephemeroptera were the most abundant orders at Murupara in most years, with Trichoptera and Coeloptera also relatively common. Diptera were also amongst the most abundant orders at Te Teko in most years, whereas Ephemeroptera were relatively abundant in samples from some years, but only rarely occurred in samples from other years. The proportion of Mollusca was higher at Te Teko than at Murupara. In most years between 22 and 32 taxa (11 and 19 EPT taxa) were identified in samples collected at Murupara, except in 2004, when only 13 taxa (3 EPT taxa) were identified (Table 8—2). In all years where data was available for both sites, less taxa were identified from Te Teko samples than from Murupara samples, with between 15 and 25 taxa (10 and 16

EPT taxa) recorded in all years at Te Teko, except in 2005 when only 8 taxa (1 EPT: only one individual *Aoteapsyche* spp.) were identified.

MCI (and QMCI) scores from the Murupara and Te Teko sites have fluctuated widely over time, indicating that the macroinvertebrate community was typical of 'severely polluted water' in some years (1999, 2001, 2002 at Murupara and 2000, 2003, 2005 at Te Teko), but clean water in others (2004, 2005, 2007 at Murupara and 2001, 2007 at Te Teko). Caution should be exercised when interpreting these results as these biotic indices were developed with macroinvertebrate taxon given scores according to their tolerances to organic pollutants, which are not necessarily reflective of their tolerances to other types of impacts (e.g., variability in water temperature or flow).

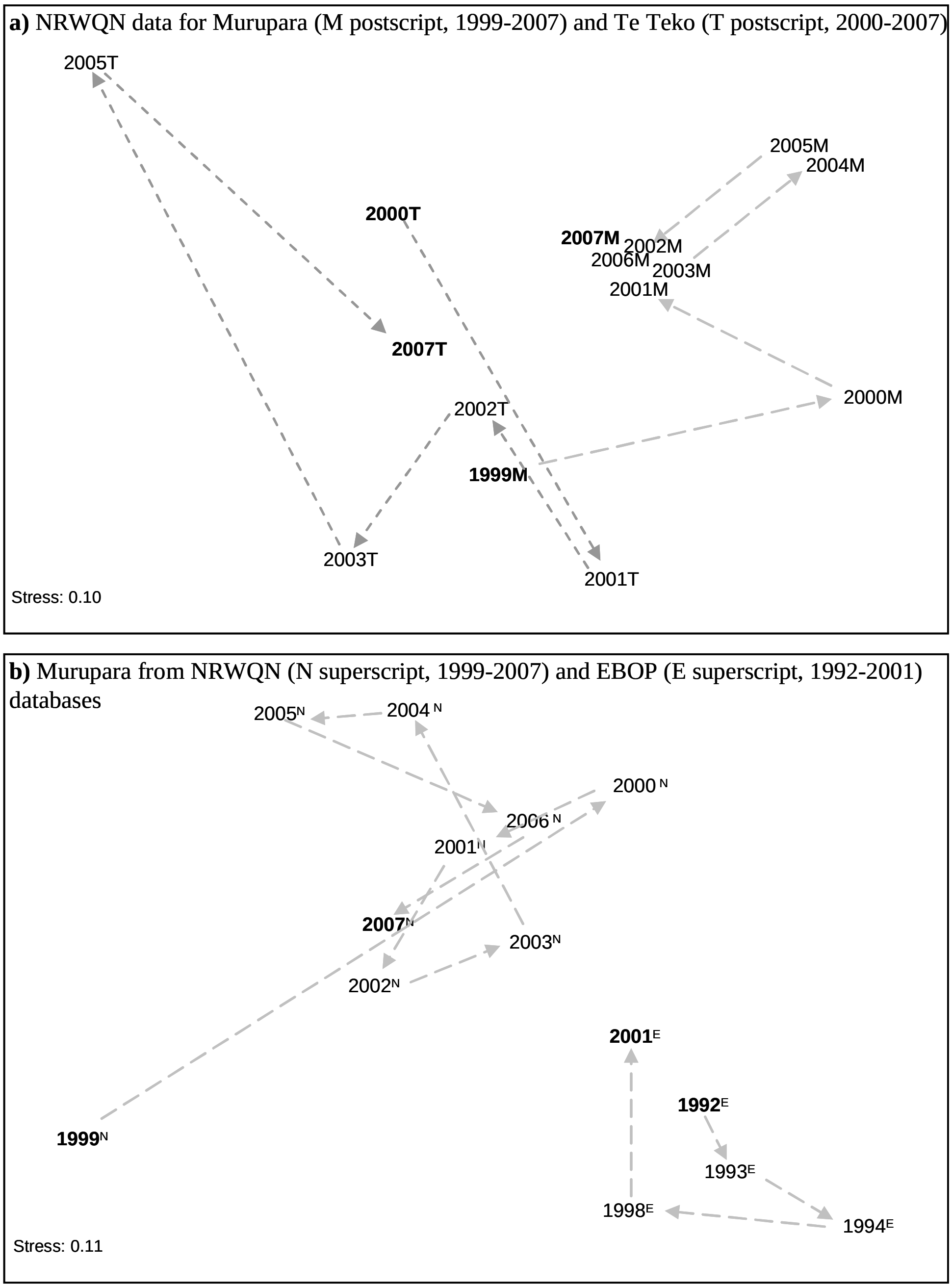


Figure 8—1: Ordinations (nMDS) displaying the similarities in structures of Rangitaiki River macroinvertebrate communities over time at a) Murupara and Te Teko, from NRWQN database, and b) Murupara from both NRWQN and EBOP databases. The first and last year of surveys at each site are shown in bold type, with arrows indicating the direction of change in community structure between successive years. In 2001 the Murupara site was surveyed for both the NRWQN and EBOP (shown with grey highlight).

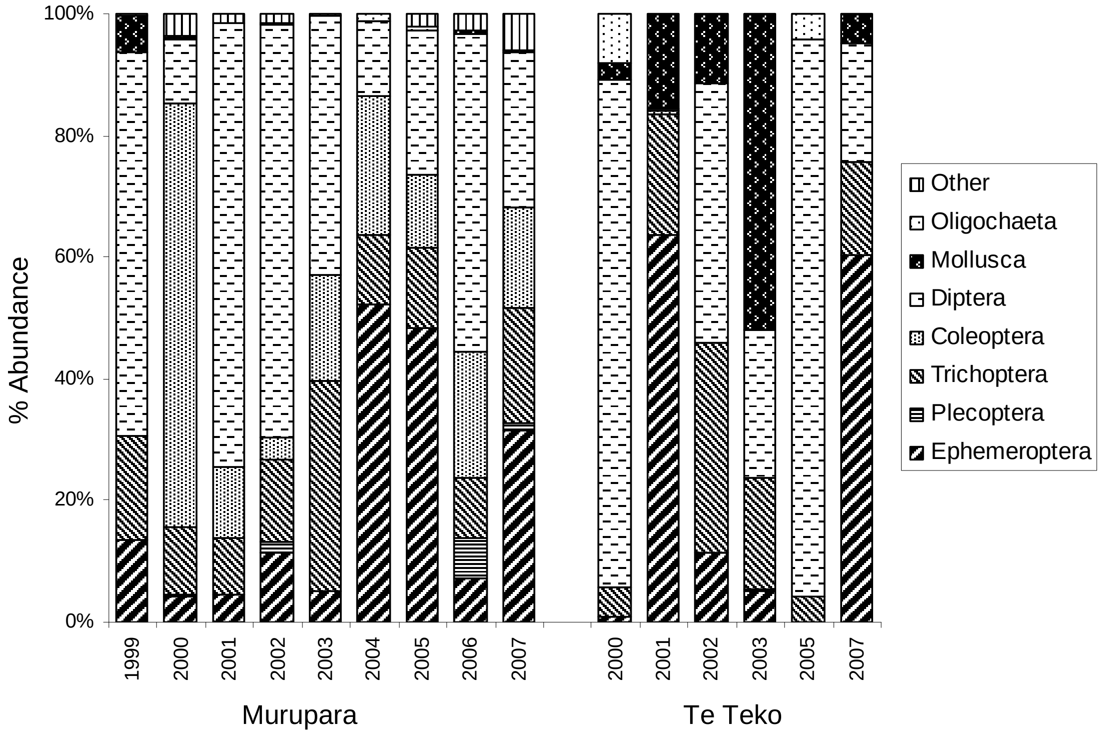


Figure 8—2: Relative abundances of taxa in macroinvertebrate communities sampled from downstream sites on the Rangitaiki River, at Murupara and Te Teko, over time (based on NRWQN data).

Upstream sites

Samples collected from the upper reaches of the Rangitaiki River in 2009 had relatively high abundances of Diptera, Ephemeroptera and Trichoptera (Figure 8—3). Downstream of the diversion, the flow was fast and substrate was predominantly bedrock and some boulders. Although there appeared to be relatively little habitat diversity within this reach, 18 taxa, including 9 EPT taxa, were present within the sample (Table 8—3). Immediately upstream of the confluence with the Wheao River, the water velocity in the Rangitaiki River was moderate and a wide range of habitats suitable for macroinvertebrates existed. The macroinvertebrate sample collected from this reach was obtained from a variety of habitats, including: riffles, submerged macrophyte beds, woody debris and shallows margins with and without overhanging bank vegetation. Fifteen taxa (7 EPT taxa) were identified in this sample.

Upstream of the Wheao River power station the habitat was mainly riffles, with fast flow and predominantly large substrate (boulders and cobbles). Some aquatic habitat was also provided by overhanging vegetation. Many macroinvertebrates (mainly

Ephemeroptera) were captured from the drift whilst electrofishing in this reach. A high proportion of the taxa identified from the macroinvertebrate sample collected from this reach were EPT taxa (11 of the 15 taxa). Downstream of the power station, less suitable habitat existed for macroinvertebrates. The middle of the channel had very rapid flow and the macroinvertebrate sample was collected from the riffle section and overhanging bank vegetation where there was access along the edge of the reach. The substrate here was highly embedded. Fourteen taxa were identified from this site, with only 4 of these being EPT taxa. Both of the upstream sites on the Rangitaiki River, and the site above the power station on the Wheao River, had relatively high MCI scores, ranging from 119 to 136 (compared to 53 to 126 at the downstream Murupara and Te Teko sites over all years), but below the Wheao River power station the MCI score was only 73.

The habitat available on the bottom of lakes and canals, i.e., fine sediment and submerged macrophytes, favoured dipterans and molluscs over EPTs and other insects (Figure 8—3). Oligochaetes were also more common in these deeper water sites than at the shallower and faster flowing river sites. Overall, the taxon richness at these deep water sites was relatively low, ranging from 9 to 15 taxa (2 to 5 EPT taxa).

Table 8—2: Variation in the numbers of taxa, numbers of EPT taxa, MCI and QMCI scores for macroinvertebrate communities sampled from the Rangitaiki River, at Murupara and Te Teko, 1999 to 2007 (based on NRWQN data).

Metric	**Sample site and year**														
	Murupara									**Te Teko**					
	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2000**	**2001**	**2002**	**2003**	**2005**	**2007**
No. of taxa	25	23	27	27	31	13	22	27	32	21	15	25	20	8	25
No. of EPT taxa	13	15	14	13	17	3	11	14	19	10	10	16	11	1	12
MCI	89	126	108	103	115	96	106	118	122	96	98	99	102	53	96
QMCI	3.89	5.98	3.82	3.76	4.76	6.82	7.36	4.93	6.15	2.89	6.75	4.00	4.01	2.83	6.34

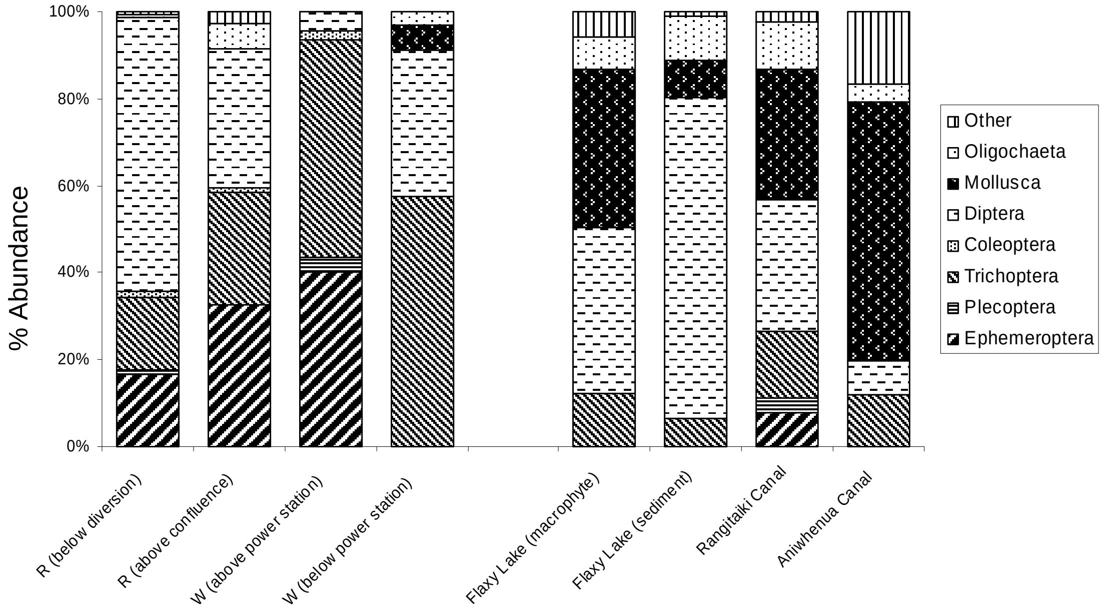


Figure 8—3: Relative abundances of macroinvertebrate taxa in samples collected from upstream sites on the Rangitaiki River in April 2009 (R = Rangitaiki River, W = Wheao River).

Table 8—3: Numbers of taxa, numbers of EPT taxa, MCI and most common taxa for macroinvertebrate communities sampled from upstream sites on the Rangitaiki River, Wheao River, Flaxy Lake, Rangitaiki Canal and Aniwhenua Canal in April 2009. (Note: MCI values were not calculated for samples collected from lakes and canals as this index was developed for rivers and streams with stony substrates).

Metric	Sample site and enumeration result							
	Rangitaiki (below diversion)	**Wheao (above confluence)**	**Wheao (above power station)**	**Wheao (below power station)**	**Flaxy Lake (macrophyte)**	**Flaxy Lake (sediment)**	**Rangitaiki Canal**	**Aniwhenua Canal**
No. of taxa	18	15	15	14	10	9	11	13
No. of EPT taxa	9	7	11	4	3	2	5	3
MCI	119	121	136	73	NA	NA	NA	NA
Common Taxa	*Diamsinae* (Diptera)	*Austroclima* (Ephemeroptera)	*Coloburiscus* (Ephemeroptera)	*Oxyethira* (Trichoptera)	Polypedilinae (Diptera)	*Chironomus* (Diptera)	Polypedilinae (Diptera)	*Potamophygrus* (Gastropoda)
	Coloburiscus (Ephemeroptera)	*Pycnocentria* (Trichoptera)	*Aoteapsyche* (Trichoptera)	Polypedilinae (Diptera)	*Potamophygrus* (Gastropoda)	Polypedilinae (Diptera)	Sphaeridae (Gastropoda)	Sphaeridae (Gastropoda)
	Aoteapsyche (Trichoptera)	*Polypedilinae* (Diptera)	*Pycnocentria* (Trichoptera)	*Aoteapsyche* (Trichoptera)	*Physa* (Gastropoda)	Oligochaeta	Oligochaeta	*Sigara* (Hemiptera)

8.3 Conclusions and recommendations

The Rangitaiki River is subject to multiple anthropogenic stressors which may influence the structure of macroinvertebrate communities. These include hydro-electricity production, forestry and agriculture. These activities are likely to exert strong influences on the hydrology, water chemistry and nature of the substrate, which are amongst the factors which have the greatest influence on the composition of macroinvertebrate communities (Winterbourn 2004a). Although there were large inter-annual fluctuations in the proportions of specific taxa present at those downstream sites for which data were available, these types of fluctuations may be natural (Winterbourn, 2004b). The MCI and QMCI scores also fluctuated widely amongst years at both Murupara and Te Teko. These indices were originally developed to assess organic pollution in stony streams by sampling in riffles (Boothroyd & Stark 2000). They have, however, been shown to be useful indicators of water quality and are sensitive to impacts from agricultural landuse (e.g., Quinn & Hickey 1990, Quinn et al. 1997, Niyogi et al. 2007), potentially to forestry (Stark & Maxted 2007), but not necessarily to natural and anthropogenic changes in hydrology, and therefore should be interpreted cautiously. Despite the high temporal variability for specific taxon and biotic indices there was no consistent directional change in the numbers of taxa, numbers of EPT taxa or the overall macroinvertebrate community structure, indicating that neither ongoing deterioration nor improvement in the condition of the lower reaches of the river has occurred over the past fifteen years. Further, in 1992 it was reported that the Murupara site had 23 taxa (with *Aoteapsyche* spp. clearly dominating, 61% of fauna), and a mean MCI score of 108 (Donald 1992), which is within the range of values from 1999–2007. The numbers of taxa, numbers of EPT taxa, MCI and QMCI scores were all consistently higher at Murupara than further downstream at Te Teko. The decrease in these indices at the most downstream reaches of the river was expected as heterogeneous stony substrates typically support more macroinvertebrate diversity than more uniform finer substrates, because these provide greater habitat diversity (Winterbourn 2004a). Further, the most downstream reaches will also be subject to all of the cumulative impacts from activities in the upper catchment. The site at Te Teko is a lowland habitat with finer substrate, and is in a reach affected by hydro generation and agricultural landuse, factors that will all have contributed to the low diversity of the macroinvertebrate community at this site. Although it was outside of the area covered by the present surveys, macroinvertebrate data from Te Teko were included for comparison to the upstream reaches.

Data from both Murupara and Te Teko demonstrated that there may be large temporal variability in the abundances of macroinvertebrate taxa within a particular site, and therefore caution should be exercised when interpreting the results from those one-off surveys in the upper catchment. However, there were some broad patterns for differences in macroinvertebrate community which were most probably related to differences in hydrology and substrate amongst the sites in the upper portion of the catchment. In the upper reaches of the Rangitaiki River (below the diversion and immediately above the confluence with the Wheao River), both the proportions of Ephemeroptera and Trichoptera taxa, and MCI scores, were relatively high. The proportions of Ephemeroptera and Trichoptera and MCI score were also high in the Wheao River above the power station. However, there were no Ephemeroptera in the sample collected from below the power station, where the MCI score was very low. The change in flow below the power station appeared to be exerting significant effects on the macroinvertebrate community. Changes in flow can exert direct effects on macroinvertebrates and also has strong influences on disturbance regimes, water chemistry, temperature and redistribution of bed substrates (Winterbourn 2004a). Targeted surveys, over a longer time period, would be required to confirm the magnitude of impact of the Wheao Power Scheme on the macroinvertebrate community and to assess how far downstream from the power station that impact persists.

Ecosystems with the greatest diversity of habitats are generally able to support more taxa (Winterbourn 2004a). The habitat in lakes and canals where water was deep, flow velocity was low and the bed substrate was relatively fine, favoured dipterans, molluscs and oligochaetes over other insects. The taxon richness and numbers of EPT taxon were consistently low in these deeper water habitats. Zooplankton are likely to be more abundant in deeper water habitats than fast-flowing river reaches. These animals are an important food source for some fish, but targeted surveys would be required to determine their distribution and densities.

Currently much spatial and temporal variability exists in the composition of the macroinvertebrate community along the length of the Rangitaiki River and its tributaries. Despite this, most of the fish species in the catchment are able to feed on a wide variety of invertebrate prey, shifting their intake depending on which taxa are most readily available. The invertebrate food source is unlikely to be a factor limiting the distribution of fish throughout the river, with the possible exception of reaches subject to high flows, where most of the invertebrate taxa may be flushed out. Inter-annual variability in the macroinvertebrate community provides no indication of a decline in the condition of the river over recent years (NRWQN data has been collected from the Rangitaiki River since 1990, only data for the last 10 years was analysed for the present report as the taxonomic resolution of data has increased over time). However, any future activity which further alters the natural hydrology, water chemistry or substrate is likely to impact aquatic macroinvertebrate communities. Conversely, there is the scope for improvement in the ecological condition of some reaches with the implementation of rehabilitation works which would minimise the impacts from surrounding land uses and restore hydrology, water chemistry and/or habitat towards a more natural condition.

9. Fish and fisheries

Paul Franklin, NIWA

Indigenous fish, in particular tuna (freshwater eels), are taonga for Ngati Manawa and an important food resource. The abundance and quality of tuna in the Rangitaiki Catchment contributed greatly to the mana and standing of Ngati Manawa (Wai 212 1993, Wai 894 2009) and discussions with elders have indicated that large feeder eels were the main life stage targeted.

A number of other species, i.e., kokopu (*Galaxias* spp.), raumahi and titarakura (*Gobiomorphus* spp.), were not only traditionally harvested but also recognised for their importance in the ecosystem. As pressures from competing demands on the river have increased, the status of the indigenous fish populations and consequently of customary fisheries have declined. Many of these pressures may also be impacting on the status of the introduced rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*) which now support significant recreational fisheries within the catchment.

9.1 Scope

The current review is limited to the fish and fisheries of the Rangitaiki River and its tributaries upstream of Aniwhenua Dam. No attempts have been made to describe traditional and customary fisheries, as these have been described elsewhere (e.g., (Kirkpatrick et al. 2004, Porima et al. 1993, Wai 212 1993, Wai 212 1998, Wai 894 2009). The scope of the work in brief is as follows:

- review data on numbers and distribution of fish species as recorded in the New Zealand Freshwater Fisheries Database (NZFFD);
- investigate any changes in fish populations;
- identify the key factors influencing the status of fish and fisheries;
- identify current knowledge gaps.

9.2 Fish distribution

The analysis of fish distribution is based primarily on data stored in the NZFFD. It is acknowledged that this is limited by the temporal and spatial coverage of the surveys recorded in the database (Figure 9—1). For example, approximately half of the records in the NZFFD for the upper Rangitaiki have been collected since 2007 as part of the projects done on tuna by NIWA. Most of these records have also been restricted to the most accessible parts of the catchment between Aniwhenua Dam and Murupara, and along the Whirinaki River. Where possible, therefore, this information has been supplemented by documented and anecdotal records of fish distributions.

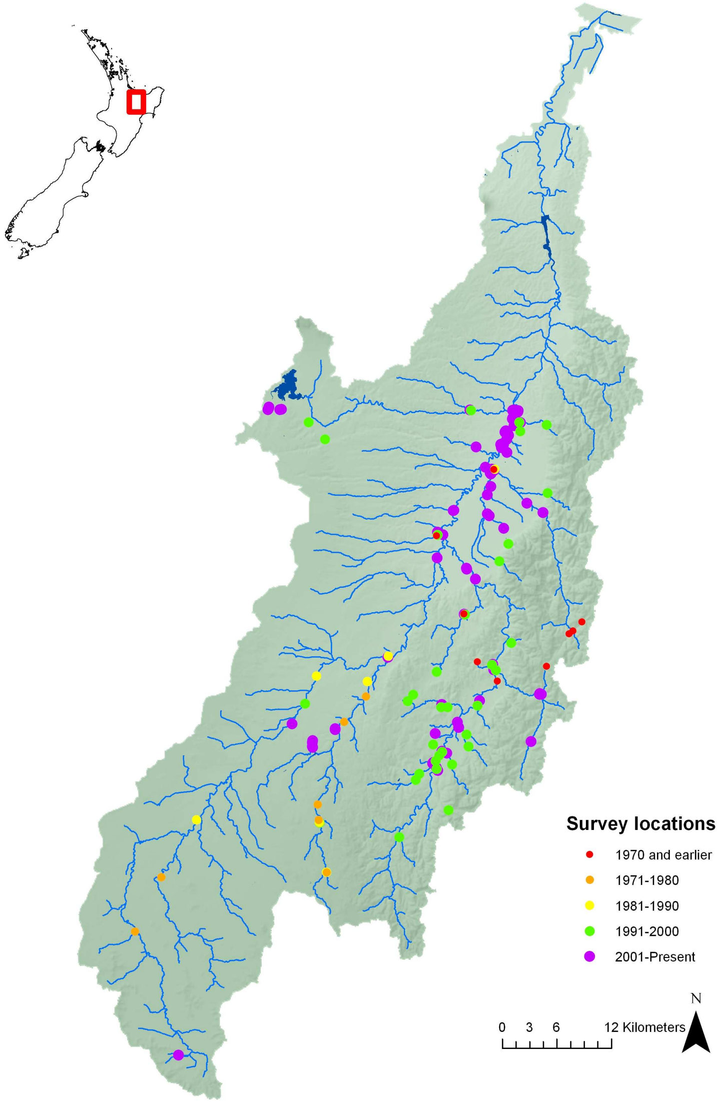


Figure 9—1: Distribution of fish records in the NZFFD by decade.

9.2.1 Tuna

Tuna have a complex life history. They are a diadromous species, meaning they require access to the sea to complete their life cycle. Mature adult tuna migrate from freshwater to the ocean to breed. After hatching, larvae drift back to New Zealand, primarily by ocean currents. Once in coastal waters, the leptocephalus larvae transform into juveniles called glass eels. These gather in river estuaries before migrating upstream into inland waters. In freshwater the glass eels develop pigmentation and turn into elvers before making their way upstream in search of suitable habitat (McDowall 1990).

Two main species of tuna are found in New Zealand, the longfin (*Anguilla dieffenbachii*) and the shortfin (*Anguilla australis*). Typically, longfins penetrate further inland than shortfins meaning that there is a decline in the ratio of shortfins to longfins with distance inland (Jellyman 1977). Shortfins are primarily lowland fish and most common in slow flowing rivers, ponds and wetlands. Longfins are also present in these habitats, but tend to penetrate further inland and can be found in stony bottomed fast-flowing streams (McDowall 1990). It is likely, therefore, that longfins would naturally predominate in the upper Rangitaiki catchment due to the distance inland and habitat type. Mitchell (1996) suggested that Aniwhenua (Aniwaniwa) Falls, a natural barrier to upstream movement, was the likely point at which the relative abundance of shortfins would naturally fall, although Best (1929) suggested elvers may have been present at this site in teeming multitudes in the past. Presently, the Rangitaiki River is subject to significant impacts from hydro-electric power developments meaning that the natural processes of dispersion are now interrupted.

Two major obstructions to tuna migration now exist on the Rangitaiki River: the Matahina Dam (completed in 1967) and, in the upper catchment, the Aniwhenua Dam (completed in 1981). These hydro-electric dams present a significant barrier to the successful upstream migration of elvers and to the downstream passage of mature adults. Since construction of Matahina Dam, large numbers of elvers are observed to congregate below the dam each year. This represents a significant restriction to the recruitment of tuna in the upper Rangitaiki catchment. In 1983 a regular elver transfer operation was initiated at Matahina Dam in an attempt to subsidise the loss of recruitment in the upstream catchment. Elvers were manually transferred from below the dam to Lake Matahina and Lake Aniwhenua. In 1992 an elver pass was also installed on Matahina Dam, while trap and transfer facilities were considerably improved in 1996–97. Elver stocking levels have subsequently increased dramatically. In recent years (2000 onwards) Lake Aniwhenua has received the bulk of the elvers transferred (over 5 million), the majority of which are shortfins (Smith et al. 2007, Smith et al. 2009). Despite this process, it is likely that the upper Rangitaiki catchment has been subject to poor recruitment of tuna for around 40 years and so analysis of tuna distribution must be carried out with this in mind.

Figure 9—2 illustrates the distribution of tuna species upstream of Aniwhenua Dam from records from the NZFFD. Figure 9—2a shows the combined distribution of longfins and shortfins. It can be seen that the majority of surveys where tuna are recorded are located in and near to Lake Aniwhenua. A reasonable number of records also show tuna to be present in the Whirinaki River. Upstream of Murupara in the Rangitaiki and Wheao Rivers there have been very few surveys where tuna were recorded. This is consistent with anecdotal evidence from Ngati Manawa who report that tuna could only be captured as far up the Rangitaiki River as Te Arawhata (Mitchell 1996). The operators of the Wheao Power Scheme on the upper Rangitaiki have also never recorded tuna on their intake screens (Boubée et al. 2001), which corroborates the assertion that the distribution of tuna may be naturally limited this far up the catchment. The only anomaly to this pattern appears to be the presence of tuna in Lake Pouarua, at the very top of the catchment. It is possible that tuna were transferred manually to this lake at some stage and a small population has become established.

Figure 9—2b and 2c show the distributions of shortfins and longfins separately and indicates a degree of spatial separation in the habitats utilised by the two species. The shortfins (Figure 9—2b) are primarily concentrated around Lake Aniwhenua, where the slow flowing habitat preferred by shortfins is most prevalent. Whilst also present around Lake Aniwhenua, the longfins (Figure 9—2c) have a much broader distribution and particularly show a much greater penetration in to the upper reaches of the Whirinaki River and some of the other eastern tributaries which have been surveyed. This is consistent with their known habitat preferences and was observed by both Young (2000) and Smith et al. (2007 & 2009). Both authors, however, note that the abundance of tuna was low in the upper reaches and that the catch was generally dominated by large females (age 40+ years), indicating they would have accessed the upper Rangitaiki prior to the building of either dam.

The prevalence of shortfins recorded in and around Lake Aniwhenua raises the question of how much this is linked to the increased number of elvers translocated into the lake since the late 1990s. As mentioned previously, it is likely that the abundance of shortfins in the upper catchment would naturally have been relatively low even prior to dam construction. To investigate this, we considered the presence/absence of shortfins in the NZFFD records pre and post-1999, when the enhanced programme to translocate elvers to Lake Aniwhenua began (Figure 9—3). These results must be treated with caution as the spatial and temporal distribution and intensity of sampling was notably lower prior to 1999. However, it can be seen from Figure 9—3a that prior to 1999, no shortfins had been recorded in the NZFFD anywhere in the catchment upstream of Aniwhenua Dam. Since 1999 (Figure 9—3b), increasing numbers of shortfins have been found in the lake (Smith et al. 2009, Smith et al. 2007) and, in low numbers, some of the eastern tributaries (Smith et al. 2007, Young 2000). Caution is required when interpreting these results due to the differences in the number and location of surveys over the two different time periods. The results of Boubée et al.

(2001) show that some shortfins must have naturally been present before the dams as indicated by the capture of migrant shortfins up to 30 years of age during their study of tuna impingement at the Aniwhenua Power Station during the 1990s. However, these observations support the hypothesis that shortfins would be naturally relatively uncommon in this part of the catchment. This is also consistent with Ngati Manawa elders comments that the ‘type’ of eels has changed since the introductions of elvers began (Mitchell 1996). The age distribution of the majority of migrant shortfins captured by Boubée et al. (2001) were also consistent with tuna maturing from the first recorded manual elver releases in 1983. Accordingly, it would appear that the translocation of shortfins to Lake Aniwhenua has had a significant impact on the tuna populations in the upper Rangitaiki catchment and that survival and growth rates of the elvers released has been good. However, because of the low proportion of longfin elvers being transferred (c. 8.5% up to 2006) the ratio between longfin and shortfin tuna upstream of the dam is being reversed. This is reflected in the results of Boubée et al. (2001) and Smith et al. (2007) which show declining and low proportions of longfins in Lake Aniwhenua respectively. On a positive note though, all the longfins aged during the 2007 survey were of an age consistent with having been part of the elver release programme suggesting that whilst numbers are low, longfins are successfully recruiting (Smith et al. 2007). The proportion of longfins present in the transferred elver population has also increased to an average of 24% over the last three years (Smith et al. 2009), which should enhance the recruitment of this species to the upper catchment and its tributaries.

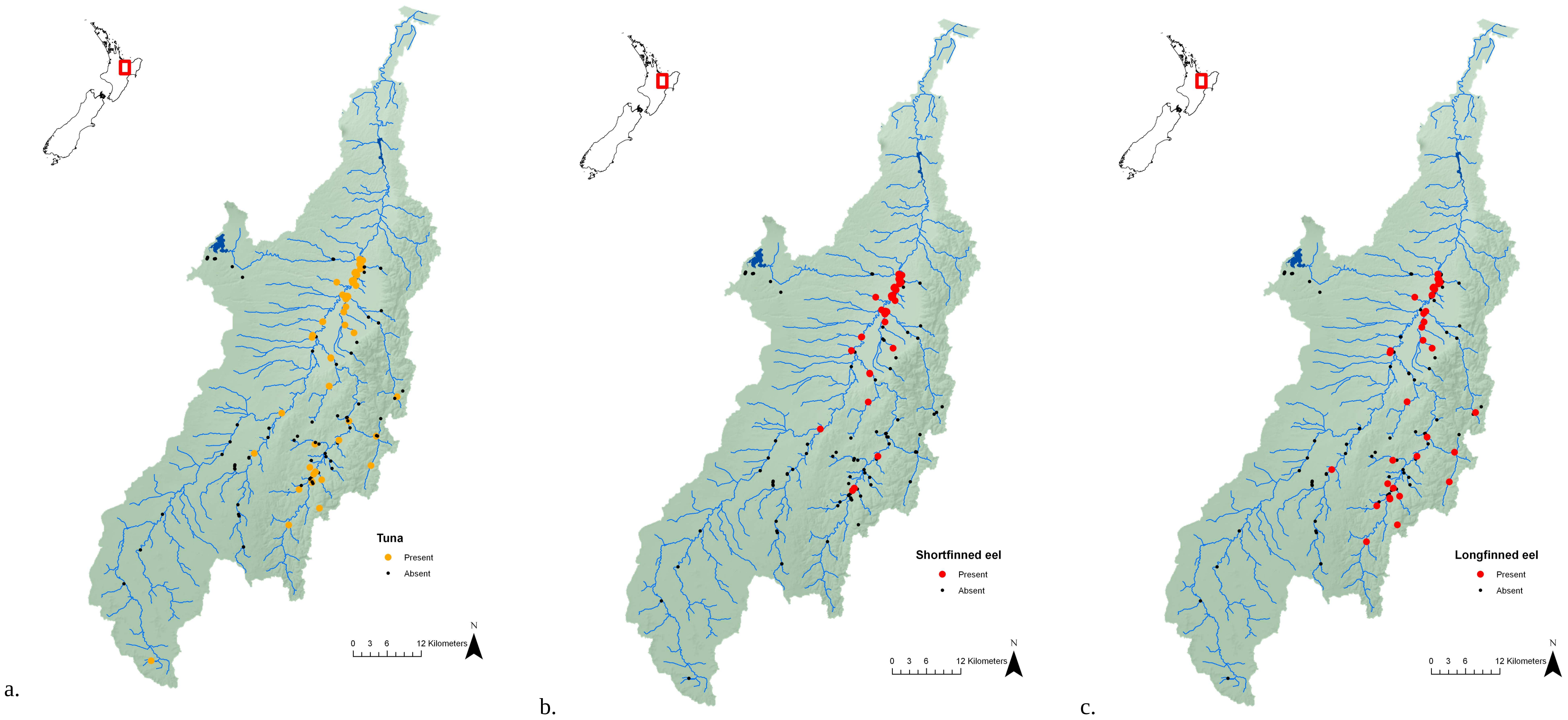
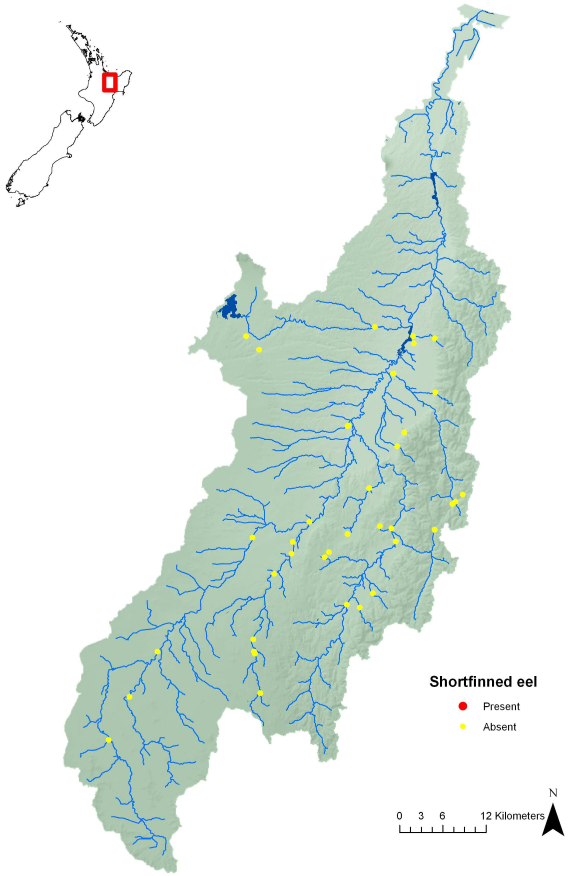


Figure 9—2: Distribution of tuna upstream of Aniwhenua Dam as recorded in the NZFFD. a) All tuna records; b) Shortfins; c) Longfins.



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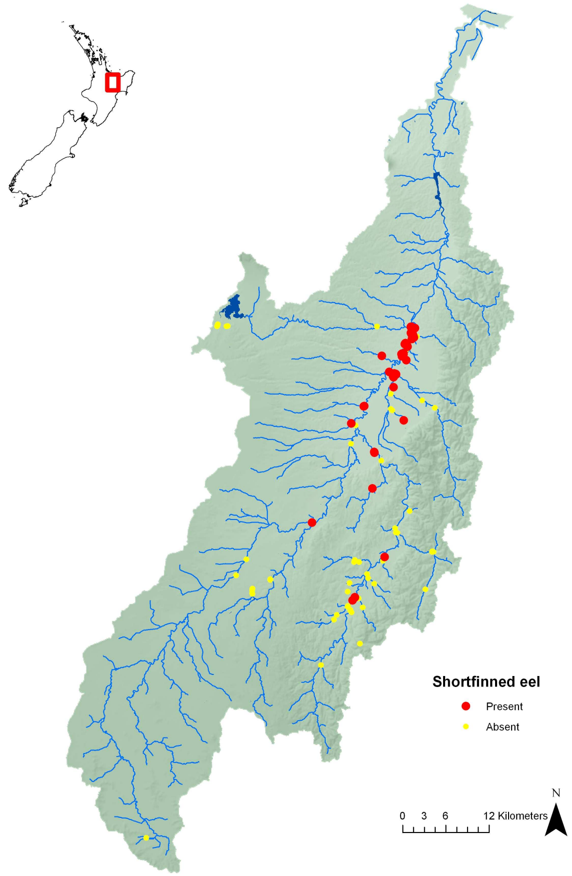


b.

Figure 9—3: Distribution of shortfin records from the NZFFD upstream of Aniwhenua Dam a) pre-1999; and b) 1999-present.

9.2.2 Indigenous fish

Unfortunately, little information is available regarding the distribution and diversity of indigenous fish species other than tuna for the period prior to construction of the dams (Young 2000). Ngati Manawa elders report that kokopu (*Galaxias spp*) were formerly found in the upper Rangitaiki catchment, particularly the Whirinaki River, in sufficient numbers to support a traditional fishery and were an important food source (Doig 2002, Mitchell 1996). Raumahehe or koaro (*Galaxias brevipinnis*) were also reported as present (Doig 2002).

The diversity and abundance of indigenous fish species, other than tuna, now appears to be relatively limited in the upper Rangitaiki catchment. The only indigenous species present in the records of the NZFFD upstream of Aniwhenua Dam are common bully (*Gobiomorphus cotidianus*) and dwarf galaxias (*Galaxias divergens*).

Common bully

Ngati Manawa elders report that titarakura (also known as toitoi or the common bully) were historically present in the upper Rangitaiki catchment. However, the common bully was only recorded in the NZFFD for the first time in the 2007 surveys of Lake Aniwhenua and was present in low abundance compared to Lake Matahina (Smith et al. 2007). There are no records in the database of bullies being present in any of the tributaries despite apparently suitable habitat being available. The common bully is regularly consumed as prey by trout (McDowall 1990) and so the success of trout in the upper Rangitaiki since their introduction in the early 1900s may have contributed to the decline of the species. It is possible that the establishment of Lake Aniwhenua, potentially supplemented by unintentional translocation of bullies with the elver transfer scheme, has provided habitat suitable for completion of the full life cycle in the upper catchment, which has led to the establishment of the present population.

Dwarf galaxias

The dwarf galaxias is a small, relatively uncommon, non-migratory galaxiid. It is most often found in small, stable, gently flowing, gravelly and rocky streams in the foothills (McDowall 1990). There are records of dwarf galaxias being present in relatively high numbers in the Kopuriki Stream (1990s) and the Horomanga River catchment (1960s) (Figure 9—4). More recent surveys (2007–08) at some of the sites where they had previously been present have failed to find any dwarf galaxias. McDowall (1990) states they occur most often upstream beyond the limits of brown trout populations and that before agricultural development and the introduction of trout, the dwarf galaxias would probably have been more widespread. Hay (2009) also suggests that the habitat of dwarf galaxias is susceptible to the effects of abstraction. It is likely therefore that this species has come under increasing pressure with the intensification of agriculture and increasing abundance of trout in the Galatea Plains. The Rangitaiki is one of only two catchments north of Hawke's Bay where this species has been recorded and thus ensuring the survival of this population is important for maintaining biodiversity.

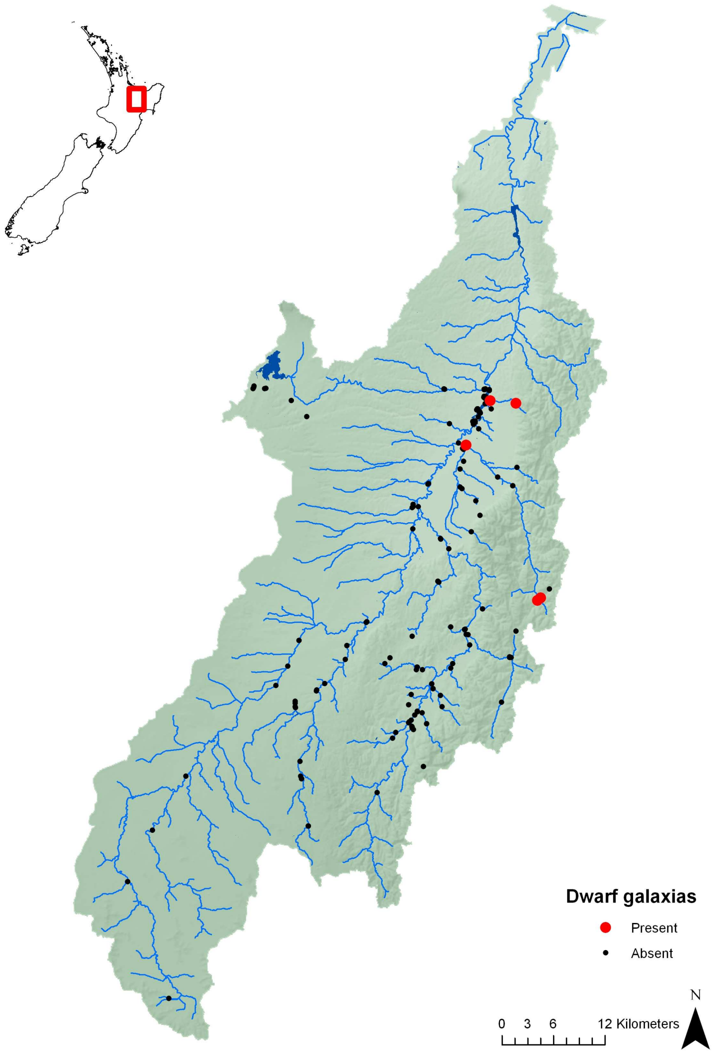


Figure 9—4: Distribution of dwarf galaxias records upstream of Aniwhenua Dam.

Kokopu

No kokopu species has been recorded in the Rangitaiki catchment upstream of Aniwhenua Dam in the NZFFD, despite Ngati Manawa elders reporting that historically they were common (e.g., Doig 2002). Both banded kokopu (*Galaxias fasciatus*) and giant kokopu (*Galaxias argenteus*) have been reported in the lower parts of the Rangitaiki River (Figure 9—5). Mitchell (1996) reported that kokopu whitebait are common below Matahina Dam and that a landlocked population of adults had probably become established in Lake Matahina. Smith et al. (2007) captured six adult and one juvenile giant kokopu in Lake Matahina and a further six adults in three tributaries of the reservoir, further supporting the idea that a self-sustaining, landlocked population is established in the lake. This should result in the production of larval kokopu in Matahina, increasing the number of whitebait moving upstream. Kokopu whitebait are excellent climbers (McDowall 1990) and have been observed scaling Aniwhenua (Aniwaniwa) Falls (J Boubée, pers. obs.). However, the Aniwhenua Dam is likely to present an impassable barrier for movement further upstream and thus is likely to prevent reestablishment of a kokopu population in the upper Rangitaiki River and its tributaries.

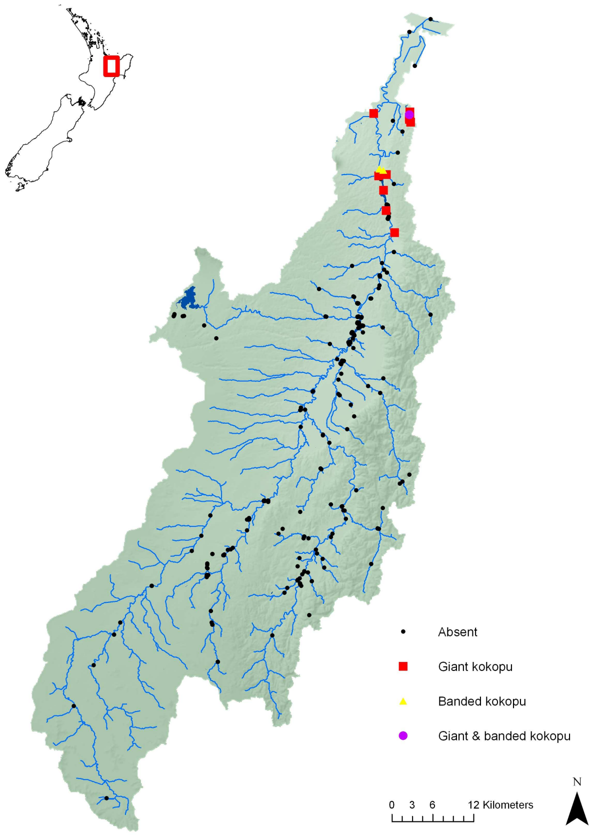
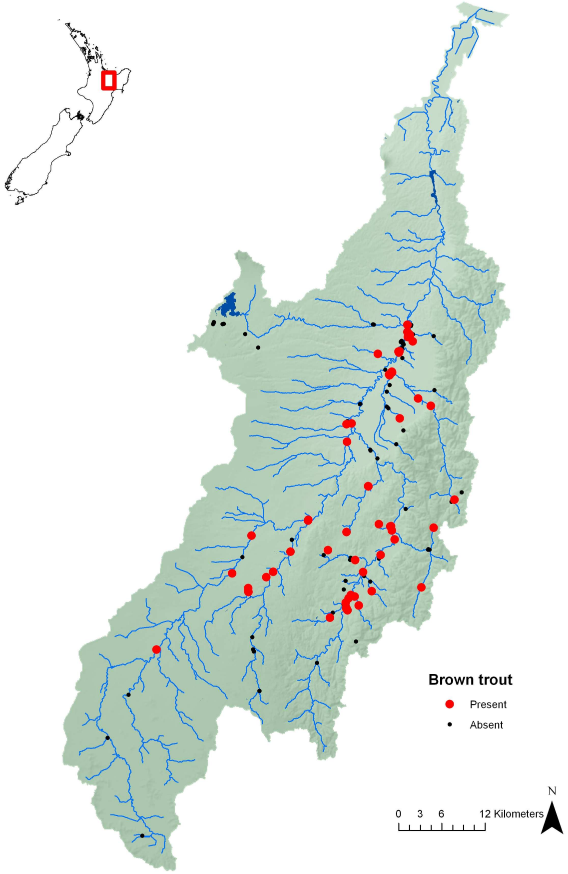


Figure 9—5: Distribution of kokopu based on records from the NZFFD.

9.2.3 Trout

Rainbow trout and brown trout are widely distributed throughout the upper Rangitaiki River and its tributaries and may be the only species present in the uppermost reaches of the Rangitaiki and Wheao Rivers (Figure 9—6). It is likely that trout were released into the catchment around 1900 (Doig 2002, Young 2000) and they now provide the basis of a regionally important recreational fishery. Adult trout are typically resident in the main rivers and Lake Aniwhenua, migrating to the tributaries for spawning in autumn. Juveniles consequently dominate the trout populations in many of the side streams for the majority of the year. Trout have an advantage over the predominantly diadromous indigenous fish species historically present in the catchment as they do not require access to the sea. Consequently, the presence of Matahina and Aniwhenua dams does not impinge on their ability to successfully complete their lifecycle and helps to explain the relative success of trout in the upper Rangitaiki. As long as connectivity to the tributaries where spawning occurs is maintained, annual recruitment can occur, subject to normal natural controls, e.g., flooding.

Following the establishment of Lake Aniwhenua, very high trout growth rates were observed. Rowe (1984) reported relatively fast growth rates of rainbow trout in the nearby Rotorua Lakes, with the highest rates recorded in Lakes Okataina and Rotoehu. Growth rates of rainbow trout in Lake Aniwhenua exceeded these rates, with fish of 2+ years of age being on average 80 mm longer and > 1.2 kg heavier than trout found in Lake Okataina and Lake Rotoehu (Wells & Clayton 2001). It was suggested that the high growth rates were linked to high production, and thus consumption, of gastropods associated with blooms of water net (*Hydrodictyon reticulatum*) in the lake (Wells & Clayton 2001). The abundance of gastropods, in addition to a prevalence of goldfish liberated during flooding of farmland following completion of the dam, also supported a significant brown trout fishery (G. Ryder, pers. comm.). As a consequence of the high growth rates and relatively low abundance of fish, the Rangitaiki River trout fisheries became renowned for the large fish they produced. Recently, there is a perception of a decline in the size and abundance of trout in the catchment which has potentially negative consequences for the fishery (G. Ryder, pers. comm.). It is possible that this trend reflects the decline of water net in the lake and consequently the abundance of food available to the trout (Wells et al. 1999). It may, however, also reflect the impacts of other changes in the catchment, including: intensification of agriculture, increased exploitation of water resources and the increased angling pressure caused by the reputation for the fishery to produce large, natural fish.



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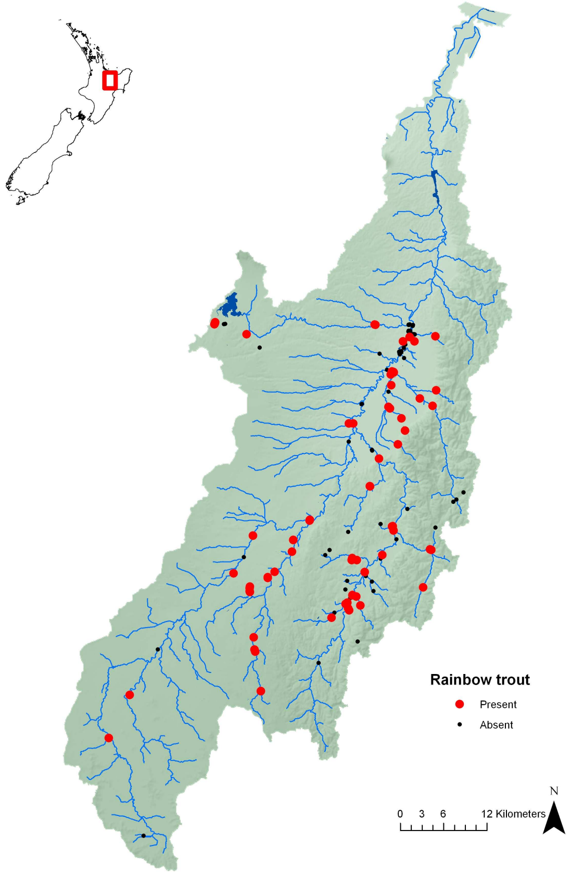

b.

Figure 9—6: Distribution of trout records from the NZFFD upstream of Aniwhenua Dam a) Brown trout; b) Rainbow trout.

9.2.4 Other introduced species

Goldfish (*Carassius auratus*) and gambusia (*Gambusia affinis*) have both been recorded in the upper Rangitaiki catchment (Smith et al. 2007). They are primarily restricted to still water environments in Lake Aniwhenua and the Murupara ponds where habitat is most suitable. It is believed that goldfish were librated following from farm ponds which contained them as Lake Aniwhenua was filled (G. Ryder, pers. comm.). The current abundance and distribution of these species are unlikely to present a significant problem. They probably provide a useful food item for larger trout and eels. Gambusia is however recognised as a pest fish that competes with other species for food. They have also been seen to show aggressive behaviour towards native galaxiid species resulting in increased mortality and competitive exclusion from preferred habitats (Rowe et al. 2007).

9.3 Key issues

The diversity and abundance of fish populations in the upper Rangitaiki River and tributaries has undoubtedly changed significantly over time. Little data is available regarding the fish populations in the upper Rangitaiki catchment prior to the establishment of hydro-electric operations on the river. However, reports from Ngati Manawa elders suggest that tuna, kokopu, koaro and bullies were historically present throughout the Rangitaiki River and its tributaries up to at least Murupara. Within the areas which have been surveyed, kokopu and koaro have never been recorded and common bullies have only recently been recorded in Lake Aniwhenua. The abundance of tuna, particularly longfins, has also undergone a significant decline and their distribution has become increasingly restricted. The dwarf galaxias has also not been recorded in the last decade. Whilst it is possible that small isolated populations of some of these species may exist in the headwaters of some of the streams where surveys have not been carried out, in general the fish communities of the upper Rangitaiki catchment have become significantly impoverished compared to historical conditions.

A range of factors have probably contributed to these changes. The most significant has been the development of hydro-electric facilities on the Rangitaiki River, which have eliminated the connectivity required by diadromous native fish species to successfully complete their life cycles. Increasing exploitation of water resources for both electricity generation and irrigation have altered flow regimes, impacting on physical habitat quality and quantity, and potentially interfering with triggers for fish movement and migration. Changes in land use throughout the catchment, including shifts to exotic forestry and dairy farming, has altered stream habitats and water quality, which have further impacted on fish recruitment and survival. Superimposed on these changes has been the introduction of exotic fish species, which increases competition for food and habitat, along with exploitation of both indigenous and introduced species for recreation and food. The discussion that follows considers each of these factors in more detail and reflects on the primary mechanisms contributing to the apparent changes in fish population structure and dynamics within the catchment.

9.3.1 Connectivity

It is increasingly evident that the fish communities of the upper Rangitaiki River and its tributaries have become impoverished as a result of the barriers to fish migration presented by the hydro-electric dams at Matahina and Aniwhenua. Many of New Zealand's native fish are diadromous meaning they require unimpeded access to both sea and freshwater to successfully complete their life cycle (McDowall 1990). Matahina Dam was completed in 1967 and recruitment of fish to the upper Rangitaiki catchment has therefore been restricted for over 40 years. Since 1984 when the Aniwhenua scheme was completed, fish movement within the catchment has become even further restricted. This has undoubtedly impacted on the recruitment rates and survival of indigenous fish in the upper catchment.

Some indigenous species, such as kokopu and koaro, are known to have established landlocked populations in some areas and thus can, with the right conditions, overcome the limitations presented by the introduced barriers to movement (McDowall 1990). There is evidence that a self-sustaining population of giant kokopu may be established in Lake Matahina (Smith et al. 2007). This could provide a source population for migration and colonisation of tributaries upstream of the lake, but the impassable barrier formed by Aniwhenua Dam will limit penetration above this point in the catchment. Unfortunately it has been suggested that a landlocked population is unlikely to occur in Lake Aniwhenua because the residence time within the lake is too short to allow the planktonic larval stage of the lifecycle to be completed successfully (Mitchell 1996).

Tuna are an obligate diadromous species and must have access to and from the sea to successfully complete their lifecycle. Consequently, they cannot form self-sustaining landlocked populations. This means that the presence of impassable barriers to migration within a river system will severely limit upstream recruitment. Whilst elvers are extremely good climbers, hydro-electric dams typically present an impassable barrier to successful upstream migration into the freshwater habitats where tuna spend most of their life. In recognition of this restriction, a manual elver transfer programme was initiated at Matahina Dam in 1983, whereby elvers that congregate at the foot of the dam are transferred into lakes Matahina and Aniwhenua. Whilst eel populations in lakes Matahina and Aniwhenua remain at a relatively low density, the transfer of elvers into the lakes appears to be having a gradual positive effect on abundance (Smith et al. 2007). In particular, the number of shortfins being recorded in Lake Aniwhenua during recent surveys (Smith et al. 2007) is indicative of successful survival and recruitment of the transferred elvers. Despite this improvement, dispersion into the tributaries appears to be relatively slow, with very few small tuna being captured (Smith et al. 2007, Young 2000). In the upper Rangitaiki, this may partially reflect the lack of suitable habitat for shortfins in many of the tributaries, which are numerically dominant in the elvers being transferred into Lake Aniwhenua. Instead, the shortfins are likely to illustrate a preference for the more lentic environment offered by the lake. Due to the low proportion of longfins being transferred to Lake Aniwhenua and the long life expectancy (female longfins take 30-50 years on average to reach sexual maturity (Chisnall & Hicks 1993)), the reestablishment of tuna populations in the tributaries is likely to take considerable time.

In addition to restricting upstream migration of elvers, dams also act as a barrier to the downstream migration of mature tuna returning to the sea for spawning (Boubée et al. 2001). When mature tuna migrate downstream to reach their spawning grounds, they inevitably become entrained in the water intakes at the hydro-electric installations. Where intake screens are small meshed e.g., at Aniwhenua Power Station, the migrant tuna become impinged and suffocate as a result of the water pressure (Boubée et al. 2001, Mitchell 1996). Where coarser screens allow the tuna to pass through, they are generally mutilated by the turbines (Mitchell & Boubée 1992). The result is that a further bottleneck is placed on tuna recruitment due to the failure of tuna to reproduce.

The reduction in connectivity between habitats caused by the construction of hydro-electric facilities on the Rangitaiki has therefore significantly impacted on the successful recruitment and maintenance of native fish populations in the upper Rangitaiki River and its tributaries.

9.3.2 Flow regime

The flow regime in the Rangitaiki River has been subjected to significant changes following the hydro-electric developments on the river. In the upper reaches the Wheao Power Scheme has diverted the upper Rangitaiki and Flaxy Creek to the Wheao River. Downstream of the diversions, the reduction in water can be equated to a loss of physical habitat, with consequential effects on instream ecology. In the Wheao River, the receiving river for the diverted water, flow is increased, but also becomes regulated by the operating regime of the power scheme. The additional flow will have increased the amount of habitat available, but regulation of the flow regime may alter community dynamics by favouring one species over another. In the past it is thought that tuna were relatively common in the lower Wheao River (Doig 2002). However, there are now very few records of tuna captured in this part of the catchment, with brown and rainbow trout dominating the fish community. The mechanisms for this shift in community are not easily established due to the catchment-wide loss of tuna, but the changes in flow regime could have contributed to the observed shift in fish communities.

As a consequence of flow regulation by the three power stations, the natural variability in flow has also changed. In the upper catchment, the Wheao Scheme has increased the frequency of small 'flushing' flows (a result of hydro peaking). The link between these modified flows and the response of fish communities is poorly understood, but there are potential impacts on food availability, habitat suitability, water quality and siltation. The Aniwhenua and Matahina power schemes are likely to have had a more significant impact on the flow regime due their more substantive reservoirs. The availability of storage provides the opportunity for greater flexibility to match generation to demand, typically resulting in a twin-peaking operating regime, with very low flows at night and peaks in flow in the morning and in the evening. Both the changes in flow rates, and the rate of change (ramping rate) caused by changes in power generation may potentially impact on fish communities through a variety of mechanisms. Similar changes in flow regime in other systems have been linked with shifts in fish communities and caused impacts on recruitment success, but the exact processes are not well understood. Insufficient data exists for the Rangitaiki catchment regarding either flows or historical fish communities to establish whether this is the case for the Rangitaiki. Downstream migration of eels has, for example, been shown to be linked to high flow events following rainfall (Boubée et al. 2001, Mitchell 1996). It is not known how artificially induced variations in flow may impact on this response.

Abstraction of both surface and groundwater has increased throughout the Galatea Plains area in response to agricultural intensification and development. Abstraction reduces the quantity of water available in a river and hence the availability of habitat. The dwarf galaxias is thought to be susceptible to reductions in flow due to its habitat preferences (Hay 2009). In recent surveys this species has not been captured along reaches on the Galatea Plains where they have been historically present. There is a possibility that this may reflect the impact of increased abstraction, but currently there is insufficient information available to confirm this. A reduction in flows due to abstraction could also potentially impact on the recruitment success of trout, as reduced flows can lead to increased siltation and decreased dissolved oxygen, which can reduce the success rate of spawning. Desiccation of marginal areas can also lead to a reduction in macroinvertebrate life and hence food supply for juvenile fish. Currently, however, little is known about the extent of these conditions or potential community responses within the Rangitaiki River or its tributaries.

9.3.3 Competition

The introduction and establishment of non-indigenous fish species in the catchment has inevitably had an impact on the status of indigenous fish populations. Direct effects include competition for space, food and increased predation, and indirectly through differing management priorities. The introduction of trout into the Rangitaiki River occurred around 1900 (Doig 2002, Young 2000). This has undoubtedly impacted on the structure and success of indigenous fish populations in the Rangitaiki River and tributaries. Trout are relatively aggressive, territorial species and are believed to out-compete some indigenous species in New Zealand. McDowall (1990) notes that when trout are present, they appear to exclude species such as giant kokopu and dwarf galaxias. The mechanisms behind this shift in distribution have not been explored well, but are likely to reflect competition for space and food. It is also likely that trout will prey on juveniles of these species; it is certain that they consume common bully (McDowall 1990, Rowe 1984).

Following introduction of trout to the Rangitaiki and the establishment of a successful trout fishery, management priorities for the river fishery became driven by a requirement to sustain the trout populations at the expense and almost complete exclusion of indigenous fisheries (Doig 2002). Tuna were considered a threat to the trout fishery because they were thought to prey on juvenile trout and were therefore actively removed and destroyed. In addition, it is suggested that inclusion of fish passage facilities at the dams were vetoed in order to protect the valuable trout fishery in the upper river from tuna (Doig 2002).

9.3.4 Exploitation

Tuna have been exploited throughout the Rangitaiki River both as an element of the traditional fishery and commercially (Doig 2002). As an important food source, Ngati Manawa have always fished for and taken tuna from the Rangitaiki River and tributaries such as the Whirinaki River. At the time when natural recruitment was unimpeded by the construction of the dams on the Rangitaiki River, the level of exploitation is likely to have been sustainable. However, if the rate if exploitation was maintained following the restriction of recruitment caused by the dams, the tuna resource would eventually become depleted due to the lack of replacement. This was, however, likely exacerbated by the high level of commercial exploitation that was encouraged in the lower and middle Rangitaiki River as part of the management of the trout fishery (Doig 2002).

Following the establishment of the trout fishery, trout also became the subject of exploitation with anglers wishing to keep their catch. Whilst bag limits imposed by Fish and Game limit the number of fish that can be taken during each visit, the largest fish tend to be those most prized and thus taken by anglers (G. Ryder, pers. comm.). Increased promotion of the Rangitaiki fishery both inside and outside of the immediate area has resulted in an increase in the number of anglers visiting the river and consequently an increase in the number of fish taken. It is believed that this increased exploitation may have contributed to the perceived decline in the status of the trout fishery in recent years to the point where catch rates have significantly declined (G. Ryder, pers. comm.).

9.4 Knowledge gaps

- Lack of reliable documented information regarding the historical diversity and distribution of fish species in the catchment, particularly in the period prior to construction of the dams.
    - Whilst significant knowledge is available amongst Ngati Manawa members, little of this is documented. Understanding where and when the different species occurred would help to identify the relative significance of different impacts.
- No information regarding the current diversity and structure of fish populations in the more inaccessible upper reaches of any of the rivers.
    - It is important to establish whether populations of indigenous fish such as kokopu, koaro or dwarf galaxias remain, so that appropriate conservation measures can be implemented.
- Little understood about the interactions between tuna and trout.
    - In order to support ongoing work on enhancing tuna stocks in the upper catchment, it would be useful to know the influence of trout on tuna recruitment and survival.
- Poor understanding of the mechanisms linking changes in flows with responses in the fish community.

- Fish communities are thought to be impacted by alterations in flow regime caused by flow regulation and abstraction. Whilst hypotheses exist regarding the nature of the processes, current understanding of the causal mechanisms is still poor, particularly for New Zealand's indigenous fish species.

9.5 Conclusions and Recommendations

There have been significant impacts on the diversity and distribution of fish species in the upper Rangitaiki River and its tributaries. These impacts are related to a range of factors including: disruption of connectivity for diadromous species, over-exploitation, loss of and changes in habitat, and competition from introduced species.

Attempts to help recovery of the tuna population through the manual transfer of elvers to the upper catchment has been successful, but have resulted in an increased and apparently unnatural ratio of shortfins to longfins. Improving successful downstream migration of mature adult tuna is however still work in progress.

Whilst no kokopu have been recorded upstream of Aniwhenua Dam in recent surveys, it appears that a self-sustaining land-locked population may have become established in Lake Matahina. This could act as a source population of whitebait for the upper catchment if the impassable barrier presented by the Aniwhenua Dam could somehow be overcome.

Overall, recovery of indigenous fish populations in the upper Rangitaiki catchment will require an integrated approach including conservation and enhancement. It will be important to quickly establish whether isolated populations of native species still remain, and to suitably protect them and their habitat. There is also a requirement to restore habitats, and connectivity between them, in order to achieve a sustainable recovery of fish communities.

10. Recommendations for further action

Environmental sphere	Item	Activity	Timing	Cost	Rank[20]
Land use	1	Changes in and intensification of land use in this catchment will increase nutrient load and degrade aquatic values. Such changes need to be recognised and controlled.	Permanent	Potentially very high	***
	2	In partnership with the broader community, develop a River Care group which involves farmers to raise awareness of impacts of farming in the catchment.	Permanent	Low	***
	3	In partnership with EBOP, provide education to farmers on responsible use of fertiliser and sustainable land use with respect to water quality.	Periodic – undertake refresher training	Medium	**
	4	Best management practices (BMP) for land uses in critical areas of the catchment need to be developed, implemented, monitored and enforced.	Permanent	High	***
	5	Review best management practices (BMP) annually to take account of monitoring and new findings.	Permanent	low	***
	6	In partnership with farmers, encourage development of a nutrient budget for each farm and identify areas of excessive N input.	Permanent	Low	***
	7	In partnership with EBOP, identify any point source inputs of N from stream/river and remediate.	Variable	Low	*
	8	In partnership with farmers and EBOP, identify and rehabilitate drained high organic matter soils in areas which have high N fluxes.	Permanent	Low	*
	9	In partnership with EBOP and farmers, install denitrification trenches to reduce N input to streams/rivers (initially, target sensitive reaches).	Permanent	High	*
	10	In partnership with farmers encourage wet high organic matter margins to waterways to assist with denitrification of overland flows.	Permanent	Low	**
	11	In partnership with farmers encourage planting of riparian buffers along streams and waterways to reduce sediment loads and enhance native habitat for terrestrial and freshwater biodiversity	Permanent	Medium	***
	12	In partnership with EBOP, develop a N budget and trading market for the catchment similar to those undertaken for Lake Taupo and Rotorua lakes.	Permanent	High	***

[20] (Note: Timing,cost and Rank shown is by the report compilers (* Recommended, *** Highly recommended)

Environmental sphere	Item	Activity	Timing	Cost	Rank[21]
Water quality monitoring	13	Through lobbying and submissions, encourage EBOP to increase water quality monitoring in the upper catchment to better assess the impacts of land use change and intensification on surface and groundwater quality. Specific sites could include: o Rangitaiki River u/s confluence with Otamatea River, say 2805050E, 6267700N (as well as existing site at SH5); o Otamatea Stream u/s confluence with Rangitaiki River, say 2804875E 6267675N (as well as existing sites); o Otangimoana Stream u/s confluence with Rangitaiki River, say 2806675E 6267600N (subject to land use change/intensification) o Mangatiti Stream u/s confluence with Rangitaiki River, say 2809450E 6272100N (forested catchment, cf. Otangimoana Stream).	Monthly for one year period and every three years thereafter	Medium (Offset by discontinuing monitoring at BOP110014 and BOP110015 and making use of NRWQN (RO3 and RO4)).	***
	14	Through lobbying and submissions, encourage EBOP to increase water quality monitoring in the Galatea Plains to better assess impact of land use change and intensification on surface and groundwater quality. Specific sites could include: Omahuru Stream (intercepts shallow groundwater), Haumea Stream (status unknown); Horomanga River (important fishery habitat).	Monthly for one year then every three years	Medium	***
	15	Through lobbying and submissions ensure that water quality monitoring is supported by ecological monitoring, e.g., periphyton and macro-invertebrates.	Once every three years, to coincide with water quality monitoring	Medium	***
	16	Through lobbying and submissions, encourage EBOP to extend phytoplankton and periphyton monitoring to Lake Aniwhenua and to the reach of the Rangitaiki River between Murupara and Rabbit Bridge.	Three times annually during summer	Medium	**
Groundwater resources	17	Through lobbying and submissions, encourage EBOP to initiate targeted investigation regarding groundwater in the upper Rangitaiki River catchment. Such work to: o better characterise groundwater catchment boundaries; o establish common understanding of issues with Hawke's Bay region who have similar land use management issues in adjacent catchments; o Identify requirements for improved land use management.	Permanent	Medium	***

[21] (Note: Timing,cost and Rank shown is by the report compilers (* Recommended, *** Highly recommended)

Environmental sphere	Item	Activity	Timing	Cost	Rank[22]
Surface and groundwater abstraction	18	Undertake an assessment of surface and groundwater hydrology for the Galatea Plains and tributaries to the Rangitaiki River upstream of Lake Aniwhenua to establish water allocation rules and ensure future water allocation is sustainable, meets life-supporting capacity as well cultural aspirations. The latter includes safeguarding the quality and yield of natural springs.	Permanent	High	***
River bed and gravel management	19	Future management of riverbed levels and gravel deposits along the Rangitaiki River and tributaries needs to have regard for impact on connectivity and potential impacts on isolated fish populations.	Permanent	High	*
Fish	20	In partnership with MFish, F&G and DoC, develop and implement a fish management plan for the catchment.	Permanent	Low	***
	21	In partnership with the operators of Matahina Dam continue the existing elver catch and transfer activities.	December to March annually	Medium	***
	22	Carry out an extensive fish survey of the catchment and adjust the fish management plan accordingly.	Every 5 years	Medium	***
	23	In partnership with F&G, and MFish appoint a part-time fishery officer to enforce fisheries regulations that are developed.	Permanent	High	**
	24	In partnership with the operators of Aniwhenua and Matahina power stations implement and monitor passage facilities for adult downstream migrating eels.	Autumn annually	Medium	***
	25	In partnership with DoC undertake a study of the upper section of stream running on the North East of the catchment to determine the distribution of kokopu type fish and develop restoration guidelines.	Once of in summer	Medium	*
	26	Reduce the harvest of longfins through education.	Permanent	Low	***
Aquatic weeds	27	In partnership with users define the nuisance aquatic weed problems (to whom, when and where). Develop and instigate control strategies.	Once off	Low	***
	28	Undertake periodic assessment of efficacy of aquatic weed management strategies.	Every three years	Low	*
Data and information availability	29	Improving future management of resources in the Ngati Manawa rohe will depend heavily on ensuring that relevant data and information are readily available to all affected parties.	On-going	Low	***

[22] (Note: Timing,cost and Rank shown is by the report compilers (* Recommended, *** Highly recommended)

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13. Appendices

13.1 Groundwater, hydrogeology and geology

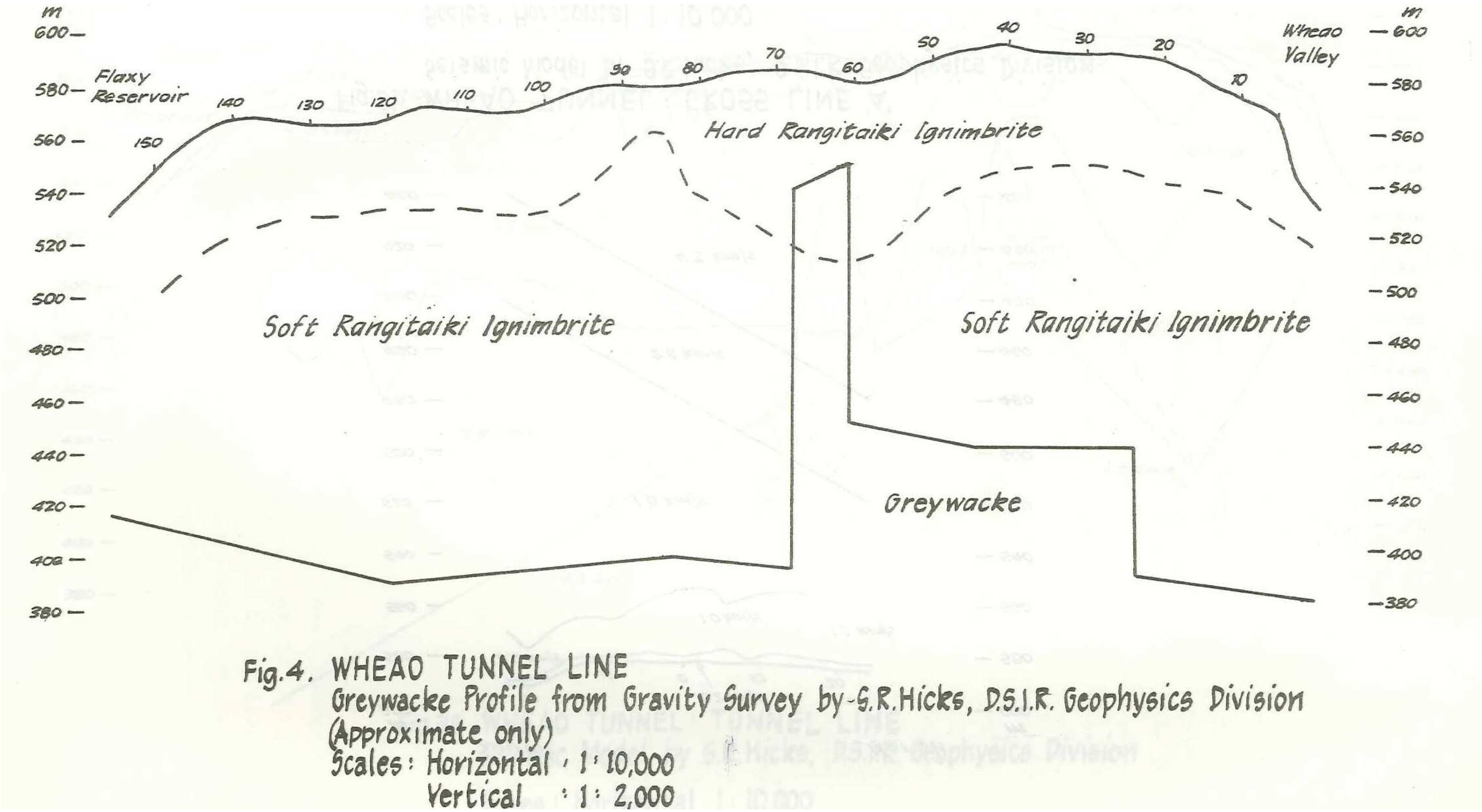

Figure 13—1: Cross-section of Wheao River to Flaxy Creek tunnel showing approximately 40 m of "hard" Rangitaiki Ignimbrite over roughly 100 m of "soft" Rangitaiki ignimbrite underlain by greywacke **[**Figure 4 from Hancock and Aust, (1979)].

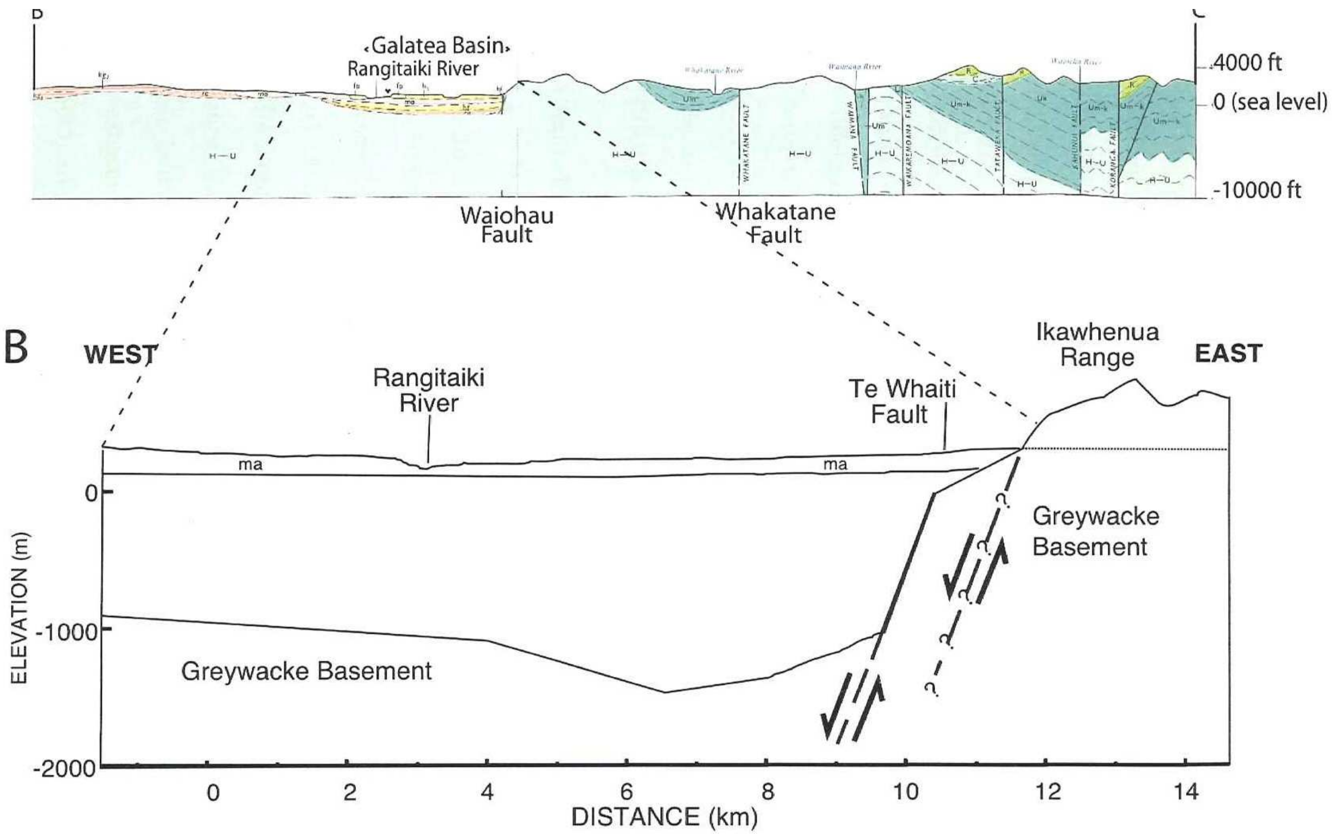

Figure 1.3. Cross sections of the Galatea Basin from previous studies. L to R = west to east. A = Cross section extrapolated from strike and dip observations (Healy, Schofield et al., 1964); B = Cross section interpreted from gravity forward modelling (Williams, 1979)

Figure 13—2: Cross-section of the Galatea Basin revealing a thin cover of Matahina ignimbrite over deeper Quaternary ignimbrites to a maximum depth of 1,500 m underlain by greywacke [Figure 1.3 from Toulmin, (2006)].

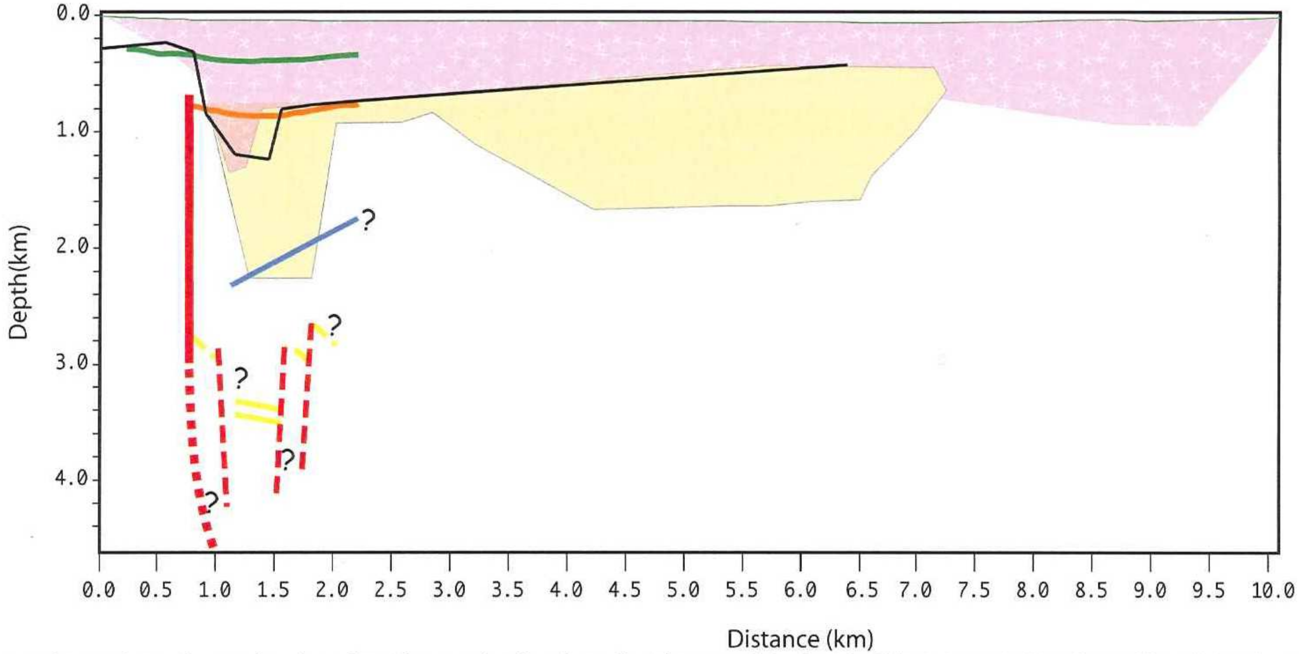

Figure 4.24. Comparison of gravity, seismic refraction and seismic reflection models for the Mangamate Road profiles (Line A gravity model) . Shaded blocks are results of gravity modelling (pink = Pleistocene volcanices; yellow = Tertiary sediments); coloured lines are layer boundaries and faults interpreted from seismic reflection interpretation (Green = late Pleistocene volcanics, orange = base of Pleistocene volcanics; blue = late to mid-Tertiary sediments, yellow = base of Tertiary sequence; red = faults); solid black line is layer 1 − layer 2 boundary from ray tracing (forward modelling) of seismic refraction arrivals. Note the agreement between models for the position of the primary fault and base of the Pleistocene units. The base of the Tertiary sequence differs by approximately 1 km between the gravity and seismic reflection models; seismic refraction does not sample the base of the Tertiary sequence.

Figure 13—3: Cross-section of the lower Galatea Plains (along Mangamate Road) shows Pleistocene volcanics (less than 1 km depth) over Tertiary sediments (to a maximum of around 2 km depth) underlain by greywacke. Note that this cross-section is viewed from the north [Figure 4.24 from Toulmin, (2006)].

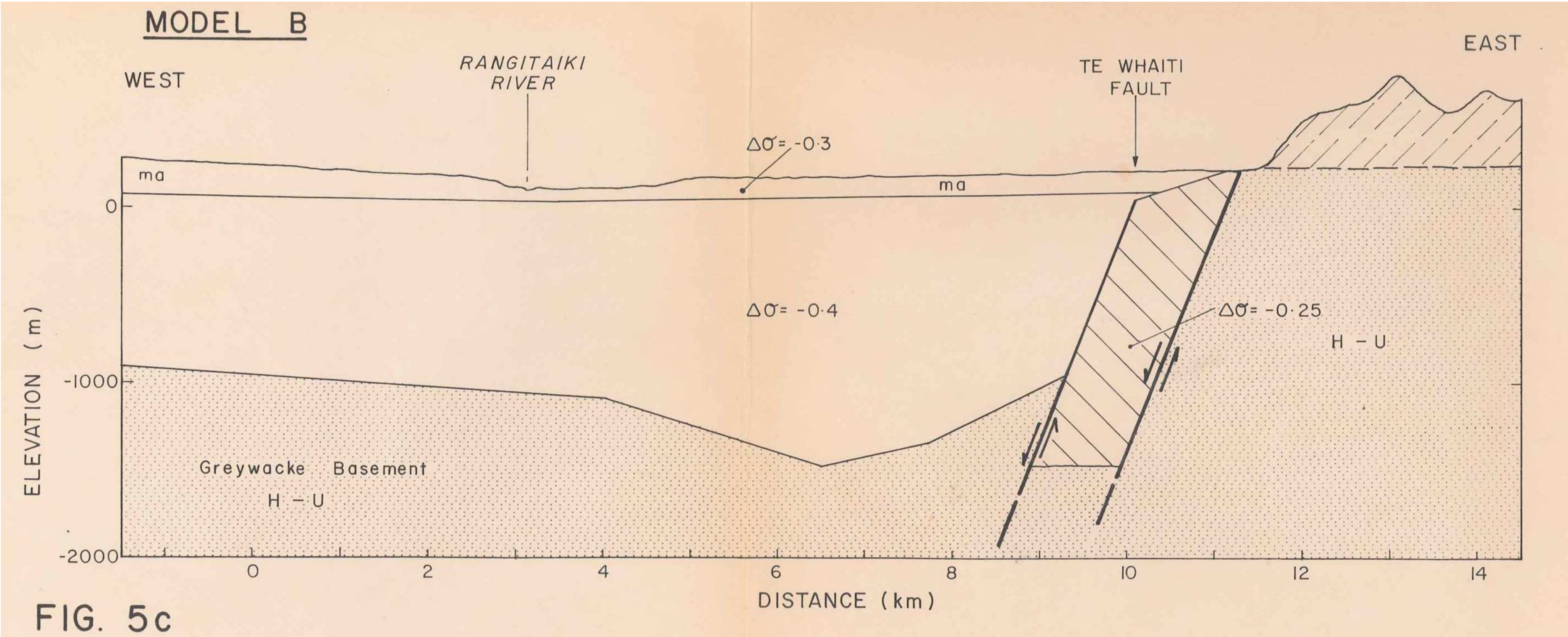

Figure 13—4: Cross-section of central Galatea Plains south of the Horomanga River. It shows a thin layer of Matahina ignimbrite over around 1,000 m of "volcanics and sediments" underlain by greywacke **[**Figure 5c from Williams (1979)].

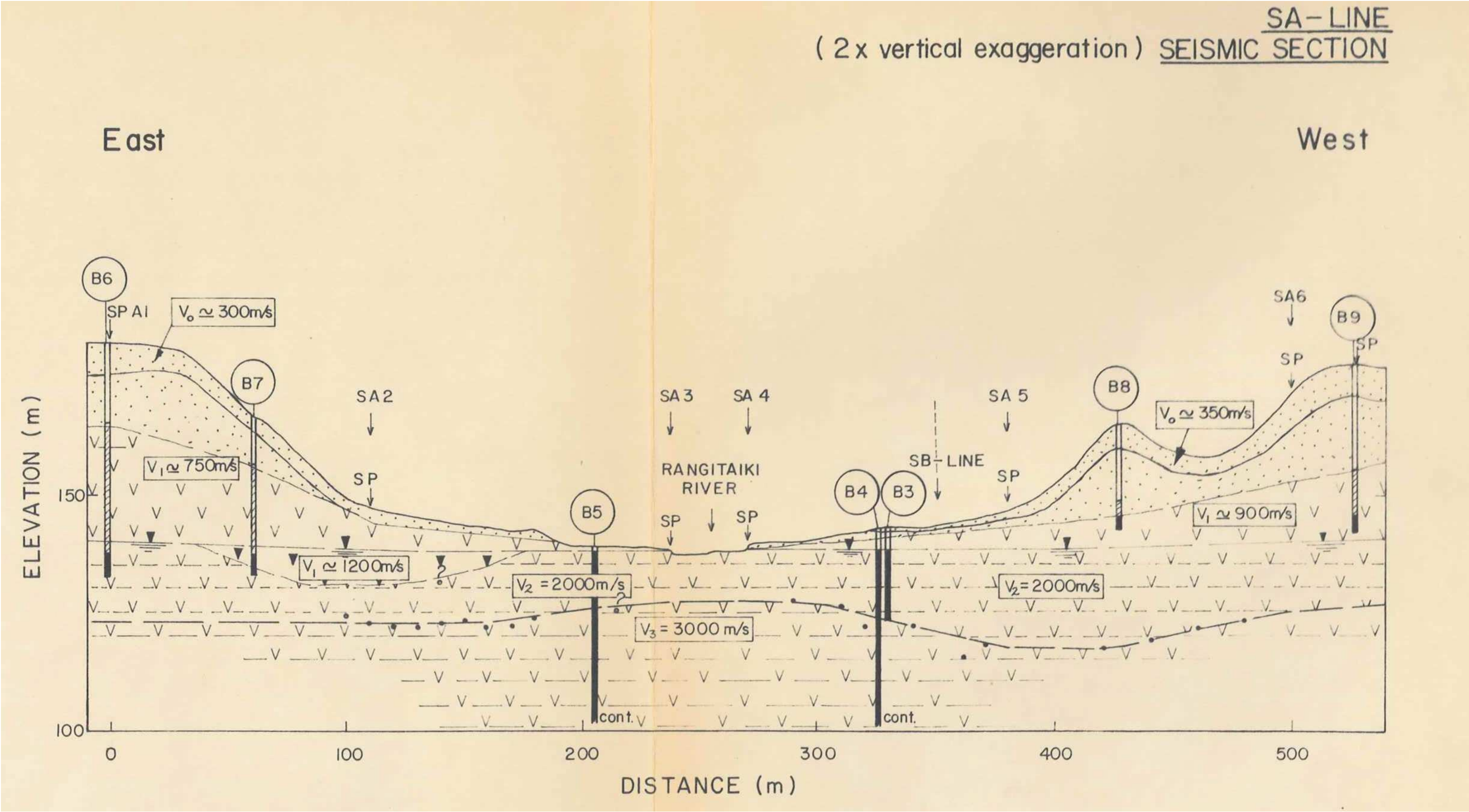

Figure 13—5: Cross-section of Aniwhenua Dam site showing a dry surface layer of pumice covering a dry subsurface layer of weathered and unweathered tuffs underlain by saturated welded tuffs to a depth under the Rangitaiki River of less than 150 m. Note that this cross-section is viewed from the north [Figure 4 from Hochstein, (1976)].

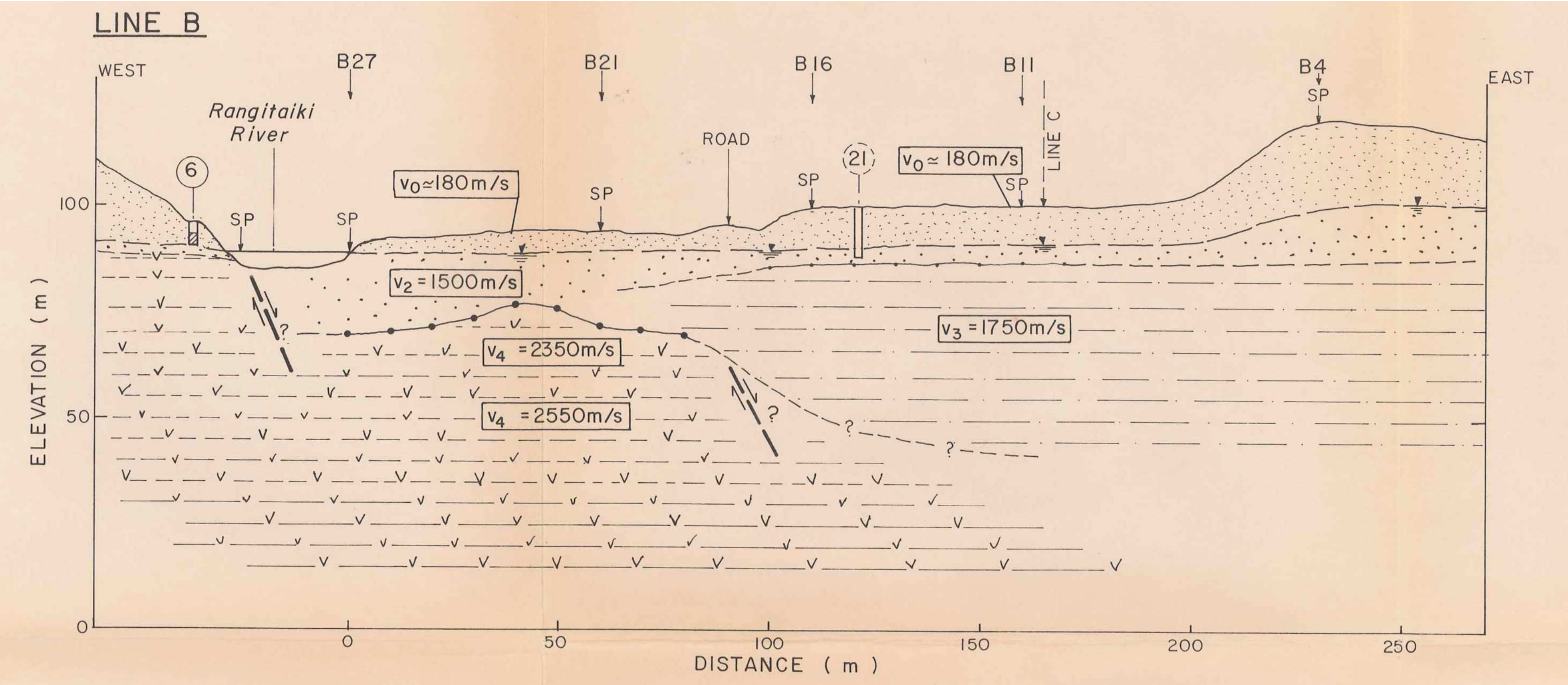

Figure 13—6: Cross-section of proposed Mangamako Dam site to the north of the Aniwhenua Dam. It shows a thin (10 m or less near the Rangitaiki River) dry surface layer of pumice, ash, alluvium, and gravel over a thin saturated layer of silt, gravel, and weathered tuffs underlain by 50 m or more of either welded tuffs (ignimbrite) or water saturated silt [Figure 2c from Williams, (1979)].

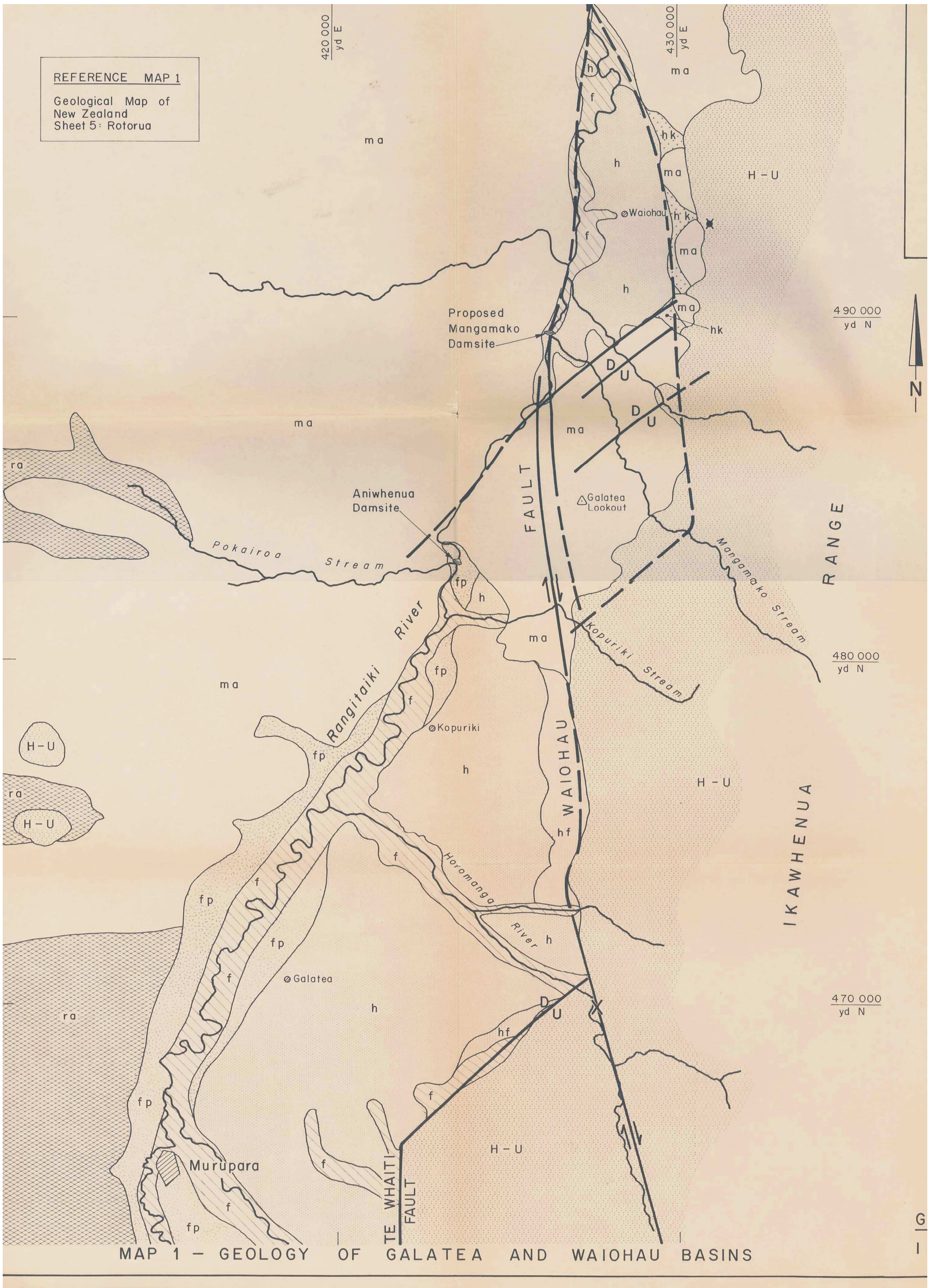

Figure 13—7: Surface geology of the Galatea and Waihohau Basins [Reference map 1 from Williams, (1979)].

Table 13—1: Information derived from drilling logs for wells in the Rangitaiki River catchment upstream of Aniwhenua Dam.

Id no.	Well no.	Description of lithology at total depth	Depth (m)	Fines	Sand	Gravel	Rock	Other
1	2811	Gray white rhyolite	84.00				1	
2	3309	Dark brown silt	9.00	1				
3	204	Rhyolite	64.01				1	
4	3135	Sands and greywacke gravel	18.00		1	1		
5	1253	Sands and gravels	19.00			1		
6	1263	Topsoil and boulders	7.50	1				
7	2920	Blue gravels	28.00			1		
8	10156	Coarse gravel	32.00			1		
9	1319	Hard Ignimbrite	51.80					1
10	108	Layered gravels and silt	24.40	1				
11	141	Gravels	24.00			1		
12	524	Brown pumice gravels	9.25			1		
13	3128	Greywacke gravel	39.00			1		
14	3215	Sands and greywacke gravel	30.00		1	1		
15	3270	Brown/grey gravels	17.00			1		
16	1219	Ingnimbrite	55.00					1
17	3485	Silts and bolders - water loss	34.00	1				1
18	3123	Sand, silt, and gravel	26.00		1	1		
19	223	Sands and gravels	9.22		1	1		
20	2583	Gravels, grey and brown bound in yellow clay	26.00	1		1		
21	127	Course gravels	12.30			1		
22	386	Hard rock (undefined)	5.21				1	
23	1273	Pumice, fine silt and sands	19.50	1	1			
24	3133	Grey silt	21.00	1				
25	10075	Sand, gravel, cobbles	29.00		1	1		
26	3127	Grey silt	27.00	1				
27	3213	Brown gravel	24.00			1		
28	2919	Fine pea sized gravels, brown in colour	9.00			1		
29	475	Gravels and sands	9.10		1	1		
30	1268	Gravels	19.50			1		
31	3214	Brown sands, gravels	39.00		1	1		
32	3670	Pea metal	33.50			1		
33	11214	Blue coarse gravel	24.00			1		
34	196	Gravels and boulders	19.00			1		1
35	3115	Various silts and gravels, some sand	27.00	1	1	1		
36	11032	White pumicey, sandy ignimbrite	96.00					1
37	3506	Grey silt	10.00	1				
38	10152	Gravel	74.00			1		
39	3212	Silts, sand, gravel	9.00	1	1	1		

Id no.	Well no.	Description of lithology at total depth	Depth (m)	Fines	Sand	Gravel	Rock	Other
40	3338	Samples of strata collected by client's engineer - various brown siltbound gravels to cobbles	70.00	1	1	1		
41	3504	Brown silt, gravel, sand	9.00	1	1	1		
42	184	Boulders and gravels	28.20		1	1		1
43	4904	Grey and white rhyolite	84.00				1	
44	203	Gravels	35.00			1		
45	2953	Brown grey sands, gravels	16.00		1	1		
46	194	Gravels	19.00			1		
47	2994	Sands Greywacke Gravel	26.00		1	1		
48	3202	Sands & Gravel	9.50		1	1		
49	3589	Grey sand, pumice, gravel	22.00		1	1		
50	1270	Gravels	17.00			1		
51	2713	Gray blue sands and gravels	18.50		1	1		
52	2979	Sands, pumice, gravels	19.00		1	1		1
53	1318	Yellow clay becoming white green pumice	26.00	1				
54	2975	Gray silt	19.00	1				
55	10153	Red rhyolite	65.00				1	
56	1148	Gravels	9.10			1		
57	3472	Boulders, rock and silts - water loss	60.00	1				1
58	3483	Coarse blue gravels - water loss	8.50			1		
59	2923	Clay bound gravel	12.80	1		1		
60	3231	Silts, sands and gravel	42.00	1	1	1		
61	3350	Gray silt	86.00	1				
62	11503	Green silts, boulders	36.00	1				1
63	3217	Brown sands and gravel	16.00		1	1		
64	3751	Gravel, silt and clay infill	53.75		1	1		
65	2987	Greywacke gravels and sands	25.00		1	1		
66	2913	Small stones brown in colour.	22.00			1		
67	10154	Indecipherable writing	57.00					1
68	11505	Various coloured ignimbrites	108.00					1
N			68.	20	23	45	5	11
Min			5.21					
Median			24.2					
Mean			31.38					
Max			108.					
Std. dev.			23.72					

Table 13—2: Well location and static water level data for wells in the Rangitaiki River catchment upstream of Aniwhenua Dam. Data sourced from EBOP.

Id no.	Well no.	Depth (m)		SWL (m)	Location (NZMG)	
		Cased	Total		Easting	Northing
1	108	24.40	24.40	11.00	2835300	6301300
2	127	20.80	21.30	7.60	2836900	6301200
3	141	24.00	24.00	0.00	2835300	6301300
4	184	26.60	28.20	13.25	2840200	6300200
5	194	13.00	19.00	0.00	2841500	6302500
6	196-N	13.00	19.00	1.00	2838400	6305100
7	203	20.00	35.00	3.00	2841000	6310900
8	204	19.00	64.01	12.19	2832600	6299400
9	206	13.70	14.00	0.00	2840500	6310800
10	223	9.22	9.22	3.80	2836700	6303500
11	384	7.32	10.70	5.49	2838100	6306900
12	385	6.41	9.10	5.49	2838100	6306800
13	386	3.05	5.20	3.66	2837100	6296300
14	475	0.00	9.10	7.00	2838100	6306900
15	524	6.70	9.25	5.30	2835300	6301700
16	1148	8.10	9.10	5.20	2842100	6303800
17	1217	13.00	14.00	4.00	2835950	6296750
18	1219	30.00	55.00	3.00	2836000	6295500
19	1220	33.00	66.00	32.62	2836000	6295800
20	1253	6.50	19.00	0.00	2833700	6297800
21	1263	6.50	7.50	1.00	2833900	6297500
22	1268	16.20	19.50	4.00	2838200	6299100
23	1270	19.50	30.50	7.00	2841800	6314500
24	1273	15.50	19.50	1.00	2837500	6302500
25	1318	19.20	26.00	9.70	2841900	6309700
26	1319-N	39.60	51.80	0.00	2835020	6296740
27	2583	23.00	26.00	9.50	2836800	6298000
28	2712	10.50	12.00	8.00	2837900	6307000
29	2713	15.60	18.50	10.00	2841800	6311500
30	2811	52.50	84.00	0.00	2802000	6253300
31	2913-N	20.00	22.00	9.50	2843300	6307300
32	2919	7.50	8.30	1.40	2838000	6302800
33	2920	0.00	0.00	0.00	2834100	6295300
34	2923	6.50	7.25	4.50	2842600	6304000
35	2953	14.00	16.00	4.00	2841000	6307800
36	2975	17.00	19.00	0.00	2841900	6306900
37	2979	15.60	19.00	0.00	2841800	6311500
38	2987	22.50	25.00	9.00	2843200	6306500
39	2994	23.20	26.00	6.00	2841500	6303500
40	3115	25.00	27.00	17.00	2838400	6299400
41	3123	23.20	26.00	11.00	2836300	6298900
42	3127	23.50	27.00	11.00	2837900	6298300

Id no.	Well no.	Depth (m)		SWL (m)	Location (NZMG)	
		Cased	Total		Easting	Northing
43	3128	36.00	39.00	12.00	2835600	6298900
44	3133	18.20	21.00	0.00	2837700	6306500
45	3135	15.30	18.00	5.00	2833300	6295100
46	3143	7.00	8.50	3.50	2833300	6295100
47	3202	6.50	9.50	7.00	2841600	6303600
48	3203	6.50	9.00	3.30	2839800	6304200
49	3212	6.50	9.00	4.00	2839100	6306400
50	3213	21.50	24.00	13.00	2837900	6299600
51	3214	33.00	39.00	21.00	2838200	6299200
52	3215	26.00	30.00	12.00	2835900	6299000
53	3216	12.50	15.00	7.00	2842400	6303500
54	3217	14.00	16.00	9.00	2843000	6305800
55	3229	0.00	21.00	0.00	2840600	6301800
56	3230	24.00	27.00	12.00	2836800	6300600
57	3231	34.00	42.00	15.00	2842600	6304800
58	3270	14.00	17.00	6.00	2835900	6302400
59	3309	5.50	9.00	3.00	2806500	6250500
60	3338	36.00	70.00	0.00	2839400	6300000
61	3350	32.50	87.00	11.00	2842600	6308900
62	3472	42.00	60.00	13.00	2842200	6303400
63	3483	6.40	8.50	2.00	2842400	6303930
64	3485	34.00	39.00	13.00	2836200	6297400
65	3504	7.00	9.00	4.00	2839900	6308300
66	3506	7.00	10.00	2.50	2838600	6306900
67	3589	19.00	22.00	8.00	2841700	6311100
68	3670	29.00	33.50	13.00	2838200	6298250
69	3751	0.00	53.75	0.00	2843120	6303470
70	4048	0.00	0.00	0.00	2840400	6301900
71	4257	0.00	50.00	0.00	2838200	6298200
72	4695	0.00	0.00	0.00	2839850	6300900
73	4725	0.00	0.00	0.00	2832600	6298100
74	4779	0.00	0.00	0.00	2840900	6311600
75	4784	0.00	0.00	0.00	2835750	6299700
76	4793	0.00	0.00	0.00	2838250	6297500
77	4809	0.00	0.00	0.00	2841900	6301700
78	4904	52.50	84.00	52.00	2802200	6253200
79	10075	26.50	29.00	1.13	2837800	6296900
80	10152	54.00	74.00	34.50	2838600	6298760
81	10153	32.50	65.00	17.60	2842000	6312000
82	10154	42.60	57.00	42.60	2843300	6311850
83	10156	26.00	32.00	18.00	2835000	6296250
84	10534	8.40	10.00	5.50	2837300	6306100
85	11032	50.00	96.00	17.10	2838400	6310600
86	11214	21.00	24.00	4.00	2838300	6305200

Id no.	Well no.	Depth (m)		SWL (m)	Location (NZMG)	
		Cased	Total		Easting	Northing
87	11503	24.20	33.00	20.90	2842900	6309700
88	11505	12.00	108.00	2.00	2843500	6308400
N						
Min		0.00	0.00	0.00		
Median		15.60	21.00	5.10		
Mean		17.69	27.17	7.52		
Max		54.00	108.00	52.00		

Data provided electronically by EBOP. "N" after well identification number indicates well is part of NERMN network.

Table 13—3: Variables included in the NERMN water quality sampling programme[1].

Field/General Variables:			Trace Elements:[2,4]
1	Conductivity	24	Al-S
2	pH	25	Sb-S
3	Temperature	26	Sb-T
4	Reactive Silica	27	Cd-S
5	Silica	28	Co-S
Major Cations:[3,4]		29	Cr-S
6	Ca-S	30	Cs-S
7	Fe-S	31	Cu-S
8	Mg-S	32	Hg-S
9	Mn-S	33	La-S
10	K-S	34	Li-S
11	Na-S	35	Mo-S
Major Anions:		36	Ni-S
12	Alkalinity-T	37	Pb-S
13	Bromide	38	Rb-S
14	Chloride	39	Se-S
15	Fluoride	40	Ag-S
16	Sulphate	41	Sr-S
Nutrients:		42	Ti-S
17	Ammonia-nitrogen	43	Sn-S
18	Nitrite-nitrogen	44	U-S
19	Nitrate-nitrogen	45	V-S
20	Combined nitrate/nitrite nitrogen	46	Zn-S
21	Total Kjeldahl nitrogen		
22	Dissolved reactive phosphorus		
23	Total phosphorus		

[1] Information from EBOP electronic data files.
[2] Standard chemical symbols used for name of element.
[3] -S indicates dissolved form, requiring sample filtration prior to analysis.
[4] -T indicates total form (i.e., not filtered prior to analysis).

Table 13—4: Water quality monitoring data for well 196[1].

Variable[2,3,4]	Units	Sampling date 09/06/2003	06/04/2004	31/03/2005	27/02/2006	06/03/2007	04/03/2008
Field/General Variables:							
Conductivity	uS/cm	147.5	187.3	-	206.	194.	149.
pH	SU	6.7	6.4	-	6.3	6.4	6.45
Temperature	^oC	15.1	15.1	15.1	15.6	15.4	14.9
Silica	mg/L	66.7	77.7	65.4	-	-	-
MajorCations:							
Ca-S	mg/L	8.65	12.3	8.91	12.2	13.7	9.5
Fe-S	mg/L	3.44	8.02	4.72	10.	10.2	5.7
Mg-S	mg/L	4.34	5.88	4.73	5.41	6.21	4.5
Mn-S	mg/L	0.783	-	0.376	0.637	0.738	0.4
K-S	mg/L	2.5	3.63	2.78	4.19	3.92	2.7
Na-S	mg/L	11.1	14.9	15.6	14.4	14.7	12.
TraceElements:							
As-S	mg/L	0.006	0.004	0.004	0.003	-	0.009
Ba-S	mg/L	-	-	-	0.055	0.08	0.038
B-S	mg/L	0.084	0.179	0.134	0.156	0.194	0.081
Sr-S	mg/L	-	-		0.169	0.185	0.13
Zn-S	mg/L	0.022	0.053	0.025	0.014	0.023	0.005
MajorAnions:							
Alkalinity-Total	mg/L-Ca_3CO_3	69.8	83.	68.9	89.2	-	69.1
Bromide	mg/L	-	-	-	-	0.025	0.025
Chloride	mg/L	7.2	7.9	8.	9.4	9.	6.7
Fluoride	mg/L	0.16	0.31	-	-	-	-
Sulfate	mg/L	1.6	1.	4.	3.1	1.2	1.4
Nutrients:							
Ammonia-nitrogen	mg/L-N	0.27	0.407	0.262	0.45	0.047	0.37
NO_2/NO_3	mg/L-N	0.01	0.003	0.001	0.005	0.037	0.009
Nitrite-nitrogen	mg/L-N	0.001	-	-	-	-	-
Nitrate-nitrogen	mg/L-N	0.009	-	-	-	-	-
TKN	mg/L-N	-	-	0.3	-	0.4	-
Total phosphorus	mg/L-P	1.83	0.07	0.414	0.222	0.252	0.76
DRP	mg/L-P	0.04	0.219	0.433	0.027	0.261	0.82

1 Information from EBOP electronic data files.

2 Standard chemical symbols used for name of element.

3 -S indicates dissolved form, requiring sample filtration prior to analysis.

Table 13—5: Water quality monitoring data for well 1319[1].

Variable[2,3,4]	Units	Sample date 09/06/2003	06/04/2004	31/03/2005	27/02/2006	06/03/2007	04/03/2008
Field/Gen Variables:							
Cond	uS/cm	230.5	229.	-	229.	209.5	225.
pH	SU	7.6	7.4	-	7.4	7.4	7.1
T	^{o}C	15.9	15.8	16.1	15.7	15.8	15.5
Silica	mg/L	62.2	65.8	72.4	-	-	-
Major Cations:							
Ca-S	mg/L	13.9	13.7	13.7	13.9	14.8	15.
Fe-S	mg/L	0.42	0.73	0.72	0.71	0.76	0.77
Mg-S	mg/L	6.79	6.94	6.82	6.65	7.61	6.7
Mn-S	mg/L	0.77	-	0.961	0.902	1.02	0.75
K-S	mg/L	3.72	3.72	3.75	3.65	3.79	3.9
Na-S	mg/L	22.8	23.7	23.4	23.1	24.4	25.
Trace Elements:							
As-S	mg/L	0.024	0.046	0.049	0.048	-	0.031
Ba-S	mg/L	-	-	-	0.031	0.048	0.032
B-S	mg/L	0.124	0.161	0.181	0.179	0.203	0.14
Sr-S	mg/L	-	-	-	0.206	0.218	0.19
Zn-S	mg/L	0.019	0.017	0.008	0.015	0.022	0.004
Major Anions:							
Alkalinity- Total	mg/L-Ca_3CO_3	113.4	103.	104.	104.	-	112.
Bromide	mg/L	-	-	-	-	0.025	0.06
Chloride	mg/L	10.9	9.4	11.3	9.9	9.3	9.5
Fluoride	mg/L	0.23	0.3	-	-	-	-
Sulfate	mg/L	0.25	0.25	1.7	0.25	0.25	0.25
Nutrients:							
Ammonia-nitrogen	mg/L-N	0.58	0.528	0.531	0.54	0.061	0.06
NO_2/NO_3	mg/L-N	0.099	0.037	0.078	0.1	0.151	0.036
Nitrite-nitrogen	mg/L-N	0.002	-	-	-	-	-
Nitrate-nitrogen	mg/L-N	0.097	-	-	-	-	-
TKN	mg/L-N	-	-	0.53	-	-	-
Total phosphorus	mg/L-P	1.13	1.54	-	1.48	1.51	1.2
DRP	mg/L-P	0.685	0.993	-	1.41	1.46	1.2

1 Information from EBOP electronic data files.

2 Standard chemical symbols used for name of element.

3 -S indicates dissolved form, requiring sample filtration prior to analysis.

Table 13—6: Water quality monitoring data for well 2913[1].

Variable[2,3,4]	Units	Sample date 06/04/2004	31/03/2005	27/02/2006	06/03/2007
Field/Gen Variables:					
Cond	uS/cm	110.	-	120.	103.4
pH	SU	7.1	-	7.3	6.9
T	°C	12.6	12.6	14.2	12.8
Silica	mg/L	43.9	45.7	-	-
Major Cations:					
Ca-S	mg/L	7.77	8.28	8.91	8.8
Fe-S	mg/L	0.01	0.01	0.06	0.04
Mg-S	mg/L	3.42	3.57	3.7	3.84
Mn-S	mg/L	-	0.001	0.004	0.001
K-S	mg/L	2.36	2.39	2.49	2.55
Na-S	mg/L	8.45	10.	8.86	9.75
Trace Elements:					
As-S	mg/L	0.001	0.001	0.001	-
Ba-S	mg/L	-	-	0.018	0.04
B-S	mg/L	0.032	0.042	0.036	0.056
Sr-S	mg/L	-	-	0.111	0.107
Zn-S	mg/L	0.024	0.033	0.032	0.028
Major Anions:					
Alkalinity- Total	mg/L-Ca_3CO_3	39.	41.3	42.5	-
Bromide	mg/L	-	-	-	0.025
Chloride	mg/L	6.	7.6	6.7	5.9
Fluoride	mg/L	0.2	-	-	-
Sulfate	mg/L	5.2	6.8	5.4	5.6
Nutrients:					
Ammonia-nitrogen	mg/L-N	0.004	0.052	0.005	0.02
NO_2/NO_3	mg/L-N	0.387	-	0.751	0.523
Nitrite-nitrogen	mg/L-N	-	-	-	-
Nitrate-nitrogen	mg/L-N	-	-	-	-
TKN	mg/L-N		0.05	-	0.3
Total phosphorus	mg/L-P	0.057	0.084	0.078	0.095
DRP	mg/L-P	0.082	0.096	0.064	0.071

1 Information from EBOP electronic data files.

2 Standard chemical symbols used for name of element.

3 -S indicates dissolved form, requiring sample filtration prior to analysis.

13.2 Water quality

Summary statistics for selected sites, (Refer to Figure 5—1 for location of sites**)**

Graphical summaries for selected sites and water quality variables (To interpret the figures please refer to Section 5.2.2/Data analysis techniques.) (Note: where no points are shown on a figure this indicates that no data was available.)

Relationships between selected water quality variables

BOP110014

	Temp. (deg. C)	DO sat (%)	DO conc (mg/L)	Flow (m3/s)	Black disk (m)	Turbidity (NTU)	pH (units)	EC (uS/cm)	Ammoniacal-N (mg/m3)	Nitrate-N (mg/m3)	TN (mg/m3)	DRP (mg/m3)	TP (mg/m3)	g340 (/m)	g440 (/m)	BOD (mg O2/L)	Total coliforms (n/100 mL)	E. coli (n/100 mL)	Enterococci (n/100 mL)	Faecal coliforms (n/100 mL)	SS (g/m3)
N of Cases	159	131	74	142	101	145	145	153	151	130	144	153	153	2	2	147	2	104	105	105	120
Minimum	5.2	97	9.3	4.14	0.09	0.56	6.31	50	1	7	56	11	18	3.02	0.91	0.05	480	0.5	0.5	1	1.1
Maximum	20.5	118	13.2	100.22	3.39	76	8.49	144	80	285	801	35	188	3.56	1.06	1.75	910	2100	1900	2300	215
Median	12	102.8	10.7	11.29	1.91	1.7	7.82	79	6	115	175	21	30	3.29	0.985	0.35	695	40	14	53	4.65
Arithmetic Mean	12.54	103.6	10.73	15.638	1.776	4.194	7.804	78.933	7.278	113.754	196.792	20.758	38.085	3.29	0.985	0.466	695	96.185	50.705	114.952	12.918
Standard Error of Arithmetic Mean	0.276	0.279	0.089	1.095	0.089	0.723	0.026	0.96	0.66	5.73	8.629	0.289	1.982	0.27	0.075	0.027	215	22.588	19.509	24.203	2.38
Standard Deviation	3.481	3.198	0.766	13.047	0.89	8.71	0.31	11.871	8.104	65.33	103.547	3.578	24.521	0.382	0.106	0.333	304.056	230.353	199.906	248.005	26.072
Percentiles																					
1.00%	6.118	97.972	9.3	4.232	0.121	0.617	7.06	56.03	1.01	7	69.16	11.06	19.03	3.02	0.91	0.05	480	0.77	0.5	2.1	1.17
5.00%	7.435	100.01	9.44	5.045	0.232	0.69	7.3	60.3	3	20	92	15	23	3.02	0.91	0.1	480	3.525	1	6.75	1.55
10.00%	8.3	100.6	9.7	5.665	0.49	0.75	7.47	63.8	3	29.5	97.7	16	24	3.02	0.91	0.15	480	7.9	1	14	2
20.00%	9.3	101.1	10.1	6.84	0.899	0.9	7.6	70	4	41.5	115.3	18	26	3.02	0.91	0.2	480	17	3	20.5	2.55
25.00%	9.9	101.23	10.3	7.39	0.993	0.993	7.61	71	4	49	124.5	19	27	3.02	0.91	0.25	480	20.5	4.5	27	2.8
30.00%	10.3	101.4	10.47	8.423	1.136	1.1	7.66	73.36	4.8	67.5	130.7	19	27	3.074	0.925	0.25	523	25.7	6	36	3.05
40.00%	11.11	102	10.6	9.994	1.664	1.325	7.705	76	5	96	152	20	28.7	3.182	0.955	0.3	609	35	11	43.5	3.8
50.00%	12	102.8	10.7	11.29	1.91	1.7	7.82	79	6	115	175	21	30	3.29	0.985	0.35	695	40	14	53	4.65
60.00%	13	104.11	10.9	13.744	2.11	2.1	7.875	81.93	7	135	203.7	22	32	3.398	1.015	0.45	781	51.9	17	67.5	6.15
70.00%	14.4	104.72	11.03	16.168	2.368	2.8	7.95	84.24	7.2	154.5	222.3	23	36	3.506	1.045	0.52	867	68.6	27	97	9.65
75.00%	15.175	105.28	11.2	18.62	2.502	3.225	8.023	86	8	167	240	23	38	3.56	1.06	0.55	910	77.5	31.25	120	12.45
80.00%	16.07	105.7	11.3	21.378	2.64	3.95	8.065	88	9	175.5	265.1	24	41	3.56	1.06	0.65	910	100	34	152	14
90.00%	17.72	108.14	11.8	31.955	2.9	7.5	8.2	93.2	11	193.5	307.3	25	58.4	3.56	1.06	0.9	910	201	64	240	25.5
95.00%	18.455	109.99	11.98	40.39	3.032	18	8.293	96.85	13.95	215	382.5	25.85	85.85	3.56	1.06	1.157	910	284	120	335	52.5
99.00%	20.319	113.14	13.008	65.086	3.377	49.4	8.48	101	61.6	257	537.8	29.97	149.82	3.56	1.06	1.605	910	1462.8	1245.5	1541	137.3

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	Temp. (deg. C)	DO sat (%)	DO conc (mg/L)	Flow (m3/s)	Black disk (m)	Turbidity (NTU)	pH (units)	EC (uS/cm)	Ammoniacal-N (mg/m3)	Nitrate-N (mg/m3)	TN (mg/m3)	DRP (mg/m3)	TP (mg/m3)	g340 (/m)	g440 (/m)	BOD (mg O2/L)	Total coliforms (n/100 mL)	E. coli (n/100 mL)	Enterococci (n/100 mL)	Faecal coliforms (n/100 mL)	SS (g/m3)
N of Cases	159	131	74	143	100	144	145	153	151	129	144	153	153	63	63	146	2	102	103	102	118
Minimum	8.4	97	9.6	8.65	0.3	0.45	6.3	61	1	348	92	11	21	0.88	0.07	0.05	128	0.5	0.5	0.5	1.3
Maximum	18.9	128.7	12.5	51.45	6.33	15	8.44	122	28	825	865	52	88	4.8	0.96	1.8	700	330	130	590	220
Median	13.3	104.4	10.6	22.38	2.145	1.3	7.71	82	7	577	611	22	31	1.8	0.4	0.4	414	16.5	8	24	5.15
Arithmetic Mean	13.152	104.7	10.67	22.699	2.246	1.575	7.687	80.767	7.391	569.837	547.646	22.477	32.118	1.976	0.44	0.474	414	39.515	17.743	51.01	9.653
Standard Error of Arithmetic Mean	0.205	0.335	0.061	0.55	0.108	0.138	0.019	0.52	0.329	8.819	17.844	0.378	0.612	0.103	0.024	0.027	286	6.571	2.529	8.499	1.893
Standard Deviation	2.58	3.833	0.521	6.574	1.077	1.655	0.226	6.427	4.046	100.167	214.125	4.678	7.571	0.819	0.191	0.331	404.465	66.362	25.665	85.832	20.566
Percentiles																					
1.00%	8.509	97.81	9.648	9.692	0.34	0.459	7.155	62	2	349.58	92.94	14	22	0.883	0.078	0.05	128	0.5	0.5	0.5	1.368
5.00%	9.39	100.21	10	12.615	0.755	0.52	7.3	70	3	385.95	125.7	17	24	0.965	0.183	0.1	128	2.6	0.825	6	2
10.00%	9.8	100.7	10.1	14.639	1.03	0.587	7.49	73	4	427.4	135.8	18	25	1.08	0.23	0.15	128	4.7	1.8	8	2.4
20.00%	10.5	101.7	10.23	17.279	1.295	0.706	7.555	77	5	482.1	435.6	20	27	1.3	0.29	0.2	128	8	3	11	3.21
25.00%	11	102	10.3	18.397	1.465	0.79	7.6	78	5	504.25	501.5	20	28	1.4	0.29	0.25	128	9	4	14	3.8
30.00%	11.22	102.78	10.37	19.144	1.64	0.9	7.62	79.04	5.8	512.6	524.1	20	29	1.44	0.32	0.25	185.2	9.1	4	16.1	4.19
40.00%	12.1	103.59	10.5	20.632	1.895	1.2	7.67	81	6	540.4	570.5	21	30	1.6	0.394	0.35	299.6	13	5.7	18.3	4.6
50.00%	13.3	104.4	10.6	22.38	2.145	1.3	7.71	82	7	577	611	22	31	1.8	0.4	0.4	414	16.5	8	24	5.15
60.00%	14	105.2	10.7	23.665	2.46	1.4	7.74	82	7	605.9	633.7	23	32	2.03	0.46	0.45	528.4	19.4	11.3	27	6.46
70.00%	14.68	106.02	10.9	25.556	2.675	1.6	7.79	83	8	620	670	24	34	2.3	0.5	0.55	642.8	29.7	15.6	36.9	8.13
75.00%	15.1	106.6	11	27.227	2.81	1.7	7.8	84	8	640	699.5	24	34	2.4	0.515	0.6	700	35	17	42	11
80.00%	15.7	107	11.07	28.113	2.985	1.9	7.81	84.88	9	655.8	718.8	25	35	2.527	0.586	0.7	700	42.4	27.8	63	13.18
90.00%	16.76	108.88	11.31	31.108	3.495	2.31	7.9	86.26	12.4	692.4	769.1	27	39.2	3	0.692	0.99	700	91.1	47.4	113	17.91
95.00%	17.255	110.69	11.66	33.165	4.195	3	8	87.955	15	728.1	794.5	30.85	43	3.635	0.874	1.13	700	202	91.55	212	21.2
99.00%	18.864	117.52	12.332	41.453	5.915	9.83	8.231	89	23.98	789.45	855.6	37.88	61.7	4.683	0.957	1.608	700	324.8	119.4	486	93.52

BOP110016

	Temp. (deg. C)	DO sat (%)	DO conc (mg/L)	Flow (m3/s)	Black disk (m)	Turbidity (NTU)	pH (units)	EC (uS/cm)	Ammoniacal-N (mg/m3)	Nitrate-N (mg/m3)	TN (mg/m3)	DRP (mg/m3)	TP (mg/m3)	g340 (/m)	g440 (/m)	BOD (mg O2/L)	Total coliforms (n/100 mL)	E. coli (n/100 mL)	Enterococci (n/100 mL)	Faecal coliforms (n/100 mL)	SS (g/m3)
N of Cases	73	0	74	43	26	64	61	68	74	45	68	74	75	45	43	59	2	54	59	59	80
Minimum	9.1	.	6	29.771	0.49	0.55	6.8	63	5	188	50	15	18	1.38	0.07	0.2	160	0.5	0.5	3	0.3
Maximum	21	.	13.8	104.354	4.79	22	7.5	135	134	536	339	68	75	6.91	1.61	6	880	1500	590	1700	19.8
Median	14.4	.	9.9	63.426	1.822	2.1	7.2	90.55	24	389	159.5	33	41	2.76	0.46	0.8	520	17	8	28	2.85
Arithmetic Mean	14.377	.	9.929	63.667	1.926	3.213	7.151	90.263	25.946	386.778	165.868	32.892	42.82	3.179	0.624	0.91	520	58.157	26.415	89.322	3.914
Standard Error of Arithmetic Mean	0.372	.	0.124	3.016	0.212	0.513	0.019	1.233	1.917	12.65	5.854	1.154	1.211	0.184	0.059	0.107	360	27.989	10.159	31.264	0.458
Standard Deviation	3.175	.	1.069	19.78	1.081	4.1	0.152	10.169	16.488	84.858	48.271	9.929	10.492	1.235	0.39	0.823	509.117	205.674	78.033	240.146	4.093
Percentiles																					
1.00%	9.123	.	6.12	29.771	0.49	0.596	6.8	64.08	5.24	188	50.72	15	18.5	1.38	0.07	0.2	160	0.5	0.5	3	0.3
5.00%	9.615	.	8.32	32.505	0.546	1.07	6.964	72.9	7.2	250.5	109.6	18.2	27.5	1.783	0.2	0.262	160	0.6	0.725	4.45	0.9
10.00%	10.28	.	9.1	40.015	0.61	1.2	7	79.02	12.7	289	119.3	20	31	2.26	0.23	0.44	160	1.9	1	7.8	1
20.00%	11.23	.	9.23	42.899	0.996	1.3	7	82.1	16	311	130	26	35	2.395	0.388	0.5	160	5.3	2	12	1.3
25.00%	11.5	.	9.46	43.366	1.3	1.4	7	84.5	17	316	136.5	26	37.25	2.49	0.46	0.5	160	6	3	15	1.4
30.00%	11.9	.	9.5	47.648	1.36	1.5	7.09	86	18	328	140	27.7	38	2.53	0.46	0.5	232	9.7	4	19.2	1.7
40.00%	13.3	.	9.8	59.254	1.487	1.7	7.1	88.7	21.1	366	147	31	40	2.7	0.46	0.607	376	15	7	23.1	2
50.00%	14.4	.	9.9	63.426	1.822	2.1	7.2	90.55	24	389	159.5	33	41	2.76	0.46	0.8	520	17	8	28	2.85
60.00%	15.43	.	10.1	68.831	1.994	2.3	7.2	93.24	25	415	169.3	34.9	43	3.105	0.578	0.9	664	23	11.9	33	3.15
70.00%	16.16	.	10.4	80.068	2.149	2.63	7.2	95	28	437	177.1	36	46	3.22	0.69	1	808	30.3	14	42.8	3.85
75.00%	16.75	.	10.4	80.576	2.475	2.8	7.2	96	32	452.5	191.5	37	48	3.45	0.69	1	880	33	20.75	47.5	4
80.00%	17.28	.	10.6	80.974	2.57	3.34	7.3	97.09	34	470.5	204.6	38.7	51	3.45	0.69	1.07	880	37.4	25.7	62.1	4.35
90.00%	19.02	.	11.105	85.154	3.555	4.77	7.4	100.7	41	506	232.5	43.1	57	5.07	1.38	1.26	880	68.2	59.8	196	8.5
95.00%	19.3	.	11.3	97.002	4.254	12.6	7.4	101.42	44	512	247.3	50.4	63.25	6.39	1.61	1.81	880	196	73.1	353	14.35
99.00%	21	.	13.392	104.354	4.79	22	7.5	129.42	115.28	536	326.4	67.52	73	6.91	1.61	5.757	880	1450.4	547.7	1607.3	19.56

Results for Site RO3

Statistic	Temp. (℃)	DO (%sat)	DO conc. (mg/L)	Flow (m3/s)	Visual clarity (m, BD)	Turbidity (NTU)	pH (units)	Electrical conductivity (uS/cm)	Ammoniacal-N (mg/m3)	Nitrate-N (mg/m3)	TN (mg/m3)	DRP (mg/m3)	TP (mg/m3)	g340 (/m)	g440 (/m)
N of Cases	239	238	238	239	239	239	237	239	226	238	222	238	235	239	239
Minimum	7.7	97	9.053	8.645	0.23	0.45	7.33	61.9	0.202	302.391	424.026	11.63	22	0.81	0.11
Maximum	18.9	128.7	13.342	51.45	6.33	15	8.44	110.1	24	1097.148	1190.008	52.2	88.224	7.3	1.9
Median	13.2	104.2	10.727	21.29	1.99	1.2	7.73	83.4	6.008	602.5	669.668	21.356	30	1.717	0.403
Arithmetic Mean	13.131	104.667	10.786	21.632	2.054	1.441	7.751	83.444	6.523	608.581	685.666	21.906	32.309	1.999	0.456
Standard Error of Arithmetic Mean	0.169	0.234	0.038	0.411	0.062	0.084	0.011	0.347	0.215	9.469	10.022	0.3	0.58	0.06	0.015
Standard Deviation	2.616	3.615	0.592	6.353	0.951	1.301	0.164	5.369	3.231	146.08	149.32	4.624	8.889	0.934	0.23
Percentiles															
1.00%	8.489	98	9.662	9.757	0.371	0.46	7.376	66.234	0.999	349.791	432.526	14.868	22.938	0.904	0.12
5.00%	9.2	100.3	9.974	12.026	0.694	0.539	7.503	75.945	2.7	396.2	473.708	17	24.284	1.012	0.19
10.00%	9.74	100.8	10.131	13.756	0.904	0.614	7.57	77.64	3.222	424.163	507.365	17.997	25.532	1.151	0.23
20.00%	10.5	101.81	10.27	16.416	1.23	0.703	7.629	80.2	4	480.029	544.999	19	27	1.324	0.288
25.00%	11	102.1	10.357	16.98	1.34	0.77	7.65	81.025	4.517	501.478	570	19.461	27.982	1.4	0.307
30.00%	11.2	102.69	10.433	18.258	1.46	0.85	7.66	81.6	5	513.942	592.599	19.869	28.452	1.439	0.345
40.00%	12.11	103.2	10.563	19.461	1.73	1	7.7	82.4	5.838	560	629.635	20.292	29.253	1.592	0.364
50.00%	13.2	104.2	10.727	21.29	1.99	1.2	7.73	83.4	6.008	602.5	669.668	21.356	30	1.717	0.403
60.00%	14	105.03	10.901	22.649	2.279	1.4	7.78	84.6	6.934	628.905	718.845	22.258	31.364	1.955	0.46
70.00%	14.78	106.1	11.074	24.558	2.48	1.54	7.81	85.68	7	680.5	764.985	23.004	33	2.235	0.5
75.00%	15.1	106.6	11.19	25.733	2.645	1.6	7.83	86.4	7.572	694.721	775	23.472	34	2.365	0.569
80.00%	15.67	107	11.279	27.216	2.794	1.8	7.86	87.17	8	715.571	795.554	24	35	2.5	0.594
90.00%	16.7	108.97	11.552	29.844	3.168	2.4	7.968	88.7	9.647	820.49	874.619	25.574	39	3.018	0.729
95.00%	17.41	110.92	11.742	32.069	3.616	3	8.056	90.465	12.2	889.823	949.887	26.997	43.468	3.669	0.863
99.00%	18.811	115.236	12.497	37.977	5.162	6.474	8.26	100.54	20.254	982.819	1084.01	43.289	80.53	5.543	1.323

Results for Site RO3

Statistic	BOD5 (mgO2/L)	EColi (/100 mL)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Alkalinity (mg/L)	Chloride (mg/L)	Sulphate (mg/L)
N of Cases	162	47	12	12	12	12	12	12	12
Minimum	0	5.2	4	1.34	7.4	2.21	24.5	3.5	1.4
Maximum	1.25	980.4	4.5	1.95	9.1	2.63	29.5	4.3	3.8
Median	0.35	20.1	4.25	1.635	8.75	2.4	27	4.1	3
Arithmetic Mean	0.376	64.564	4.25	1.646	8.558	2.409	27.125	4	2.758
Standard Error of Arithmetic Mean	0.017	23.95	0.045	0.042	0.151	0.038	0.469	0.076	0.195
Standard Deviation	0.222	164.191	0.157	0.145	0.525	0.133	1.625	0.263	0.676
Percentiles									
1.00%	0	5.2	4	1.34	7.4	2.21	24.5	3.5	1.4
5.00%	0.05	9.355	4.01	1.362	7.46	2.213	24.55	3.5	1.47
10.00%	0.1	11.14	4.07	1.494	7.82	2.231	24.85	3.5	1.89
20.00%	0.2	13.49	4.1	1.578	8.09	2.303	25.45	3.86	2.19
25.00%	0.2	14.5	4.1	1.58	8.2	2.32	26	3.9	2.25
30.00%	0.25	14.72	4.11	1.58	8.31	2.331	26.5	3.91	2.32
40.00%	0.3	18.74	4.2	1.595	8.49	2.346	26.65	4.03	2.65
50.00%	0.35	20.1	4.25	1.635	8.75	2.4	27	4.1	3
60.00%	0.4	23.94	4.3	1.675	8.87	2.454	27.7	4.1	3
70.00%	0.45	29.92	4.39	1.717	8.99	2.469	28	4.19	3
75.00%	0.5	31.55	4.4	1.73	9	2.51	28.5	4.2	3.15
80.00%	0.55	41.33	4.4	1.74	9	2.552	29	4.2	3.32
90.00%	0.7	84.12	4.43	1.803	9.03	2.588	29.15	4.23	3.59
95.00%	0.75	308.08	4.49	1.929	9.09	2.624	29.45	4.29	3.77
99.00%	1.088	980.4	4.5	1.95	9.1	2.63	29.5	4.3	3.8

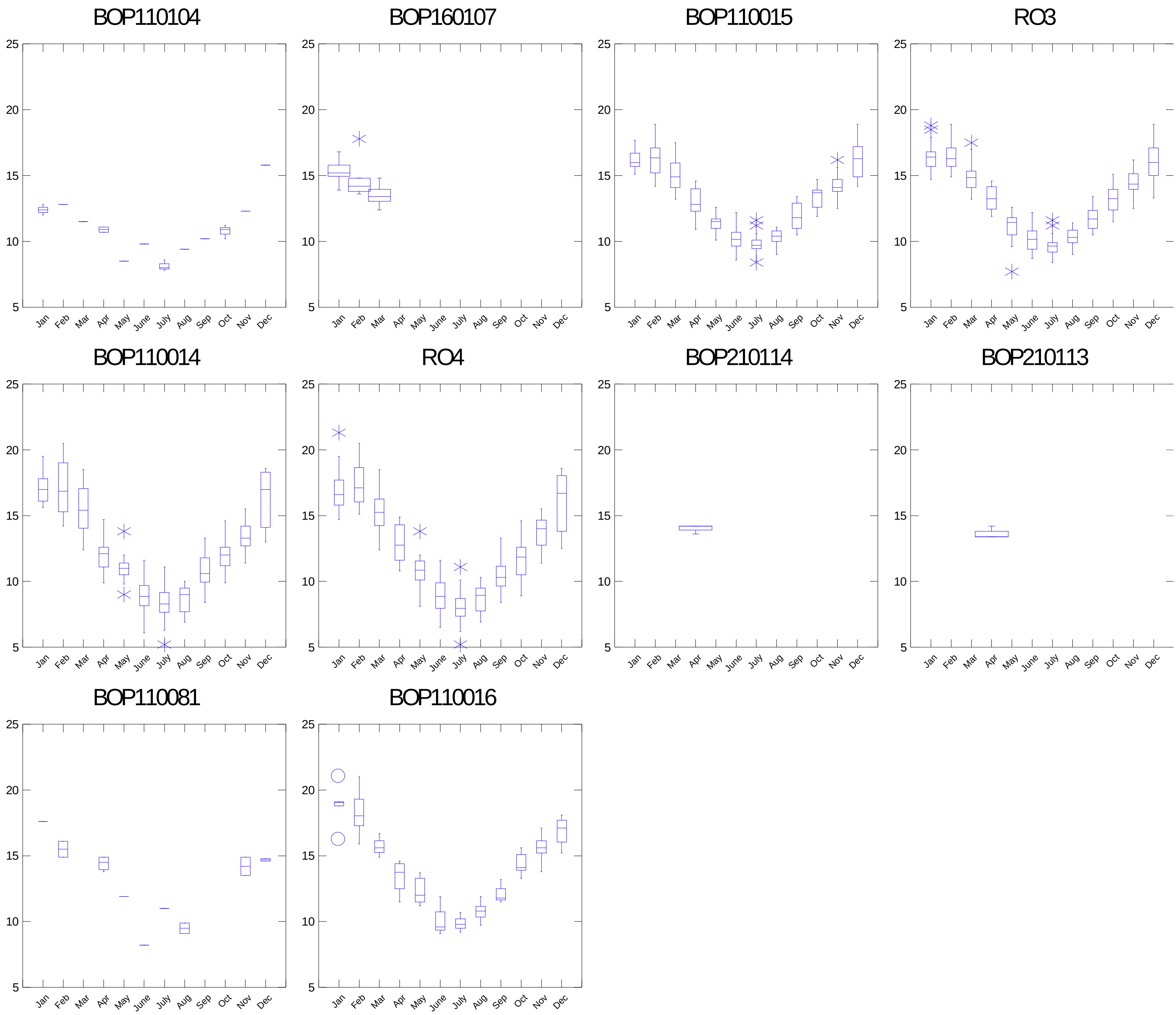
Results for Site RO4

Statistic	Temp. (℃)	DO (%sat)	DO conc. (mg/L)	Flow (m3/s)	Visual clarity(m, BD)	Turbidity (NTU)	pH (units)	Electrical conductivity(uS/cm)	Ammoniacal-N (mg/m3)	Nitrate-N (mg/m3)	TN (mg/m3)	DRP (mg/m3)	TP (mg/m3)	g340 (/m)	g440 (/m)
N of Cases	239	238	238	239	239	239	237	239	226	238	221	238	236	239	239
Minimum	5.2	97	8.986	3.323	0.085	0.56	7.34	50	-0.063	5	70	9	18	2	0.241
Maximum	21.3	118	13.192	100.22	4.08	76	8.49	109.9	15	298.432	993.584	28.821	236.164	14	3.3
Median	12.1	102.4	10.767	11.28	1.82	1.6	7.83	80.3	5	118.773	207.013	20.632	30.294	3.088	0.67
Arithmetic Mean	12.542	103.163	10.779	14.84	1.654	4.292	7.853	79.982	5.325	119.425	218.099	20.471	38.186	3.563	0.747
Standard Error of Arithmetic Mean	0.226	0.184	0.054	0.751	0.055	0.573	0.016	0.686	0.174	4.357	7.335	0.201	1.654	0.104	0.024
Standard Deviation	3.5	2.838	0.832	11.605	0.858	8.865	0.244	10.608	2.619	67.218	109.039	3.102	25.404	1.609	0.367
Percentiles															
1.00%	6.2	98.376	9.109	3.736	0.109	0.62	7.379	56.612	0.591	7.199	77.331	12.76	20.571	2.071	0.305
5.00%	7.19	100	9.6	4.488	0.245	0.724	7.49	61.9	1.997	15.2	95.027	15	23	2.232	0.4
10.00%	8.14	100.33	9.705	5.262	0.452	0.8	7.56	66.08	2.629	29.738	110	16.059	24.524	2.412	0.46
20.00%	9.13	101	9.989	6.846	0.763	0.979	7.649	71.06	3.069	51.089	131.298	18	26.666	2.6	0.516
25.00%	9.8	101.1	10.127	7.458	0.933	1.025	7.678	72.725	3.516	60	140.561	18.67	27	2.695	0.524
30.00%	10.2	101.3	10.218	8.184	1.082	1.1	7.69	74.52	4	72.947	156.426	19	27.952	2.769	0.555
40.00%	11.2	101.9	10.503	9.684	1.454	1.355	7.76	77.3	4.463	103.899	179.928	19.98	29	2.915	0.63
50.00%	12.1	102.4	10.767	11.28	1.82	1.6	7.83	80.3	5	118.773	207.013	20.632	30.294	3.088	0.67
60.00%	13.39	103.4	11.029	13.401	1.979	2.09	7.89	82.49	5.502	139.809	223.303	21.417	32.612	3.28	0.706
70.00%	14.7	104.21	11.237	16.222	2.228	2.68	7.97	84.88	6	161.739	244.663	22.343	35.498	3.525	0.767
75.00%	15.3	104.6	11.347	18.008	2.337	3.175	8.023	87.275	6.491	169.83	265.841	22.75	38.115	3.799	0.838
80.00%	15.7	105.3	11.491	21.035	2.444	4	8.061	88.47	7	179.282	288.853	23	41	4.1	0.894
90.00%	17.56	107.21	11.858	29.192	2.738	7.22	8.188	94.48	8.685	209.4	324.517	24.261	54.883	5.217	1.188
95.00%	18.4	108.46	12.262	38.569	2.906	18	8.29	97.675	10.2	227.637	379.5	25	84.1	6.887	1.471
99.00%	20.411	111.12	12.644	54.269	3.354	49.199	8.48	102.918	14	271.518	602.016	26.569	155.25	9.711	1.99

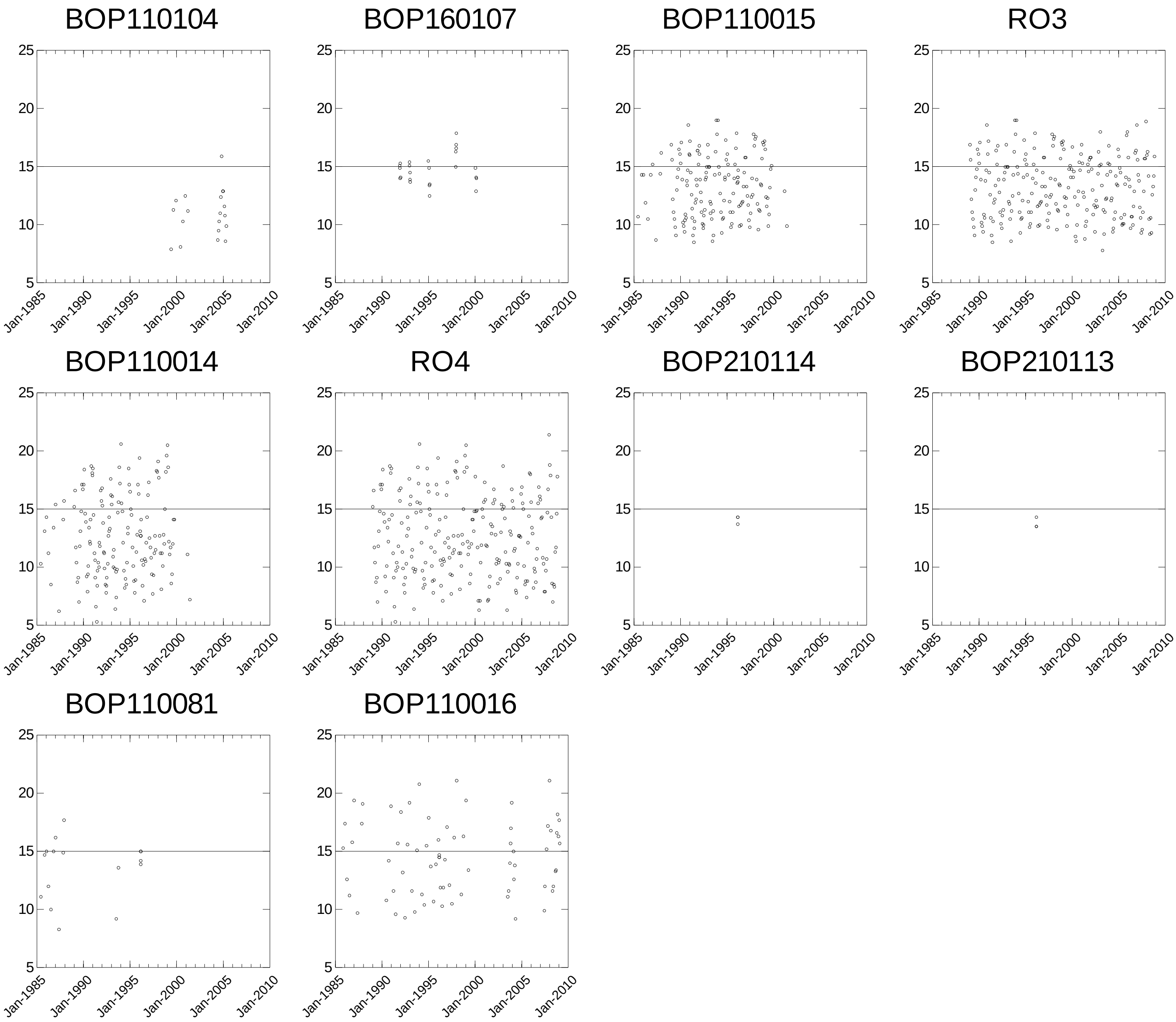
Results for Site RO4

Statistic	BOD5 (mgO2/L)	EColi (/100 mL)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Alkalinity (mg/L)	Chloride (mg/L)	Sulphate (mg/L)
N of Cases	162	47	12	12	12	12	12	12	12
Minimum	0	4.1	4.1	1.1	6.6	1.1	19.5	3.8	2.2
Maximum	1.75	1986.28	5.8	1.94	9	1.72	30.5	7.3	3.8
Median	0.35	41.9	5.1	1.58	8	1.55	25.75	5.9	3.15
Arithmetic Mean	0.379	95.214	5.042	1.563	7.967	1.551	25.667	5.7	3.175
Standard Error of Arithmetic Mean	0.021	41.83	0.159	0.064	0.234	0.048	0.867	0.315	0.128
Standard Deviation	0.264	286.771	0.55	0.221	0.812	0.168	3.003	1.09	0.443
Percentiles									
1.00%	0	4.1	4.1	1.1	6.6	1.1	19.5	3.8	2.2
5.00%	0.05	10.045	4.13	1.128	6.63	1.138	19.8	3.85	2.26
10.00%	0.1	12.84	4.31	1.296	6.81	1.366	21.6	4.15	2.62
20.00%	0.2	18.7	4.49	1.38	7.17	1.489	22.95	4.57	2.89
25.00%	0.2	19.7	4.6	1.415	7.3	1.49	24	4.9	2.9
30.00%	0.25	21.12	4.71	1.457	7.44	1.494	25	5.21	2.92
40.00%	0.265	29.89	4.83	1.535	7.83	1.533	25.15	5.45	3.1
50.00%	0.35	41.9	5.1	1.58	8	1.55	25.75	5.9	3.15
60.00%	0.4	44.92	5.3	1.632	8.31	1.609	26.7	6.14	3.34
70.00%	0.45	63.38	5.48	1.677	8.49	1.675	27.45	6.29	3.49
75.00%	0.5	66.15	5.55	1.685	8.7	1.68	27.5	6.4	3.55
80.00%	0.55	78.64	5.6	1.702	8.9	1.683	27.65	6.56	3.6
90.00%	0.7	142.6	5.66	1.849	8.93	1.713	29.45	7.16	3.66
95.00%	0.9	173.58	5.78	1.927	8.99	1.719	30.35	7.28	3.78
99.00%	1.332	1986.28	5.8	1.94	9	1.72	30.5	7.3	3.8

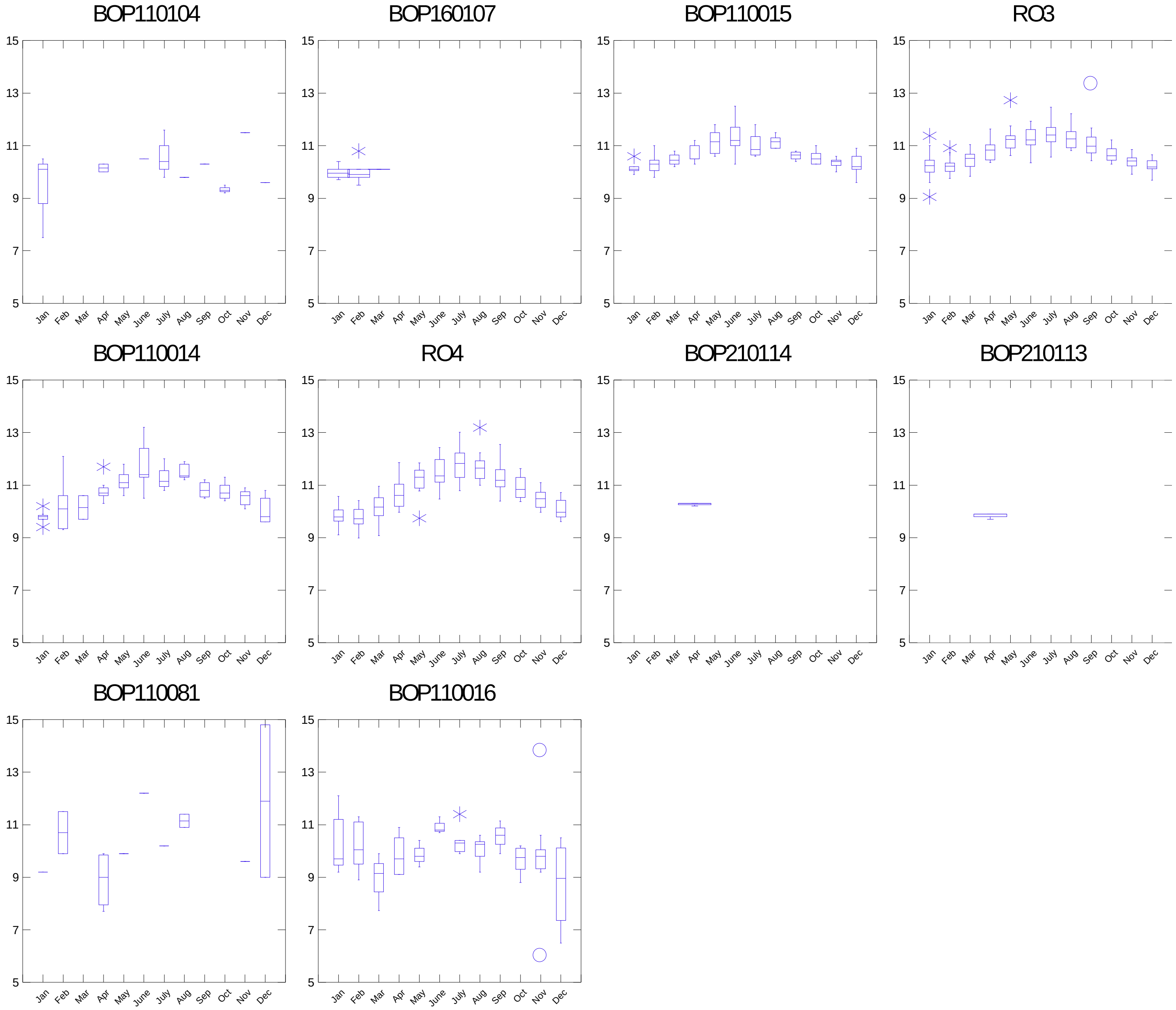
Temperature (deg. C)



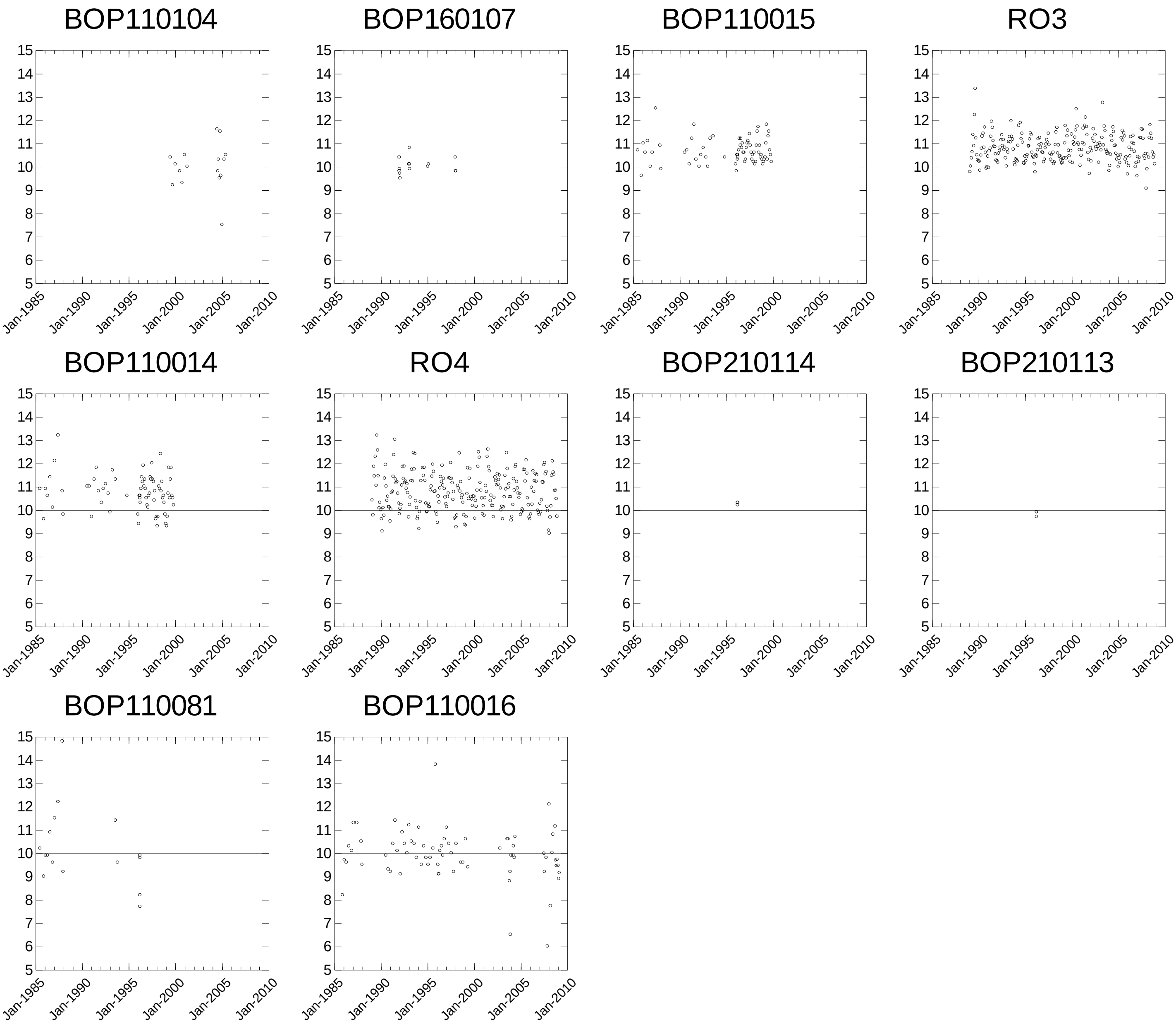
Temperature (deg C)



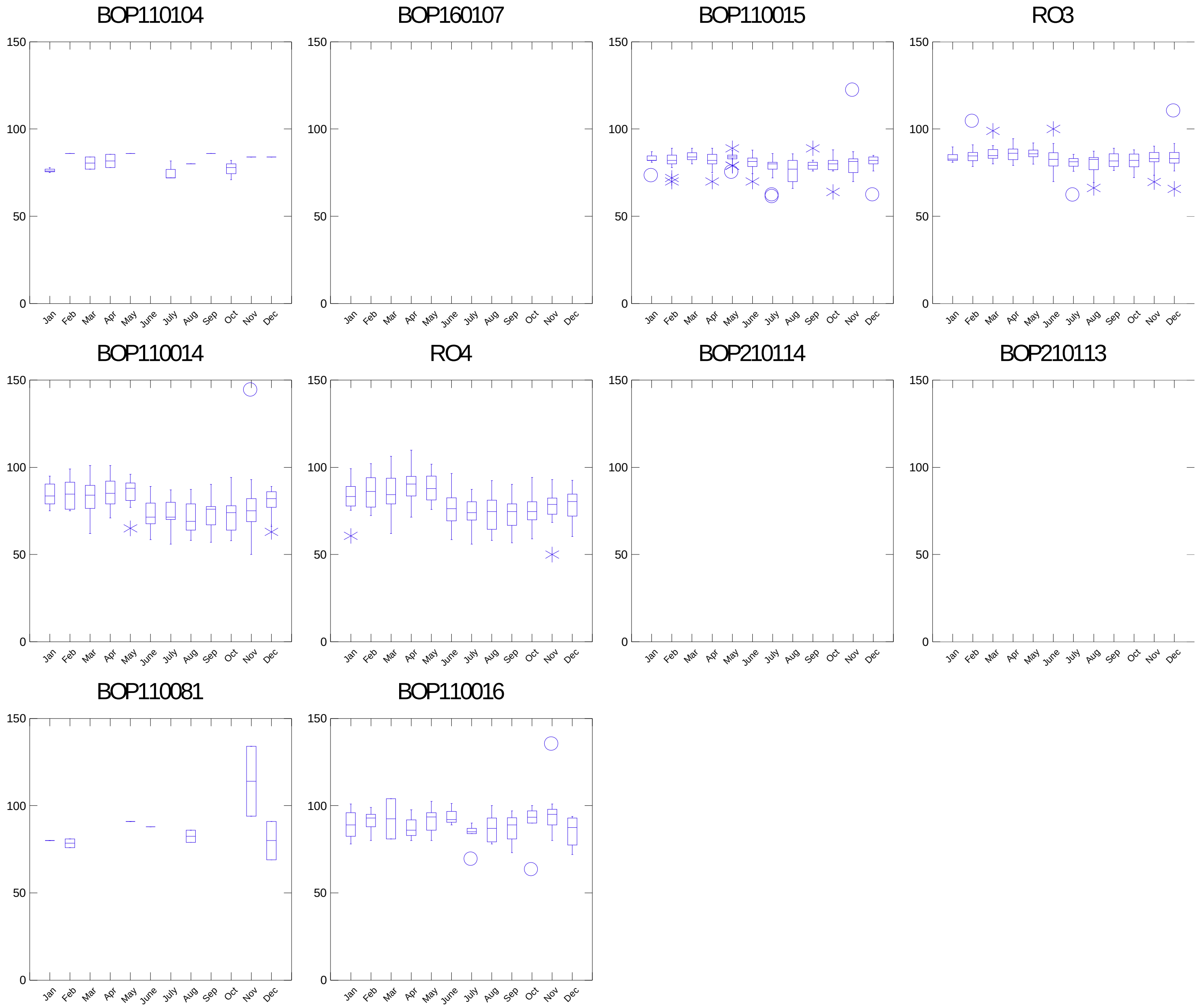
Dissolved oxygen conc. (mg/L)



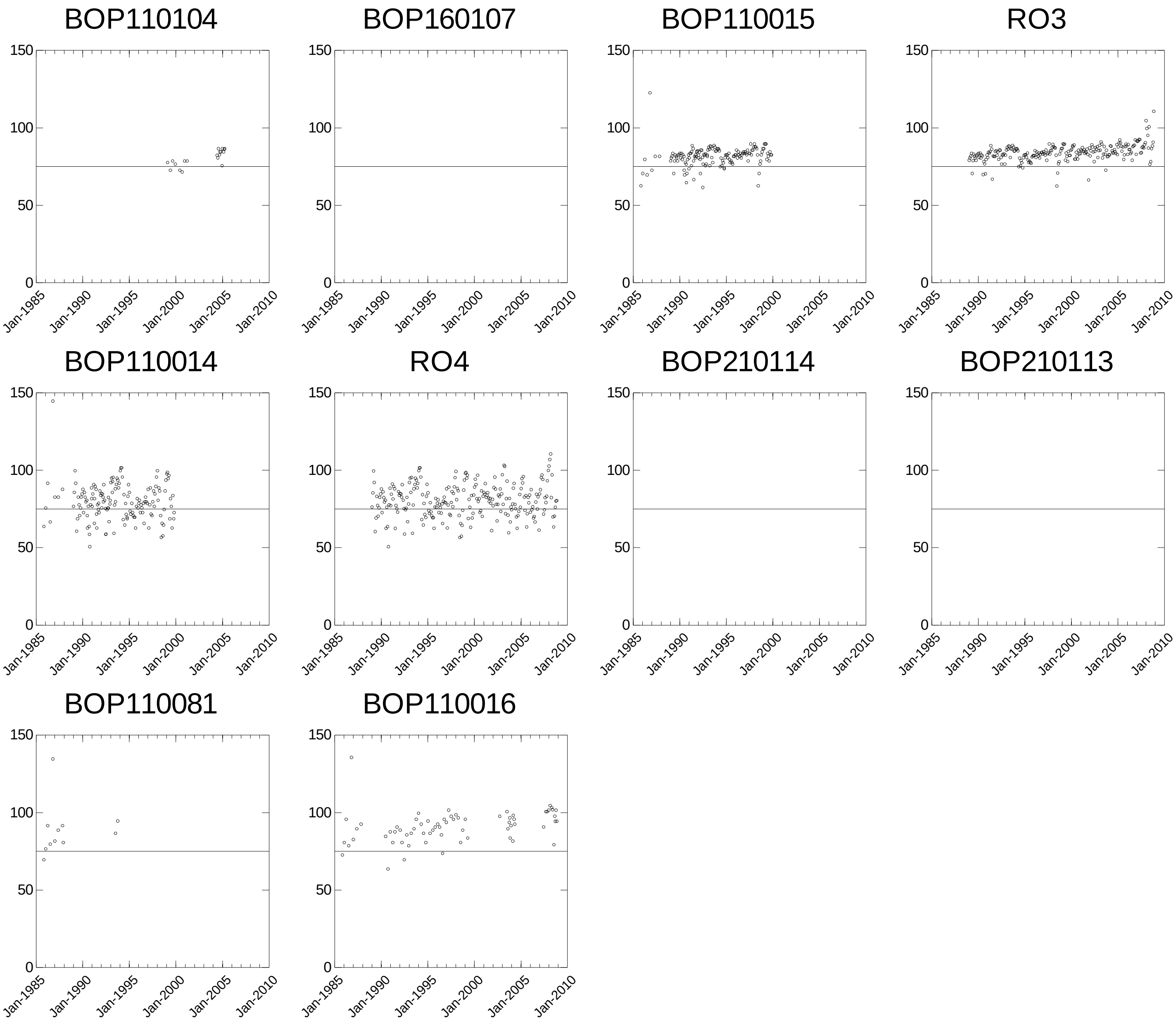
DO concentration(mg/L)



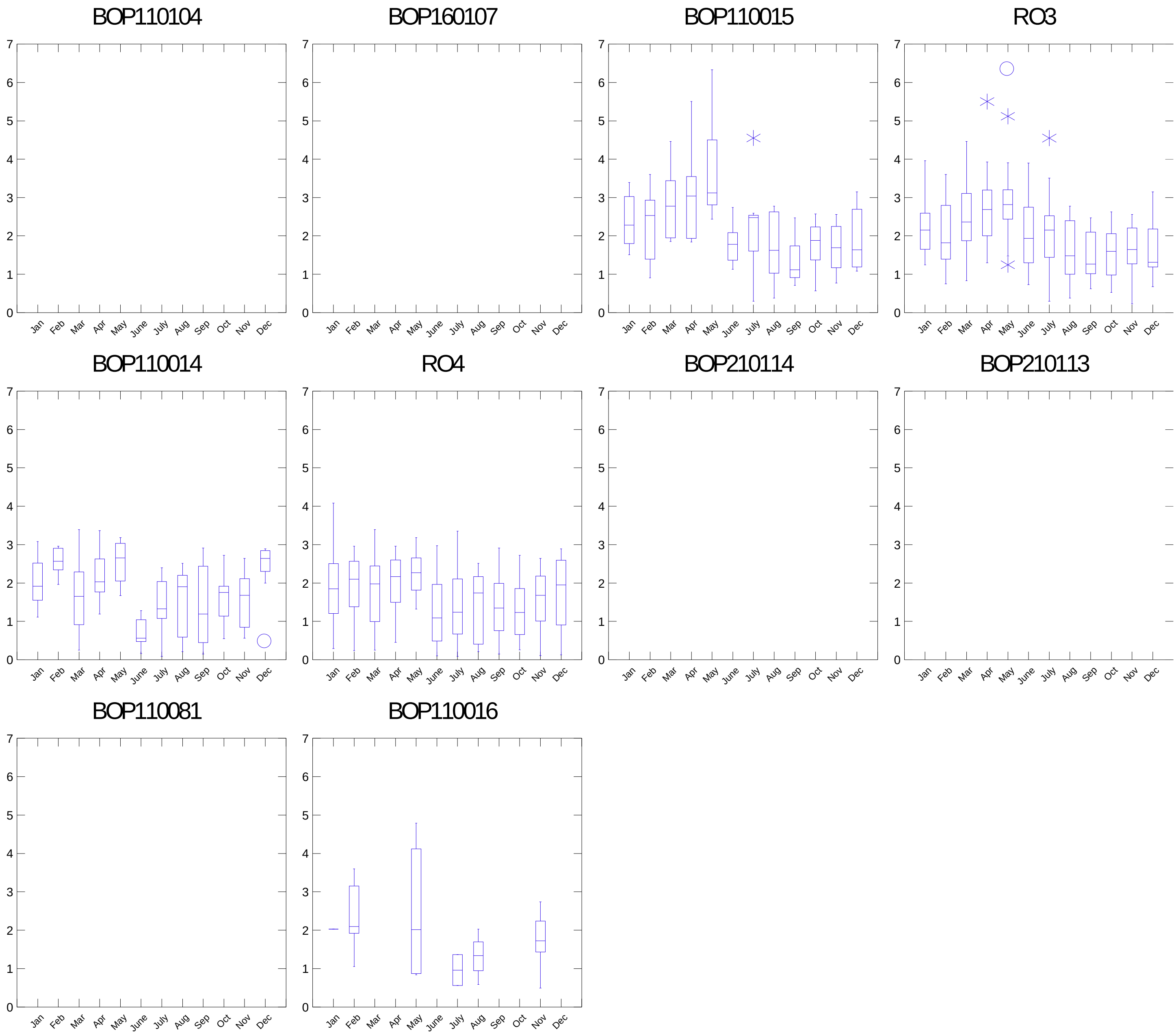
Electrical conductivity (uS/cm)



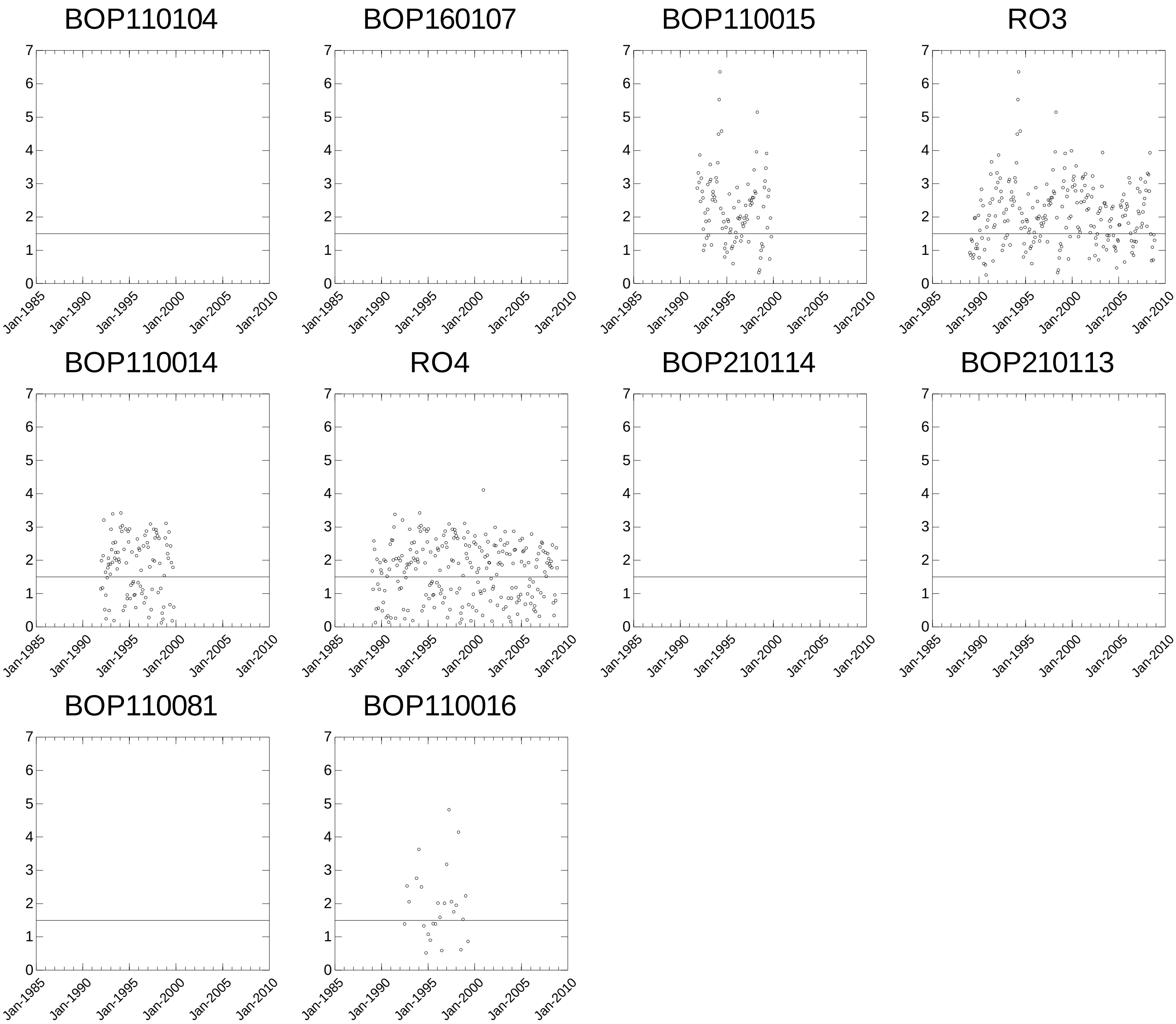
Electrical conductivity (uS/cm)



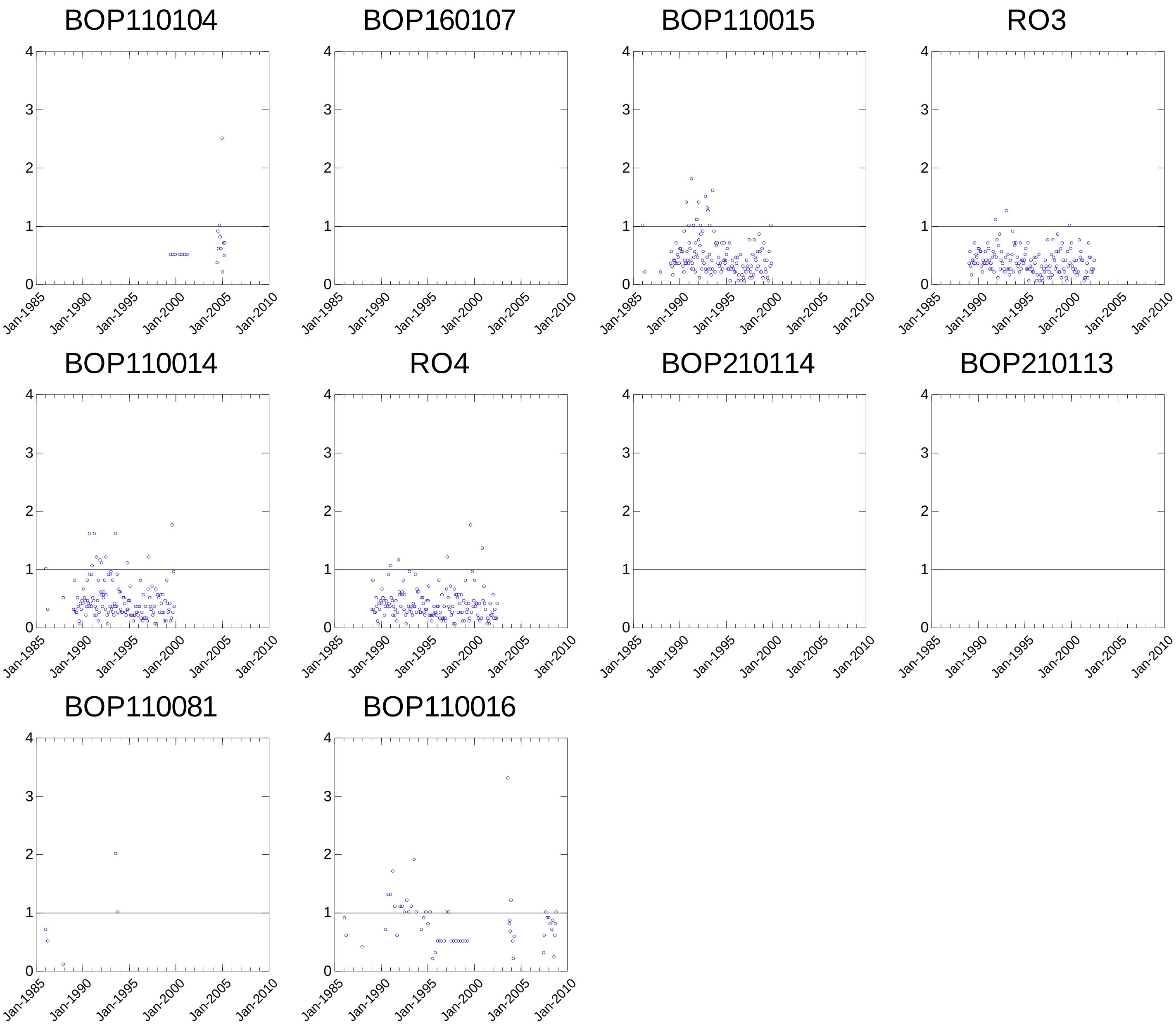
Visual clarity (m)



Black disk clarity (m)

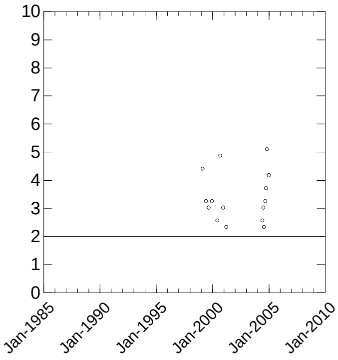


BOD_5 (mg/L)

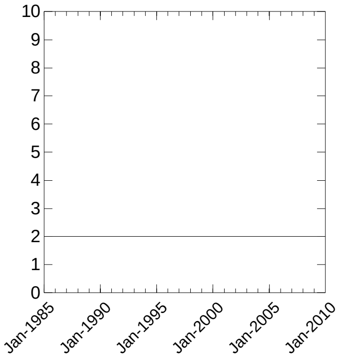

BOP110104
BOP160107
BOP110015
RO3
BOP110014
RO4
BOP210114
BOP210113
BOP110081
BOP110016
0
1
2
3
4
Jan-1985
Jan-1990
Jan-1995
Jan-2000
Jan-2005
Jan-2010

g340 (/m)

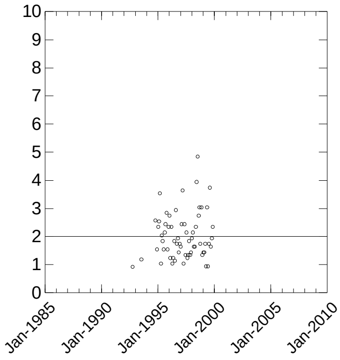
BOP110104



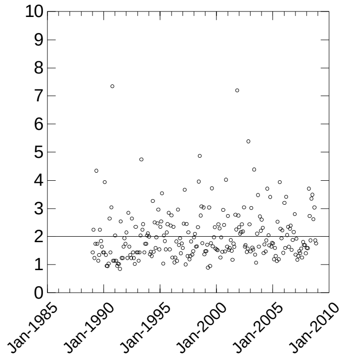
BOP160107



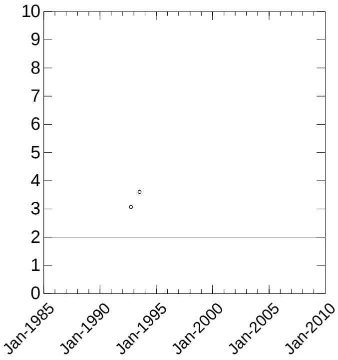
BOP110015



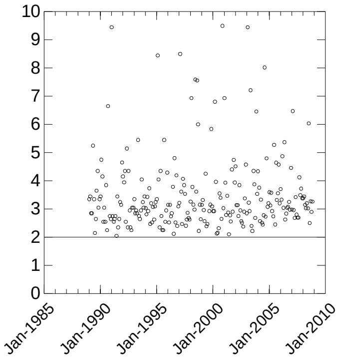
RO3



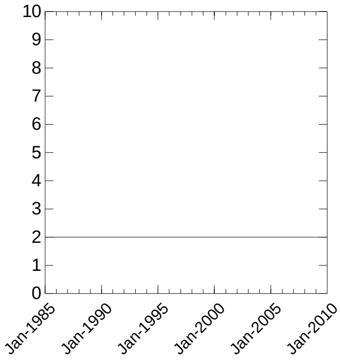
BOP110014



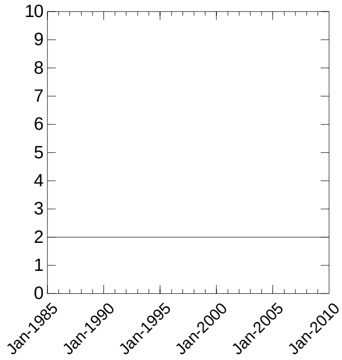
RO4



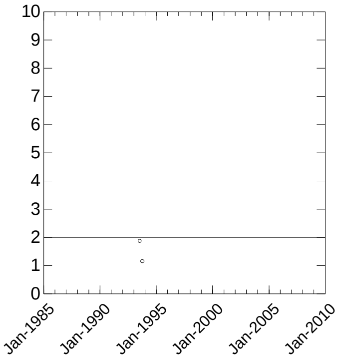
BOP210114



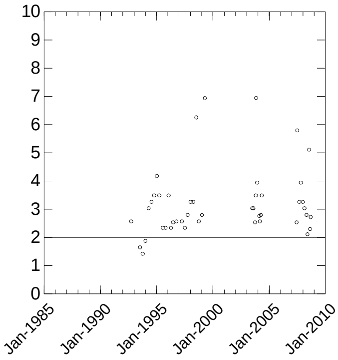
BOP210113



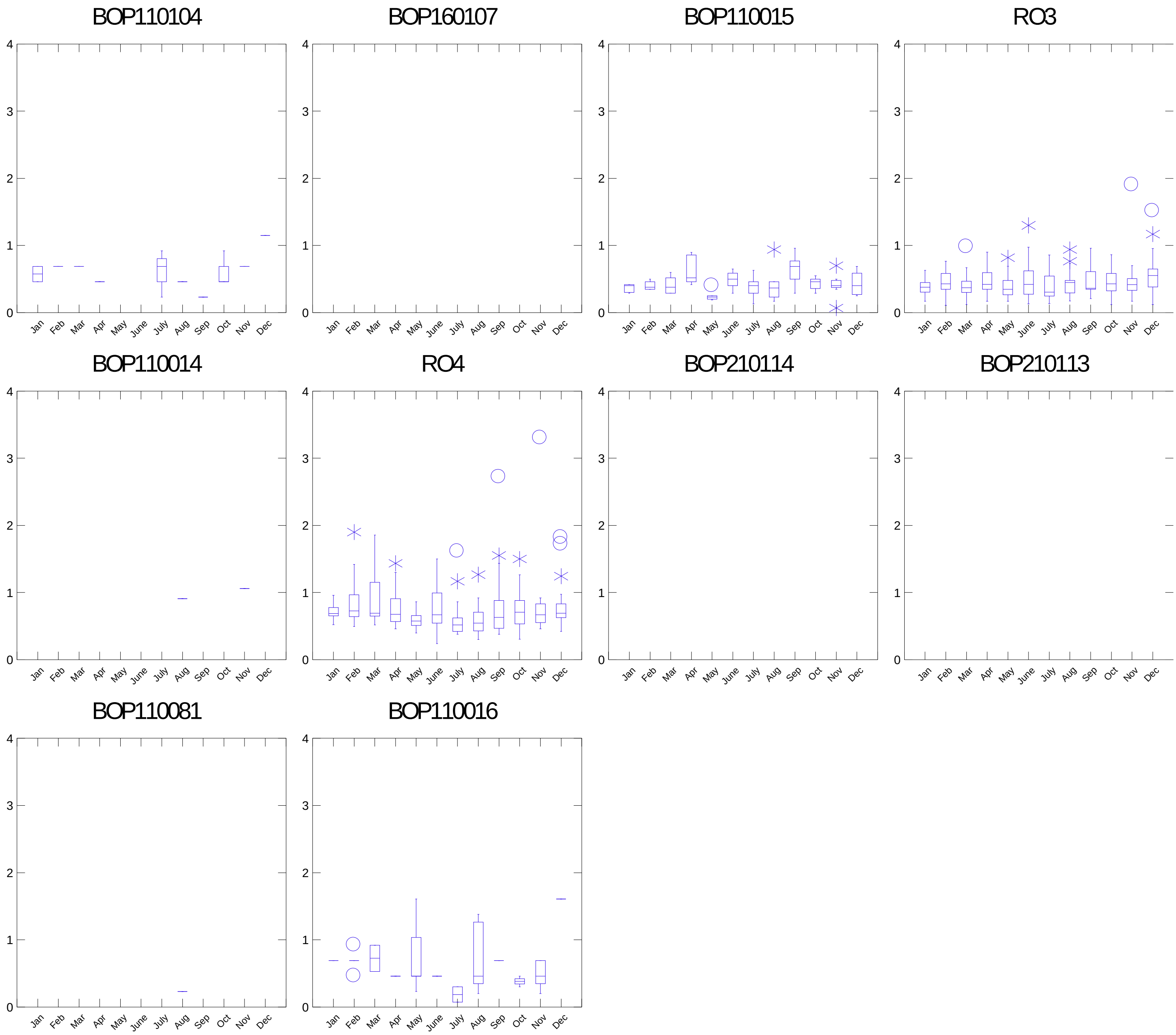
BOP110081



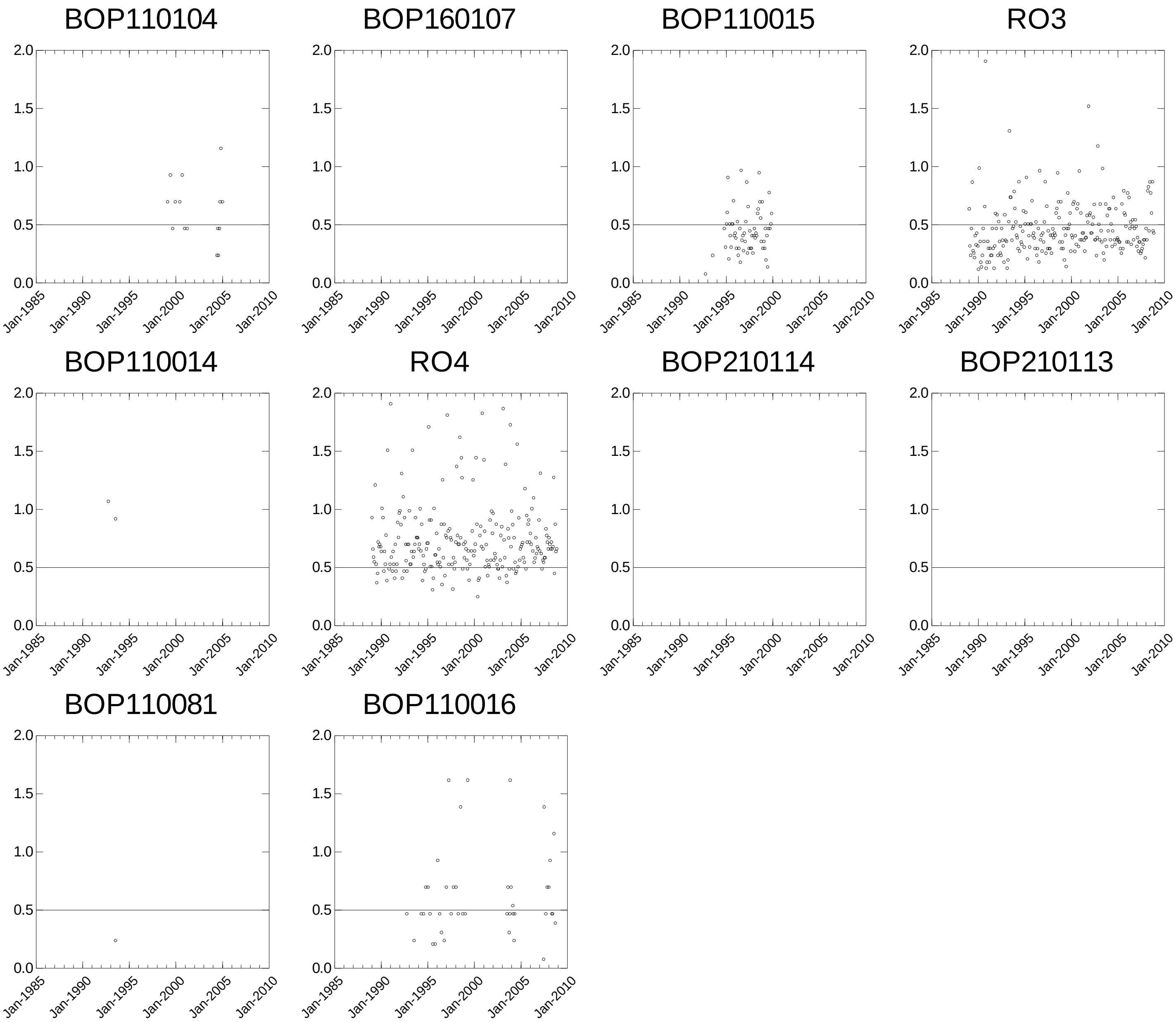
BOP110016



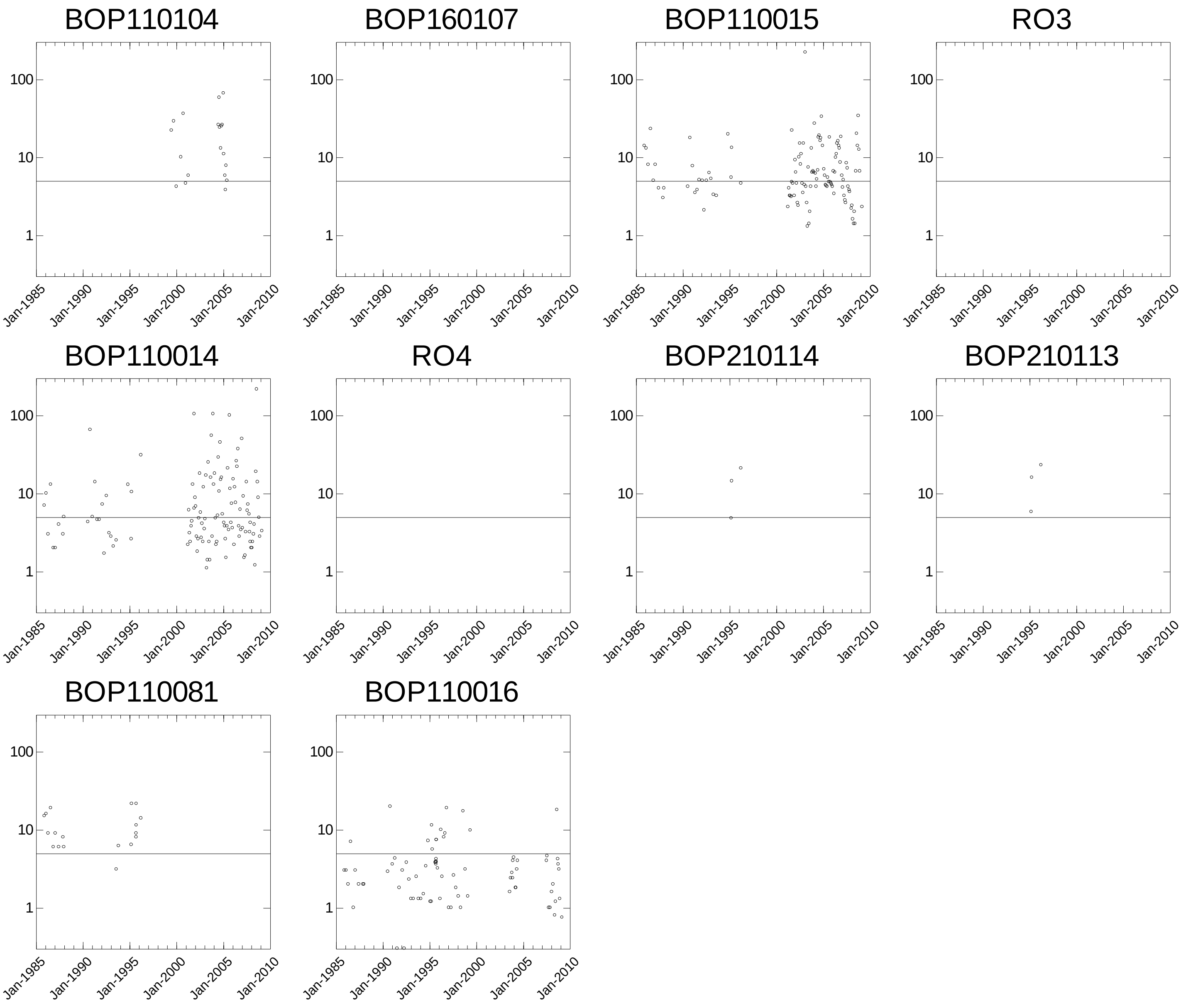
g440 (/m)


BOP110104
BOP160107
BOP110015
RO3
BOP110014
RO4
BOP210114
BOP210113
BOP110081
BOP110016
0
1
2
3
4
Jan
Feb
Mar
Apr
May
June
July
Aug
Sep
Oct
Nov
Dec

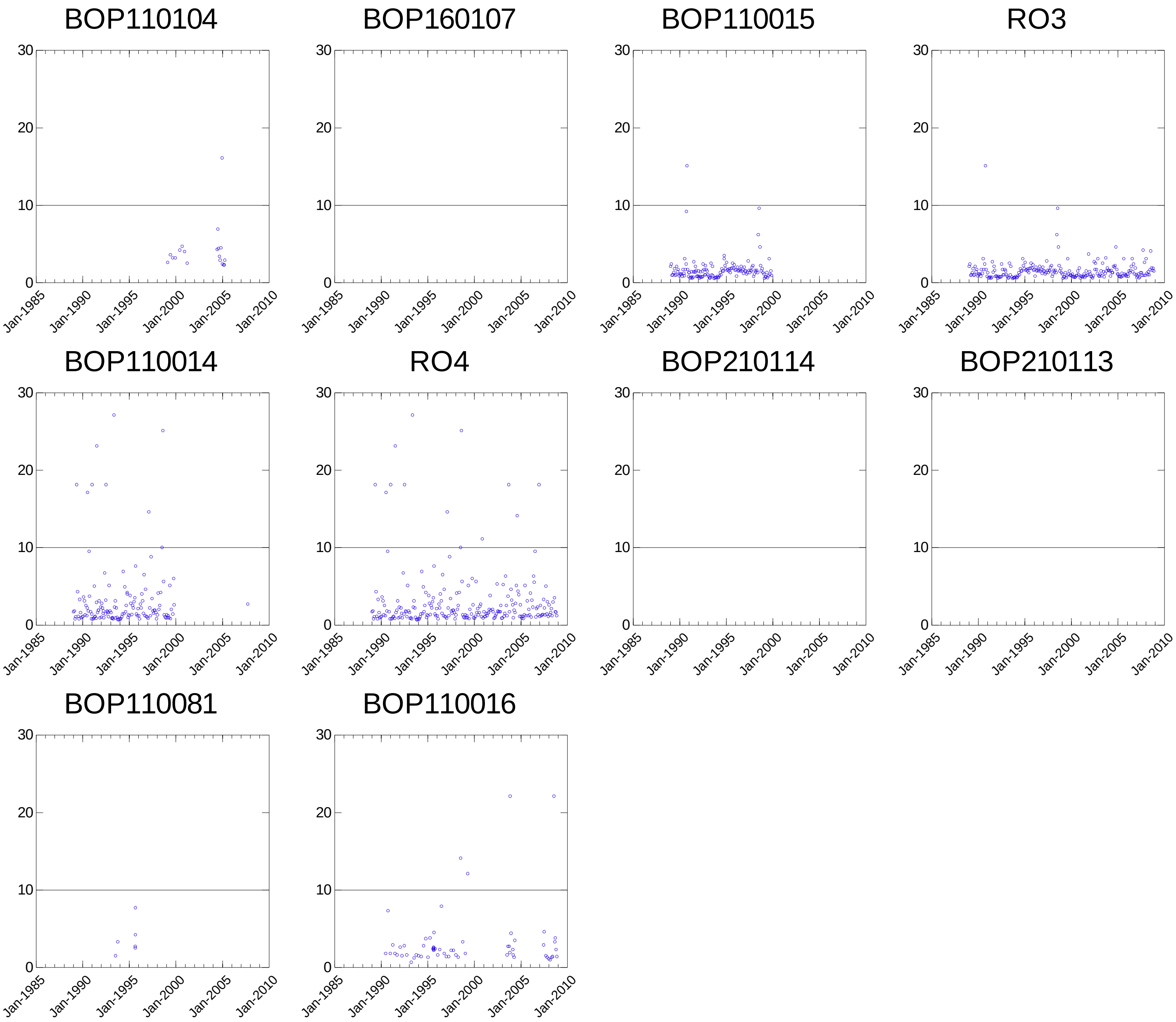
g440 (/m)


BOP110104
BOP160107
BOP110015
RO3
BOP110014
RO4
BOP210114
BOP210113
BOP110081
BOP110016
0.0
0.5
1.0
1.5
2.0
Jan-1985
Jan-1990
Jan-1995
Jan-2000
Jan-2005
Jan-2010

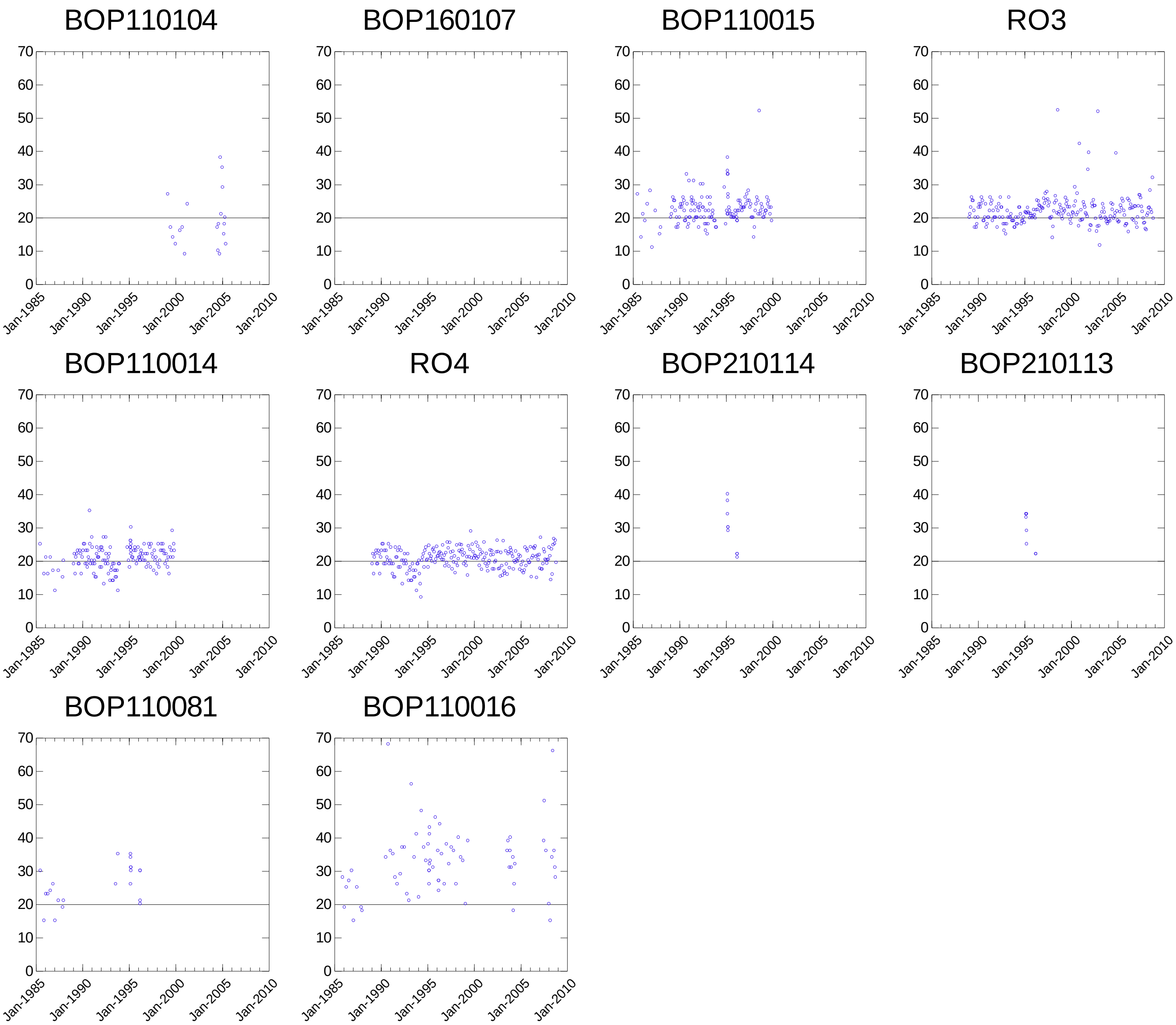
Suspended solids conc. (g/m^3)



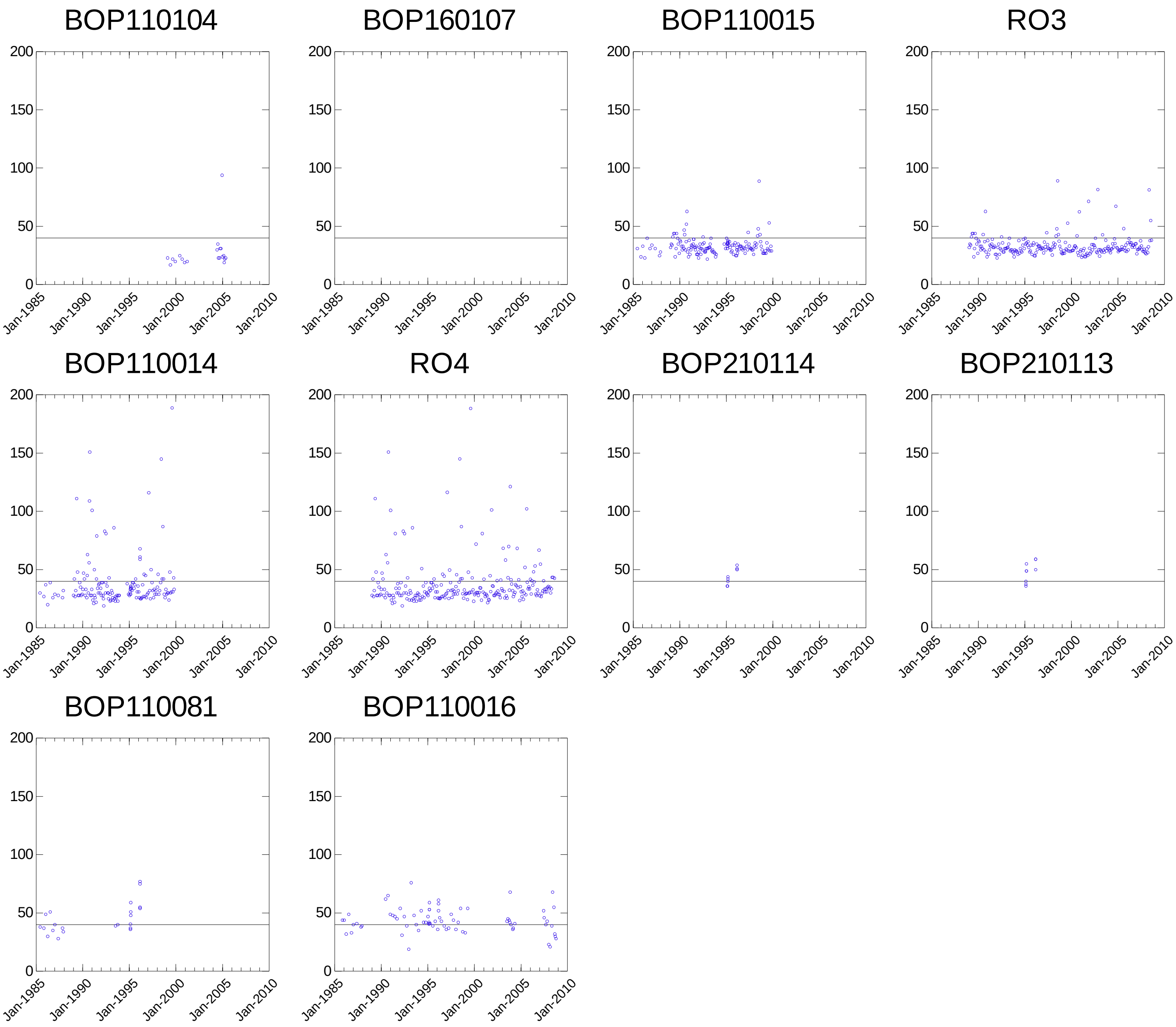
Turbidity (NTU)



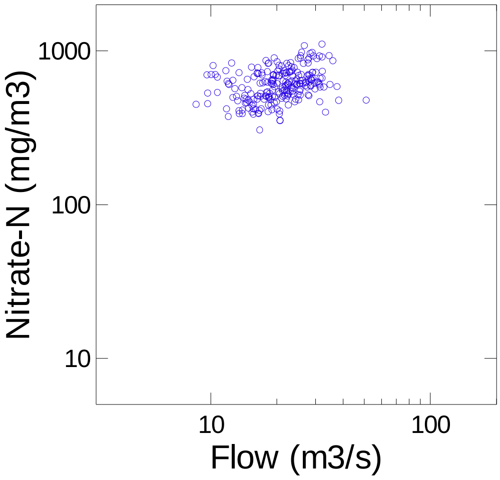
DRP conc. (mg/m^3)



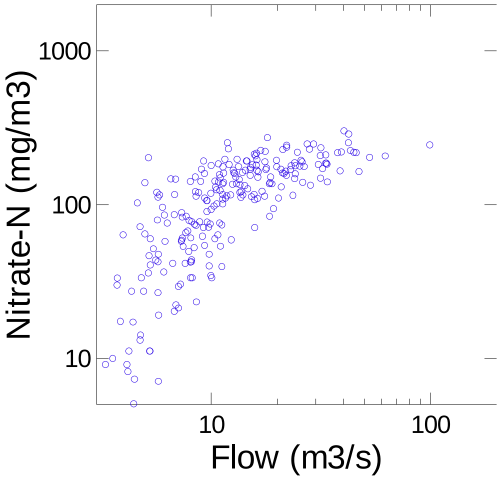
Total P conc. (mg/m^3)



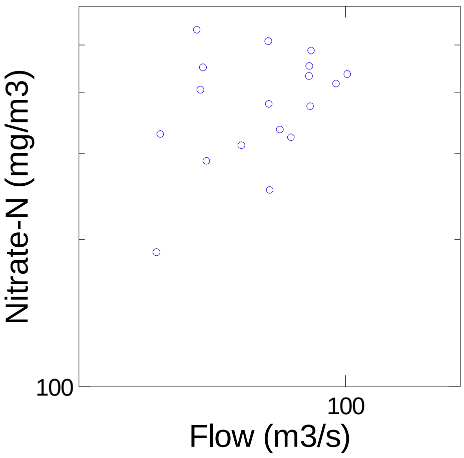
RO3



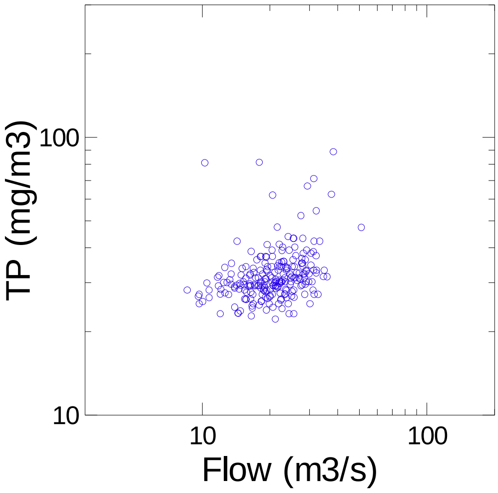
RO4



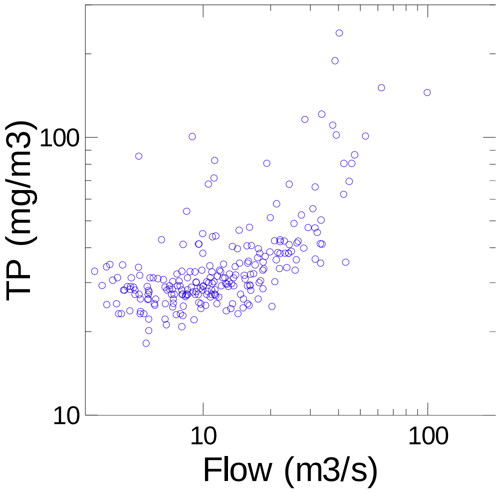
BOP110016, Aniwhenua canal



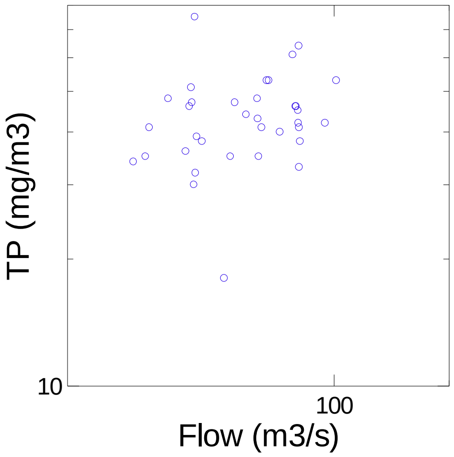
RO3



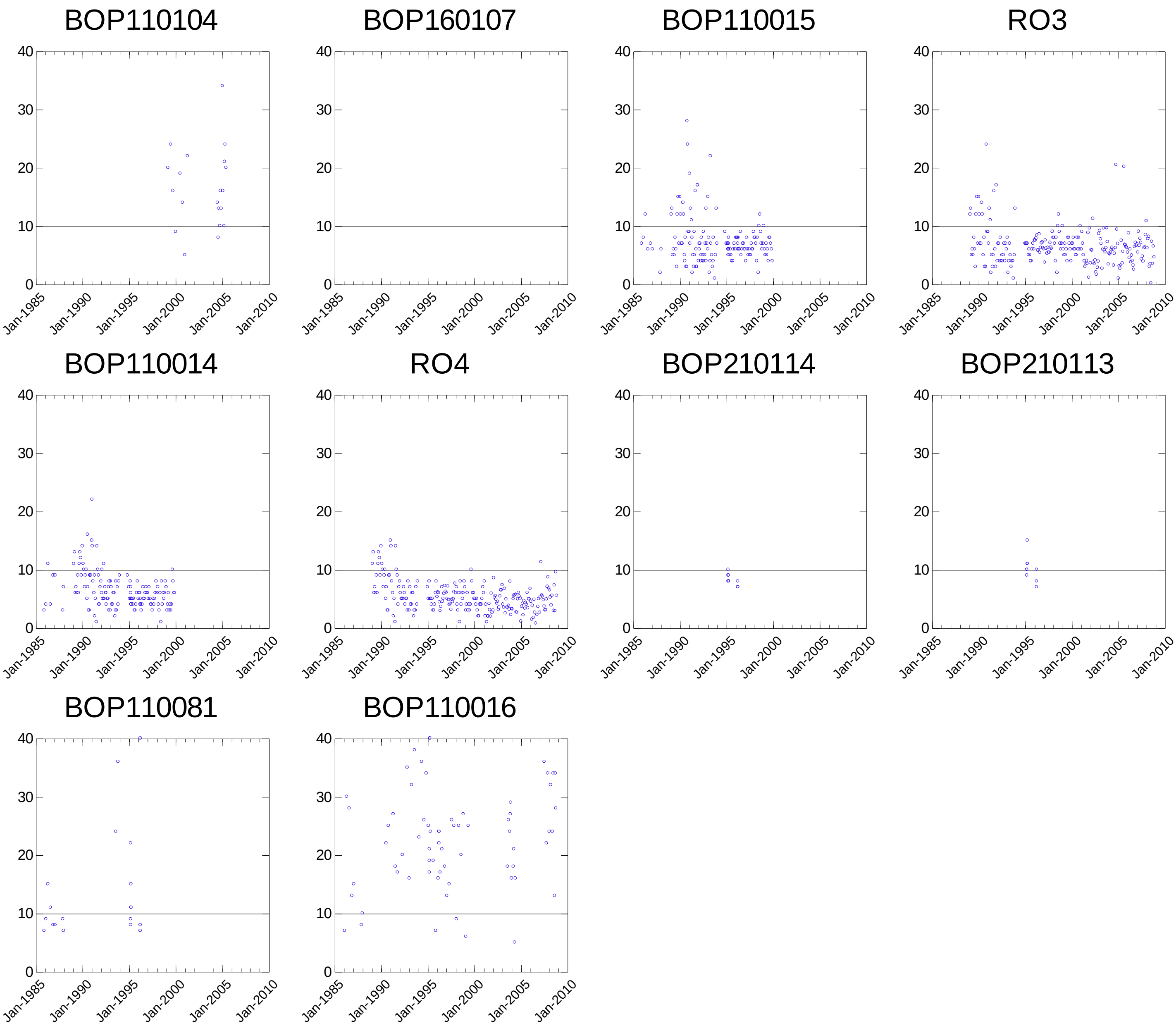
RO4



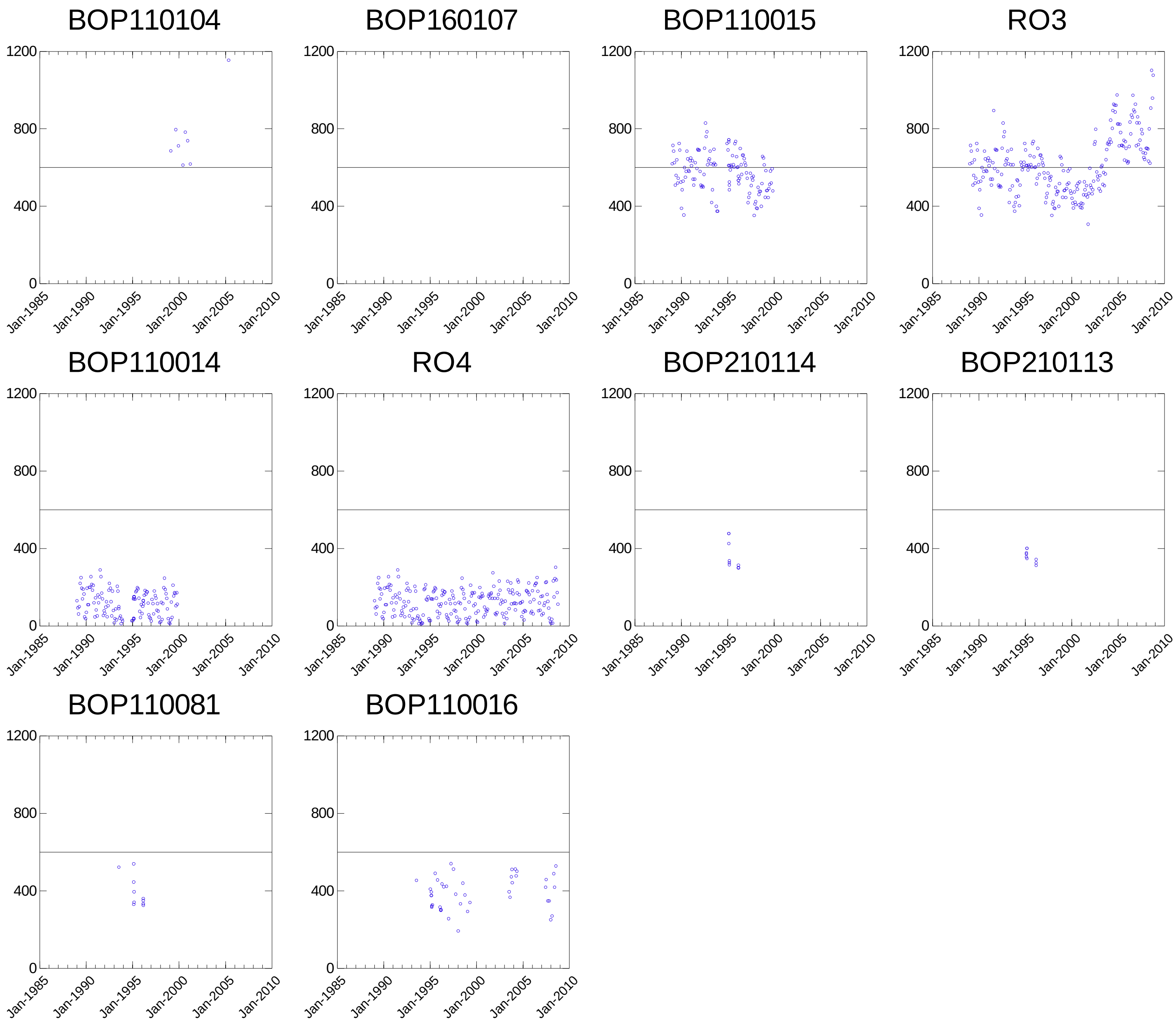
BOP110016, Aniwhenua canal



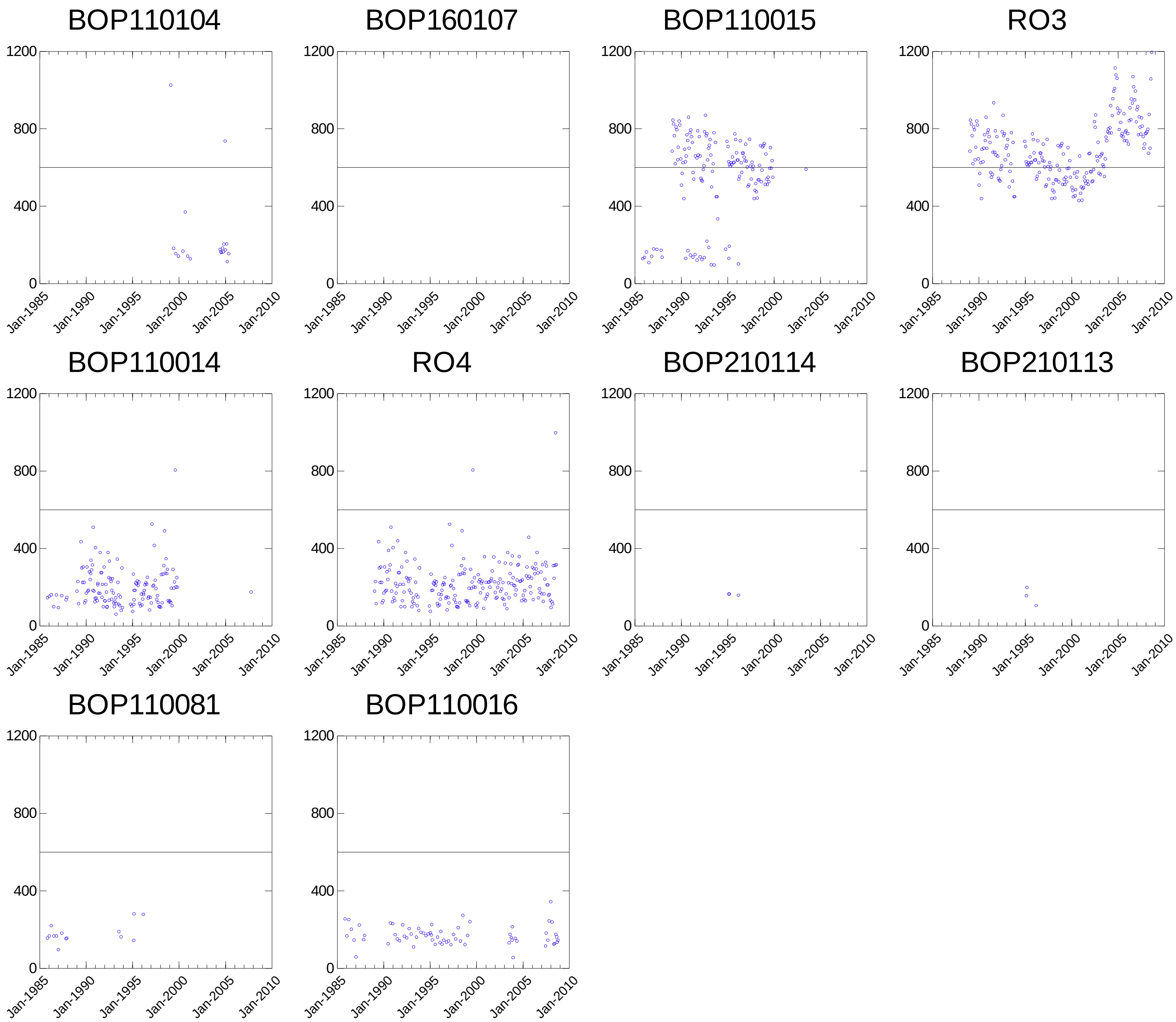
Ammoniacal-N conc. (mg/m^3)



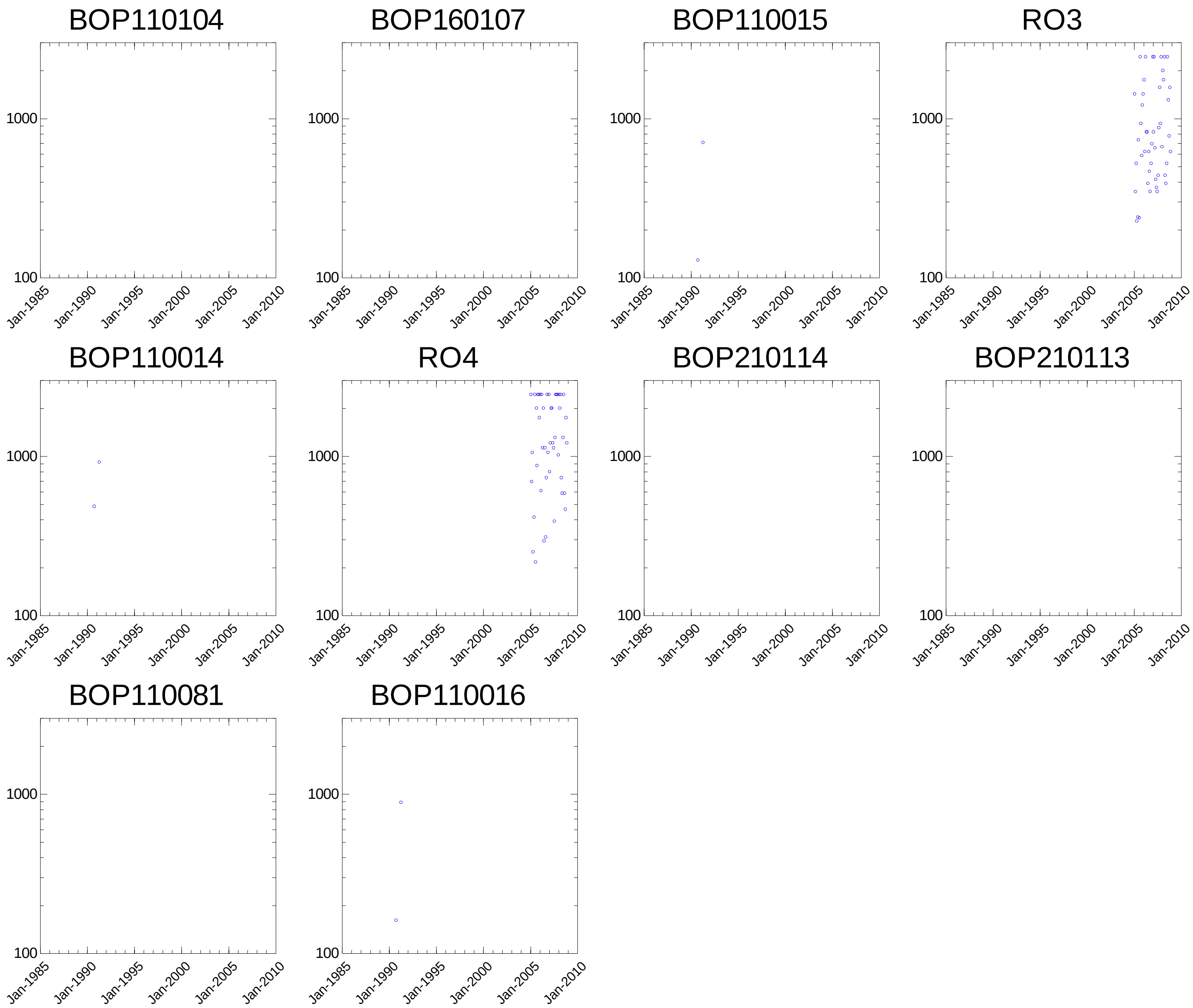
Nitrate-N conc. (mg/m^3)



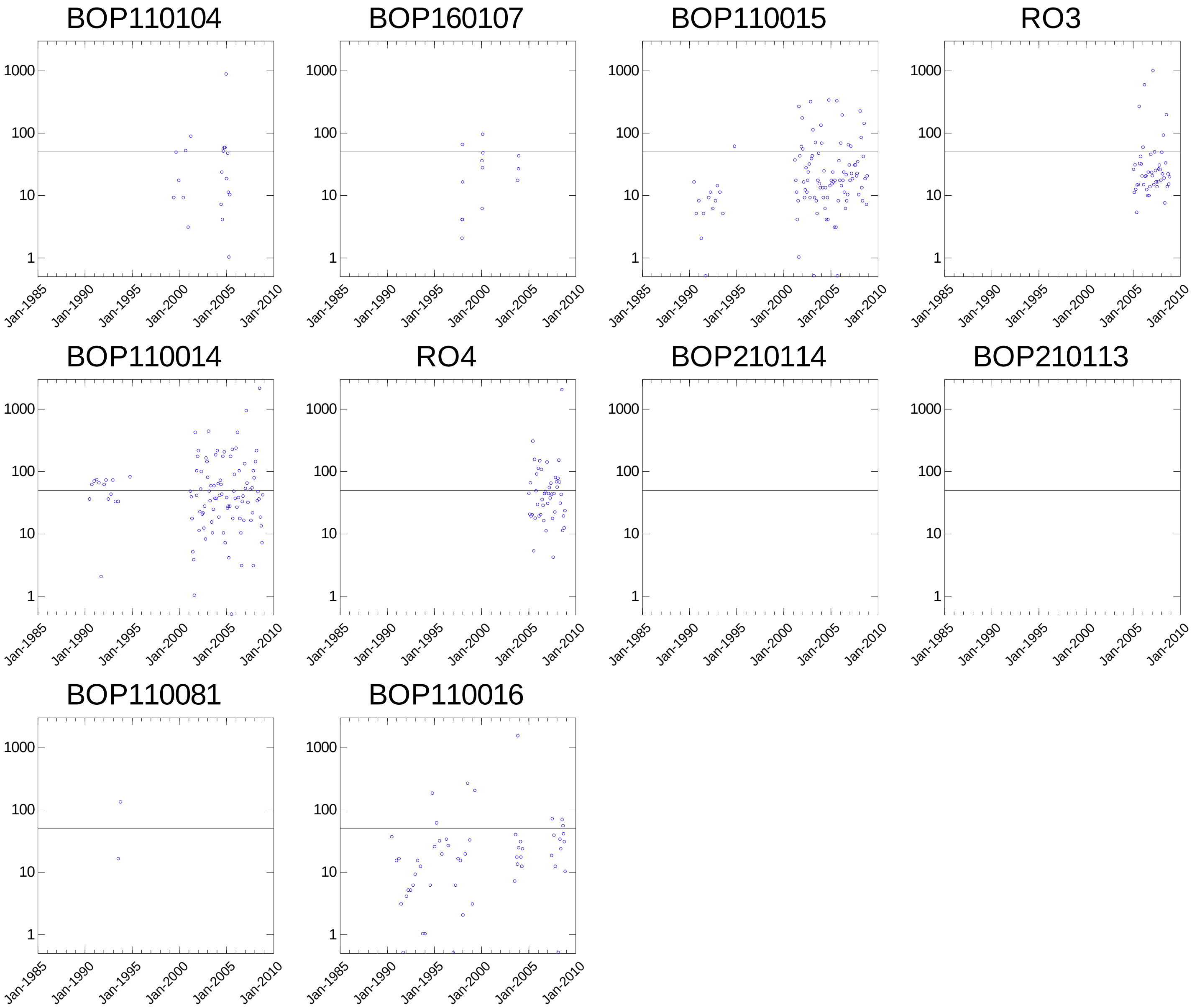
Total N conc. (mg/m^3)



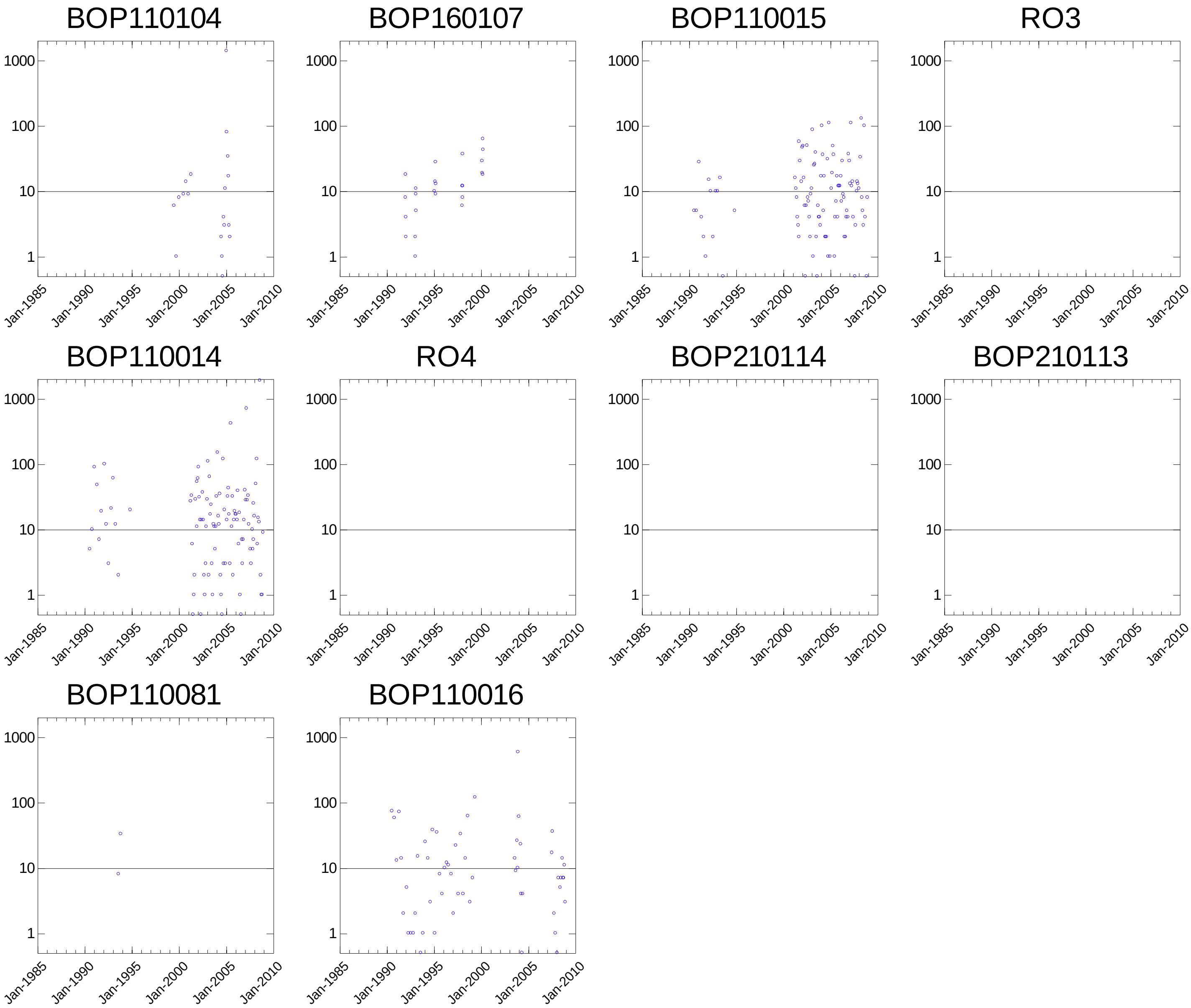
Total coliform conc. (n/100 mL)



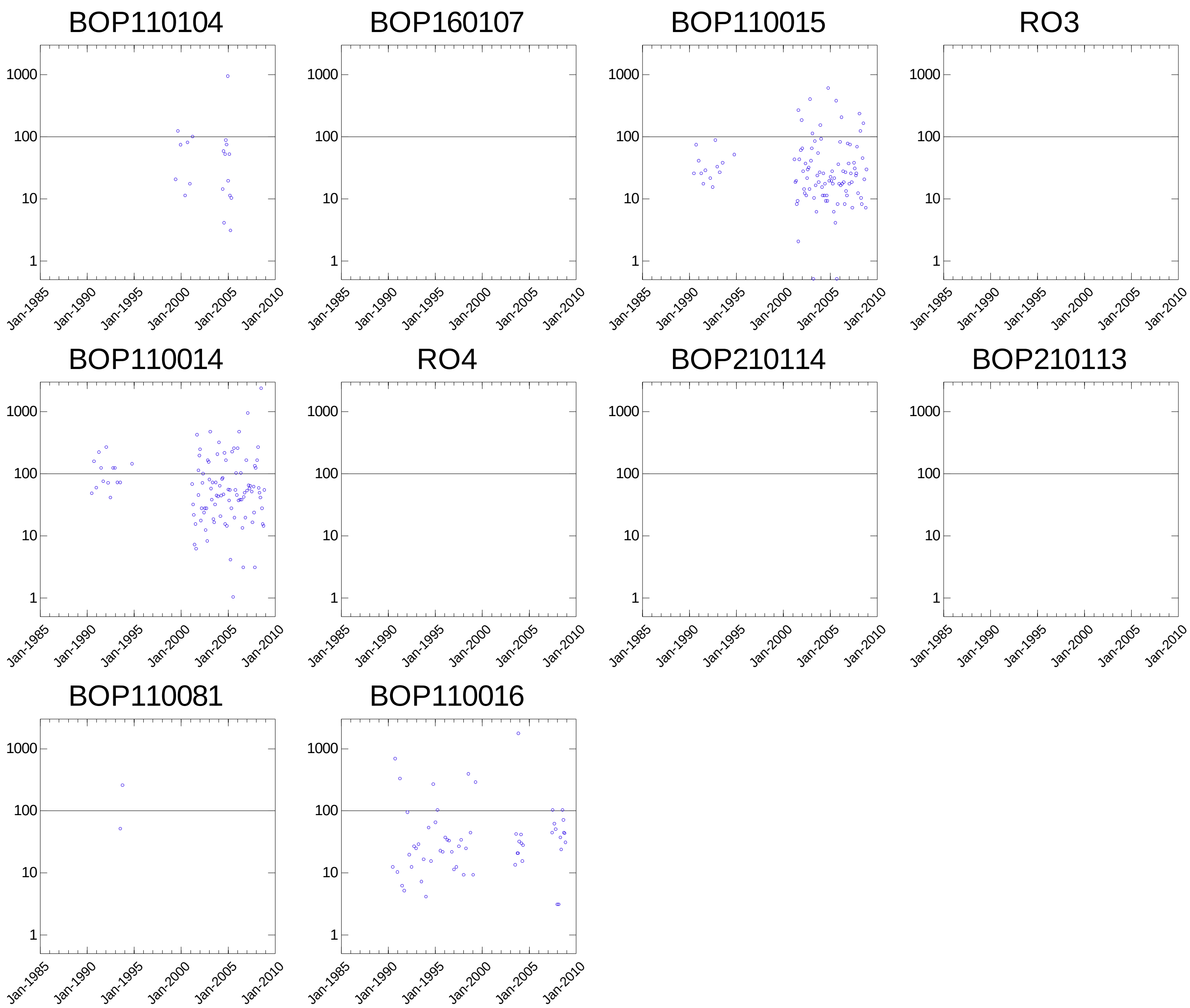
E. coli conc. (n/100 mL)

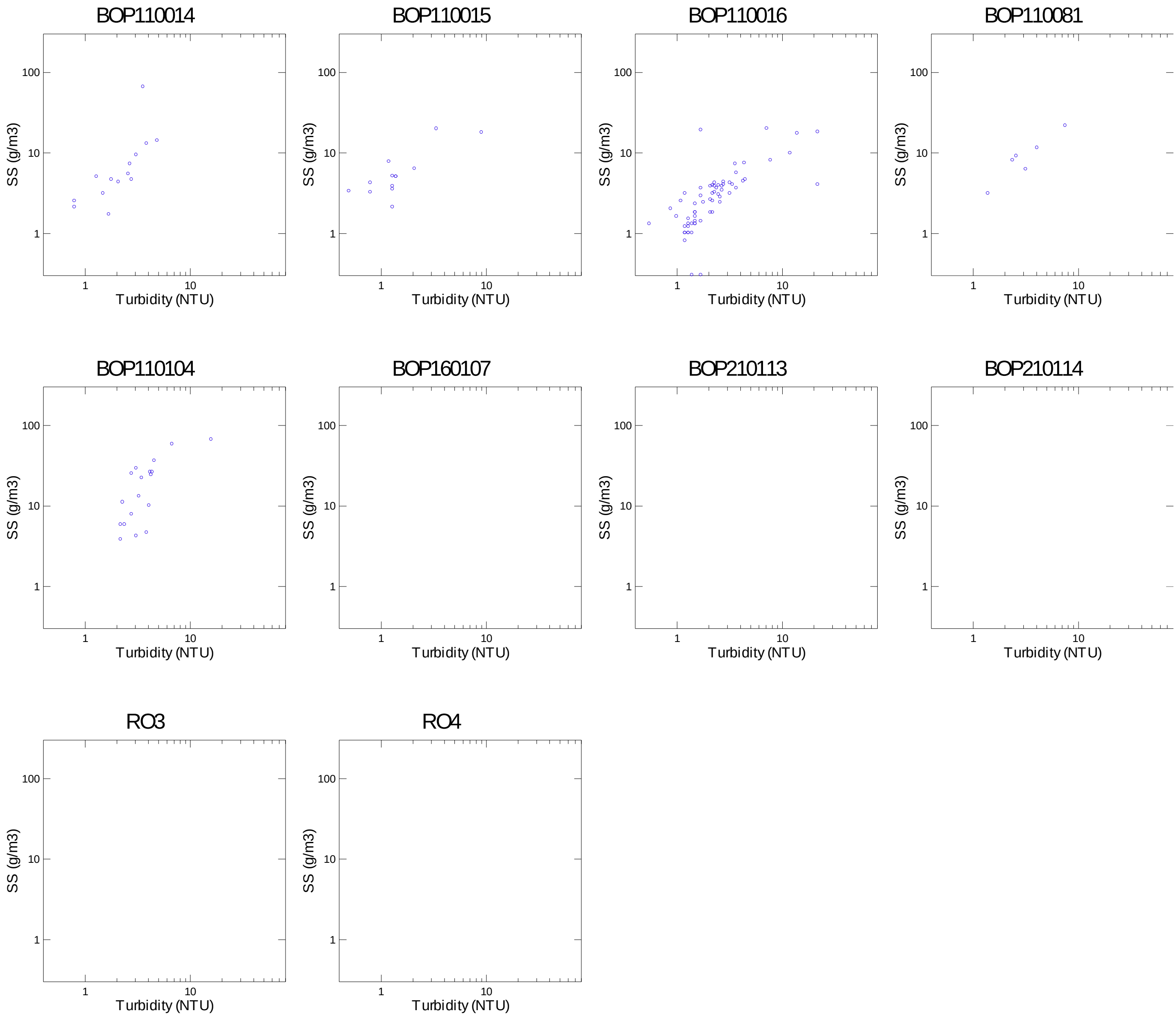


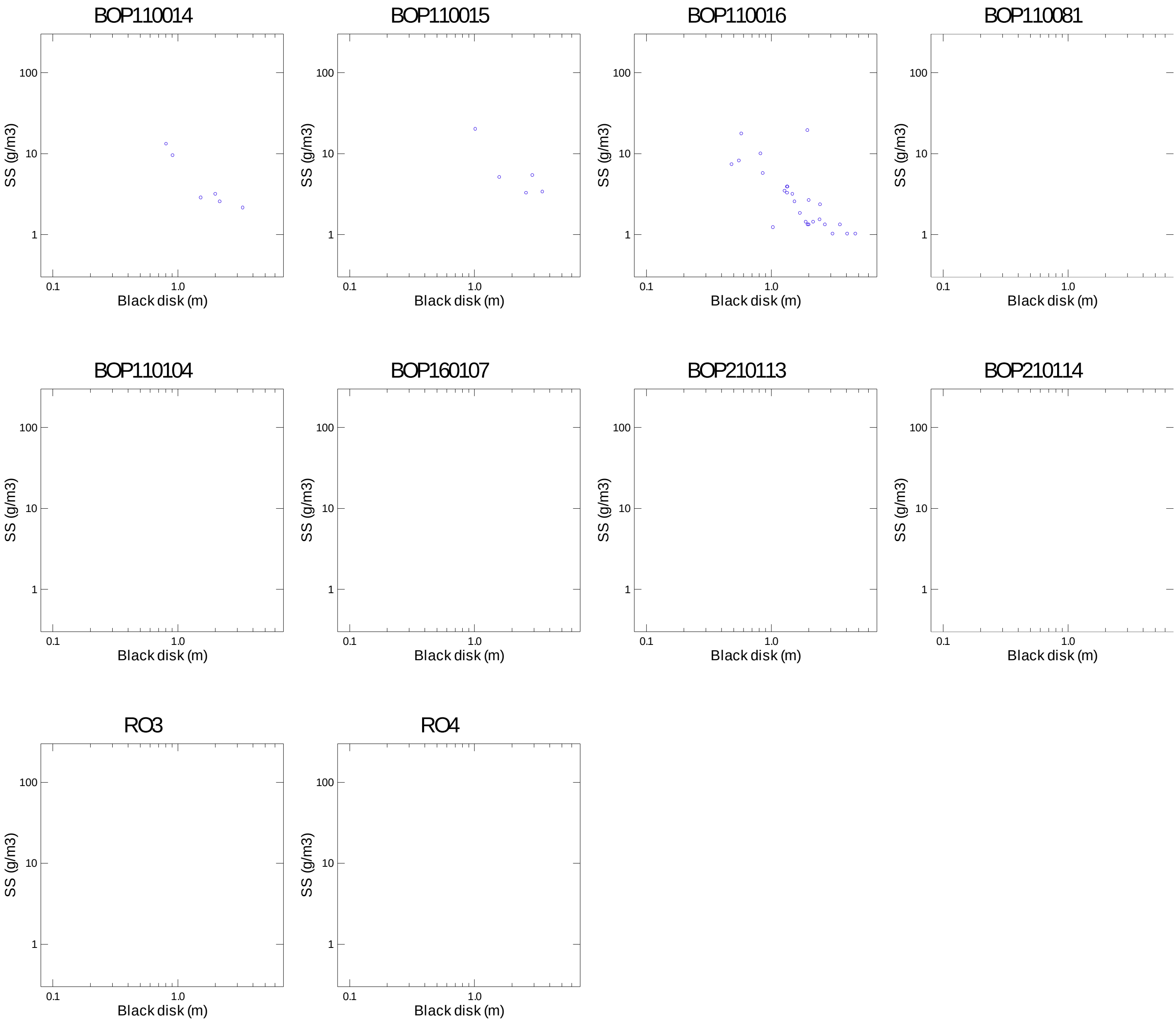
Enterococci conc. (n/100 mL)



Faecal coliform conc. (n/100 mL)




BOP110014
BOP110015
BOP110016
BOP110081
BOP110104
BOP160107
BOP210113
BOP210114
RO3
RO4
SS (g/m3)
Turbidity (NTU)
100
10
1


BOP110014
BOP110015
BOP110016
BOP110081
BOP110104
BOP160107
BOP210113
BOP210114
RO3
RO4
SS (g/m3)
100
10
1
0.1
1.0
Black disk (m)