Mangatarere Stream catchment water quality investigation

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Executive summary

The Mangatarere catchment investigation was launched in August 2008 in response to concerns about poor water quality in the lower reaches of the Mangatarere Stream, a small gravel-bed stream in central Wairarapa. The stream, which has soluble nutrient concentrations that are elevated from both a regional and national perspective, is recognised in Greater Wellington Regional Council's Regional Freshwater Plan as needing enhancement for aquatic ecosystem purposes. It is also recognised for its trout spawning values and provides habitat for four species of threatened native fish. The Mangatarere Stream discharges into the Waiohine River, a waterway with very good water quality and significant cultural, recreational and ecological values.

Specific objectives of the Mangatarere catchment investigation were:

- To determine the state of water quality in the Mangatarere Stream and its main tributaries (Enaki Stream, Hinau Gully Stream, Kaipaitangata Stream and Beef Creek);
- To assess temporal trends in water quality within the catchment (i.e., is water quality getting better or worse over time?); and
- To estimate nutrient loads within the catchment, with the view to identifying likely contaminant sources.

Addressing these objectives involved a combination of a 13-month catchment investigation and a review of Greater Wellington's long-term State of the Environment (SoE) surface water and groundwater monitoring data as well as monitoring information for selected resource consents exercised within the Mangatarere catchment.

The catchment investigation was undertaken over September 2008 to October 2009 and involved regular sampling of surface water and ground water quality, and a one-off assessment of soil quality and aquatic ecological health. Monthly water sampling was undertaken at 11 stream sites for 12 months, with stream flow gauged or estimated at the time of sample collection. Groundwater samples were collected from 13 bores at two-monthly intervals (seven sampling occasions). Both surface water and groundwater samples were tested for a range of variables such as suspended sediment, nutrients and *E. coli* bacteria, as well as trace metals and major ions on several occasions. Macroinvertebrate and periphyton samples were also collected in some reaches of the Mangatarere Stream and its tributaries in late summer 2009. Soil sampling was conducted once during spring 2009 at 16 locations under various land uses and soil types. Samples were tested for physical soil structure, organic resources, nutrients, fertility and trace elements.

The results of the investigation show that degradation of water quality in the Mangatarere Stream generally begins downstream of the Gorge, where the stream opens onto the more intensively farmed plains. Degradation in stream water quality is evident in the form of elevated dissolved nutrient concentrations, *E. coli* bacteria counts above guideline values for stockwater and/or contact recreation and, at some locations in the lower catchment, reduced water clarity.

Both dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP) loads increase with distance down the catchment. Based on the September 2008–August 2009 stream sampling period, the patterns of increase differ, with DIN loads increasing consistently with distance downstream, and DRP loads increasing significantly in the lower reaches of the catchment, primarily as a result of the Carterton Wastewater Treatment Plant (WWTP) discharge. The Carterton WWTP discharge also contributes DIN to the Mangatarere Stream, both directly and indirectly via seepage to groundwater underneath the oxidation ponds, wetland cells and land application area adjacent to the stream. However, the DIN input is relatively minor at higher stream flows when non-point sources account for the majority of the DIN. Ecological sampling undertaken by Carterton District Council confirms that the discharge has a measurable impact on invertebrate health, particularly in the summer months when stream flows are lower.

The application of wastewater to land at Reid's piggery in the mid reaches of the catchment is having a measurable impact on soil, groundwater and stream water quality. Groundwater quality monitoring results for shallow bores sampled immediately downgradient of the piggery indicate impacts, principally in the form of elevated nitrate nitrogen concentrations, migrating off-site. This nutrient-rich groundwater enters the Mangatarere Stream at some point downstream of Andersons Line. However, the nature of the surface water/groundwater connection is not completely understood and dairying in the mid catchment reaches will also be contributing to nutrient concentrations in the shallow unconfined groundwater aquifer and hydraulically connected streams.

Beef Creek has very poor water quality and during the investigation period was found to contribute 33% and 14% of the mean DIN and DRP loads (respectively) exiting the Mangatarere Stream into the Waiohine River. This creek, which enters the Mangatarere Stream below SH 2, has a catchment that comprises both dairying and drystock farming, highlighting the impact intensive agriculture can have on water quality. As well as groundwater-sourced nutrient inputs, it is likely that surface water runoff is a significant source of the nutrient (and other contaminant) loads in the lower reaches of Beef Creek. The soils in this area are poorly drained and soil quality monitoring results indicate a high degree of compaction; such conditions are ideal for ponding and surface water runoff.

The impacts of drystock and dairy farming on nutrient loads were not quantified as part of this investigation. However, impacts on physico-chemical and microbiological water quality were clearly present as a result of stock access at some sites, and the impacts due to surface runoff of dairyshed effluent have the potential to be very high. Despite Greater Wellington's 2009/10 inspections indicating a high level of compliance with resource consent conditions for the discharge of dairyshed effluent to land, 24 of the 30 active permits are currently exercised without any deferred storage. This means that dairyshed effluent generally has to be applied to land within a few days of being generated, regardless of soil or weather conditions.

Overall, elevated dissolved nutrient concentrations, as well as a lack of riparian vegetation cover and periods of low or stable stream flow, are contributing to nuisance periphyton growth and reduced invertebrate health, particularly in the lower reaches of the Mangatarere Stream. Long-term SoE monitoring data for the Mangatarere Stream at SH 2 indicate DRP and ammoniacal nitrogen concentrations are increasing over time, while invertebrate health appears to be declining. However, impacts on stream health are also evident further up in the catchment and appear to reflect more than just degraded water quality. A lack of flow in streams and degraded instream habitat (e.g., as a result of direct stock access and a lack of riparian vegetation at some sites) appear to be significant factors, with water temperatures in some parts of the catchment high enough to stress some sensitive aquatic life.

Although the complete drying of some stream reaches (e.g., Mangatarere Stream at Andersons Line) during summer is considered "natural", it is highly likely that both surface water and groundwater abstraction are increasing the frequency and duration of low flows and periods when stream reaches are dry. This highlights that intensive land use in the Mangatarere catchment generates multiple stressors (water abstraction, stock access and point and non-point source discharges) that cumulatively have significant impacts on stream health.

Efforts by Greater Wellington and landowners to rehabilitate the riparian margins of the lower reaches of the Enaki Stream subcatchment over the last nine years appear to be offsetting some of the adverse effects of intensive land use on stream health evident further up the catchment. However, water quality in the Enaki subcatchment remains degraded and considerably more work is needed to improve water quality and aquatic ecosystem health across the wider catchment. Removal (complete or even partial) of the Carterton WWTP discharge from the lower Mangatarere Stream would significantly reduce the existing DRP loading on the stream and related nuisance periphyton growth. However, DRP:DIN ratios in stream waters and the presence – albeit to a lesser extent – of nuisance periphyton growth upstream suggest that nitrogen inputs also need to be managed. In the case of DIN, the primary contribution is from diffuse sources, indicating that wastewater application to land and agricultural management practices need closer attention. This is especially the case in the Beef Creek subcatchment which appears to be contributing a significant amount of DIN (and DRP) relative to other parts of the catchment. This contribution was not known at the time of commencing the catchment investigation, Greater Wellington's long-term SoE site on the Mangatarere being located upstream of the Beef Creek confluence, at SH 2.

A significant amount of knowledge about the Mangatarere catchment has been gained as a result of the targeted 13-month investigation, analysis of long-term SoE water quality monitoring data and review of selected resource consent monitoring information. However, there were a number of limitations and knowledge gaps associated with the investigation. These include a lack of farm-scale information on soil types and land use and management, as well as a lack of long-term stream flow data and a thorough understanding of the interactions between groundwater and surface water in some of the subcatchments. A number of recommendations are made, including areas for possible further investigation and considerations for Greater Wellington's second generation regional plans.

Contents

1. Introduction

The Mangatarere Stream is a small gravel-bed river in the central Wairarapa that is recognised in Greater Wellington Regional Council's Regional Freshwater Plan (WRC 1999) as needing enhancement for aquatic ecosystem purposes (Figure 1.1). The stream is also recognised for its trout spawning values and provides habitat for four species of threatened native fish. It discharges into the Waiohine River, a waterway with very good water quality and significant cultural, recreational and ecological values (WRC 1999).

Routine State of the Environment (SoE) monitoring has consistently shown that water quality in the lower reaches of the Mangatarere Stream is amongst the poorest in rivers and streams of the Wellington region (e.g., Perrie 2008, Perrie 2007), particularly in terms of dissolved nutrient concentrations. The catchment is subject to multiple stressors, including water abstraction, intensive land use, and the discharge of treated municipal wastewater from Carterton township.

This report documents the results of a 13-month investigation of water quality in the Mangatarere catchment. The investigation was undertaken over September 2008 to October 2009 and involved regular testing of surface water and ground water quality, and a one-off assessment of soil quality and aquatic ecological health. The principal aim of the investigation was to better understand surface water quality within the Mangatarere catchment, with the view to determining the primary nutrient sources and the potential migration of nutrients from the soil zone to receiving waters, both groundwater and surface water. Addressing this aim involved a combination of the catchment investigation and a review of Greater Wellington's long-term SoE surface water and groundwater monitoring data as well as monitoring information for selected resource consents exercised within the Mangatarere catchment.

Figure 1.1: The Mangatarere Stream in its upper reaches

1.1 Report outline

The report begins with an overview of the Mangatarere catchment, including hydrology, hydrogeology, soils, land use, instream values and consented activities. The rationale for and scope of the 13-month catchment investigation are then briefly outlined in Section 3, followed by detailed summaries of the surface water, groundwater and soil sampling programmes in Sections 4, 5 and 6 respectively. Section 7 presents a summary of surface water and groundwater quality monitoring data from long-term SoE monitoring sites and Section 8 provides a summary of relevant resource consent monitoring data relating to water and soil quality. The key findings from Sections 4 to 8 are then brought together in Section 9 in a discussion on the impacts land use activities in the catchment are having on water quality. Conclusions and recommendations are presented in Section 10.

2. The Mangatarere catchment

2.1 Introduction

The Mangatarere Stream is the main tributary of the Waiohine River in the middle Wairarapa Valley (Figure 2.1), draining a catchment of 157 km^2. Rising in the foothills of the Tararua Range, the stream flows for some 31 km before its confluence with the Waiohine River at State Highway 2, south of Carterton township. The Waiohine River also originates in the Tararua Range

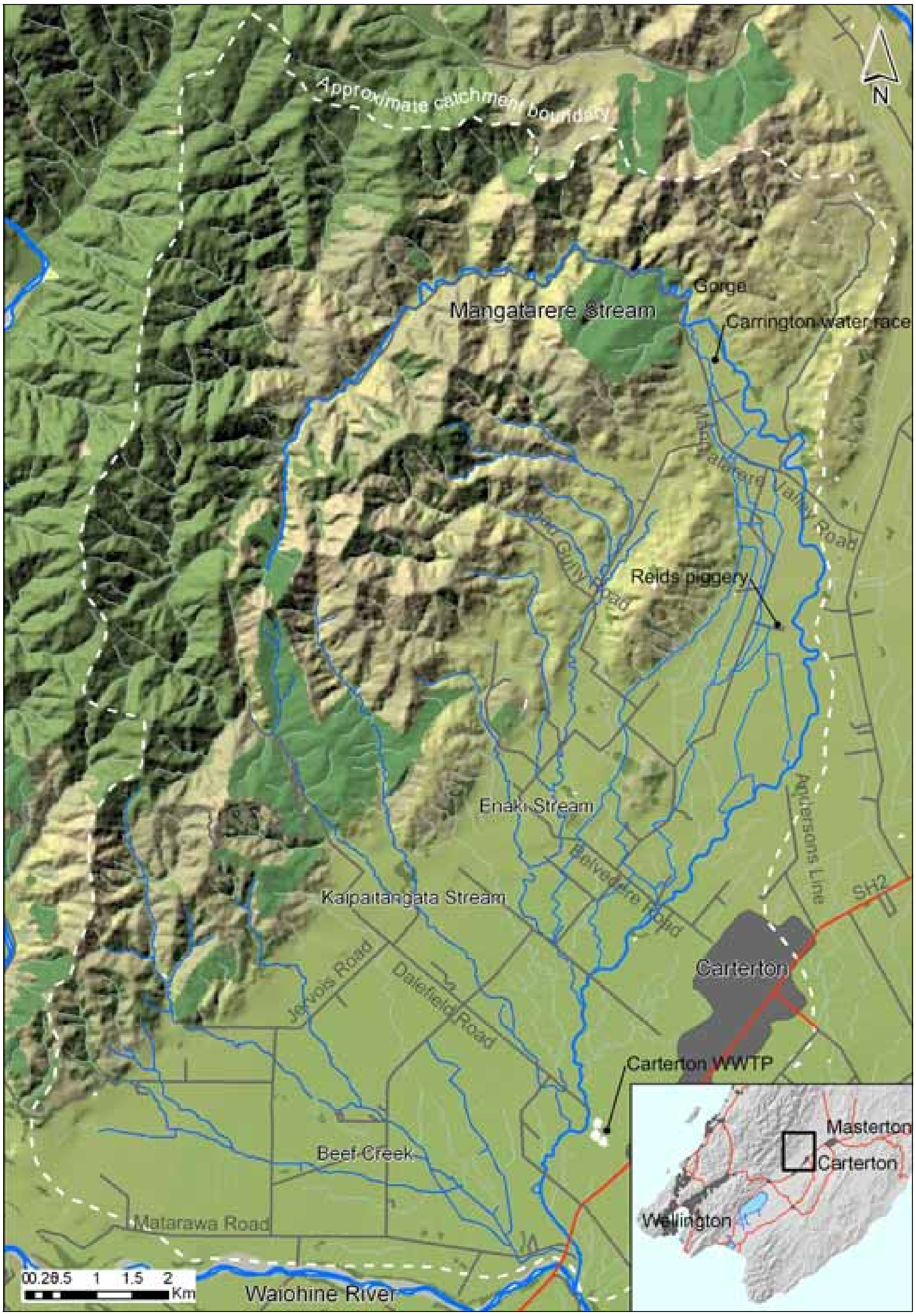

Figure 2.1: The Mangatarere catchment

and enters the Ruamahanga River approximately 6 km downstream of the Mangatarere confluence. Three main tributaries discharge into the Mangatarere Stream: Enaki Stream[1], Kaipaitangata Stream and Beef Creek.

This section provides an overview of the Mangatarere catchment hydrology, hydrogeology, soils, landuse, instream values and significant consented activities.

2.2 Hydrology

Mean annual rainfall in the Mangatarere Stream catchment varies from about 900 mm on the Wairarapa plains near Carterton, up to around 3,000 mm at the top of the catchment, in the foothills of the Tararua Range. The wettest months are usually June, July, August and October, while the driest months tend to be January to April.

Flow in the Mangatarere Stream is continuously monitored by Greater Wellington at the site 'Mangatarere Stream at Gorge', just upstream from where the stream emerges onto the plains from the foothills (Figure 2.1). At this point, the stream has a mean flow of 1,900 L/s, a median flow of 840 L/s and a mean annual low flow of 136 L/s (based on data from 1999-2009).

Once emerging onto the plains, the Mangatarere Stream tends to lose water to groundwater, and then gains flow from groundwater downstream of Andersons Line (Gyopari & McAlister 2010; Figure 2.2). In the vicinity of Andersons Line, the stream is known to dry up completely during extreme dry periods; however, flow is usually permanent downstream of the Belvedere Road bridge (Keenan 2009). The patterns of flow gain and loss are influenced by fault lines (see Section 2.3).

The Mangatarere Stream's main tributaries – Enaki Stream, Kaipaitangata Stream and Beef Creek – enter in its middle and lower reaches. The flow in these tributaries is not continuously monitored. Mean instantaneous flows at the bottom of these tributaries, based on monthly gaugings from September 2008 to August 2009, were 602 L/s, 387 L/s and 1,373 L/s respectively.

Significant surface water/groundwater interaction also exists in the lower reaches of Beef Creek and the Enaki and Kaipaitangata streams. For example, during winter Beef Creek gains by over 1,000 L/s in its middle reach between Jervois Road and Watersons Line (Gyopari & McAlister 2010). Like the Mangatarere Stream, sections of the lower Enaki and Kaipaitangata streams can dry up in summer (Figure 2.3), as can the middle reaches of Beef Creek.

[1] One branch of this stream is known as Hinau Gully Stream.

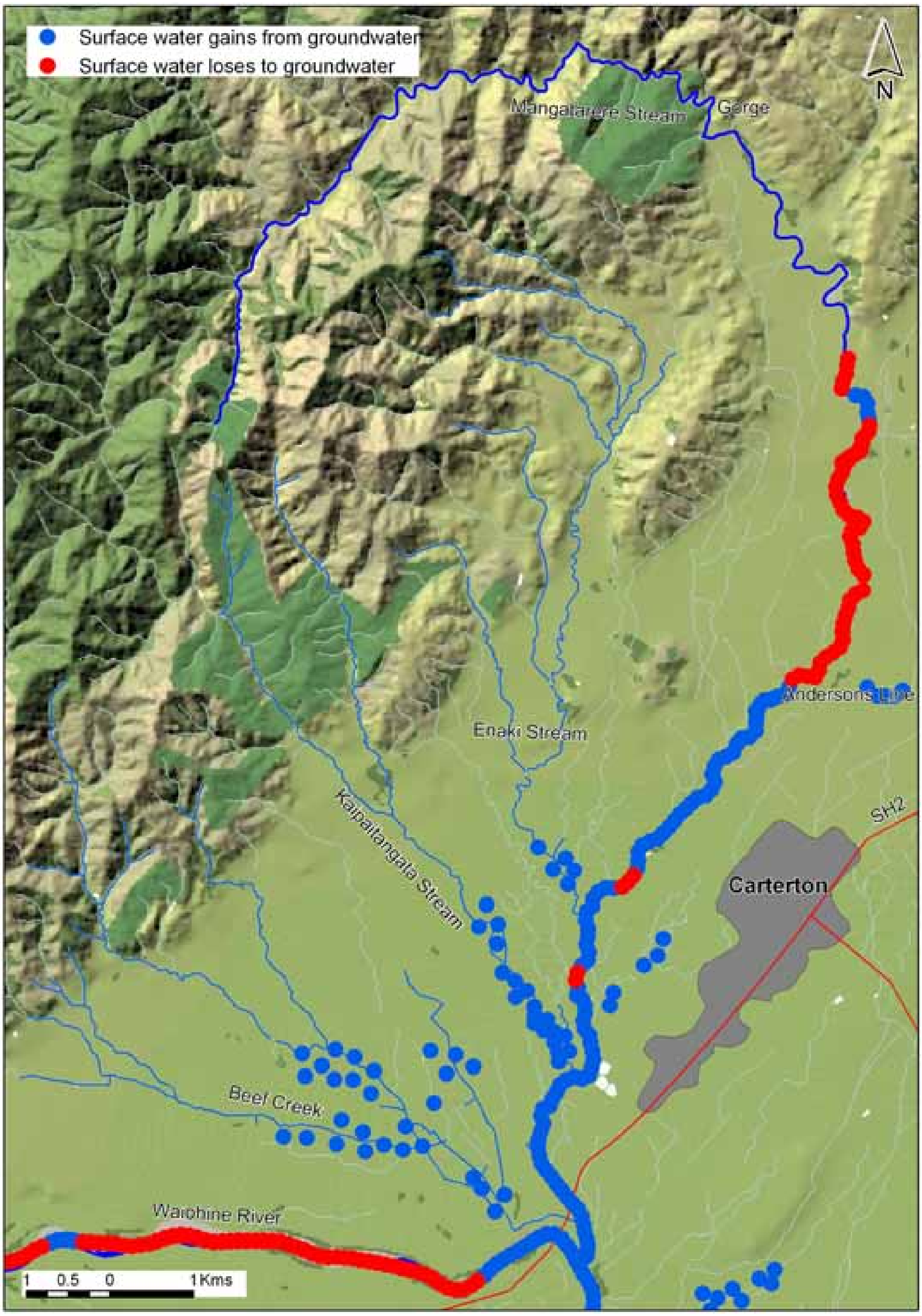

Figure 2.2: Gains and losses of surface water to groundwater in the Mangatarere catchment based on <u>summer</u> conditions modelled by Gyopari and McAlister (2010) as part of the Wairarapa Valley groundwater investigation. Gains from groundwater are larger during winter when groundwater levels are higher.

Figure 2.3: The lower reaches of Enaki Stream reduced to a few pools in January 2008

The Mangatarere Stream enters the Waiohine River just downstream of State Highway 2. At the confluence, the estimated mean annual low flow of the Mangatarere Stream is 305 L/s (Keenan 2009), and the estimated mean annual low flow of the Waiohine River is 3,190 L/s (both 1-day flow durations). Therefore, during times of low flow the Mangatarere Stream contributes approximately 10% of the flow in the Waiohine River at this point. During times of mean or high flows the contribution may be more or less depending on groundwater levels and rainfall distribution.

Similar to many catchments within the Wairarapa Valley, the Mangatarere catchment has a gravity-fed water race system – the Carrington Water Race – where water is diverted from the Mangatarere Stream into a series of unlined channels for use as stock water supply and limited irrigation. The Carrington system comprises a channel network extending southwards through the area west of the Mangatarere Stream. The race system discharges water back to the Mangatarere Stream between Andersons Line and Brooklyn Road for much of the year, particularly during wetter periods (the channels will receive surface water runoff) but the volume of this discharge has not been quantified (Gyopari & McAlister 2010).

2.3 Hydrogeology

A general description of hydrogeology in the Mangatarere/Carterton area is summarised here from Gyopari and McAlister (2010). The area comprises a heterogeneous sequence of late Quaternary age fan gravels in the west. A low-yielding unconfined aquifer is present over much of this alluvial fan area. Eastwards, from about the Mangatarere Stream, the fan sequence becomes more permeable and a more layered aquifer sequence gradually develops towards Carterton. Here, a shallow unconfined aquifer is underlain by an aquitard and a deeper semi-confined aquifer within which most higher-yielding bores are located. Features such as the Carterton Fault deform the alluvial deposits and influence groundwater flow patterns (Figure 2.4). Along the Mangatarere Stream shallow Quaternary 1 gravels mark the extent of Recent/Holocene higher permeability alluvium. These deposits form a shallow unconfined aquifer (5–10 m deep) connected to the stream.

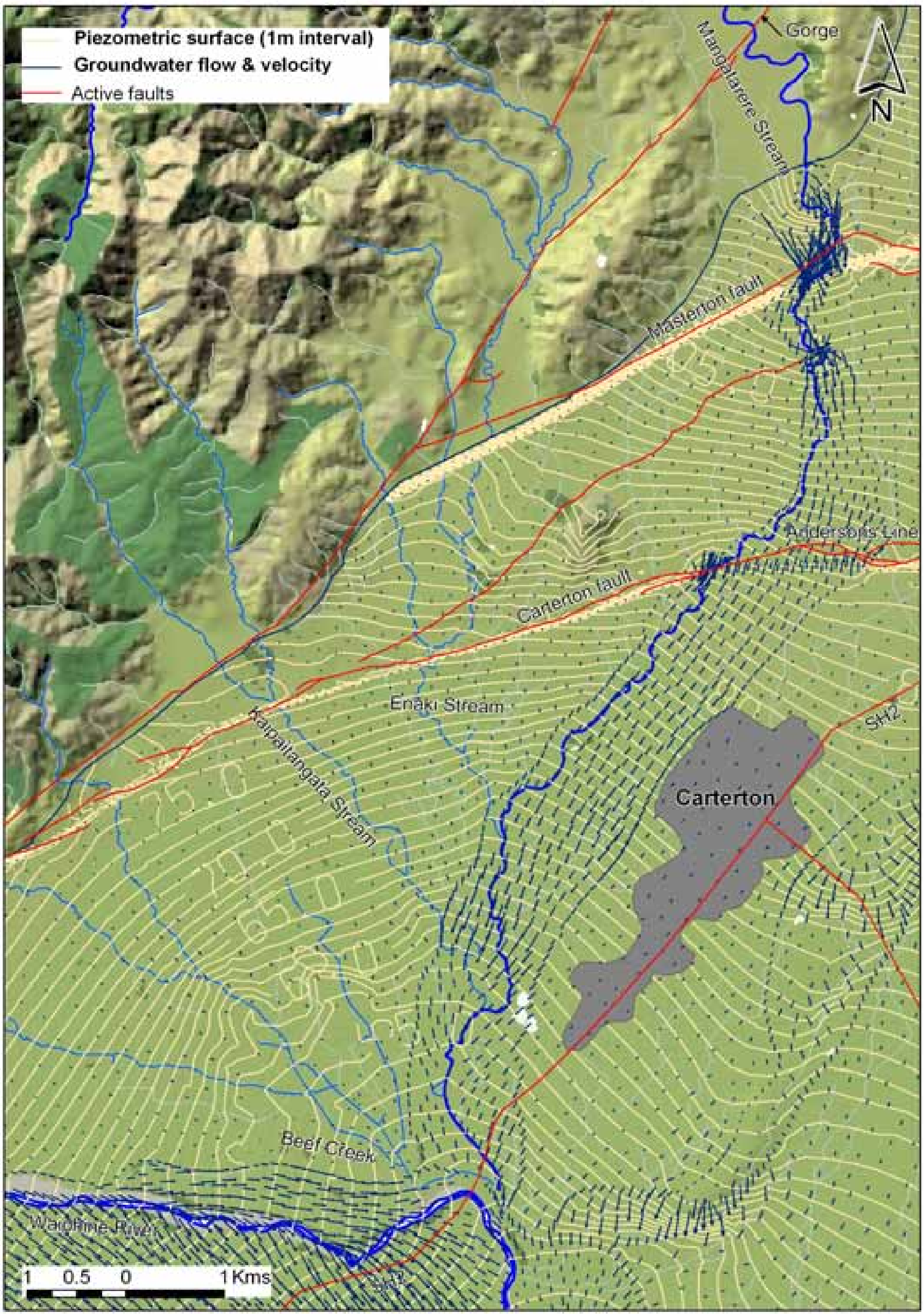

Figure 2.4: Piezometric surface and velocity vectors generated using a FEFLOW numerical groundwater flow model for the middle Wairarapa Valley (Gyopari & McAlister 2010). The influence of two major fault lines can be seen in both contours and velocity vectors. Note that the arrows indicate the direction of groundwater flow and their length is proportional to velocity.

Piezometric surveys suggest that groundwater moves from the hill country and discharges as base flow into the lower reaches of Beef Creek, and Enaki and Kaipaitangata streams, the Mangatarere Stream south of Andersons Line and the Waiohine River (Figures 2.2 and 2.4). Hydraulic conductivity is low in the area from the Tararua Range to the Mangatarere Stream but improves from the Mangatarere Stream towards Carterton. Recharge is thought to come primarily from rainfall and run-off from side valleys, and leakage from the Mangatarere Stream above Andersons Line (Gyopari & McAlister 2010).

2.4 Soils

Information on the soils within the Mangatarere catchment is limited. The New Zealand Land Resource Inventory (NZLRI) provides some information, as well as previous soil mapping work which is documented in Heine (1975). Figure 2.5 presents a map of the different soil orders in the Mangatarere catchment based on the NZLRI and Heine (1975).

The top of the catchment is characterised by well drained brown soils throughout the hills, terraces and alluvial plains. Brown soils occur in places where summer dryness is uncommon and that are not waterlogged in winter (Hewitt 1998). The soil types include Kohinui loam, Opaki brown stony loam and Tauherenikau stony silt loam, which all have a drainage class of 5 (Milne et al. 1995), indicating well-drained soils. The area bordering the middle reaches of the Mangatarere Stream contains some poorly drained recent soils (Ahikouka silt loam) as well as some gley soils (Otukura silt loam), which also have poor drainage. The margins of the lower reaches of the Mangatarere Stream contain Greytown silt loam and sandy loam which are well drained recent soils. Soils with poor drainage and impermeable gravel layers, such as Ahikouka silt loam and Moroa loam and stony loam, are present at the bottom end of Kaipaitangata Stream and Beef Creek subcatchments.

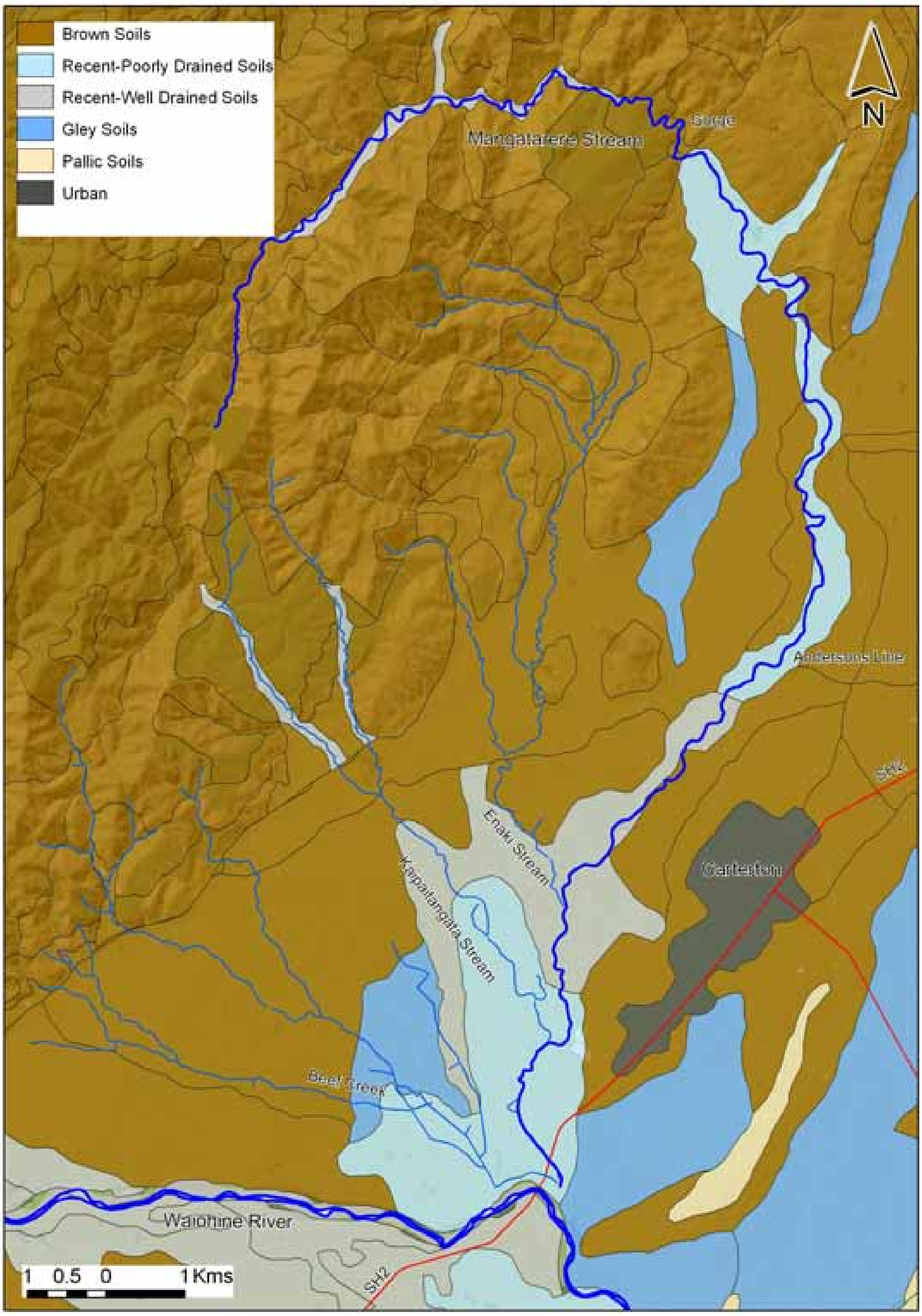

Figure 2.5: Soil orders of the Mangatarere catchment based on the NZLRI and Heine (1975). The current investigation and an earlier investigation by Webb (2006) revealed a few differences. These are discussed in Section 6.5.

2.5 Land use

The Mangatarere catchment comprises an area of approximately 15,670 ha. Nearly half of the catchment is contained within the Tararua Forest Park, and is covered in forest (mainly indigenous but also exotic), while the majority of the alluvial river terraces have been developed into pasture and are used extensively for agriculture, particularly dairy and drystock[2] farming (Figure 2.6).

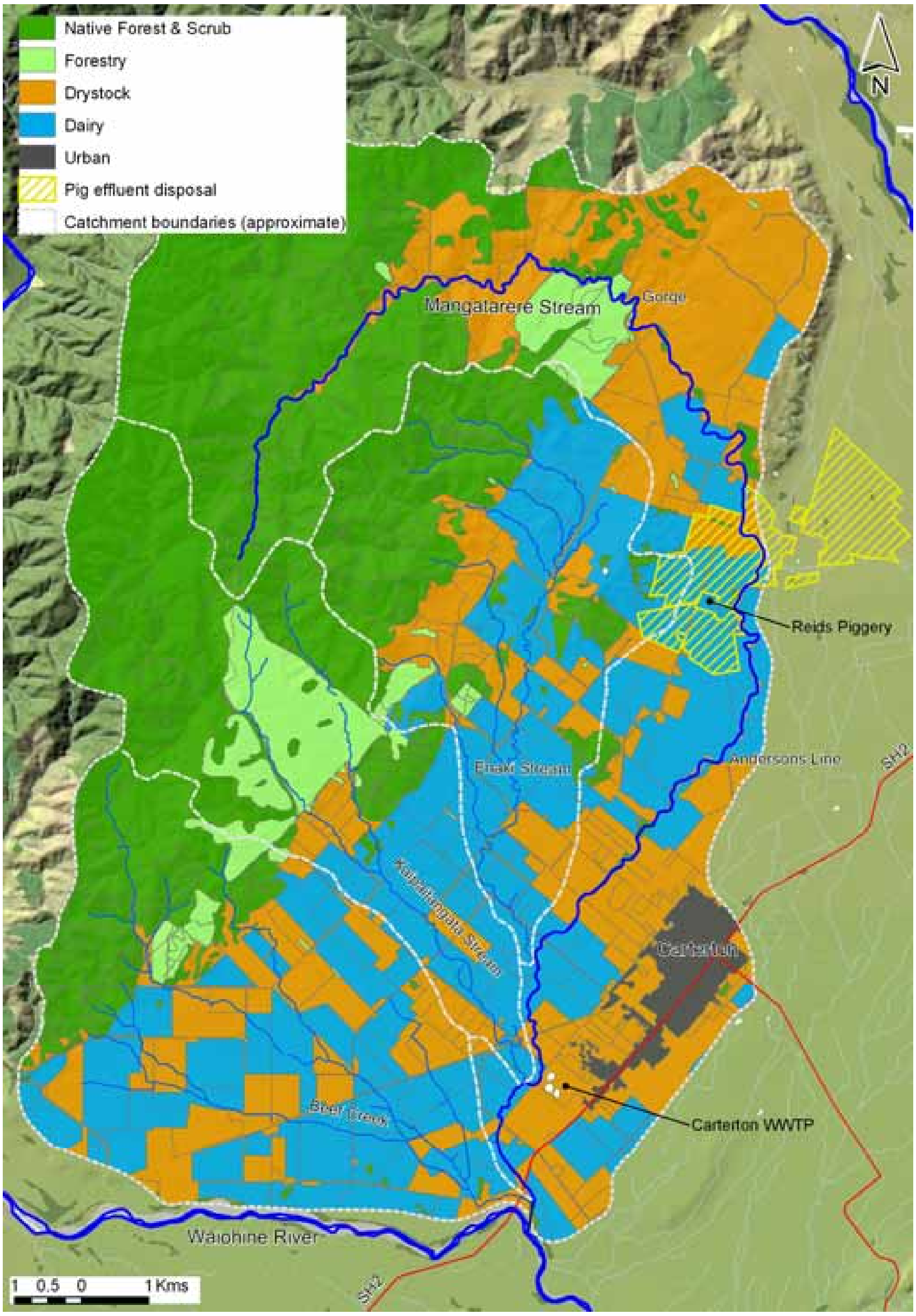

Figure 2.6: Land use in the Mangatarere catchment, based on the New Zealand Land Cover Database (LCDBv2) and an Agribase National Farms spatial dataset

2 For the purpose of this investigation drystock farming includes sheep, beef and deer farming as well as horses and smaller lifestyle blocks.

Information on the present land use within the catchment is limited. Figure 2.6 was derived from a combination of information found in the New Zealand Land Cover Database (LCDBv2) and an Agribase National Farms spatial dataset. The LCDBv2 was created by interpreting satellite images of New Zealand from 2001/02, and translating them into information which describes different types of land cover that exist on the ground (e.g., pastures, lakes, forests, or concrete). While the LCDBv2 doesn't distinguish between different farm types on pastoral land, it does provide information on different forest types. Agribase is a national database of farms. It is a central register of farms and an index of farm ownership, farm type, management and stock and crop details. The Agribase dataset was purchased from Agriquality New Zealand, and is based on information collected up to 2001. Despite the lack of more recent land use data, the dominant land uses on the low-lying terraces and river plain remain the same: dairy and drystock farming.

A large proportion (39%) of the Mangatarere catchment is covered in indigenous forest and scrub (Table 2.1). Drystock and dairy farming each comprise 27% of the catchment area. Drystock farming is undertaken predominantly on the rolling hill country, while dairy farming occurs on the plains. There are small areas within the catchment of planted forestry (mainly *Pinus radiata*), and many farms also have planted shelter belts. The only significant piece of indigenous forest not located within the Tararua Forest Park is the 48 ha Fensham Reserve, 3 km northwest of Carterton. The land surrounding Carterton has historically been used for drystock farming but in recent times has been subdivided into smaller "lifestyle" blocks, which for the purposes of this investigation have still been categorised as drystock.

Table 2.1: Major land uses within the Mangatarere catchment, derived from the New Zealand Land Cover Database (LCDBv2) and an Agribase National Farms spatial dataset

Land use	Area (ha)	Percentage of catchment area (%)
Indigenous Forest & Scrub	6,051	39
Forestry	842	5
Drystock	4,224	27
Dairy[1]	4,290	27
Urban	263	2
Total	15,670	

[1] A small portion of dairying land is used for piggery effluent application.

Within the three main subcatchments (Figure 2.6), the Beef Creek and Enaki subcatchments contain the highest proportions of dairying (44% and 40% respectively) and drystock farming (29% and 20% respectively). In contrast, dairying and drystock farming account for less than 20% and 7% (respectively) of the land use in the Kaipaitangata Stream subcatchment. The Kaipaitangata catchment has retained the largest cover of native forest and scrub (55% compared with 38% and 24% in the Enaki Stream and Beef Creek catchments respectively), reflecting its use as a protected water supply catchment. This catchment also has a significant exotic forestry component (18%).

While LCDB2v2 and Agribase provide generic information on land use, enabling land parcels to be categorised into different land uses, they lack specific information about individual farm practices. On-farm practices are important because all farms operate differently. Farms often have different stocking rates, cow wintering systems, cropping rotations, fertiliser usage, irrigation systems and so on, which all affect the land in different ways. Therefore, while a farm may be categorised as 'drystock' or 'dairy' for the purpose of this investigation, it is important to note that the management of individual farms often varies quite widely.

2.6 Instream values

The Mangatarere Stream, its tributaries, and associated wetlands provide a wide range of habitat types. While much of the lower valley area has been developed for agricultural use, the intact indigenous forest and scrub cover in the upper catchment areas of the Mangatarere Stream and its tributaries, along with remnant pockets of native forest/wetland scattered throughout the valley (e.g., Fensham Reserve) provide for high ecological values overall.

The Mangatarere Stream, along with two of its tributaries, Beef Creek and the Kaipaitangata Stream, are listed in Greater Wellington's Regional Freshwater Plan (RFP, WRC 1999) as water bodies with important trout habitat, with the requirement that water quality is managed for fishery and fish spawning purposes. According to Fish and Game (Jordan[3], pers. comm., 2010), the Mangatarere Stream is considered to be the most valuable brown trout spawning and rearing stream in the Wellington region, and is recognised as extremely important in maintaining the trout fishery of the entire Ruamahanga River catchment.

Based on fishing records in NIWA's National Freshwater Fish Database (NZFFD, accessed in March 2010), 11 species of native freshwater fish and one native decapod (koura) have been recorded within the Mangatarere Stream catchment (Table 2.2). Of the 11 fish species, four are classified as threatened species by the Department of Conservation (Hitchmough et al. 2007): longfin eel, dwarf galaxias, lamprey and brown mudfish. Koura are also classed as a threatened species. For some of the species it may be the smaller tributaries and adjacent wetlands that provide significant habitat (e.g., brown mudfish typically inhabit wetland environments rather than riverine environments). In addition to brown trout, the only other introduced species recorded in NZFFD for the catchment is perch (which along with brown trout are classed as a sports fish).

The high number of native diadromous fish species (i.e., species that typically migrate between freshwater and ocean environments to complete a part of their lifecycle) along with the presence of several threatened species led to the Mangatarere Stream (grouped within the Waiohine River catchment) being listed in Greater Wellington's (2010) second-generation Proposed Regional Policy Statement as a water body with a significant indigenous ecosystem.

[3] Corina Jordan, Resource Officer, Wellington Fish & Game

Table 2.2: Fish and decapod crustacean records from NIWA's New Zealand Freshwater Fish Database (NZFFD, accessed March 2010) in the Mangatarere Stream catchment and subcatchments

Site	Diadromous?	Enaki Stream	Kaipaitangata Stream	Beef Creek	Mangatarere Stream
Number of NZFFD records		9	7	2	18
Longfin eel	Yes	✓	✓	✓	✓
Shortfin eel	Yes	✓	✓		✓
Torrentfish	Yes	✓	✓		✓
Dwarf galaxias	No	✓			✓
Inanga	Yes				✓
Lamprey	Yes				✓
Cran's bully	No	✓			
Upland bully	No	✓	✓		✓
Common bully	Yes	✓		✓	✓
Redfin bully	Yes		✓		
Brown mudfish[1]	No	✓	✓	✓	
Koura (freshwater crayfish)	No	✓	✓	✓	✓
Perch[2]	No	✓			✓
Brown trout [2]	No	✓	✓		✓

[1] Note that mudfish are generally associated with the wetlands adjacent to streams rather than the streams themselves.
[2] Introduced species.

In addition to high trout spawning and native fish values, the Mangatarere catchment also holds many important values for local Maori, particularly relating to mauri, waahi tapu and mahinga kai. The main recreational use of the river is fishing. However, while swimming more commonly occurs downstream in the Waiohine River, local swimming holes are known to exist within the Mangatarere Stream catchment, such as at Belvedere Road Bridge (Rowland4, pers. comm. 2009) and in the vicinity of State Highway 2 (Coffey 2008).

2.7 Significant consented activities

2.7.1 Water abstraction

In addition to an unknown number of permitted activity takes[5], there are seven resource consents authorising the abstraction of surface water from the Mangatarere Stream and its tributaries (Figure 2.7). The most significant of these is Water Permit WAR010202 held by Carterton District Council (CDC); this permit allows up to 113 L/s of water to be taken from the Mangatarere Stream (just downstream of the Gorge) for the Carrington Water Race[6]. CDC also exercises Water Permit WAR020050 which authorises up to 80 L/s of water to be taken from the Kaipaitangata Stream for Carterton township's water supply. The remaining water permits authorise instantaneous abstraction rates in the order of 6 L/s to 26 L/s, mostly for irrigation.

[4] Matt Rowland, Senior Monitoring Officer, Greater Wellington Regional Council.

[5] In accordance with Rule 7 of the RFP (WRC 1999), up to 20 m^3/day of surface or groundwater may be taken for reasonable domestic and/or stockwatering purposes as a permitted activity (i.e., no resource consent is required).

[6] CDC's application for a replacement consent – currently being processed by Greater Wellington – is seeking 200 L/s.

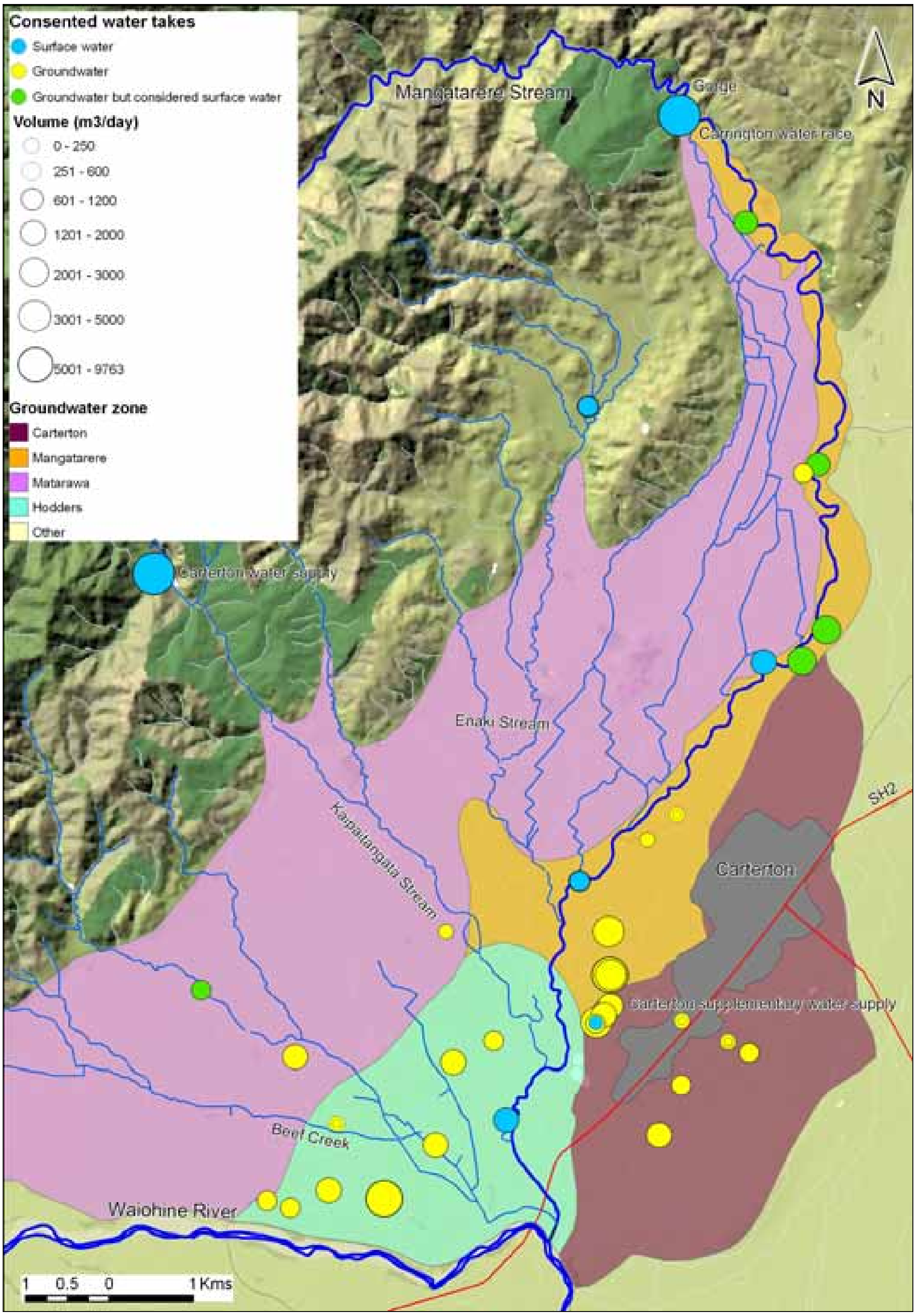

Figure 2.7: Location and daily volumes of consented surface water and groundwater takes in the Mangatarere catchment. Existing groundwater management zones defined in the Regional Freshwater Plan (WRC 1999) are also shown.

Based on existing allocation volumes in the RFP, the Mangatarere catchment is fully-allocated; no new water permits to take surface water have been granted since 2003. Groundwater is still available within the Mangatarere catchment, although two of the main groundwater zones (‘Matarawa’ and ‘Hodders’, Figure 2.7) only have low to moderate abstraction potential (Gyopari &

McAlister 2010). The other principal groundwater zone, Mangatarere Groundwater Zone, has direct linkages to the Mangatarere Stream (Gyopari[7], pers. comm. 2010). The effect on stream flows of abstracting water from this zone (at least from bores near to the stream) may inhibit further consented use of groundwater within this area.

Of the approximately 30 resource consents currently classified as groundwater abstractions within the Mangatarere catchment (Figure 2.7), most authorise instantaneous rates of take between 10 L/s and 30 L/s. Two of the more significant takes are from two deep groundwater bores that provide supplementary water supply for Carterton township (authorised under Water Permit WAR050013). Up to 1,728 m^3/day of water can be taken from each of these bores at a maximum instantaneous rate of 20 L/s.

With the Mangatarere Stream losing water to groundwater between the Gorge and Andersons Line and often drying up around Andersons Line, restrictions on water takes are frequently imposed during the summer months. Restrictions apply to most surface water takes when stream flows are reduced and a handful of groundwater takes that have been shown to affect stream flow.

2.7.2 Dairying

Greater Wellington's consenting records show 30 discharge permits authorising the application of dairyshed effluent to land are currently exercised within the Mangatarere catchment. Hydraulic application rates are generally set based on soil type while the land application area is calculated on the basis of ensuring that the annual soil nitrogen loading rate does not exceed 150 kg/ha (e.g., 4 ha per 100 cows if untreated effluent is discharged to land).

Stock numbers in the catchment vary from 130 to 1,050 cows per herd, with the total number of cows in the catchment calculated from 2009/10 compliance inspections at 9,343. This compares with an authorised total across the 30 permits of 8,970 cows. Consistent with many dairying areas elsewhere in New Zealand, it is thought that stock numbers have intensified over the last decade. However, there is limited information to confirm if this is the case; data from Livestock Improvement Corporated (LIC) actually suggest a decline in cow numbers in the Mangatarere catchment, from around 12,103 in 2003 to 9,183 in 2009. However, some records of herd numbers for dairy permits held with LIC were incomplete, especially in recent years; this could be because some permits were transferred or expired or because herd numbers were not submitted to LIC by permit holders. Anecdotal evidence suggests a number of farms have been subdivided into lifestyle blocks within the catchment.

Greater Wellington resource consent information supports the possibility that stock numbers have declined in the Mangatarere catchment over the last 8-10 years. In 2002 there were 47 dairy permits in the catchment but since then 17 of these permits were surrendered, transferred or expired (and were not renewed). Information from LIC suggests that although the total number of cows in the catchment has decreased, the average herd size has increased from

[7] Dr Mark Gyopari, Hydrogeologist, Phreatos Limited.

258 cows/herd in 2003 to 340 cows/herd in 2009. This suggests that stock registered under discharge permits that were surrendered, transferred or expired may have been bought by neighbouring farms (i.e., fewer but potentially larger farms).

2.7.3 Reid's piggery

Reid's piggery, one of New Zealand's largest commercial piggery operations, is located on Haringa Road in the mid reaches of the Mangatarere catchment. The piggery has been in operation since the 1960s and exercises resource consents authorising the discharge of contaminants to air and land.

In early 2007, the piggery was granted a replacement consent, Discharge Permit WAR050090, [24586], which authorises the discharge to land of up to 550 m^3/day of primary treated piggery wastewater and associated screwpress solids. Under the permit, wastewater can be applied to land at a rate of up to 15 mm/hour, with a requirement that the nitrogen loading rate does not exceed 150kg per hectare per year (down from the previously authorised 200 kg/ha/year). Up to 529 hectares of grazed dairy pasture can receive wastewater annually (up to 4 hectares daily) via spray irrigation, using travelling irrigators, tankers/spray carts and drop-down hoses.

According to Reid's 2008/09 annual consent monitoring report, the farm had 11,117 pigs in April 2008. By the following April, the piggery had reduced this number by 20% to 8,882 pigs, in an attempt to remedy non-compliance with the consented nitrogen application rate (Shivas & Hosken 2009). The total number of pigs in April 2010 stood at 9,464 (Shivas & Hosken 2010).

Reid's piggery is required to undertake a range of environmental monitoring in relation to the application of piggery effluent to land[8], including monthly testing of effluent quality and stream water quality at five locations, three-monthly sampling of groundwater quality in approximately ten bores, and annual monitoring of soil quality at various locations. Some of the results of this monitoring are discussed in detail in later sections of this report.

2.7.4 Carterton wastewater

Treated wastewater from Carterton township (population 4,122[9]) is discharged into the lower reaches of the Mangatarere Stream, below Dalefield Road (refer Figure 2.1 for location). Under Discharge Permit WAR950148, CDC can discharge up to 3,270 m^3/day of treated wastewater directly into the stream; discharge volumes are more typically in the order of 780 m^3/day during summer and can exceed as much as 8,000 m^3/day during peak winter flows as a result of groundwater and rainfall infiltration overloading the sewerage system. Carterton's wastewater is predominantly domestic in origin, with approximately 10% from industrial sources, principally Premiere Bacon, a small 'home kill' meat processor, and a factory which manufactures paua shell products (NZET 2009).

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8 Note that there are dairy farms operating within the piggery wastewater disposal area (i.e., both piggery and dairyshed effluent is discharged to land (refer Figure 2.6).

9 2006 Census of Population and Dwellings, cited in NZET (2009).

Permit WAR950148 expired in March 2009, but legally continues to be exercised while Greater Wellington processes CDC's application for a new consent. A condition of the permit required CDC to cease discharging wastewater into the Mangatarere Stream during the summer months of January to March, other than when soil moisture content was too high to allow treated wastewater to be discharged to land[10]. A short-term consent (WAR030146) was subsequently granted in 2003 to enable a trial land disposal and treatment system during the summer months of 2006. This system was constructed by the end of 2003 and incorporated surface flow wetlands to further treat effluent from the oxidation ponds prior to a discharge to land or the stream (Figure 2.8).

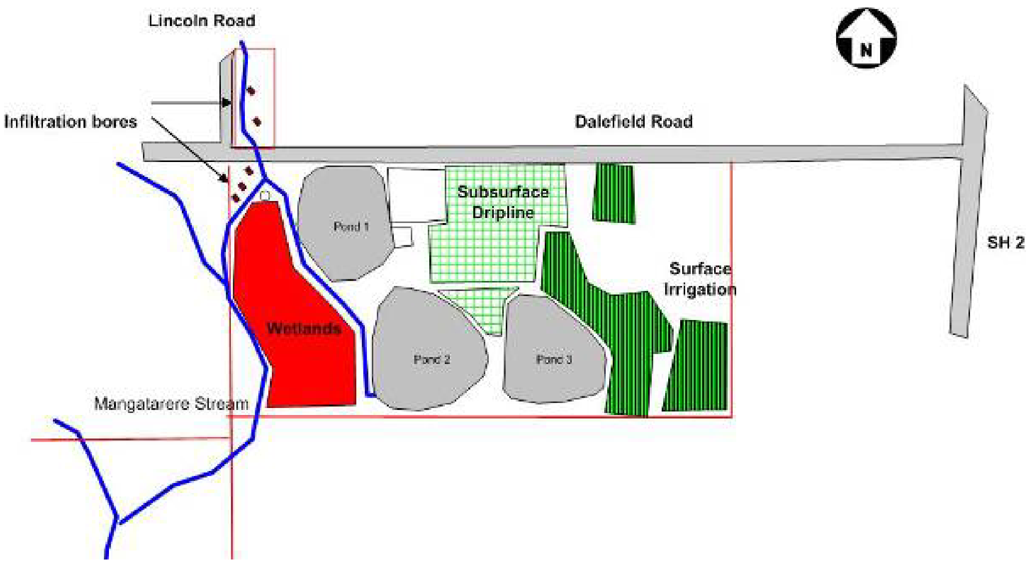

Figure 2.8: Schematic of CDC's Carterton WWTP at Dalefield Road (NZET 2007). The current wastewater treatment process comprises a fine screen, clarifier, sludge digester, a two-stage oxidation pond system (ponds 1 and 3 operate in parallel while pond 2 provides a polishing function) and 16 wetland plots. During periods where soil moisture allows a discharge to land, the wetland effluent is irrigated to 8 drip-line fields and 3 infiltration bores[11].

Under permit WAR030146, tertiary treated wastewater could be discharged into groundwater via direct injection into infiltration bores/trenches, and to land via drip line irrigation and soakage through the base of the oxidation ponds and wetlands. A short-term replacement consent was issued in 2007 (WAR060211) which enabled an extension of the land-disposal trial, including the application of wastewater to land year-round whenever soil conditions allowed. This permit expired in March 2009, but, together with permit WAR950148, continues to be exercised while Greater Wellington processes CDC's application for a new consent. A long-term land-based treatment and disposal system is still being investigated by CDC. At this stage, the main proposed upgrade to the existing treatment process is to incorporate a membrane filtration step as a final treatment stage prior to discharge to water or farmland.

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[10] CDC was also required to reduce the faecal indicator bacteria levels in the discharge for the rest of the year to below 3,000 cfu/100 mL. These conditions were imposed in response to monitoring results which showed the direct oxidation pond discharge was having a significant effect on the colour, bacterial content and nuisance periphyton growth in the Mangatarere Stream (Pickford 2007).

[11] Initially there were five infiltration bores and since 2006 the infiltration bores have received negligible flows (NZET 2009).

A pilot micro-filtration membrane plant was trialled for a fixed period from June 2008 (NZET 2009).

The conditions of Discharge Permits WAR950148 and WAR060211 require CDC to undertake regular monitoring of oxidation pond effluent, wetland effluent, and stream and groundwater quality, as well as six-monthly ecological monitoring in the Mangatarere Stream upstream and downstream of the wastewater outfall. The results of some of this monitoring are discussed in later sections of this report.

2.7.5 Carterton Landfill

The Carterton Landfill is located adjacent to CDC's WWTP on Dalefield Road. The landfill was in operation for over 40 years, with the last resource consent (WAR940047) granted in May 1996 authorising the discharge of up to 5,500 m^3/year of municipal solid waste to land and up to 43 m^3/day of associated leachate to land and groundwater. Groundwater monitoring was required as a condition of consent because, with the exception of the more recently constructed cells, the landfill has no liner or leachate collection system and the depth to groundwater beneath the site is only in the order of 1–1.2 m.

Although Discharge Permit WAR940047 does not expire until February 2016, the landfill closed in September 2004 after CDC decided to support a more cost-effective option to export waste to an alternative landfill. Areas of the landfill receive treated wastewater from the WWTP. As a result, CDC continues to monitor groundwater quality underneath and downgradient of the landfill.

2.7.6 Other activities

Stormwater from the western side of Carterton township is discharged into the Mangatarere Stream, via a network of stormwater pipes which drain into the Waikakariki Stream. The Waikakariki Stream enters the Mangatarere Stream in the lower portion of the catchment just west of the corner of Lincoln and Dalefield Roads. The stormwater discharges, which contain contaminants such as oil, heavy metals and sediment, are authorised by Discharge Permit WAR950011, which also allows for the diversion of high flows in the Waikakariki Stream at two weirs downstream of Belvedere Road and adjacent to Lincoln Road. No monitoring of contaminants from the Carterton stormwater network is required, nor is any receiving water quality monitoring undertaken.

There are several resource consents in the Mangatarere catchment authorising instream works associated with flood protection and/or erosion protection purposes. These consents are generally held by private landowners but Greater Wellington also exercises consents to manage the lower reaches of the Mangatarere Stream under its Waiohine/Mangatarere flood protection scheme. These consents may involve one-off or semi-regular instream works. For example, under consent WAR000364, Greater Wellington is allowed to realign up to 75 m of stream channel and install up to 100 m of rail groynes per year in the Mangatarere Stream (covering the reach from its confluence with the Waiohine River up to Brooklyn Road). In addition to these consented activities, a number of works such as willow planting, cabling and lopping, and associated minor channel works meet Greater Wellington's permitted activity rules and therefore do not require resource consent.

There are also a few discharge permits authorising on-site wastewater discharges to land in the Mangatarere catchment. However, the majority of on-site wastewater discharges in the catchment would meet Greater Wellington's permitted activity rules and therefore do not require resource consent.

3. Overview of catchment investigation

This section provides a brief overview of the Mangatarere catchment investigation and the scope of the investigation, including sampling sites and variables. Detailed information on the surface water, groundwater quality and soil quality sampling programmes are provided in Sections 4, 5 and 6 respectively.

3.1 Background

The Mangatarere catchment investigation took place over a 13-month period commencing in spring 2008. It was launched in response to concerns over consistently elevated nutrient concentrations being measured in routine surface water samples from Greater Wellington's long-term State of the Environment (SoE) monitoring site on the Mangatarere Stream at State Highway 2. The median dissolved inorganic nitrogen (DIN) concentration at this site for the five-year period leading up to the commencement of the catchment investigation was 1.47 mg/L (based on monthly testing), and DIN concentrations regularly exceeded 2.0 mg/L during this time (Figure 3.1). This compares with a typical benchmark concentration of 0.444 mg/L[12] for lowland streams in New Zealand (ANZECC 2000, see Section 4.3.1) and a national median of 0.55 mg/L for lowland pastoral streams (NIWA 2008)[13].

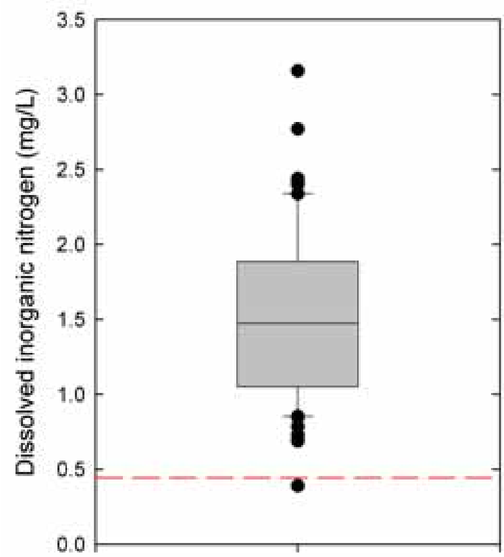

Figure 3.1: Box-and-whisker plot summarising dissolved inorganic nitrogen concentrations recorded in water samples collected at monthly intervals over September 2003 to August 2008 (*n*=60) from the Mangatarere Stream at State Highway 2. The horizontal red dashed line indicates the ANZECC (2000) nitrite-nitrate nitrogen trigger value for lowland streams.

Note:

- the lower and upper boundaries of the box represent the lower (25%) and upper (75%) quartiles of the data respectively – a minimum of 3 data points are needed to generate the box
- the horizontal line inside the box represents the median value
- the "whiskers" extending below and above the box represent the 10th and 90th percentile values respectively
- the black dots represent outliers

[12] This benchmark actually applies to nitrite-nitrate nitrogen (NNN) – in most surface waters DIN concentrations are the same or only slightly higher than NNN concentrations. The national median is based on regional council monitoring data (1997-2002) and was used to support the Ministry for the Environment's (2007) national state of the environment report.

In addition to elevated DIN concentrations, dissolved reactive phosphorus (DRP) concentrations at this site are typically the highest of 56 river and stream sites monitored monthly across the region (e.g., Perrie 2009, Perrie 2007)[13]. The median DRP concentration for the five-year period leading up to the commencement of the catchment investigation was 0.077 mg/L, with 20% of DRP sample results over this period exceeding 0.200 mg/L (Figure 3.2); this compares with a typical benchmark concentration of 0.010 mg/L for lowland streams in New Zealand (ANZECC 2000, see Section 4.3.1) and a national median of 0.014 mg/L for lowland pastoral streams (NIWA 2008).

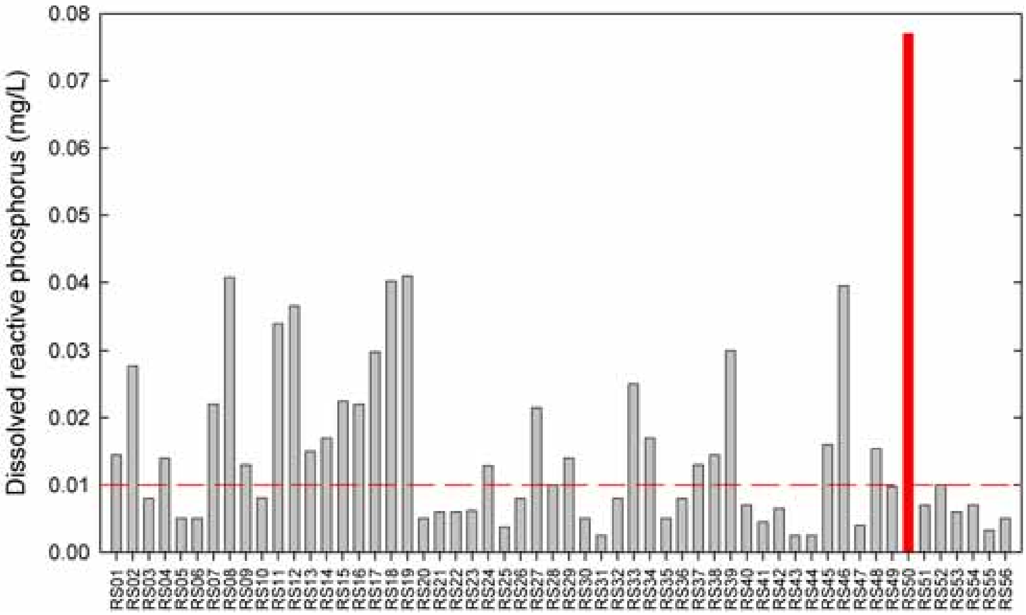

Figure 3.2: Median dissolved reactive phosphorus concentrations recorded in water samples collected at monthly intervals over September 2003 to August 2008 (*n*=60) from Greater Wellington's 56 RSoE monitoring sites, with the Mangatarere Stream at State Highway 2 coloured in red. The horizontal red dashed line indicates the ANZECC (2000) trigger value for lowland streams.

There was also concern elsewhere in the catchment, with water quality monitoring on the lower Enaki Stream undertaken as part of a riparian rehabilitation programme revealing little improvement in water quality over an eight-year period despite intensive riparian rehabilitation (Perrie 2008). Impacts on water quality in the lower reaches were attributed to intensive dairying in the upstream catchment but no assessments of upstream water quality had been undertaken.

3.2 Investigation scope and study area

In an attempt to better understand water quality within the Mangatarere catchment, including potential contaminant sources, a network of surface water, groundwater (predominantly shallow groundwater) and soil quality monitoring sites were selected throughout the catchment (Figure 3.3). Site selection took into account the location of existing SoE sites, tributary inputs, land use activities and soil types. With the exception of the one-off ecological

[13] The number of RSoE sites dropped from 56 to 55 in September 2009.

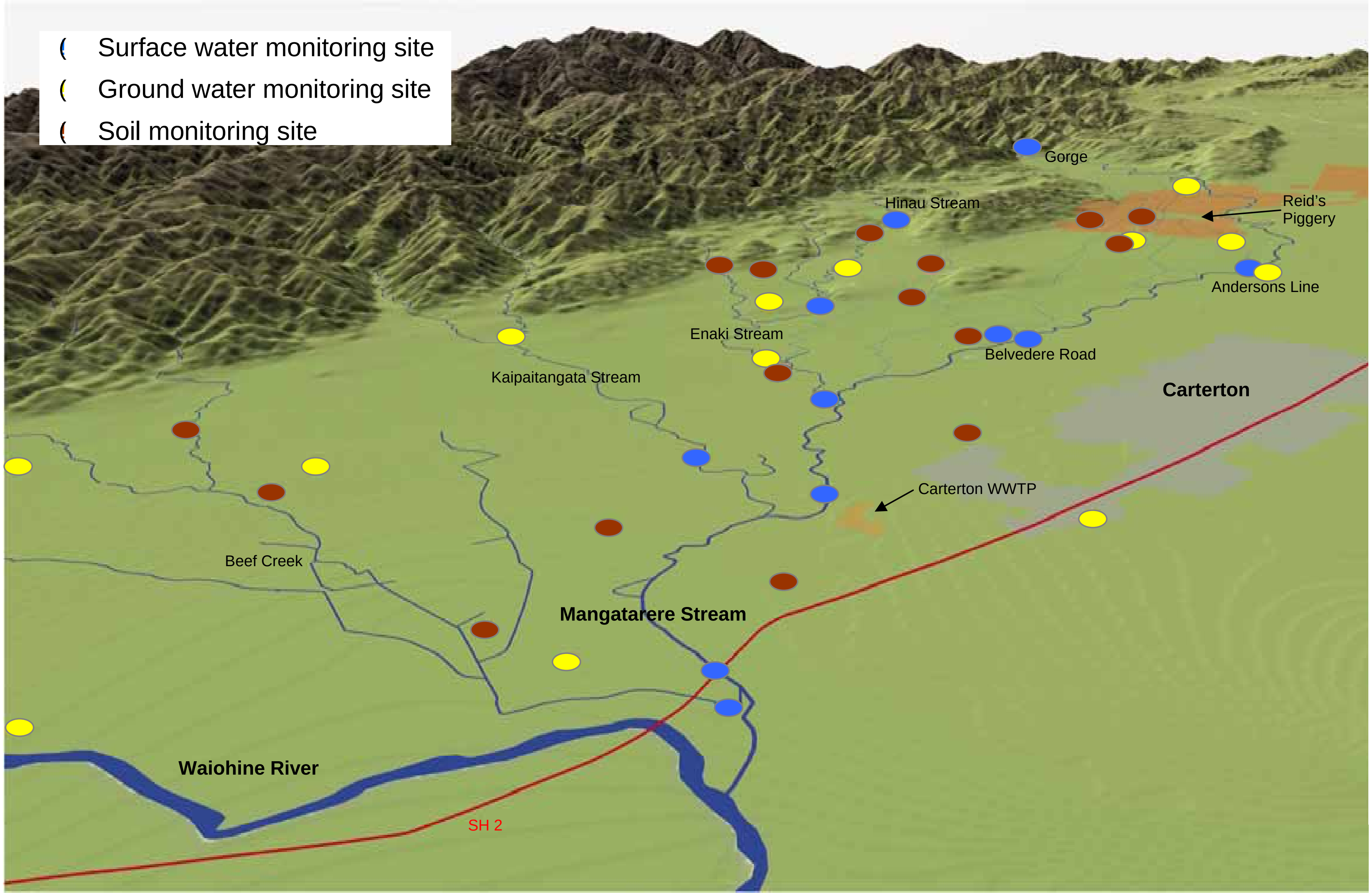

Figure 3.3: Surface water, groundwater and soil locations sampled over September 2008 to October 2009. The Carrington Water Race network is indicated in light blue. The location of Reid's piggery and the Carterton WWTP are also shown.

Base map generated by Geographix Ltd

assessment, sampling sites were restricted to the middle and lower catchment area downstream of the Mangatarere Gorge flow site; field measurements taken during an initial site visit on 20 August 2008 confirmed that although water quality is not pristine at the gorge (low intensity farming is present in the foothills upstream), it is generally of excellent quality.[14] Downstream of this point, land use intensifies and water quality declines markedly.

3.2.1 Key objectives

Specific objectives of the Mangatarere catchment investigation were:

- To determine the state of water quality in the Mangatarere Stream and its tributaries;
- To assess temporal trends in water quality within the catchment (i.e., is water quality getting better or worse over time?); and
- To estimate nutrient loads within the catchment, with the view to identifying likely contaminant sources.

Addressing these objectives involved a combination of the catchment investigation and a review of both long-term SoE water quality monitoring data and recent resource consent monitoring information.

3.2.2 Sampling sites and variables

Spot water samples were collected monthly for 12 months from 11 stream sites (Figure 3.3), with stream flow gauged or estimated at the time of sample collection. Groundwater samples were collected at two-monthly intervals (seven sampling occasions) from 13 groundwater bores[15]. Both surface water and groundwater samples were tested for a range of variables such as suspended sediment, nutrients and *E. coli* bacteria, as well as trace metals and major ions on several occasions. Macroinvertebrate and periphyton samples were also collected in some reaches of the Mangatarere Stream and its tributaries in late summer 2009.

Soil sampling was conducted once during spring 2009 at 16 locations under various land uses and soil types. Samples were tested for physical soil structure, organic resources, nutrients, fertility and trace elements.

3.3 Nomenclature and definitions

Throughout much of the remainder of this report, the names of some water quality variables and guideline documents have been abbreviated. Generally, the names will be mentioned in full on their first use in each section. The abbreviations of water quality variables are made in the text only and include: total organic carbon (TOC), nitrate nitrogen (nitrate), nitrite nitrogen (nitrite), nitrite-nitrate nitrogen (NNN, also known as total oxidised nitrogen), dissolved inorganic nitrogen (DIN), total Kjeldahl nitrogen (TKN), ammoniacal nitrogen

[14] Water quality at this site complies with all commonly used guidelines (see Section 4).

[15] Twenty one bores were sampled initially in October 2009, with 13 bores selected from this suite for ongoing sampling (see Section 5).

(ammonia), dissolved reactive phosphorus (DRP), and *Escherichia coli (E. coli)*. From this point on State Highway 2 is also abbreviated to SH 2.

In various locations in this report reference is made to “intensive agriculture.” This is intended to refer to both dairy and beef farming, although it is recognised that the definition of intensive agriculture depends on stocking rates and inputs (e.g., feed, fertiliser, etc.).

4. Surface water quality and ecology

4.1 Sampling sites and frequency

4.1.1 Water quality

Surface water sampling was undertaken at 11 sites in the Mangatarere catchment at monthly intervals over September 2008 to August 2009 inclusive (Figure 4.1, Appendix 1). Only nine of these sites were new; the Mangatarere

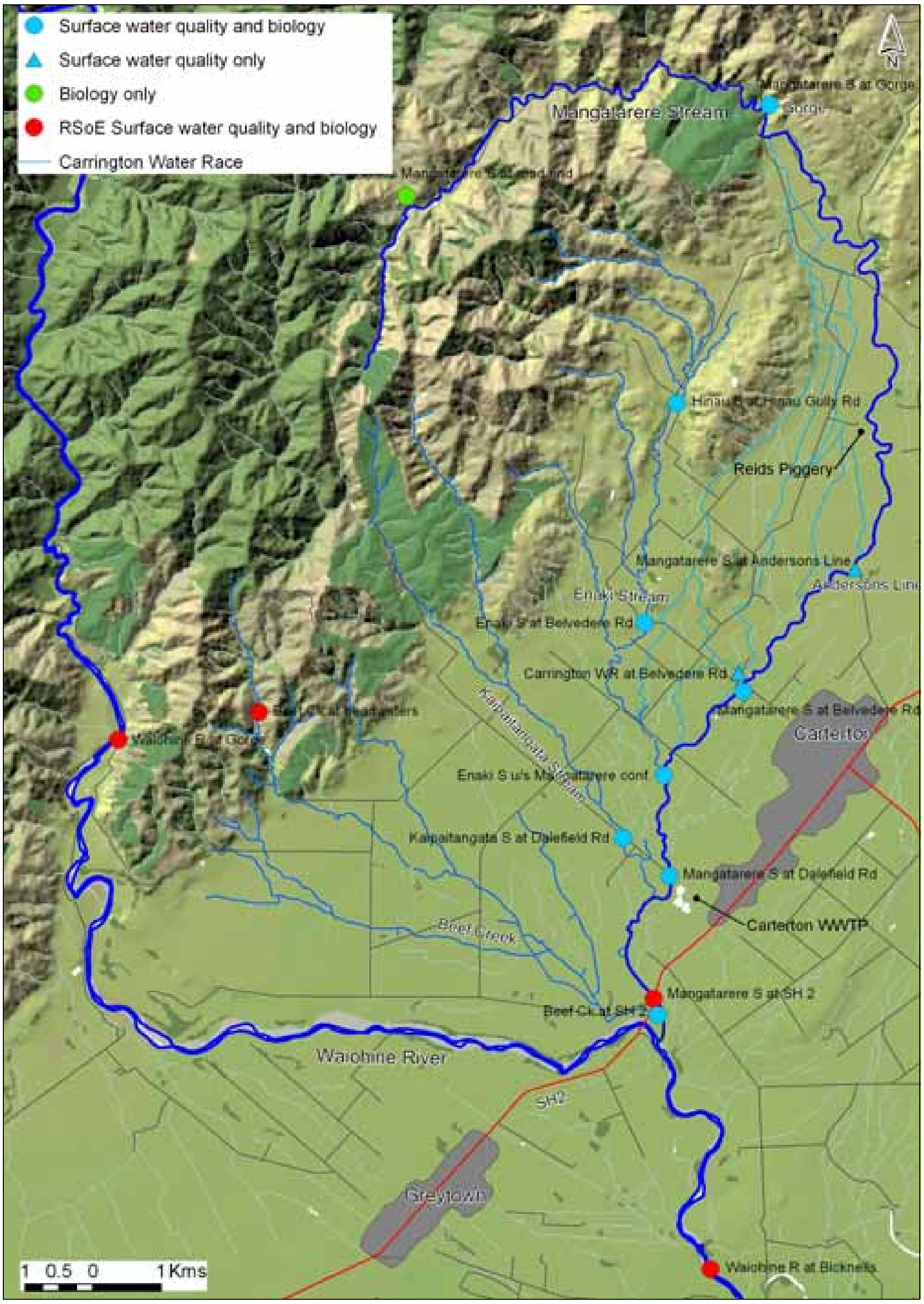

Figure 4.1: Location of the surface water and ecological sites sampled in the Mangatarere catchment over September 2008 to August 2009. Greater Wellington's SoE monitoring sites on Beef Creek and the Waiohine River (also sampled monthly, but on a different day) are also shown.

Stream site at SH 2 has been sampled at monthly intervals since 1998 as part of Greater Wellington's Rivers State of the Environment (RSoE) monitoring programme, and the lower Enaki Stream site (near the Mangatarere confluence) has been sampled monthly since early 2002 as part of Greater Wellington's riparian rehabilitation monitoring programme. Monitoring results from this Enaki Stream site also form part of the Ministry for the Environment's (2009) national reporting of stream health under the under the Dairying and Clean Streams Accord.

Sites included in the investigation were selected to represent the full gradient of land use impacts within the Mangatarere Stream catchment, with the uppermost water quality site at Mangatarere Gorge taken to be a reference site for the catchment below this point. Sites were also located near the bottom of each of the three main tributaries of the Mangatarere Stream to enable estimates to be made of the relative contribution of nutrients from the Enaki, Kaipaitangata and Beef Creek subcatchments. Two additional sites were located along the Enaki Stream and there was one site on the Carrington Water Race (Figure 4.1). It is important to note that the most downstream site located on the Mangatarere Stream (at SH 2) is above its confluence with Beef Creek; the results of sampling in Beef Creek at SH 2 have to be taken into account when assessing the impact of the quality of the water entering the Waiohine River from the Mangatarere catchment[16].

Figure 4.1 shows three additional RSoE monitoring sites that were not included in the 12-month catchment sampling programme: Beef Creek at Headwaters, Waiohine River at Gorge and Waiohine River at Bicknells, 5 km downstream of the Mangatarere Stream confluence (see Appendix 1 for site details). Temporal trends in long-term monitoring data for these RSoE sites, as well as the Mangatarere Stream at SH 2 and the Enaki Stream above the Mangatarere confluence, are examined in Section 7.

4.1.2 Periphyton and macroinvertebrates

A one-off ecological assessment was undertaken at 10 stream sites on 4-5 February 2009. The sites sampled included nine of the 11 water quality sites (the Mangatarere Stream at Andersons Line and Carrington Water Race at Belvedere Road were not sampled due to lack of flow) and an additional reference site at the headwaters of the Mangatarere Stream (at "Road End" – see Figure 4.1, Appendix 1). Key habitat characteristics of these sites, including substrate type and riparian features, are summarised in Appendix 1.

4.2 Sampling methods and sample analysis

4.2.1 Water quality

All surface water samples were collected by trained Greater Wellington staff using standard protocols. Due to time constraints, samples for dissolved nutrient, major ion and trace metal analysis were not field-filtered. Field measurements (temperature, dissolved oxygen, conductivity and pH) were taken using a YSI-556 or WTW 350i field meter, with the field meter calibrated on the day of

[16] It was too difficult to sample the outflow from the Mangatarere Stream.

sampling. Other field measurements included visual clarity (black disc), stream flow (see Section 4.2.2) and the percentage of streambed cover of nuisance periphyton (assessed using the RAM-1 method specified in Biggs and Kilroy (2000)).

Water samples were stored on ice upon collection and transported to Hill Laboratories in Hamilton for analysis within 24 hours of sampling. Samples were tested for a range of physico-chemical and microbiological variables, including pH, electrical conductivity, turbidity, dissolved and total nutrients, total organic carbon (TOC) and *E. coli*. Samples were also tested for dissolved concentrations of major ions (calcium, magnesium, potassium, sodium, chloride, sulphate, fluoride and bicarbonate), aluminium, iron, manganese and boron on four occasions (three months apart) and heavy metals (arsenic, cadmium, chromium, copper, lead, nickel and zinc) on the first sampling occasion in September 2008[17]. The full suite of analyses and the laboratory's analytical methods are provided in Appendix 2.

Due to the limitations of spot water temperature measurements[18], stowaway tidbit loggers were also used to monitor water temperature continuously at five sites during late February and March of 2009: Hinau Stream at Hinau Gully Road, Enaki Stream above the Mangatarere Stream confluence, Mangatarere Stream at Gorge, Mangatarere Stream at Belvedere Road and Mangatarere Stream at Dalefield Road.

4.2.2 Stream flow

Flow was gauged at 8 of the 11 monitoring sites at the time of water sample collection, except in May and August 2009 when gaugings were not possible at most sites due to high stream flows. On these occasions flow was either derived from correlations with a continuous flow recorder located at the Mangatarere Stream at Gorge or estimated using known flows from other sites located upstream and/or downstream. At the other three monitoring sites, flow was determined from correlations with continuous flow records from the Mangatarere Stream at Gorge (Enaki Stream upstream of the Mangatarere confluence), a flow rating based on stage measurements along with one gauged result (Mangatarere Stream at Belvedere Road), or a mixture of gauging results and continuous flow measurements (Mangatarere Stream at Gorge). See Appendix 2 for further information.

4.2.3 Periphyton and macroinvertebrates

Macroinvertebrate samples were collected from riffle-type habitats using protocol C1 of the national macroinvertebrate sampling protocols (Stark et al. 2001). At least one sample was collected from each site; at six sites three replicate samples were collected in an attempt to better characterise macroinvertebrate community composition (see Appendix 2).

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17 The exception was the Mangatarere Stream at SH 2 (RSoE site downstream of the Carterton WWTP discharge) where water samples were tested for heavy metals on a monthly basis.

18 Spot measurements rarely capture the daily minima and maxima temperatures experienced in streams. An indication of the maximum temperatures recorded within the Mangatarere catchment was considered important given that low flows are common in summer.

Periphyton biomass was assessed at each site from both riffle and run-type habitats using an adaptation of method QM1-a[19] (Biggs & Kilroy 2000). At least one sample was collected from each habitat type at each site; at six sites two replicate samples were collected from each habitat type to better quantify biomass variation at a reach scale (see Appendix 2). Samples were analysed for chlorophyll *a* and ash free dry mass. Taxonomic identification was also undertaken.

4.3 Data interpretation and analysis

4.3.1 Water quality

During data processing, concentrations of any water quality variables reported by the laboratory as less than the analytical detection limit were replaced by values one half of the detection limit. These "halved values" were used in the calculation of summary statistics, notably median values.

Key physico-chemical and microbiological variables were summarised and compared against appropriate national water quality guidelines (Appendix 3) to provide an overview of the state of water quality at each stream site. In most instances the guideline values used were the Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) "default trigger values" for lowland aquatic ecosystems (herewith denoted as ANZECC 2000), with toxicant results (e.g., metals) compared against the ANZECC (2000) trigger values for protection of aquatic life (95% species protection level). There were a few exceptions, such as temperature and dissolved oxygen (assessed using Quinn and Hickey (1990) and the WRC (1999) RFP standards), water clarity (assessed using the MfE (1994) recreation standard of 1.6 m) and microbiological water quality (assessed against both the ANZECC (2000) stockwater trigger value as well as the "action level" (550 *E. coli*/100 mL) of the MfE/MoH (2003) microbiological water quality guidelines for freshwater recreational areas). Although much of the Mangatarere catchment is not used for contact recreation, as noted in Section 2.5, there are several local swimming holes in the catchment and the Mangatarere Stream flows into the Waiohine River, a waterway with very high recreational use.

The ANZECC (2000) trigger values for lowland aquatic ecosystems and stockwater are intended to be compared against the *median* values from independent samples at a site. These trigger values are not legal standards and breaches do not necessarily mean an adverse environmental effect would result. Rather, they can be considered "nominal thresholds" (Ballantine et al. 2010), where a breach is an 'early warning' mechanism to alert resource managers to a potential problem or emerging change that *may* warrant site-specific investigation or remedial action (ANZECC 2000).

Inter-site comparisons were conducted in Sigmaplot (Version 11.0) using the non-parametric Wilcoxon Signed Rank Test.

[19] Five rocks were assessed instead of the ten rocks recommended in method QM1-a[19] (Biggs & Kilroy 2000). Extensive macrophyte growth in Beef Creek at SH 2 prevented collection of periphyton samples from this site.

4.3.2 Periphyton and macroinvertebrates

Periphyton streambed cover and biomass were assessed against relevant MfE (2000) guidelines. Macroinvertebrate Community Index (MCI) and Semi Quantitative MCI (SQMCI) scores were assessed against thresholds recommended by Stark and Maxted (2007). The proportion of sensitive Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa compared to total taxa richness was also calculated. Periphyton guidelines and macroinvertebrate thresholds are listed in Appendix 3.

4.4 Water quality sampling results

The results of surface water quality samples collected and analysed over September 2008 to August 2009 are summarised here in five sub-sections. The complete results are provided in Appendix 4, together with stream flow gauging and streambed periphyton cover measurements.

4.4.1 Water temperature, dissolved oxygen, conductivity and pH

Monthly spot measurements of water temperature exceeded the 19°C threshold (see Appendix 3) on one or more occasions at five sites during the catchment investigation (Table 4.1). The Mangatarere Stream at both Andersons Line and SH 2 exceeded this threshold on three occasions during December 2008 and January and February 2009. The highest spot measurement of water temperature was 22.2°C at Andersons Line.

The Mangatarere Stream at Gorge was the only one of the five sites where continuous water temperature loggers were deployed (23 February to 31 March 2009) that did not exceed the 19°C threshold. The Hinau Stream at Hinau Gully Road, Enaki Stream upstream of Mangatarere confluence, and the Mangatarere Stream at both Belvedere Road and Dalefield Road all exceeded this threshold on at least several occasions during the six-week monitoring period (Figure 4.2). No site exceeded the RFP trout fishery and spawning standard of 25°C (WRC 1999).

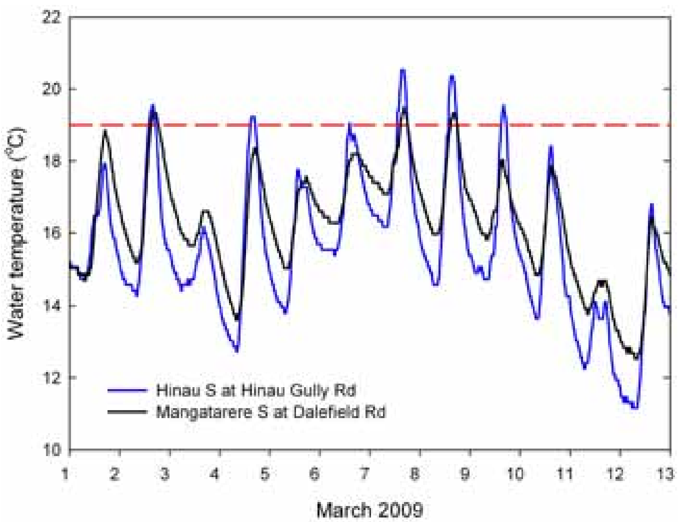

Figure 4.2: Continuous water temperature in the Hinau Stream at Hinau Gully Road and Mangatarere Stream at Dalefield Road over 13 days in March 2009. The dashed red line represents the upper thermal tolerance for sensitive invertebrate species (Quinn & Hickey 1990).

Table 4.1: Summary of field and turbidity measurements from 11 surface water sites sampled in the Mangatarere catchment from September 2008 to August 2009 (*n*=12 unless indicated otherwise). The number of times sample results did not meet guideline values is also listed, with bold font used to indicate where a median result for a site did not meet a guideline value.

Site name	Water temperature (˚C)			Dissolved oxygen (% saturation)			Dissolved oxygen (mg/L)			Conductivity (µS/cm)		pH			Visual clarity (m)				Turbidity (NTU)		
	Median	Range	*n* >20	Median	Range	*n* <80	Median	Range	*n* <6	Median	Range	Median	Range	*n* <6.5	Median	Range	*n*	*n* <1.6	Median	Range	*n* >5.6
Mangatarere S at Gorge	10.6	6.7–16.2	0	97.4	95.2–103	0	10.8	9.50–12.2	0	67.5	45-73	6.7	5.4[1]–7.3	5	3.85	0.46–6.15	10	2	0.49	0.22–6.3	2
Mangatarere S at Andersons Line	13.5	7.8–22.2	3	97.3	83.5–106	0	9.5	8.58–12.3	0	87.0	65.6-99	6.8	6.4–7.2	1	3.96	0.25-–6.70	10	2	0.74	0.29–23	2
Mangatarere S at Belvedere Rd	13.6	7.8–18.1	0	89.2	82.0–102	0	8.8	7.77–12.1	0	98.5	70.5-117	6.6	6.3–7.1	4	3.59	0.21–9.65	10	2	0.89	0.21–30	2
Carrington WR at Belvedere Rd	12.2	5.8–19.4	1	65.9	22.0–91.7	8	6.5	2.22–11.2	3	101	80-181	6.6	6.2–7.0	5	0.55	0.12–1.09	7	7	4.35	0.63–56	5
Hinau S at Hinau Gully Rd	11.7	7.8–18.3	0	96.8	75.2–111	1	10.7	7.27–11.9	0	109	76-123	7.0	6.2–7.9	4	1.29	0.18–2.39	10	8	2.95	1–40	3
Enaki S at Belvedere Rd	12.7	7.8–20.7	2	99.5	89.6–110	0	10.6	8.88–11.7	0	123	86-134	7.2	6.3–7.6	2	1.11	0.16–2.14	9	7	1.95	0.71–54	4
Enaki S u/s Manga. conf.	13.3	8.1–19.0	0	91.5	73.1–99.5	1	9.3	7.11–11.6	0	122	97-126	6.8	6.4–7.1	3	2.52	0.17–6.6	10	3	1.45	0.25–41	2
Kaipaitangata S at Dalefield Rd	13.5	9.3–16.0	0	85.6	58.7–109	5	9.0	6.07–11.3	0	93.8	74-98	6.7	6.1–7.2	6	3.54	0.39–4.22	10	3	0.85	0.17–18	2
Mangatarere S at Dalefield Rd	13.7	8.4–19.2	2	95.9	83.2–105	0	9.8	8.64–11.9	0	112	80.8-123	6.8	6.4–7.4	1	3.10	0.25–4.55	10	2	0.90	0.32–29	2
Mangatarere S at SH 2	14.0	8.5–20.1	3	100	79.7–143	1	10.6	8.33–13.0	0	119	83.8-145	6.8	6.3–7.0[2]	2	2.18	0.18–4.32	10	3	1.60	0.49–260	3
Beef Ck at SH 2	13.6	9.1–18.2	0	94.4	77.2–118	1	9.8	8.07–12.0	0	160	124-166	6.8	6.4–7.3	2	1.01	0.32–4.24	9	6	2.90	1.2–25	3

[1] Two very low pH readings were recorded at this site without any apparent problem with the pH meter.

[2] A maximum pH of 9.0 was removed from the data-set because field staff noted a problem with the pH meter (i.e., *n*=11)

The Carrington Water Race at Belvedere Road was the only one of the 11 monitoring sites with a median dissolved oxygen level below the RMA 1991 critical threshold of 80% saturation (65.9%). Four other sites fell below the 80% threshold on one sampling occasion: Hinau Stream at Hinau Gully Road, Enaki Stream above the Mangatarere Stream confluence, Mangatarere Stream at SH 2 and Beef Creek at SH 2. Dissolved oxygen was below the critical threshold on five occasions in the Kaipaitangata Stream at Dalefield Road. The highest maximum dissolved oxygen measurement recorded across all sites was 143% in the Mangatarere Stream at SH 2 in January 2009.

Median conductivity concentrations ranged from 67.5 µS/cm for the Mangatarere Stream at Gorge to 159.5 µS/cm recorded in Beef Creek at SH 2. Median conductivity concentrations generally increased with downstream progression in the five sites located on the Mangatarere Stream and the three sites located on the Enaki Stream (Table 4.1).

Median pH values for most sites were slightly acidic (6.6–6.8) (Table 4.1). Only two sites recorded a median pH of 7.0 or higher: Hinau Stream at Hinau Gully Road (7.0) and Enaki Stream at Belvedere Road (7.2).

4.4.2 Visual clarity, turbidity and suspended solids

Median clarity (black disc) values ranged from 0.55 m for the Carrington Water Race at Belvedere Road to 3.96 m for the Mangatarere Stream at Andersons Line. Four of the 11 sites recorded median values below the MfE (1994) contact recreation guideline of 1.6 m (Table 4.1): Beef Creek at SH 2 (1.01 m), Carrington Water Race at Belvedere Road (0.55 m), Hinau Stream at Hinau Gully Road (1.29 m) and Enaki Stream at Belvedere Road (1.11 m). Clarity tended to be higher at sites on larger streams (i.e., those located on the Mangatarere Stream) than at sites on smaller streams, although there was a notable reduction in clarity in the Mangatarere Stream between Dalefield Road (median 3.10 m) and SH 2 (median 2.18 m) (Figure 4.3). The difference between these two sites was statistically significant (Wilcoxon Signed Rank Test, p=0.002).

Based on median values, visual clarity improved with distance down the Enaki Stream; the most downstream site (Enaki Stream above the Mangatarere confluence) recorded the highest median value (2.52 m) and was the only site in the Enaki subcatchment to comply with the MfE (1994) guideline. The difference in visual clarity between the two most downstream sites on the Enaki Stream was statistically significant (Wilcoxon Signed Rank Test, p =0.004).

Reduced clarity typically occurred with elevated stream flows, although on at least one occasion poor clarity was measured in the Enaki Stream at Belvedere Road when dairy cows were present in the water upstream. This was the case on 21 January 2009 when clarity was measured at just 0.16 m.

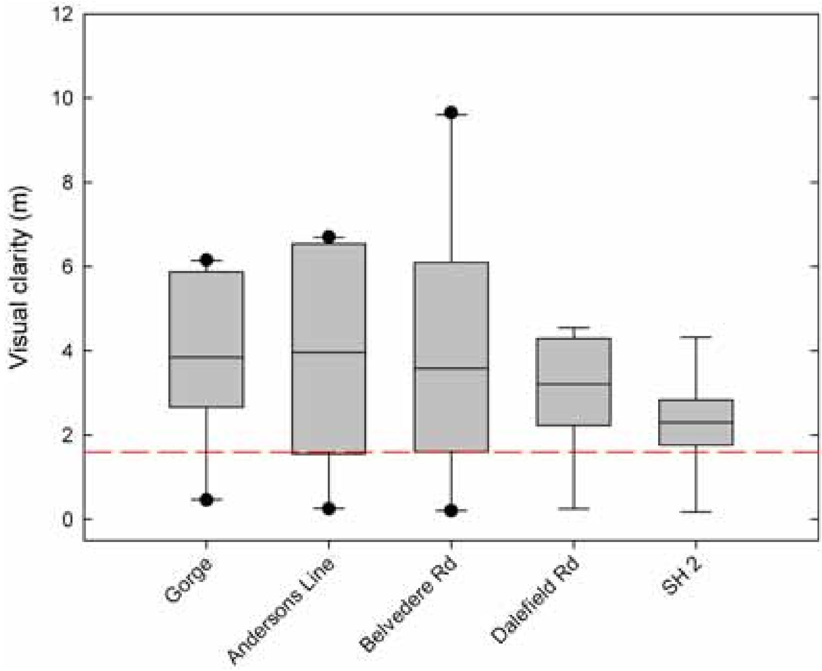

Figure 4.3: Box-and-whisker plots summarising visual clarity (black disc) values measured at monthly intervals over September 2008 to August 2009 (when flow conditions allowed, n=10) at five locations along the Mangatarere Stream. The horizontal red dashed line indicates the MfE (1994) guideline and represents a minimum value.

Median turbidity values at all sites complied with the ANZECC (2000) trigger value of 5.6 NTU, ranging from 0.49 NTU for the Mangatarere Stream at Gorge to 4.35 NTU for the Carrington Water Race at Belvedere Road (Table 4.1). As expected, turbidity was highest when stream flows were elevated after rainfall. There were a few exceptions, notably in the Enaki Stream at Belvedere Road when sampling occasions coincided with stock in the water upstream. Turbidity gradually increased with distance downstream at monitoring sites located along the length of the Mangatarere Stream but decreased with distance down the Enaki Stream.

Total suspended solid concentrations were frequently below detection limits at all sites located on the Mangatarere Stream except for the most downstream site at SH 2 (Table 4.2). The highest median concentrations were recorded in samples from Beef Creek at SH 2 (3.2 mg/L) and the Carrington Water Race at Belvedere Road (4.2 mg/L). Similar to median turbidity values, median suspended sediment concentrations decreased with distance down the Enaki Stream.

4.4.3 TOC and nutrients

Median TOC concentrations ranged from 0.9 mg/L (Kaipaitangata Stream at Dalefield Road) to 5.75 mg/L (Carrington Water Race at Belvedere Road). Median concentrations remained relatively stable with distance downstream at sites located on the Mangatarere Stream. In contrast, sites located along the Enaki Stream showed a slight decrease in median concentrations with distance downstream (Table 4.2). Of the three major tributaries, Beef Creek at SH 2 recorded the highest median concentration (3.4 mg/L).

Table 4.2: Summary of suspended solids, TOC, nutrient and *E. coli* concentrations recorded in water samples collected at monthly intervals from September 2008 to August 2009 (*n*=12 unless indicated otherwise) at 11 surface water sites in the Mangatarere catchment. Median values in bold font exceed guideline values. The number of times individual sample results exceeded guideline values is also listed.

Site name	Suspended solids (mg/L)		TOC (mg/L)		Nitrite-nitrate nitrogen (mg/L)			Ammoniacal nitrogen (mg/L)			Total nitrogen (mg/L)			Dissolved reactive phosphorus (mg/L)			Total phosphorus (mg/L)		
	Median	Range	Median	Range	Median	Range	N >0.444	Median	Range	N >0.021	Median	Range	N >0.614	Median	Range	N >0.010	Median	Range	N >0.033
Mangatarere S at Gorge	1	<2–8.9	1.7	0.73–4.9	0.055	0.016–0.16	0	0.005	<0.01–0.018	0	0.12	<0.11–035	0	0.005	<0.004–0.007	0	0.008	<0.004–0.025	0
Mangatarere S at Andersons Line	1	<2–27	1.5	0.9–4.7	0.615	0.280–1.4	7	0.005	<0.01–0.018	0	0.75	0.35–1.5	7	0.010	0.007–0.015	5	0.014	0.008–0.055	2
Mangatarere S at Belvedere Rd	1	<2–36	1.45	<0.5–3.7	1.20	0.420–2.2	11	0.005	<0.01–0.060	1	1.35	0.77–2.3	12	0.010	0.006–0.020	4	0.014	0.007–0.068	2
Carrington WR at Belvedere Rd	4.2	<2–81	5.75	<0.5–14	0.29	<0.002–2.8	5	0.041	<0.01–0.110	7	1.20	0.18–3.3	9	0.020	0.008–0.077	11	0.068	0.021–0.370	9
Hinau S at Hinau Gully Rd	3	<2–58	2.95	1.3–6.1	0.46	0.042–1.6	6	0.005	<0.01–0.067	2	0.73	0.27–2.4	7	0.026	0.016–0.050	12	0.042	0.025–0.130	8
Enaki S at Belvedere Rd	1.8	<2–71	2.7	1.5–11	0.75	0.033–1.8	8	0.005	<0.01–0.110	3	1.45	0.2–2.5	9	0.024	0.013–0.130	12	0.035	0.018–0.270	7
Enaki S u/s Mang. S conf.	1.5	<3–3.3	1.95	1.3–5.3	0.905	0.140–1.6	10	0.009	<0.01–0.030	2	1.30	0.27–2.3	10	0.016	0.009–0.034	11	0.028	0.014–0.120	2
Kaipaitangata S at Dalefield Rd	1	<2–15	0.9	<0.5–2.7	0.21	0.035–0.5	1	0.005	<0.01–0.014	0	0.32	0.12–0.65	1	0.003	<0.004–0.008	0	0.008	<0.004–0.040	1
Mangatarere S at Dalefield Rd	1	<2–36	1.7	1.1–5.3	1.40	0.600–2.2	12	0.005	<0.01–0.018	0	1.60	1.1–2.4	12	0.012	0.006–0.017	7	0.018	0.011–0.075	2
Mangatarere S at SH 2	2.5	<2–120	2.05	1.5–4.7	1.45	0.600–2.2	12	0.098	0.018–0.220	10	1.85	1.1–2.8	12	0.097	0.028–0.370	12	0.125	0.058–0.390	12
Beef Ck at SH 2	3.2	<2–34	3.4	1.5–7.0	2.15	1.0–2.9	12	0.019	<0.01–0.080	5	2.55	1.3–3.4	12	0.038	0.029–0.086	12	0.092	0.053–0.140	12

Median concentrations of nitrite-nitrate nitrogen (NNN) exceeded the ANZECC (2000) lowland trigger value of 0.444 mg/L at eight of the 11 monitoring sites (Table 4.2). The three sites that complied with the trigger value were the Mangatarere Stream at Gorge (0.055 mg/L), the Carrington Water Race at Belvedere Road (0.290 mg/L) and the Kaipaitangata Stream at Dalefield Road (0.210 mg/L). The highest median concentration was recorded in samples from Beef Creek at SH 2 (2.15 mg/L). Median NNN concentrations increased with distance down both the Enaki and Mangatarere streams (Figure 4.4).

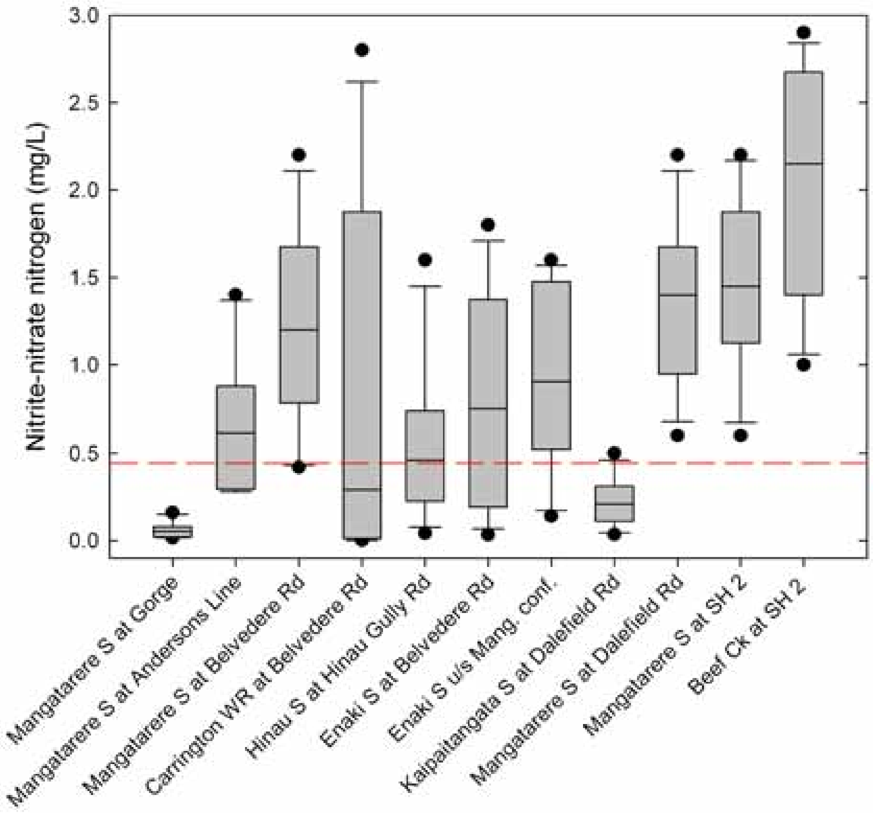

Figure 4.4: Box-and-whisker plots summarising nitrite-nitrate nitrogen concentrations recorded in water samples collected at monthly intervals over September 2008 to August 2009 (*n*=12) from 11 sites in the Mangatarere catchment. Sites are presented in approximate order moving down the catchment. The horizontal red dashed line indicates the ANZECC (2000) trigger value for lowland streams.

Strong seasonal variation in NNN concentrations were apparent at some sites, including Beef Creek at SH 2 and the Enaki Stream above its confluence with the Mangatarere Stream (Figure 4.5); at these sites the lowest concentrations were typically recorded over summer months. At other sites there was no clear seasonal pattern (e.g., Mangatarere Stream at Gorge, Figure 4.5).

Median ammoniacal nitrogen concentrations were above the ANZECC (2000) lowland ecosystems trigger value of 0.021 mg/L at two sites: the Carrington Water Race at Belvedere Road (0.041 mg/L) and the Mangatarere Stream at SH 2 (0.098 mg/L). Concentrations at the latter site exceeded the trigger value on 10 of the 12 sampling occasions (Table 4.2), but – taking into account pH recorded at sampling time – the ANZECC (2000) toxicity trigger value was not exceeded on any occasion.

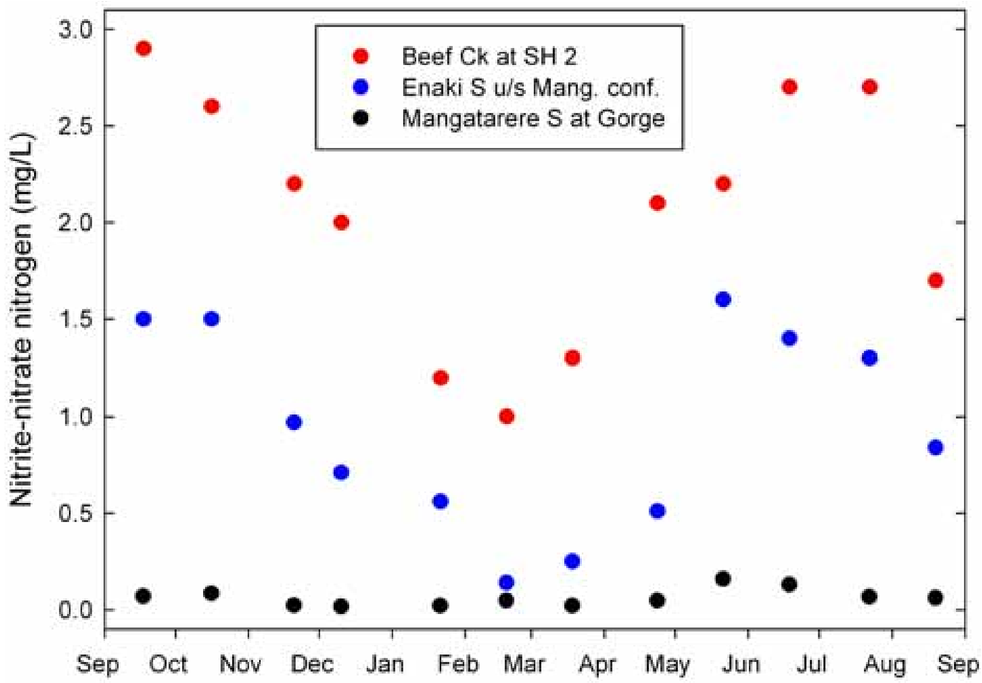

Figure 4.5: Nitrite-nitrate nitrogen concentrations recorded in water samples collected at monthly intervals over September 2008 to August 2009 from Beef Creek at SH 2, the Enaki Stream above the Mangatarere Stream confluence and the Mangatarere Stream at Gorge

Median total nitrogen concentrations ranged from 0.12 mg/L (Mangatarere Stream at Gorge) to 2.55 mg/L for water samples collected from Beef Creek at SH 2 (Table 4.2). Nine of the 11 monitoring sites exceeded the ANZECC (2000) lowland trigger value of 0.614 mg/L. Median results for all of these nine sites, except for the Carrington Water Race at Belvedere Road, also exceeded the ANZECC (2000) NNN trigger value. Total nitrogen concentrations increased with distance downstream at sites located on both the Enaki and Mangatarere streams.

Seven of the 11 monitoring sites recorded median dissolved reactive phosphorus (DRP) concentrations above the ANZECC (2000) lowland trigger value (Table 4.2). The four sites that complied with the trigger value were located on the Mangatarere Stream (at the Gorge, Andersons Line and Belvedere Road) and the Kaipaitangata Stream at Dalefield Road. The highest median concentration was recorded in water samples collected from the Mangatarere Stream at SH 2 (0.097 mg/L). This concentration was significantly higher (Wilcoxon Signed Rank Test, $p<0.001$) than the median concentration 2.5 km upstream at Dalefield Road (0.012 mg/L) (Figure 4.6). In contrast, median DRP concentrations decreased with distance downstream at sites located along the Enaki Stream (Table 4.2).

Seasonal variation in DRP concentrations was apparent at some sites such as Beef Creek at SH 2 (Figure 4.7), where the highest concentrations were recorded during summer months. The Mangatarere Stream at SH 2 also recorded higher concentrations during summer months although the pattern was less clear. Some sites showed little seasonal variation (e.g., Kaipaitangata Stream at Dalefield Road, Figure 4.7).

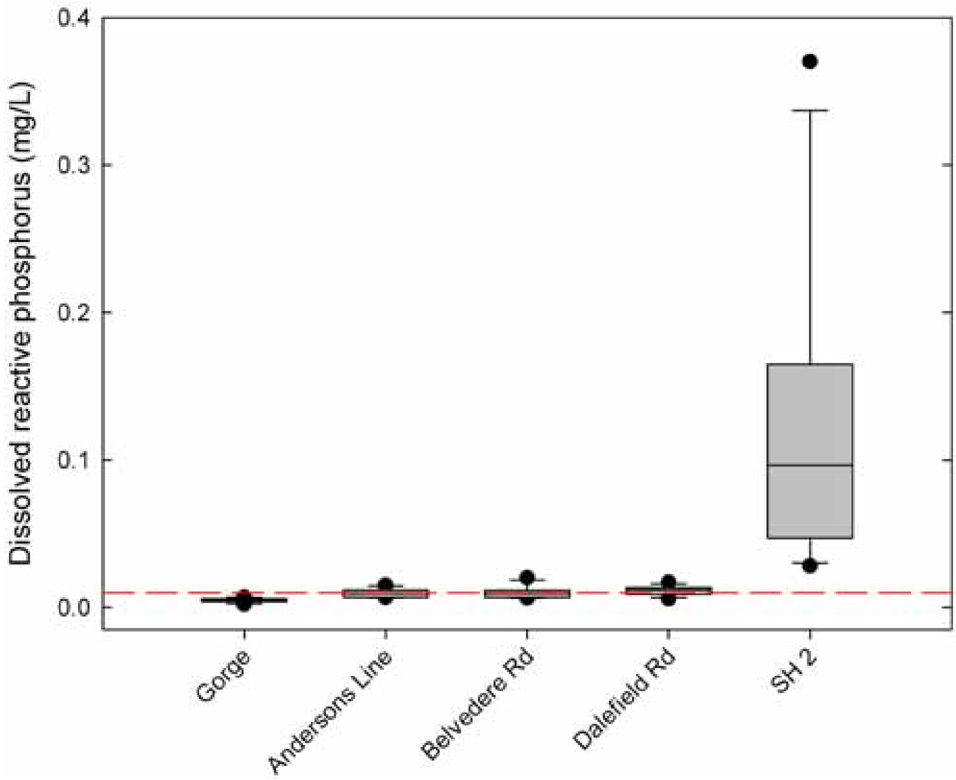

Figure 4.6: Box-and-whisker plots summarising dissolved reactive phosphorus concentrations recorded in water samples collected at monthly intervals over September 2008 to August 2009 (*n*=12) from the five sites located along the Mangatarere Stream. The horizontal red dashed line indicates the ANZECC (2000) trigger value for lowland streams.

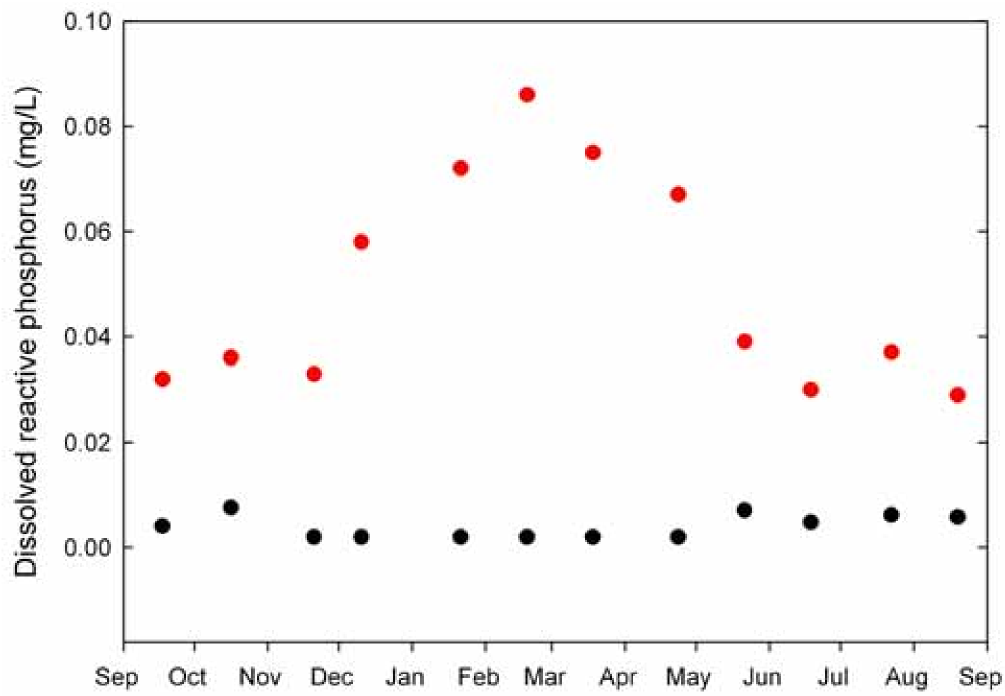

Figure 4.7: Dissolved reactive phosphorus concentrations recorded in water samples collected at monthly intervals over September 2008 to August 2009 from Beef Creek at SH 2 (red circles) and the Kaipaitangata Stream at Dalefield Road (black circles)

Table 4.3 summarises instantaneous flows and dissolved and total nutrient loads for each monitoring site over the 12-month sampling period. Instantaneous nutrient loads were calculated by multiplying the gauged/estimated stream flow (L/s) at the time of sampling by the nutrient concentration measured in stream water samples. For nitrogen, the dissolved inorganic (DIN) load is given, representing the sum of both nitrate-nitrate nitrogen (NNN) and ammoniacal nitrogen.

Nitrogen loads increased steadily with distance down the main stem of the Mangatarere Stream (Figure 4.8). Similar increases with distance downstream – but on a much smaller scale – were also observed in the Enaki subcatchment. The majority of the nitrogen load (over 70% on average for most sites but only 43% at the Gorge and 51% for the Carrington Water Race) was in the dissolved (soluble) form. Of the three main tributaries, Beef Creek contributed the most significant load; the mean instantaneous load during the 12-month investigation equated to one third of the total DIN load exiting the Mangatarere Stream into the Waiohine River (Table 4.3).

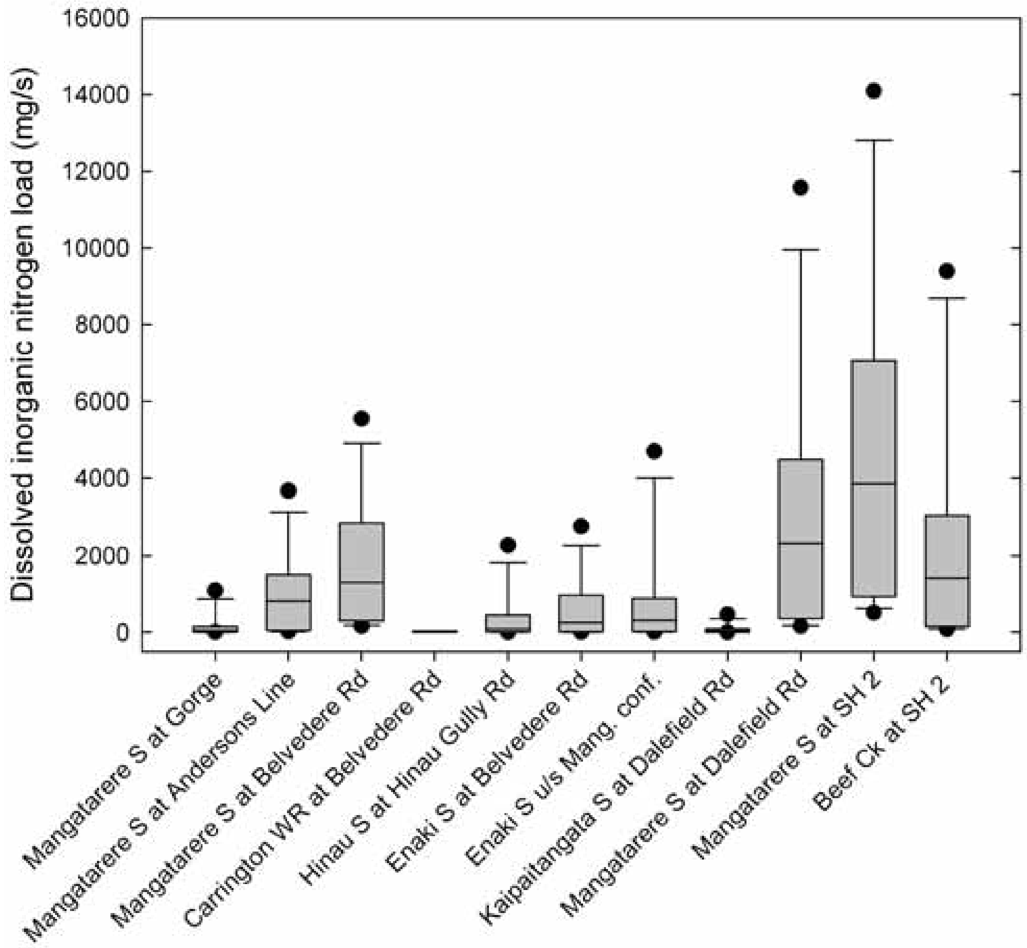

Figure 4.8: Box-and-whisker plots summarising instantaneous dissolved inorganic nitrogen loads for the 11 water quality sites sampled monthly from September 2008 to August 2009 inclusive (*n*=12 for all sites except the Carrington Water Race (*n*=8))

Table 4.3: Summary of instantaneous stream flows and nutrient loads at each of the 11 monitoring sites in the Mangatarere catchment for the period September 2008 to August 2009 (*n*=12 except for the Carrington Water Race where only 8 flow measurements were possible). The mean loads presented here represent the mean of the individual loads calculated for each sampling event.

Site name	Flow (L/s)		Dissolved inorganic nitrogen (mg/s)			Total nitrogen (mg/s)			Dissolved reactive phosphorus (mg/s)			Total phosphorus (mg/s)		
	Mean	Range	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Mangatarere S at Gorge	1,561	216–6,350	164	5.6	1,086	381.6	12.1	2,159	9.23	0.4	44.5	25.94	0.6	138.4
Mangatarere S at Andersons Line	2,067	29–10,658	993	18.1	3,677	1,462	22.1	6,501	18.43	0.3	101.3	77.02	0.4	458.3
Mangatarere S at Belvedere Rd	2,227	140–10,658	1,751	154.7	5,542	2,309	154	8,207	21.43	1.1	106.6	92.92	1.5	532.9
Carrington WR at Belvedere Rd	20	2–72	20.5	0.1	62.3	40.1	1.4	129.6	0.91	0.1	3.4	2.95	0.2	14.4
Hinau S at Hinau Gully Rd	360	26–1,359	351	1.5	2,265	540	8.6	3,261	10.58	0.7	53.0	30.86	1	176.7
Enaki S at Belvedere Rd	422	37– 1,443	550	3.1	2,756	729	13.3	3,607	11.05	1.4	49.1	33.20	1.8	187.6
Enaki S above Manga S conf.	656	14-2,877	825	8.1	4,690	1,162	11.6	6,617	16.71	0.2	97.8	54.27	0.3	345.2
Kaipaitangata S at Dalefield Rd	257	37–895	78.7	1.7	459.5	105	6.5	582.2	1.44	0.1	6.36	5.32	0.1	35.83
Mangatarere S at Dalefield Rd	2,998	96–13,100	3,076	154.1	11,567	4,015	172.8	15,720	41.54	1	222.7	162.2	1.2	982.5
Mangatarere S at SH 2	4,133	360–15,415	4,646	510.5	14,089	6,435	612	23,123	231.1	33.5	554.9	503.0	39.6	2,466
Beef Ck at SH 2	1,052	50–4,143	2,325	81.4	9,389	2,911	100.5	12,430	37.49	3.4	161.6	116.6	4.2	580.1
Mangatarere S outflow[1]	5,185	410–19,558	6,971	591.9	23,478	9,346	712.5	35,553	268.6	36.9	716.5	619.6	43.8	3,046

[1] The Mangatarere Stream outflow to the Waiohine River, calculated here by summing the instantaneous flows and loads from monitoring sites located on the Mangatarere Stream at SH 2 and Beef Creek at SH 2.

Figure 4.8 indicates significant variability in instantaneous DIN loads during the 12-month sampling period, particularly for the two sites on the lower Mangatarere Stream and Beef Creek at SH 2. The highest loads at these (and all) sites were recorded in May and August 2009 when stream flows were high following sustained rainfall over several days[20]. The lowest DIN loads were recorded during January to April 2009 inclusive, coinciding with the lowest stream flows. The general increase in DIN loads with stream flow is demonstrated for four sampling sites in the lower Mangatarere catchment in Figure 4.9.

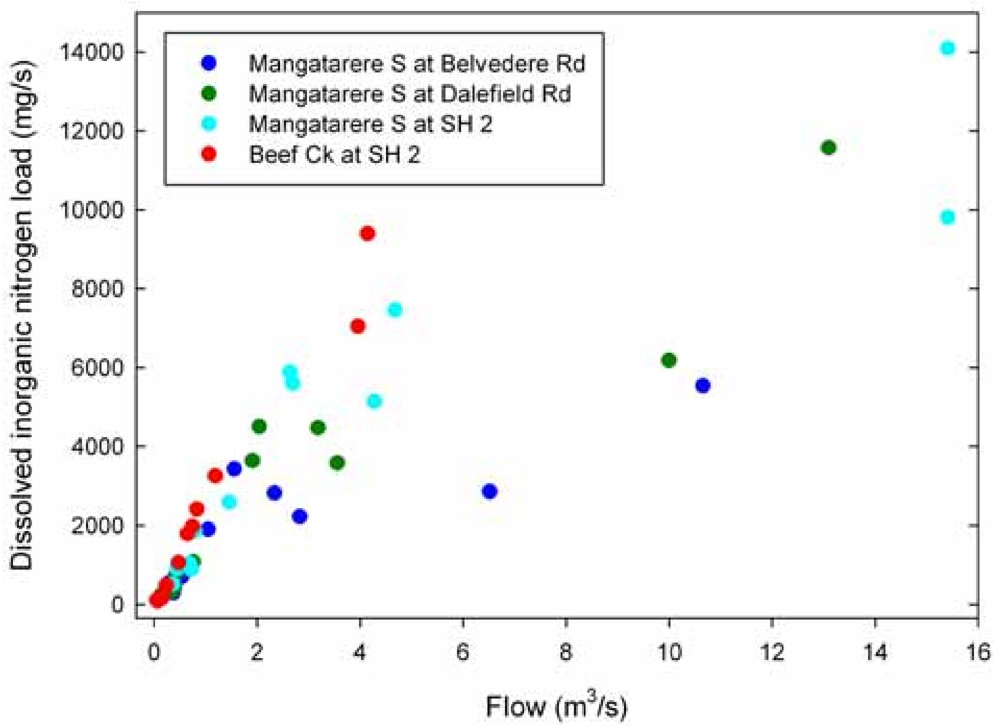

Figure 4.9: Instantaneous dissolved inorganic nitrogen loads for four stream sites in the lower Mangatarere catchment sampled monthly from September 2008 to August 2009 inclusive (*n*=12)

Phosphorus loads also increased down the Mangatarere Stream (Figure 4.10). However, the increase was more gradual until the very lower stream reaches where there was a sharp increase in loads between Dalefield Road and SH 2 where the Carterton WWTP discharge enters the stream; the mean instantaneous DRP load recorded at SH 2 during the course of the 12-month sampling period (231 mg/s) was over four times greater than the mean load at Dalefield Road (Table 4.3). On average, nearly 46% of the phosphorus load at the SH 2 site was in the soluble form; this compares with just 23-36% for all other sites. As for DIN, Beef Creek contributed the most significant load of the three tributary streams; the mean instantaneous load during the 12-month sampling period equated to 14% of the total DRP load exiting the Mangatarere Stream into the Waiohine River. An increase in phosphorus loads was observed with distance down the Enaki Stream (Table 4.3); the most downstream site near the confluence with the Mangatarere Stream recorded a mean load equating to 6% of the total load exiting the Mangatarere catchment.

20 59 mm and 60 mm of rain were recorded at the Valley Hill rain gauge in the 72 hours prior to sampling in May and August respectively.

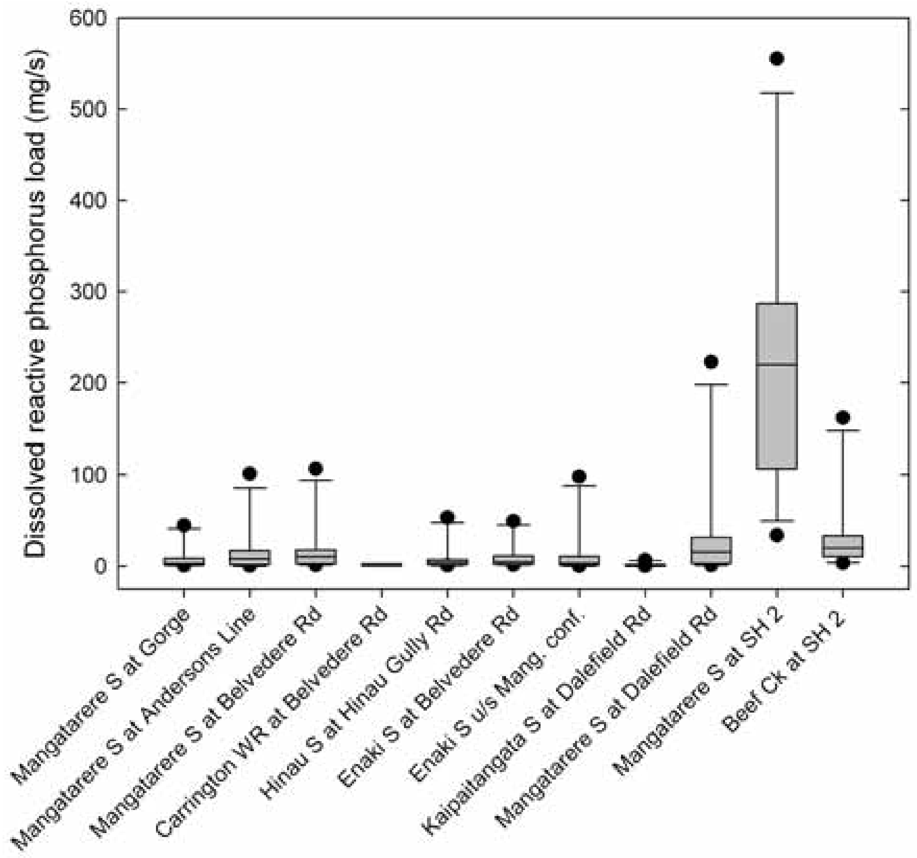

Figure 4.10: Box-and-whisker plots summarising instantaneous dissolved reactive phosphorus (DRP) loads for the 11 water quality sites sampled monthly from September 2008 to August 2009 inclusive (*n*=12 for all sites except the Carrington Water Race (*n*=8))

Similar to DIN, there was significant variation in instantaneous DRP loads during the 12-month sampling period (Figures 4.10 and 4.11), with the lowest loads recorded from January to April 2009 inclusive when stream flows were low and the highest loads recorded in May and August 2009 when stream flows were high. The Mangatarere Stream at SH 2, located downstream of the Carterton WWTP discharge, opposed the general trend and recorded high DRP loads (relative to all other sites) at most stream flows (Figure 4.11). The main exception was the period January to March when there was no direct discharge of treated wastewater into the Mangatarere Stream.

Overall, if the DRP loads calculated for each of the 12 sampling events are split into two equal groups according to stream flow (six lowest and six highest), it is clear that the relative contribution from the Carterton WWTP is higher at low flows. The mean DRP load at SH 2 during lower flows equated to 91.3% of the total load exiting the Mangatarere Stream into the Waiohine River (this compared with a mean contributing load at Dalefield Road of just 2.3%). In contrast, under higher flows, the mean DRP load at SH 2 reduced to 82.9% while the contribution upstream at Dalefield Road increased to 20.9% of the total load. Contributions from the subcatchments to the total DRP load exiting the Mangatarere Stream also increased at higher flows. For example, the mean DRP load contribution from the Beef Creek subcatchment increased from 6.4% under lower flows to 17.1% under higher flows.

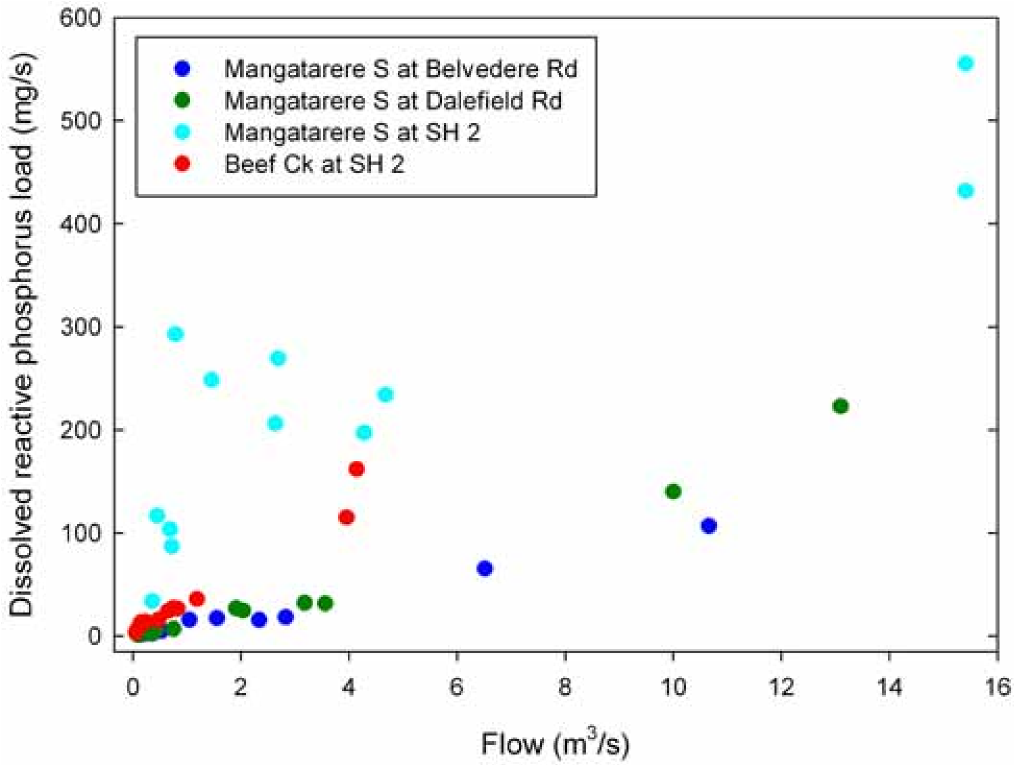

Figure 4.11: Instantaneous dissolved reactive phosphorus loads for four stream sites in the lower Mangatarere catchment sampled monthly from September 2008 to August 2009 inclusive (*n*=12)

4.4.4 *E. coli* indicator bacteria

Median *E. coli* counts exceeded the ANZECC (2000) stock drinking water trigger value of 100 cfu/100 mL in water samples from eight of the 11 monitoring sites (Table 4.4) and all but two sites recorded maximum values above 1,000 cfu/100 mL. The three sites with median values below the stock drinking water trigger value were the Mangatarere Stream at Gorge (90 cfu/100 mL, the Kaipaitangata Stream at Dalefield Road (36 cfu/100 mL) and the Mangatarere Stream at SH 2 (90 cfu/100 mL). In terms of contact recreation, the MfE/MoH (2003) action guideline was exceeded on two or more occasions at most sites, with two sites on the Enaki Stream exceeding the guideline on seven occasions each.

Median *E. coli* counts fluctuated slightly at monitoring sites located along the Mangatarere Stream but there was no obvious trend. In contrast, median counts decreased with distance down the Enaki subcatchment (Table 4.4). The highest median *E. coli* count was recorded in the Hinau Stream at Hinau Gully Road Bridge (1,000 cfu/100 mL), while the highest individual count was recorded in a sample from the Enaki Stream at Belvedere Road (17,000 cfu/100 mL) (Figure 4.12). This latter count was recorded in January 2009 when a herd of dairy cows were in the water upstream of the sampling site and was one of a few exceptions to the general trend of the highest *E. coli* counts being measured in water samples collected following rain events (May and August 2009). The Hinau Stream and Carrington Water Race monitoring sites were the other sites to record some elevated *E. coli* counts during dry weather.

Table 4.4: Summary of *E. coli* counts recorded in water samples collected at monthly intervals from September 2008 to August 2009 (*n*=12) at 11 surface water sites in the Mangatarere catchment. The number of times sample results exceeded the ANZECC (2000) stock water trigger value and MfE/MoH (2003) contact recreation guideline (action mode) is also listed.

	E. coli (cfu/100 mL)				
	Median	Min	Max	N >100	N >550
Mangatarere S at Gorge	53	21	280	5	0
Mangatarere S at Andersons Line	160	36	1,200	7	2
Mangatarere S at Belvedere Rd	170	23	1,800	8	2
Carrington WR at Belvedere Rd	370	2	11,000	8	5
Hinau S at Hinau Gully Rd	1,000	270	8,000	12	7
Enaki S at Belvedere Rd	645	70	17,000	11	7
Enaki S u/s Mangatarere S conf.	205	22	2,000	9	4
Kaipaitangata S at Dalefield Rd	36	2	130	3	0
Mangatarere S at Dalefield Rd	190	26	2,100	8	2
Mangatarere S at SH 2	90	15	2,300	5	2
Beef Ck at SH 2	430	210	4,200	12	5

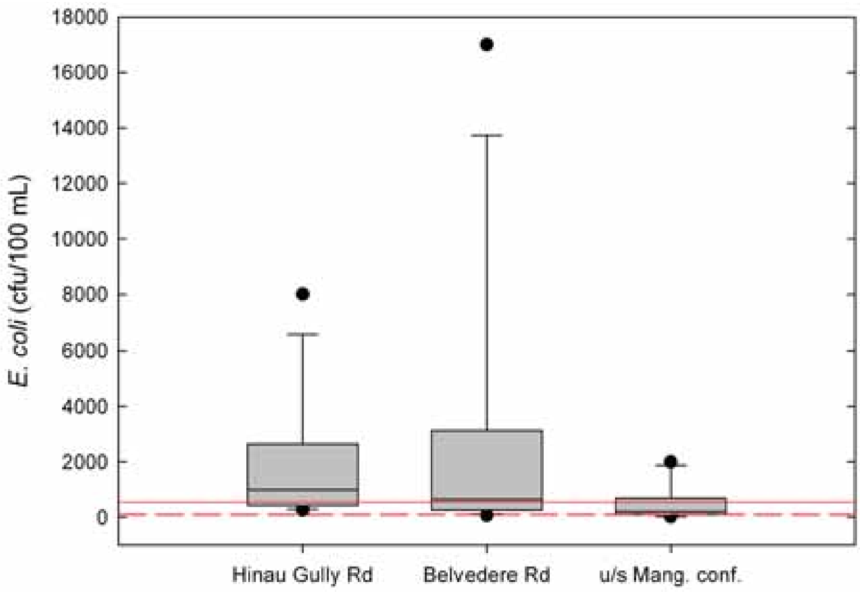

Figure 4.12: Box-and-whisker plots summarising *E. coli* counts measured in water samples collected at monthly intervals over September 2008 to August 2009 (*n*=12) from the three Enaki catchment monitoring sites. The solid and dashed red lines represent the action mode of the MfE/MoH (2003) recreational water quality guidelines and the ANZECC (2000) trigger value for stock drinking water respectively.

4.4.5 Major ions and trace elements

Dissolved concentrations of a selection of anions, cations and trace metals are summarised for each monitoring site in Table 4.5. Total hardness values all fell within the soft category (14–48 mg/L as $CaCO_3$). Calcium, sulphate and manganese concentrations tended to increase with distance down the Mangatarere Stream, while water samples from Beef Creek at SH 2 consistently

Table 4.5: Summary of the range of dissolved concentrations of selected anions, cations and trace metals recorded in water samples collected at monthly intervals from September 2008 to August 2009 at 11 surface water sites in the Mangatarere catchment (*n*=4 except for the RSoE site, Mangatarere Stream at SH2 (*n*=12)). Total alkalinity and hardness concentrations are also reported.

Site name	Total alkalinity (mg/L as $CaCO_3$)	Bicarbonate (mg/L at 25°C)	Total hardness (mg/L as $CaCO_3$)	Iron (mg/L)	Manganese (mg/L)	Boron (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Chloride (mg/L)	Sulphate (mg/L)	Fluoride (mg/L)
Mangatarere S at Gorge	17—19	20–23	14–17	<0.020	<0.0005	0.013–0.021	3.6–4.4	1.2–1.5	0.53–0.74	6.5–7.2	8.4–8.6	2.3–3.5	<0.050–0.078
Mangatarere S at Andersons Line	18–21	22–25	20–21	<0.020	<0.0005–0.0016	0.013–0.17	5.2–6.0	1.6–2.0	0.94–1.3	7.0–8.5	10–12	4.0–5.0	0.056–0.081
Mangatarere S at Belvedere Rd	19–23	23–28	24–28	<0.020	<0.0005–0.0014	0.013–0.017	6.2–7.2	2.2–2.3	1.1–1.5	8.0–9.2	11–12	5.5–6.6	0.055–0.066
Carrington WR at Belvedere Rd	21–33	26–41	18–44	0.093–0.24	0.00071–0.019	0.012–0.024	4.7–11	1.5–4.4	1.0–2.6	8.1–13	11–24	1.1–10	0.053–0.098
Hinau S at Hinau Gully Rd	21–28	25–34	22–32	0.032–0.043	0.00061–0.0038	0.012–0.015	5.9–8.7	1.7–2.5	1.3–2.0	8.5–9.7	11–13	5.4–12	0.072–0.110
Enaki S at Belvedere Rd	22–30	26–37	31–37	<0.020–0.021	<0.0005–0.0023	0.012–0.018	8.7–10	2.3–2.8	1.6–2.3	8.8–10	13–14	8.2–13	0.068–0.098
Enaki S above Mang. S conf.	21–28	25–34	28–34	<0.020–0.046	<0.0005–0.0023	0.012–0.017	7.4–9.2	2.2–2.7	1.8–2.0	8.9–10	12–14	8.2–12	<0.050–0.094
Kaipaitangata S at Dalefield Rd	23–26	28–32	22–26	<0.020	<0.0005–0.0025	0.022–0.028	5.9–7.0	1.9–2.1	0.68–0.75	7.1–8.6	10–12	4.0–4.6	0.064–0.076
Mangatarere S at Dalefield Rd	20–24	24–29	27–30	<0.020–0.025	0.00063–0.0024	0.013–0.017	6.8–7.9	2.4–2.6	1.3–1.7	8.3–9.7	12–13	6.7–9.0	0.066–0.072
Mangatarere S at SH 2	18–30	22–36	20–34	<0.020–0.110	0.0026–0.0075	0.011–0.027	5.3–8.7	1.7–3.1	1.1–1.8	7.0–13	8.9–16	5.9–9.6	<0.050–0.092
Beef Ck at SH2	27–41	33–50	41–48	0.091–0.14	0.0096–0.043	0.016–0.022	10–13	3.7–4.3	1.4–2.3	11–12	15–17	11–15	0.078–0.130

the highest calcium, chloride, magnesium, sodium, sulphate, iron and manganese concentrations. Total hardness values were also highest in samples from this site (41-48 mg/L). Samples from the Kaipaitangata Stream recorded the highest dissolved boron concentrations.

Stream water samples collected in September 2008 were also analysed for selected metals and metalloids (arsenic, cadmium, chromium, copper, lead, nickel and zinc). The dissolved concentrations of these metals were below their respective ANZECC (2000) toxicity trigger values in samples from all 11 stream sites (see Appendix 4). In most cases concentrations were also below analytical detection limits. The exceptions were:

- copper (0.00061 mg/L in the Carrington Water Race at Belvedere Road, 0.00095 mg/L in the Mangatarere Stream at SH 2 and 0.00072 mg/L in Beef Creek at SH 2);
- zinc (0.0018 mg/L in the Carrington Water Race at Belvedere Road, 0.0013 mg/L in the Kaipaitangata Stream at Dalefield Road, 0.0042 mg/L in Mangatarere Stream at SH 2 and 0.0017 mg/L in Beef Creek at SH 2).

Metal analysis continued at the Mangatarere Stream site at SH 2 for the duration of the 12-month investigation. Over this period measurable dissolved concentrations of copper and zinc were found in four and eleven samples respectively (Appendix 4), although none exceeded their respective ANZECC (2000) toxicity trigger values (95% protection level).

4.5 Periphyton and macroinvertebrate sampling results

The one-off periphyton and macroinvertebrate sampling results for February 2009 are summarised here and provided in full in Appendix 4. A summary of streambed periphyton cover assessments made monthly at the time of water sampling is presented first.

4.5.1 Periphyton cover

The number of monthly observations of periphyton streambed cover varied across the 11 monitoring sites. Extensive submerged and emergent macrophyte growth restricted the number of observations made in Beef Creek at SH 2 and the Carrington Water Race at Belvedere Road to just six and four respectively. High flows and increased turbidity during some sampling occasions also limited the number of observations that could be made at some other sites.

Four of the 11 sites exceeded the Ministry for the Environment (MfE 2000) guideline for filamentous periphyton streambed cover on at least one occasion during the 12-month sampling period (Table 4.6): the Hinau Stream at Hinau Gully Road (seven times), Enaki Stream at Belvedere Road (once), Kaipaitangata Stream at Dalefield Road (four times) and the Mangatarere Stream at SH 2 (four times). Apart from the Carrington Water Race at Belvedere Road, which typically had extensive cover of emergent macrophytes, the Enaki Stream above the Mangatarere Stream confluence (Greater Wellington's riparian rehabilitation monitoring site) was the only site where no filamentous periphyton cover was observed during sampling events.

Table 4.6: Summary of monthly observations of visible streambed cover (September 2008 to August 2009) with filamentous and mat-forming periphyton, along with the number of times the MfE (2000) guidelines were exceeded

Site name		Filamentous cover (%)				Mat cover (%)			
	n	Median	Min	Max	N >30%	Median	Min	Max	N >60%
Mangatarere S at Gorge	10	0	0	7	0	0	0	43	0
Mangatarere S at Andersons Line	9	0	0	3.5	0	0	0	30	0
Mangatarere S at Belvedere Rd	9	0	0	6	0	0	0	0	0
Carrington WR at Belvedere Rd	4	0	0	0	0	0	0	0	0
Hinau S at Hinau Gully Rd	10	47	0	94	7	0	0	28	0
Enaki S at Belvedere Rd	9	7	0	54	1	0	0	19	0
Enaki S u/s Mangatarere S conf.	10	0	0	0	0	0	0	0	0
Kaipaitangata S at Dalefield Rd	11	13	0	95	4	0	0	3	0
Mangatarere S at Dalefield Rd	10	0	0	14	0	0	0	24	0
Mangatarere S at SH 2	10	0	0	93	4	0	0	1	0
Beef Ck at SH 2	6	0	0	3	0	0	0	0	0

All 11 sites complied with the MfE (2000) mat periphyton streambed guideline of less than 60% cover (Table 4.6). The highest individual mat cover measurement (43%) was recorded in the Mangatarere Stream at Gorge on 23 April 2009.

4.5.2 Periphyton biomass

Chlorophyll *a* concentrations varied greatly between sites, between the types of habitat sampled (i.e., riffle versus run), and sometimes between replicate samples from within the same habitat type at a site (e.g., Mangatarere Stream at Dalefield Road; Table 4.7). The lowest chlorophyll *a* concentration recorded from any sample was 0.86 mg/m^2 from a one-off sample in run habitat in the Mangatarere Stream at Belvedere Road. The highest concentration was recorded from a sample collected in riffle habitat from the Mangatarere Stream at Dalefield Road (1,038 mg/m^2). Ash Free Dry Mass (AFDM) concentrations generally mirrored chlorophyll *a* concentrations (see Appendix 4), with the two sites that recorded the lowest and highest chlorophyll *a* concentrations also recording the lowest and highest AFDM concentrations respectively.

Three sites in the lower catchment exceeded the MfE (2000) chlorophyll *a* guideline for benthic biomass: the Kaipaitangata Stream at Dalefield Road, Mangatarere Stream at Dalefield Road, and the Mangatarere Stream at SH 2. Four replicate samples were collected from these two Mangatarere Stream sites (two each from riffle and run habitats), and chlorophyll *a* concentrations exceeded the guideline in all but one of the replicate samples. Only the riffle samples from the Mangatarere Stream at Dalefield Road exceeded the MfE (2000) AFDM guideline, although all other sites that exceeded the chlorophyll *a* guideline generally had higher AFDM concentrations compared with other sites.

Table 4.7: Periphyton biomass (chlorophyll *a* in mg/m[2]) in samples collected from two different habitat types (riffles and runs) across nine sites in the Mangatarere catchment during February 2009. Where two replicate samples were taken, the average biomass is also presented. Values in bold font indicate that they exceed the MfE (2000) guideline for benthic biomass.

Site name	Run 1	Run 2	Mean	Riffle 1	Riffle 2	Mean	Overall Mean
Mangatarere S at MV Rd end	8.74	–	–	2.56	–	–	5.65
Mangatarere S at Gorge	15.35	1.83	8.59	11.82	37.13	24.47	16.53
Mangatarere S at Belvedere Rd	0.86	–	–	1.33	–	–	1.1
Hinau S at Hinau Gully Rd	22.21	19.37	20.79	20.98	34.43	27.71	24.25
Enaki S at Belvedere Rd	28.2	38.96	33.58	6.64	3.68	5.16	19.37
Enaki S above Mang. S conf.	2.09	2.7	2.39	2.38	0.98	1.68	2.04
Kaipaitangata S at Dalefield Rd	21.01	–	–	140.9	–	–	80.97
Mangatarere S at Dalefield Rd	41.52	595.6	318.5	842.7	1,038	940.2	629.4
Mangatarere S at SH 2	72.45	75.92	74.18	137.9	148.0	142.9	108.6

Across all sites periphyton biomass in riffle habitats was typically greater than that in run habitats. This difference was particularly pronounced in the Mangatarere Stream at SH 2 where biomass in riffle habitat was almost twice that found in samples taken from run habitat. There were also examples of considerable variation within a habitat type at the same site. The two samples from run habitat in the Mangatarere Stream at Dalefield Road yielded biomass results of 41.5 and 595.6 mg/m^2 which reflected the patchy distribution of periphyton in the run at this site (Figure 4.13).

Figure 4.13: Patchy filamentous periphyton cover in the Mangatarere Stream at Dalefield Road during sampling in February 2009. *Vauchera* spp. and *Spirogyra* spp. dominated the periphyton biomass at this site.

Dominant and abundant periphyton taxa (based on Biggs & Kilroy 2000) varied between sites sampled and at two sites – Hinau Stream at Hinau Gully Road and Enaki Stream at Belvedere Road – the dominant taxa varied between habitat types sampled (Table 4.8). Both the run and riffle habitat in the Mangatarere Stream at SH 2 were dominated by *Melosira varians*, a species which tends to be more common in enriched environments (Biggs & Kilroy 2000). Samples from the Mangatarere Stream at Belvedere Road and the Enaki Stream upstream of the Mangatarere confluence contained very little periphyton and taxa could not be assigned a dominance rating.

Table 4.8: Dominant (D) and abundant (A) periphyton taxa (based on Biggs & Kilroy 2000) in samples collected from two different habitat types (riffles and runs) across nine sites in the Mangatarere catchment during February 2009

Site name	Habitat type	
	Run	Riffle
Mangatarere S at MV Rd end	*Gomphonema* spp. (D)	*Gomphonema* spp. (D)
Mangatarere S at Gorge	*Cymbella* cf. *tumida* (D)	*Cymbella* cf. *tumida* (D)
Mangatarere S at Belvedere Rd	Little algae present	Little algae present
Hinau S at Hinau Gully Rd	*Melosira varians* (D)	*Spirogyra* spp. (D)
Enaki S at Belvedere Rd	*Gomphoneis minuta* var. *cassieae* (D), *Melosira varians* (A), *Stigeoclonium spp.* (A) and *Oedogonium sp.* (A).	*Navicula* cf. *gregaria* (D)
Enaki S u/s Mang. S conf.	Little algae present	Little algae present
Kaipaitangata S at Dalefield Rd	*Spirogyra* spp.(D) and Oedogonium sp. (A)	*Spirogyra* spp. (D)
Mangatarere S at Dalefield Rd	*Vaucheria* spp. (D) and *Spirogyra* spp. (A)	*Vaucheria* spp. (D) and Nitzschia spp. (A)
Mangatarere S at SH 2	*Melosira varians* (D)	*Melosira varians* (D) *and Spirogyra spp.* (A)

4.5.3 Macroinvertebrate health

The MCI, QMCI and %EPT scores are summarised for each site in Table 4.9. The lowest scores across all three metrics were recorded for the macroinvertebrate sample collected from Beef Creek at SH 2, while the highest scores were generally recorded in the Mangatarere Stream at the forested headwaters site at the Mangatarere Valley Road end.

There was a trend of decreasing metric scores with distance downstream from the Mangatarere Stream headwaters (Table 4.9). The three sites located on the Enaki Stream (including the uppermost site on the Hinau Stream) showed an opposite, yet less pronounced trend, with metric scores generally increasing with distance downstream.

Of the 10 sites macroinvertebrate samples were collected from, two had MCI scores that indicated excellent invertebrate community health: the Mangatarere Stream at Road End (138.4) and the Mangatarere Stream at Gorge (128.1). Five sites recorded MCI quality classes of "good", two sites were "fair" and one site (Beef Creek at SH 2) recorded a quality class of "poor" (73.3). QMCI scores were generally comparable with MCI scores although typically indicated a healthier quality class, with four sites classified as "good" and no sites classified as "poor".

The proportion of EPT individuals also largely reflected QMCI and MCI scores, with a greater proportion of sensitive EPT taxa present at sites with higher QMCI and MCI scores. However, the highest EPT "score" was recorded at the Enaki Stream at Belvedere Road (91.5 %), a site only classified as "good" using the MCI and QMCI metrics. The lowest proportion of EPT individuals was recorded at the bottom of the catchment in Beef Creek at SH 2 (0.3 %).

Table 4.9: Mean (+/- 1 std dev.) macroinvertebrate community metric scores (and quality classes from Stark and Maxted (2007)) for stream sites in the Mangatarere catchment where one-off macroinvertebrate samples were collected in February 2009

Site name	No. reps	MCI			QMCI			EPT (%)	
		Mean Score	Quality Class	SD	Mean Score	Quality Class	SD	Mean score	SD
Mangatarere S at MV Rd end	1	138.4	Excellent	–	8.05	Excellent	–	83.1	–
Mangatarere S at Gorge	3	128.1	Excellent	4.2	6.92	Excellent	0.36	74.9	5.98
Mangatarere S at Belvedere Rd	1	116	Good	–	6.68	Excellent	–	80.8	–
Hinau S at Hinau Gully Rd	3	98.4	Fair	9.81	5.02	Good	0.5	78.6	11.8
Enaki S at Belvedere Rd	3	106.6	Good	0.7	5.77	Good	0.08	91.5	4.41
Enaki S above Mang. S conf.	3	114.5	Good	4.25	6.81	Excellent	0.29	69.7	4.32
Kaipaitangata S at Dalefield Rd	1	101.1	Good	–	4.87	Fair	–	10.1	–
Mangatarere S at Dalefield Rd	3	109.7	Good	2.18	5.61	Good	0.38	56.2	7.38
Mangatarere S at SH 2	3	95.7	Fair	1.73	4.55	Fair	0.22	27.4	18.2
Beef Creek at SH 2	1	73.3	Poor	–	4.48	Fair	–	0.3	–

4.6 Discussion

4.6.1 Physico-chemical and microbiological water quality

The results of the 12 months of surface water sampling clearly indicate a decline in physico-chemical and microbiological water quality with distance down the Mangatarere Stream (Figure 4.14). Water quality meets Greater Wellington's definition of "excellent" at the Gorge (see Perrie 2009 and Appendix 3), but is rated only "fair" at all main stem sites further downstream due to median dissolved nutrient and *E. coli* concentrations exceeding ANZECC (2000) thresholds for aquatic ecosystems. Water quality can be classified as "poor" at two of the three monitoring sites in the Enaki subcatchment and in the Beef Creek at SH 2; the reduced classification at these sites reflects elevated nutrient and *E. coli* concentrations as well as low visual clarity. The Kaipaitangata Stream at Dalefield Road was the only monitoring site below the Gorge with a water quality classification of "excellent". However, this site was subject to low dissolved oxygen concentrations at times during summer and, as noted in Section 4.6.4, nuisance periphyton growth.

Elevated water temperatures were measured in some parts of the catchment during summer, with potential to cause stress to aquatic life. This was particularly the case in the vicinity of Andersons Line where the Mangatarere

Stream is known to dry up in summer; this occurred for a short time in February 2009 and prevented any biological sampling at this site (Figure 4.15).

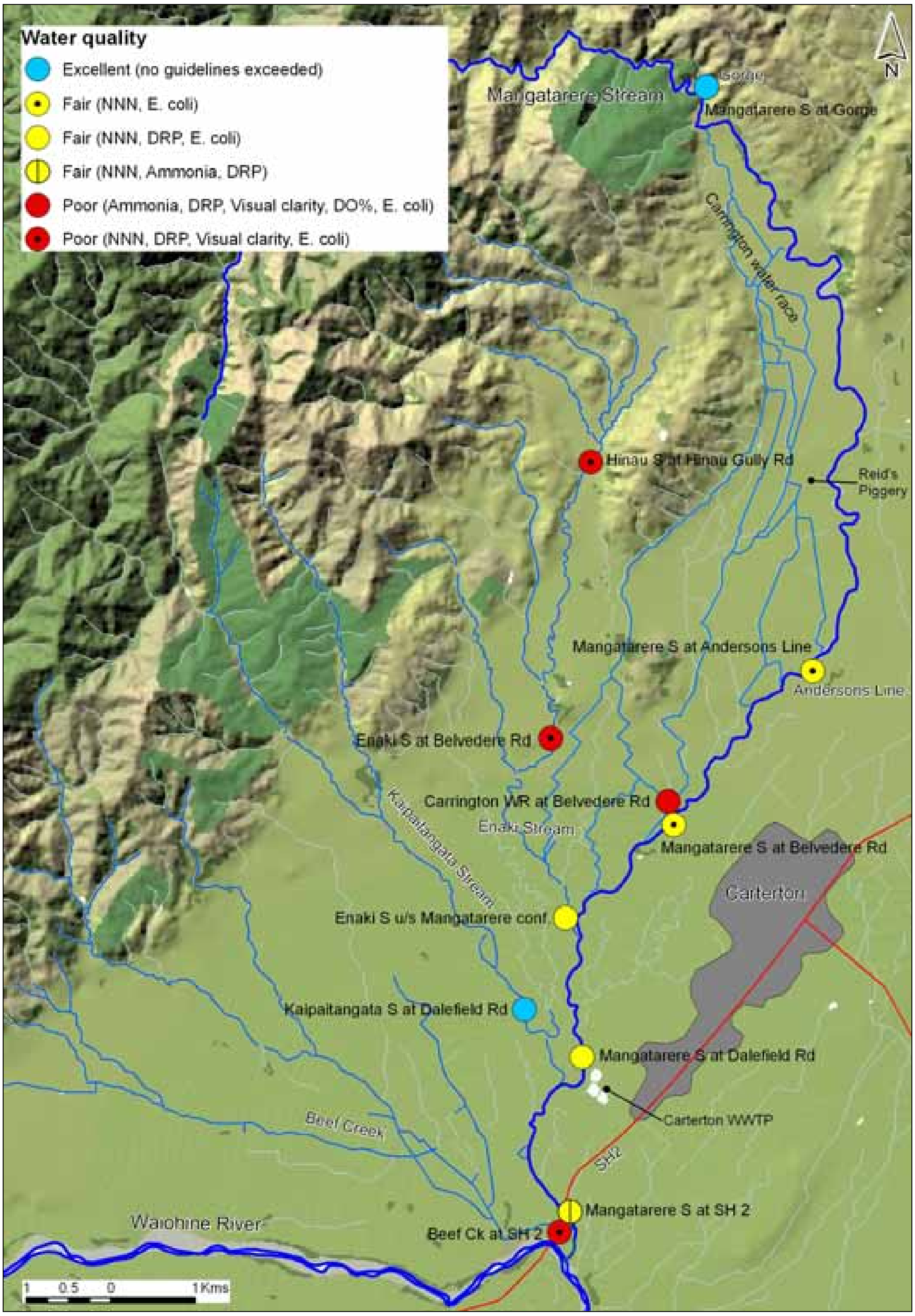

Figure 4.14: Overview of surface water quality in the Mangatarere catchment, based on a comparison of median concentrations (from monthly sampling over September 2008 to August 2009) of six key water quality variables against guideline values (see Appendix 3). The legend indicates which variables exceeded guideline values.

Figure 4.15: The Mangatarere Stream at Andersons Line in February 2009 – there was no flow

Elevated water temperatures are likely to be a more widespread problem as well, particularly given the lack of riparian vegetation cover throughout much of the catchment. Only limited continuous water temperature data were collected during the sampling period. However, water temperature has been measured continuously in the Mangatarere Stream at SH 2 since late 2009; data from January and February 2010 suggest that temperatures at this site may also exceed 19°C regularly during summer – despite this stream reach – and the lower reaches of the main tributaries – receiving recharge from significantly cooler groundwater. It is expected that without these groundwater inputs, maximum water temperatures would be higher and pose an even greater threat to stream life.

Water clarity is typically lower in a stream following rainfall events. However, in this investigation poor clarity was also evident in dry weather at monitoring sites on the upper and middle reaches of the Enaki Stream (Hinau Gully Road and Belvedere Road sites). This is attributed to dairy cows which had access to the stream at these sites on at least one sampling occasion (Figure 4.16). As well as poor water clarity and elevated suspended solid concentrations, stock access at these sites also resulted in a significant deterioration in other aspects of water quality, including spiked nutrient concentrations and poor microbiological water quality. For example, of the 12 samples collected from each of these sites for microbiological testing, just one sample from the Belvedere Road site was below the ANZECC (2000) stockwater trigger value. While this trigger value may be considered overly conservative at just 100 cfu/100 mL (the ANZECC 1992 guideline was 1,000 cfu/100 mL), the median *E. coli* counts recorded at Hinau Gully Road and Belvedere Road (1,000 cfu/100 mL and 645 cfu/100 mL respectively) also rendered the water unsuitable for contact recreation.

Stock access to streams was not limited to the Enaki subcatchment. Beef cows were observed at the water's edge at several other sites, including the Mangatarere Stream at Dalefield Road (Figure 4.17) and the Carrington Water Race. However, the impacts on microbiological water quality were less apparent at these sites.

Figure 4.16: Enaki Stream on 21 January 2009, looking upstream from the Belvedere Road Bridge where dairy cows had open access to the stream channel (left), and a stock crossing on the Enaki Stream near Upper Belvedere Road

Figure 4.17: Stock (beef cattle) with access to the Mangatarere Stream at Dalefield Road in November 2008

Overall, Beef Creek at SH 2 had the poorest water quality of the monitoring sites located on the three main tributary streams. This site recorded the highest conductivity, suspended sediment, TOC and nutrient concentrations. Nutrient-enriched groundwater inputs and artificial drainage carrying surface runoff from poor draining soils in some parts of the subcatchment are likely to be key aggravating factors. This is discussed further in Section 9.

In contrast to DIN and total nitrogen concentrations – which increased down the Enaki Stream – the lowest median TOC, *E. coli*, DRP and total phosphorus concentrations in this subcatchment were actually recorded at the most downstream site. Optical water quality properties were also better at this site (lower median turbidity and suspended sediment and greater visual clarity), which occurs within a reach that was fenced and planted in 2001 as part of Greater Wellington's riparian rehabilitation programme. With stock excluded from the area adjacent to and upstream of this site, and well established plantings in place along both stream banks, it appears that riparian rehabilitation is contributing to some noticeable improvements in the stream environment at this site. This was also evident in the biological sampling results; periphyton cover did not exceed nuisance thresholds at this site on any sampling occasion (compared with at Hinau Gully Road) and macroinvertebrate metrics were generally higher at this site than at the two upstream sites.

While riparian rehabilitation is clearly helping to improve the instream habitat and some aspects of water quality in the lower reaches of the Enaki Stream, it is likely that instream soluble nutrient concentrations are being influenced more by other factors. For example, lower DRP concentrations at the site may be due to uptake by periphyton further upstream and interactions with shallow groundwater. This is discussed further in Section 9.

The high water quality observed in the lower reaches of the Kaipaitangata Stream probably reflects the large proportion of its catchment under forest or scrub cover (73%). Groundwater inputs are also expected to influence water quality in the lower reaches.

4.6.2 Nutrient sources and loads

Median nitrogen concentrations increase steadily with distance down the main stem of the Mangatarere Stream, with most nitrogen present in the dissolved (soluble) form as nitrate nitrogen. Based on mean instantaneous DIN loads calculated for the September 2008-August 2009 reporting period, just over 2% of the load that exits the Mangatarere Stream into the Waiohine River is present in the stream at the Gorge. This increases to 14% at Andersons Line, 25% at Belvedere Road, 44% by Dalefield Road and nearly 67% at SH 2. The remaining 33% of the DIN load is attributed to the Beef Creek subcatchment which drains into the Mangatarere Stream just downstream of SH 2.

At all sites, DIN loads increase with stream flow. In the case of the Mangatarere Stream site at SH 2 – located downstream of the Carterton WWTP discharge – there is a significant change in the relative contribution to the stream's total DIN load at this site during higher stream flows. Based on the six lowest stream flow sampling events, the mean DIN load at SH 2 represents 79.2% of the total load exiting the Mangatarere Stream. This compares with 30.3% at Dalefield Road upstream of the Carterton WWTP; with the contribution from the Kaipaitangata Stream being just 0.6%[21], this indicates that the WWTP discharge contributes around 48% of the DIN. However, under the six higher flow events, the mean DIN load contribution in the Mangatarere Stream at SH 2 reduces to 65%, while the contributions at Dalefield Road and from the Kaipaitangata Stream increase to means of 46% and 1.2% respectively. This indicates that the WWTP discharge typically contributes less than 18% of the total DIN load at higher stream flows (most of which is in the form of ammonia). Therefore, during higher stream flows, non-point source (diffuse) inputs from the upstream catchment, along with inputs from the Beef Creek subcatchment, make up the majority of the total DIN stream load.

[21] Calculated at Dalefield Road. It is likely that the DIN contribution is slightly higher at the confluence 1.2 km downstream.

In contrast with nitrogen, less than half of the total phosphorus load was present in the soluble form. This suggests that a significant amount of sediment-bound phosphorus is present at most sites. The most likely sources of this phosphorus are streambank sediment as a result of stock damage and/or erosion (Figure 4.18) during high flows (many stream reaches were unfenced) and surface runoff. These sources are explored further in Section 9.3.2.

Figure 4.18: The Enaki Stream at upper Belvedere Road in September 2008, showing obvious signs of bank erosion

In terms of soluble phosphorus, median DRP concentrations increase only gradually with distance down the main stem of the Mangatarere Stream, until Dalefield Road. Based on mean instantaneous loads calculated for the September 2008-August 2009 reporting period, just over 3% of the load that exits the Mangatarere Stream into the Waiohine River is present in the stream at the Gorge. This contribution increases to nearly 16% by Dalefield Road and 86% at SH 2, highlighting that, on average, the Carterton WWTP discharge is responsible for around 70% of the DRP load that enters the Mangatarere Stream (the Kaipaitangata Stream contribution is negligible at 0.5%). The actual contribution varies with stream flow; based on the six lowest stream flow sampling occasions during the reporting period, the mean contribution was around 90%[22].

The remaining 14% of the DRP load (based on mean figures for the 12-month sampling period) exiting the Mangatarere Stream catchment is attributed to the Beef Creek subcatchment. The contribution from this subcatchment – as with the contributions from the other subcatchments – varied with flow, from a mean of 6.4% under the six lowest stream flow sampling occasions to a mean of

[22] This is an estimate only, calculated by subtracting the mean percentage contribution upstream at Dalefield Rd (2.3%) from that at SH 2 (93.6%). In reality, there will be a small input of DRP between these two sites from other minor sources (e.g., drains, groundwater). In addition, it is possible that the DRP contribution from the Kaipaitangata Stream is slightly higher at the confluence than at the Dalefield Road sampling site.

17.6% under the six highest flows. The Mangatarere Stream at Dalefield Road exhibited a similar pattern, highlighting that non-point sources of DRP make a significant contribution to total instream loads during wet weather and high stream flows.

In comparison with the Beef Creek subcatchment, the contribution to the total DIN and DRP loads exiting the Mangatarere Stream into the Waiohine River from the Enaki and Kaipaitangata subcatchments is very small. The relatively small soluble nutrient contributions from the Enaki subcatchment are surprising because this catchment is similar in area and land-use to the Beef Creek subcatchment (refer Section 2.6). Lower stream flows in the Enaki Stream (compared with Beef Creek) only account for around half of the difference in mean nutrient loads from the two subcatchments, highlighting how much lower instream nutrient concentrations are in the Enaki subcatchment. Greater surface water/groundwater interaction and different land management practices and soil properties – resulting in differing amounts of overland runoff and nutrient leaching – may account for the lower nutrient concentrations in the Enaki subcatchment. This is revisited in Section 9.3, together with mean nutrient loads for long-term SoE monitoring sites in the catchment and estimated loads at two further sites on the Mangatarere Stream monitored by Reid's piggery (see Section 8.1).

4.6.3 Limiting nutrients

The ratio of DIN to DRP can be a useful indicator of which nutrient may be limiting periphyton growth. These ratios should only be interpreted as providing an indication of nutrient limitation, especially with only 12 data points being available; more robust methods (e.g., use of nutrient diffusing substrates) are required to provide definite answers (Ausseil 2008). However, based on the data available it appears that phosphorus-limited conditions tend to dominate in the Mangatarere catchment, with some sites in the Enaki subcatchment possibly switching between phosphorus and nitrogen-limited conditions depending on seasons/flows (Figure 4.19). Co-limited conditions likely exist in the upper reaches (e.g., the Mangatarere Stream at Gorge) while in the lower reaches of the Mangatarere Stream and Beef Creek highly elevated concentrations of both DIN and DRP mean that neither nutrient is likely to be limiting periphyton growth.

Due to elevated concentrations of both DIN and DRP in the lower reaches of the Mangatarere Stream and Beef Creek, along with the potential switching of the limiting nutrient at some sites in the wider catchment, management of both nitrogen and phosphorus appears important for greater control of instream periphyton and macrophyte growth. This is supported by other studies (e.g., McArthur et al. 2009; Ausseil 2008) which have also shown that within a catchment nutrient limitation can vary spatially, temporally (e.g., seasonally) and over different flow conditions. This is also supported by other findings from the current investigation, such as the presence of nuisance periphyton growth upstream of the major contributor of DRP – the Carterton WWTP discharge. Nuisance periphyton growth is discussed further in the next section.

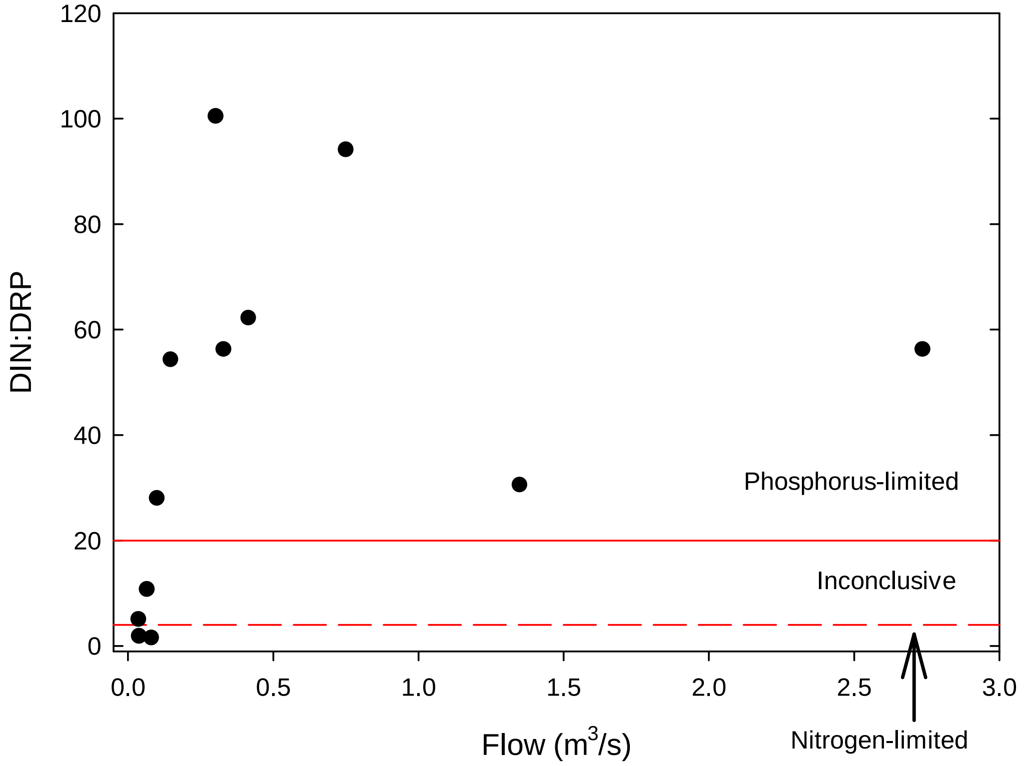

Figure 4.19: The DIN:DRP ratio compared with flow for the Enaki Stream at Belvedere Road, based on samples collected monthly from September 2008 to August 2009. Points above the solid red line are ratios that indicate phosphorus-limited conditions and points below the dashed red line represent ratios that indicate nitrogen-limited conditions.

4.6.4 Ecological health

Three sampling sites exceeded the 30% nuisance threshold for filamentous periphyton cover on four or more sampling occasions, with the Hinau Stream at Hinau Gully Road exceeding this threshold seven times. In addition, the two most downstream sites located on the Mangatarere Stream (at Dalefield Road and SH 2), along with the Kaipaitangata Stream at Dalefield Road, all exceeded periphyton biomass guidelines indicating that prolific periphyton growth at these sites may be having a negative impact on benthic biodiversity. This is supported by the invertebrate metrics; both MCI scores and % EPT taxa values tended to be lower at the sites with high algal biomass.

While elevated soluble nutrient concentrations are likely exacerbating nuisance periphyton growth in the two Mangatarere Stream sites, nutrient concentrations were low in the Kaipaitangata Stream at Dalefield Road. Periods of low or stable stream flow and a general lack of riparian cover are more likely to be favouring periphyton growth at this site.

High streambed periphyton cover and biomass reduces aesthetic values and, together with reduced stream flows and elevated water temperatures, can adversely affect trout spawning. Trout spawn from May through to September by depositing their eggs among gravels in fast flowing waters (McDowall 1990).

Invertebrate health typically reflected water quality; a general deterioration in metric scores was seen with distance down the catchment from “excellent” at headwater sites and the Gorge to “good” at most mid catchment sites – as well as the Mangatarere Stream at Dalefield Road – to “fair” at SH 2 below the Carterton WWTP discharge (Figure 4.20). Beef Creek at SH 2 recorded the poorest invertebrate health which is a reflection of the poor quality of the habitat at this site (channelised and dominated by macrophytes that are supported by siltation of the channel bed) as much as poor water quality.

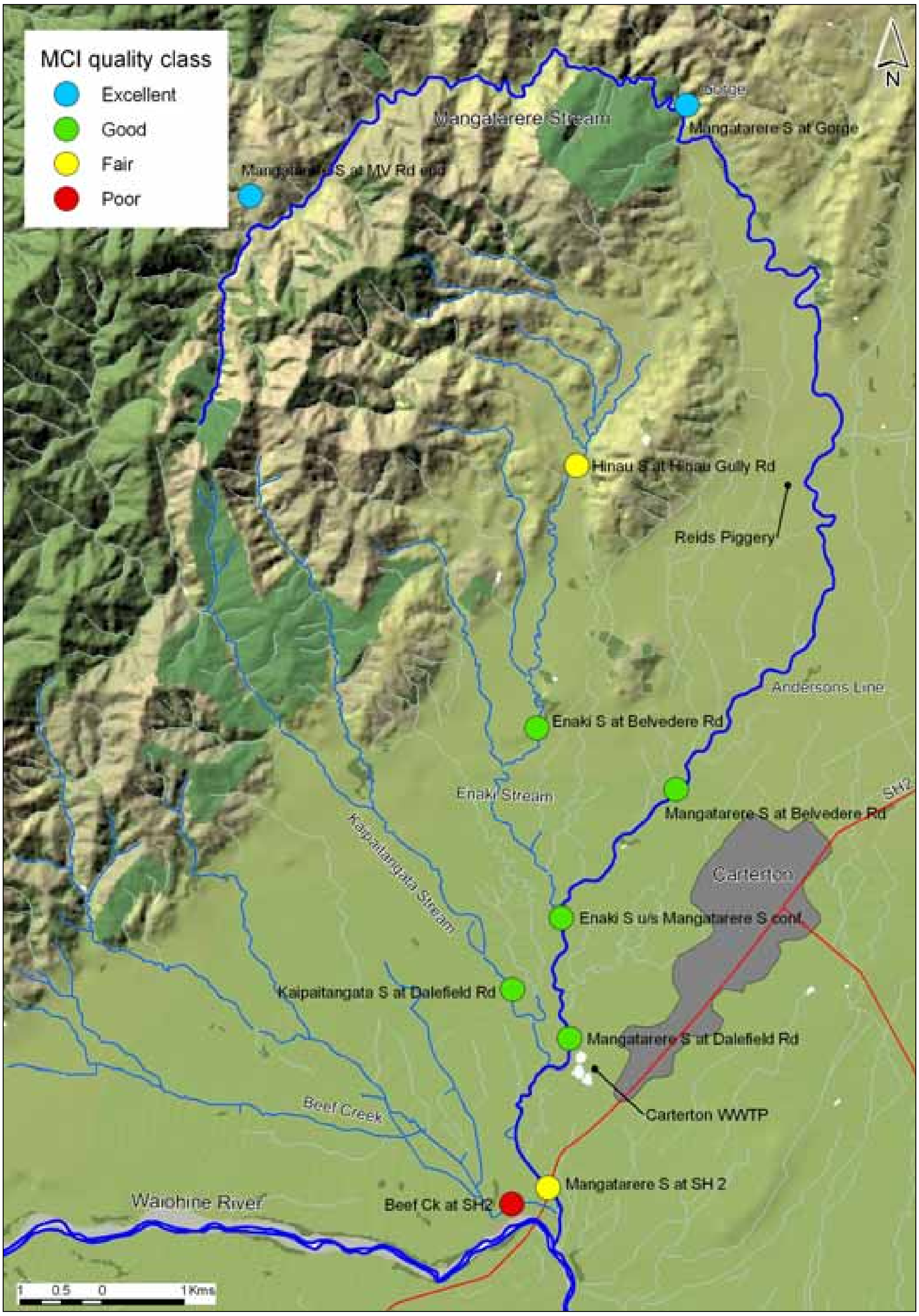

Figure 4.20: MCI quality ‘grades’ (from Stark & Maxted 2007) for surface water sites in the Mangatarere catchment sampled during February 2009

Overall, it is combination of degraded water quality and instream habitat (e.g., alteration of the substrate as a result of increased periphyton cover, damage through stock access or instream channel works) and low stream flows that account for the decline in aquatic health downstream of the Mangatarere Gorge. Low flows and the drying of stream reaches (Figure 4.21) are likely to be exerting a particularly strong influence on macroinvertebrate and fish communities. This is discussed further in Section 9.

Figure 4.21: Low flow and prolific periphyton growth in the lower Kaipaitangata Stream on 11 February 2009

5. Groundwater quality

5.1 Sampling sites and frequency

Groundwater sampling was undertaken in 21 bores in October 2008 as part of a pre-screening exercise to identify bores which would be most suitable for the Mangatarere investigation (Figure 5.1). Of these bores, 13 were then selected for ongoing monitoring at two monthly intervals through until October 2009 (seven sampling occasions in total). The bores sampled in the investigation

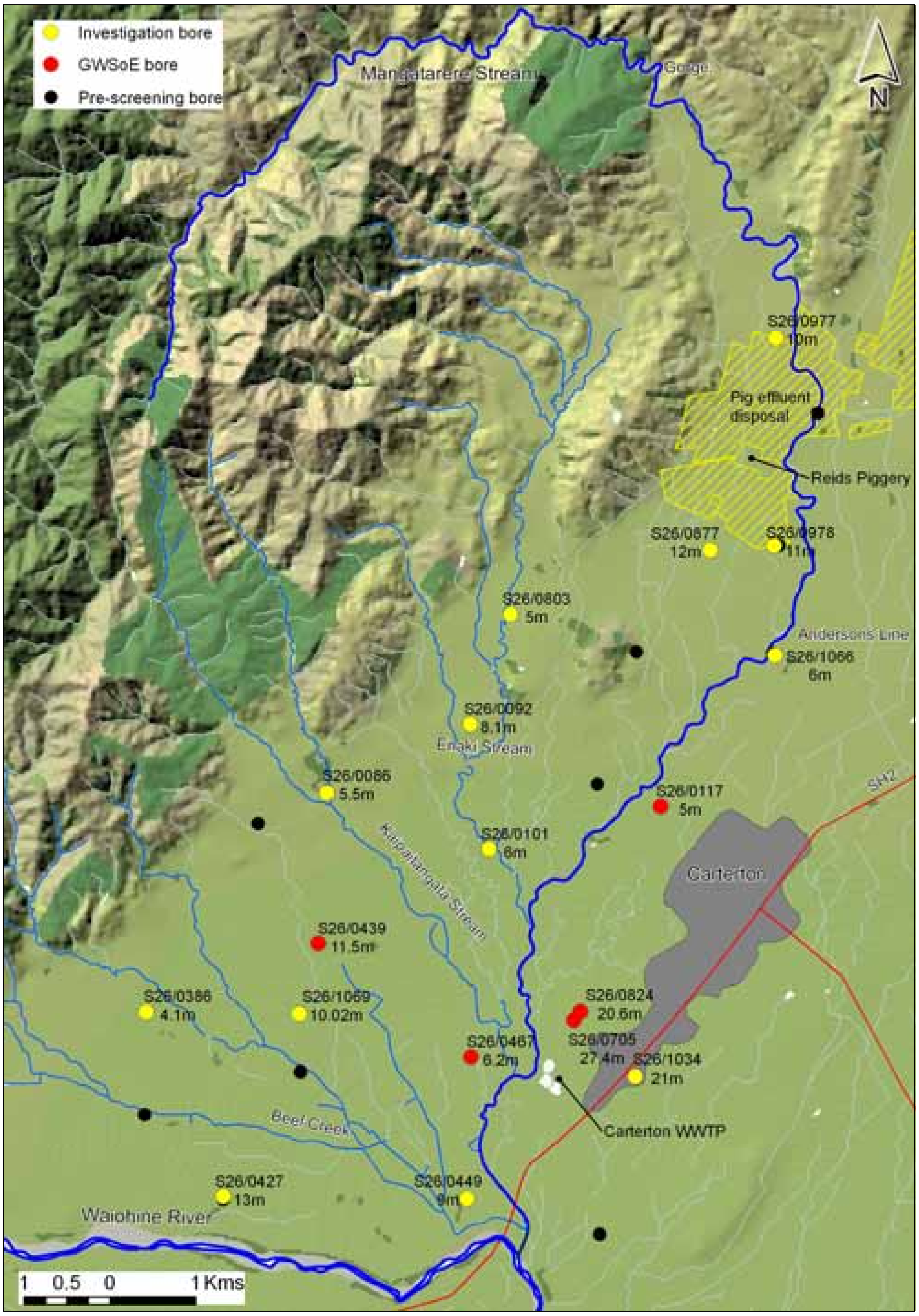

Figure 5.1: Location (and depth to groundwater) of the 13 groundwater bores sampled on seven occasions from October 2008 to October 2009 in the Mangatarere area. One-off investigation bores and Greater Wellington's SoE monitoring bores (sampled quarterly) are also shown.

were selected to ensure good spatial coverage of the catchment and that typical land uses were represented. Shallow bores (<15m deep) were primarily selected because the impacts of above ground land use are generally more evident in the shallow unconfined groundwater aquifer and in the Mangatarere catchment; these impacts have flow-on effects for connected surface water systems. Complete details of the bores sampled are presented in Appendix 1.

Five Groundwater State of the Environment bores (GWSoE) were also sampled quarterly over the same time period, with historic water quality results for these sites used in temporal trend analysis in Section 7). GWSoE bore details are provided in Appendix 1.

5.2 Sampling methods and sample analysis

Groundwater samples were collected by trained Greater Wellington staff using nationally accepted protocols (Ministry for the Environment 2006). This involved purging the bore for a predetermined amount of time to remove any standing water and monitoring the pumped water continuously until field measurements (e.g., conductivity) stabilised. These practices were employed to make sure that the water sampled was representative of the aquifer.

Groundwater level was measured in each bore prior to purging; this was not possible for two bores (S26/1066 and S26/0101) because these were permanently capped. Field measurements (temperature, conductivity, pH and dissolved oxygen) were taken using a YSI-556, WTW350i or WTW P4 field meter and flow cell. Field meters were calibrated on the day of sampling. Water samples were stored on ice upon collection and transported to Hill Laboratories in Hamilton for analysis within 24 hours of sampling. Samples were tested for a range of physico-chemical and microbiological variables, including pH, electrical conductivity, turbidity, dissolved and total nutrients, total organic carbon (TOC) and *E. coli*. Samples were also tested for dissolved concentrations of major ions (calcium, magnesium, potassium, sodium, chloride, sulphate, fluoride and bicarbonate) aluminium, iron, manganese and boron on three occasions (six months apart) and heavy metals (arsenic, cadmium, chromium, copper, lead, nickel and zinc) on one occasion (October 2009)[23]. The laboratory's analytical methods are provided in Appendix 2.

5.3 Data interpretation, analysis and presentation

During data processing, concentrations of any water quality variables reported by the laboratory as less than the analytical detection limit were replaced by values one half of the detection limit. These "halved values" were used in the calculation of summary statistics, notably median values.

Groundwater sample results were compared against the Drinking Water Standard for New Zealand (DWSNZ 2005). This standard applies to water used for human consumption and sets a health-related maximum acceptable value (MAV) or an aesthetic guideline value (GV) for a number of variables. The MAVs and GVs used are outlined in Appendix 3.

[23] Samples were tested for zinc on two occasions (six months apart) and samples from one bore (S26/0499) were tested for arsenic on six sampling occasions, following a high result on the first sampling occasion. Nickel was also tested in three samples from this bore.

Similar to Daughney and Randall (2009), the groundwater nutrient results were also compared against the ANZECC (2000) lowland trigger values for aquatic ecosystems (see Section 4.3.1 and Appendix 3). This is because shallow groundwater is known to discharge into a number of surface water bodies in the Mangatarere catchment, with potential for adverse ecological effects (e.g., nuisance periphyton growth) where nutrient concentrations are high. It is recognised that using these trigger values as a direct comparison assumes that groundwater makes up the entire surface water flow. In reality, there will be some dilution of groundwater by surface water.

Groundwater nitrate nitrogen (nitrate) concentrations were also evaluated in terms of likely human influence as groundwater in New Zealand rarely has nitrate concentrations above 1 mg/L naturally (Close et al. 2001). A threshold of 3 mg/L was adopted as a means of defining nitrate contamination from anthropogenic sources (Close et al. 2001). This threshold follows the findings of a US study of nitrates (Madison & Brunett 1985) that concluded concentrations of nitrate in groundwater above 3 mg/L were due to human influence. In this section, reference to "elevated" nitrate concentrations indicates the concentrations are above 3 mg/L. To provide further distinction between "elevated" concentrations and concentrations above the DWSNZ (2005) MAV of 11.3 mg/L, an additional (and arbitrary) "highly elevated" threshold of 7 mg/L is used in this report.

E. coli indicator bacteria results were compared against both the DWSNZ (2005) and the ANZECC (2000) stockwater trigger value. This is because some of the groundwater bores sampled are used for potable supply and others are used for stockwater supply.

5.4 Water quality sampling results

The results of groundwater quality samples analysed over October 2008 to October 2009 are summarised here in four sub-sections: field measurements, nutrients and microbiology, major ions, and metals and metalloids. The results are provided in full in Appendix 4.

5.4.1 Field measurements and turbidity

Groundwater temperature was generally between 12.5^{o}C and 14.7^{o}C over the monitoring period (Table 5.1). However, maximum temperatures of 17^{o}C and 18.8^{o}C were measured in February (summer) in bores S26/0803 (5 m deep) and S26/1066 (6 m deep) respectively. A minimum temperature of 9.9^{o}C was measured in August 2009 on one sampling occasion in bore S26/1066.

All median pH values, though not atypical of groundwater, were outside the range for the DWSNZ (2005) pH GV (7.0–8.5) with the exception of bore S26/0977 (Table 5.1). In general, the pH of groundwater in the Mangatarere catchment was slightly acidic with a minimum pH value of 5.3 measured on one or more sampling occasions in bores S26/0086, S26/0092 and S26/0803.

Table 5.1: Summary of field and turbidity measurements from 13 groundwater bores sampled in the Mangatarere catchment from October 2008 to October 2009 (*n*=7 for most variables, *n*=4 for water level). Guideline values (GV) from DWSNZ (2005) are also shown where applicable.

Variable	DWSNZ (2005)[1]		S26/0086	S26/0092	S26/0101	S26/0386	S26/0427	S26/0449	S26/0803	S26/0877	S26/0977	S26/0978	S26/1034	S26/1066	S26/1069
Water level (mm)		Median	-3160	-2551		-2165	-3121.5	-3180	-2075	-2532.5	-3265	-4340	-5239		-1350
		Min	-3292	-5180		-2940	-4600	-3500	-2670	-2760	-3613	-4765	-6363		-2150
		Max	-2971	-1500		-1600	-2210	-2870	-1501	-2160	-2806	-3950	-4408		-800
Water temperature (°C)		Median	13	13.6	12.8	13.7	13.8	13.7	12.6	14.1	13.4	13.6	13.8	12.5	14.7
		Min	11.7	11.9	10.9	11.8	13.3	13.1	11.7	14	12.7	13.4	13.6	9.9	13.8
		Max	15.4	16.3	16.2	15.5	14.3	13.8	17	15	15.9	14.7	14.4	18.8	15.3
pH	7.0 to 8.5	Median	5.7	5.5	5.9	6.1	5.9	6.8	5.5	5.8	7.0	6.7	6.4	6.2	6.1
		Min	5.3	5.3	5.8	6.0	5.4	6.7	5.3	5.7	6.7	6.4	6.1	6.0	6.1
		Max	6.1	5.9	6.1	6.7	6.0	6.9	5.8	6.3	7.1	7.0	6.5	6.3	6.3
Electrical conductivity (µS/cm)		Median	118	202	127	188	137	240	157	206	191	276	204	101	203
		Min	100	195	116	156	130.2	234	115	191	172	252	199	86.3	190
		Max	138	224	158	220	138	280	189	236	203	322	226	114	205
Dissolved oxygen (% Saturation)		Median	36.6	66.2	31.2	32.7	54.8	1	51.6	32.80	8.2	3	4	49.9	62.9
		Min	18.2	39.1	13.1	17.6	37.5	0.1	7.5	7.1	3.2	1.2	1	12.1	26.4
		Max	73.2	102	48.6	59.4	87.4	2.4	78.2	60	23.5	7.4	6.16	88	79.3
Dissolved oxygen (mg/L)		Median	3.8	6.49	3.53	3.26	5.48	0.09	5.16	3.23	0.82	0.3	0.41	4.87	6.37
		Min	1.82	4.07	1.36	1.8	3.81	0.01	0.72	0.71	0.33	0.13	0.11	1.12	2.63
		Max	7.77	10.4	4.54	6.16	9.02	0.26	8.12	6.16	2.42	0.78	0.6	9.56	8.19
Turbidity (NTU)	2.5	Median	0.65	0.42	0.12	2.7	1.8	52	0.18	7.8	1,100	19	6.1	0.16	14
		Min	0.38	0.15	0.084	1.4	0.77	11	0.1	1.2	12	5	3.6	0.11	4.8
		Max	3.3	2.9	0.29	64	5.9	62	1.1	29	26,000	3,100	16	0.52	23

[1] DWSNZ (2005) guideline values for aesthetic determinands.

Median conductivity concentrations ranged from 101 µS/cm to 276 µS/cm (Table 5.1). Conductivity concentrations were generally lower in bores close (<50 m) to streams which lose water to groundwater (e.g., bores S26/0086, S26/0101, S26/0803 and S26/1066). However, bore S26/0449, which is located at the bottom of the catchment close to Matarawa Road (formerly Swamp Road) and the Mangatarere Stream, had conductivity concentrations that ranged between 234 µS/cm and 280 µS/cm.

Median concentrations of dissolved oxygen were generally between 3 mg/L and 10.5 mg/L, although bores S26/0449, S26/0977, S26/0978 and S26/1034 had median concentrations below 1 mg/L (Table 5.1) – not atypical for older and/or deeper groundwater.

Median turbidity values in six of the 13 bores sampled complied with the DWSNZ (2005) GV of 2.5 NTU (Table 5.1). Of the seven bores that did not meet this GV, three (S26/0386, S26/0427 and S26/0877) are used to supply water for potable use. Maximum turbidity measurements of 2,600 NTU and 3,100 NTU were measured in groundwater samples from two monitoring bores (S26/0977 and S27/0978 respectively) associated with Reid's piggery. These bores were re-developed in June 2009 on the advice of Greater Wellington and Wilson (2009) because it was thought poor bore construction was contributing to turbid groundwater conditions in these bores. After re-development groundwater samples from both bores were noticeably less turbid (Figure 5.2).

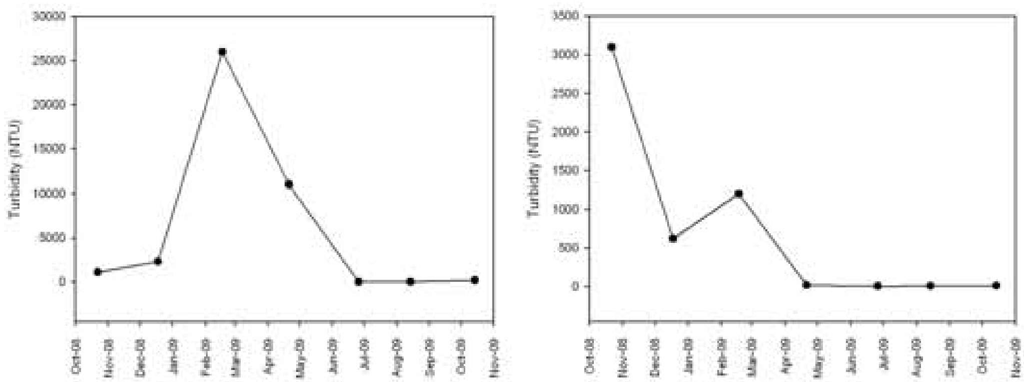

Figure 5.2: Turbidity measurements in groundwater samples collected from bores S26/0977 (left) and S26/0978 (right) on seven sampling occasions over October 2008 to October 2009. Both bores were re-developed in June 2009 after high turbidity measurements were recorded.

5.4.2 *E. coli*, TOC and nutrients

Groundwater samples contained counts of *E. coli* bacteria greater than the DWSNZ (2005) MAV (<1 cfu/100mL) on one or more sampling occasions in all but two bores (S26/0449 and S26/0877) over the monitoring period (Table 5.2). The maximum *E. coli* count of 320,000 cfu/100mL was measured in a sample from the large diameter well S26/0386 located on a private property in the upper Beef Creek catchment. Counts greater than 30 cfu/100mL were also measured on the other six sampling occasions in this bore. Other notable maximum counts of *E. coli* were found in groundwater samples from bores S26/0427 (47 cfu/100mL), S26/0803 (240 cfu/100mL) and S26/1034 (29 cfu/100mL). Counts

Table 5.2: Summary of *E. coli* bacteria, TOC and nutrient concentrations in groundwater samples collected from 13 bores in the Mangatarere catchment over October 2008 to October 2009 (*n*=7 for most variables). The DWSNZ (2005) guidelines and ANZECC (2000) lowland ecosystem trigger values are also listed.

Variable	DWSNZ[1]	ANZECC		S26/0086	S26/0092	S26/0101	S26/0386	S26/0427	S26/0449	S26/0803	S26/0877	S26/0977	S26/0978	S26/1034	S26/1066	S26/1069
E. coli (cfu/100mL)	<1	100[2]	Median	1	0.5	0.5	1,700	1	0.5	0.5	1	1	0.5	0.5	4	0.5
			Min	<1	<1	<1	30	1	<1	<1	<1	<1	<1	<1	<1	<1
			Max	4	17	6	320,000	47	<1	240	<2	8	22	29	25	1
Total organic carbon (mg/L)			Median	1.2	0.72	0.84	1.8	0.69	3.1	1.7	1.1	1.8	2.5	1.2	0.91	0.81
			Min	<0.5	<0.5	<0.5	<0.5	<0.5	<5	<0.5	<0.5	2.5	<1	<0.5	<0.5	<0.5
			Max	2.4	7.4	3.6	5	10	6.2	2.6	2.6	24	6.5	1.6	1.3	2.2
Nitrite-nitrogen (mg/L)	0.06		Median	0.001	0.001	0.001	0.001	0.001	0.008	0.001	0.001	0.012	0.043	0.013	0.001	0.001
			Min	<0.002	<0.002	<0.002	<0.002	<0.002	0.005	<0.002	<0.002	0.006	0.008	0.011	<0.002	<0.002
			Max	0.001	0.001	0.003	0.007	0.001	0.014	0.002	0.003	0.027	0.098	0.025	0.003	0.006
Nitrate-nitrogen (mg/L)	11.3	0.444 (as NNN)	Median	2.1	9.9	1.3	4.8	4.2	0.006	6.4	9.7	2.4	10	3.9	1.1	5.5
			Min	0.57	9.3	0.25	2.8	3.8	<0.002	1.9	8.6	1.7	0.21	3.7	0.26	4.9
			Max	2.7	11	2	6.7	4.6	0.021	9.3	14	2.8	14	4.2	1.2	5.8
Ammoniacal nitrogen (mg/L)		0.021	Median	0.005	0.005	0.005	0.005	0.005	0.79	0.005	0.005	0.018	0.48	0.034	0.005	0.005
			Min	<0.01	<0.01	<0.01	<0.01	<0.01	0.7	<0.01	<0.01	<0.01	0.35	0.015	<0.01	<0.01
			Max	0.005	0.052	0.005	0.032	0.005	1	0.019	0.014	0.055	2.21	0.042	0.024	0.014
Total Kjeldahl nitrogen (mg/L)			Median	0.12	0.05	0.05	0.14	0.05	0.94	0.14	0.05	0.71	0.46	0.05	0.05	0.05
			Min	<0.1	<0.1	<0.1	<0.1	<0.1	0.83	<0.1	<0.1	<0.1	0.27	<0.1	<0.1	<0.1
			Max	0.2	0.2	0.13	0.75	0.17	1.2	0.27	0.18	7.4	2.3	0.05	0.18	0.05
Total nitrogen (mg/L)		0.614	Median	2.1	9.9	1.3	4.8	4.2	0.95	6.5	9.9	2.9	10	3.9	1.2	5.5
			Min	0.64	9.4	0.27	2.9	4	0.84	1.9	8.7	1.9	7.7	3.8	0.31	5
			Max	2.9	11	2.1	7.5	4.7	1.2	9.6	14	9.6	17	4.3	1.4	5.9
Dissolved reactive phosphorus (mg/L)		0.010	Median	0.008	0.024	0.013	0.026	0.022	1.7	0.007	0.01	0.004	0.002	0.18	0.015	0.018
			Min	0.007	0.023	0.012	0.021	0.014	0.52	0.007	0.006	<0.004	<0.004	0.11	0.011	0.016
			Max	0.016	0.029	0.015	0.028	0.026	1.9	0.01	0.012	0.011	0.012	0.2	0.018	0.02
Total phosphorus (mg/L)		0.033	Median	0.017	0.026	0.013	0.031	0.023	1.8	0.008	0.018	0.65	0.015	0.18	0.013	0.022
			Min	0.008	0.021	0.009	0.021	0.017	1.7	0.004	0.005	0.010	0.002	0.14	0.009	0.018
			Max	0.021	0.038	0.023	0.33	0.031	2	0.018	0.023	12	1.5	0.25	0.014	0.038

[1] Maximum Acceptable Values for inorganic determinands of health significance.

[2] Stockwater trigger value.

of *E. coli* were above the ANZECC (2000) stock water trigger value (100 cfu/100mL) on one sampling occasion in bore S26/0803 (used for potable and stock water) and on six occasions in bore S26/0386 (not used for potable or stock water).

Median TOC concentrations ranged from 0.69 mg/L to 3.1 mg/L, with the highest individual TOC concentration of 24 mg/L measured in a sample from bore S26/0977 (Table 5.2). This bore is 10 m deep and is located upgradient of Reid's piggery. TOC concentrations in 11 of the 13 bores fluctuated throughout the 12-month sampling period; concentrations were highest during June through to November (winter/spring) and lowest during October through to May (summer/autumn), mirroring seasonal changes in groundwater level (Figure 5.3). In contrast, TOC concentrations did not appear to show any seasonal patterns in bores S26/0977 and S26/0978.

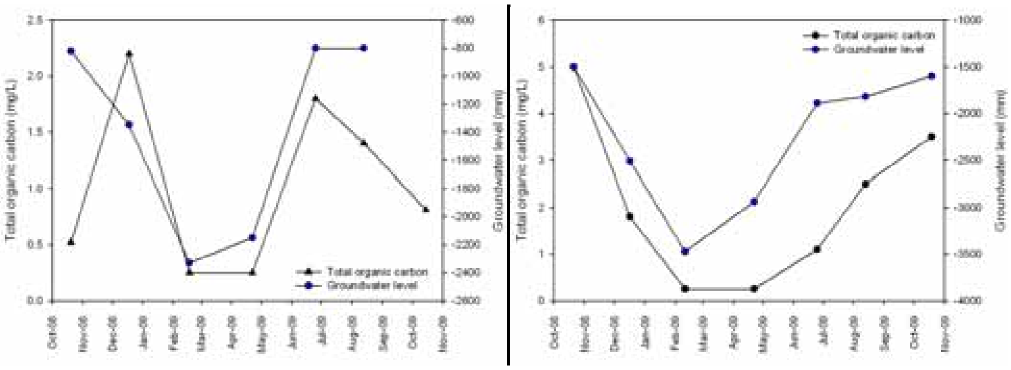

Figure 5.3: Total organic carbon concentrations and groundwater levels in bores S26/1069 (left) and S26/0386 (right) in the Mangatarere catchment, based on seven sampling occasions over October 2008 to October 2009

Median concentrations of nitrite nitrogen (nitrite) were below the DWSNZ (2005) MAV of 0.06 mg/L in all bores (Table 5.2). One sample result from bore S26/0978 (0.098 mg/L) exceeded the MAV. This bore is located immediately downgradient of Reid's piggery and is not used for potable supply.

Median concentrations of nitrate nitrogen (nitrate) ranged from 0.006 mg/L to 10 mg/L and did not exceed the DWSNZ (2005) MAV (11.3 mg/L). However, nitrate concentrations in two samples from bores S26/0877 and S26/0978 (both 14 mg/L) were above the MAV (Table 5.2, Figure 5.3). These bores are located approximately 800 m apart, downgradient of Reid's piggery. Samples from bores S26/0803, S26/0092, S26/1069, S26/0427 and S26/1034 had elevated concentrations of nitrate. All of these bores are located in areas of agriculture except bore S26/1034, which is located near a disused septic tank. Median concentrations of nitrite-nitrate nitrogen (NNN) were above the ANZECC (2000) trigger value for lowland streams (0.444 mg/L) in groundwater samples from all bores except S26/0449 at the bottom of the catchment near Matarawa Road (Figure 5.4).

Ammoniacal nitrogen (ammonia) concentrations were generally below the analytical detection limit in most groundwater samples (<0.01 mg/L). However, concentrations of 1 mg/L and 2.21 mg/L were measured in samples from bores S26/0449 and S26/0978 respectively (Table 5.2, Figure 5.4).

Median concentrations of ammonia were also above the ANZECC (2000) trigger value for lowland streams (0.021 mg/L) for samples from bores S26/0449, S26/1034 and S26/0978.

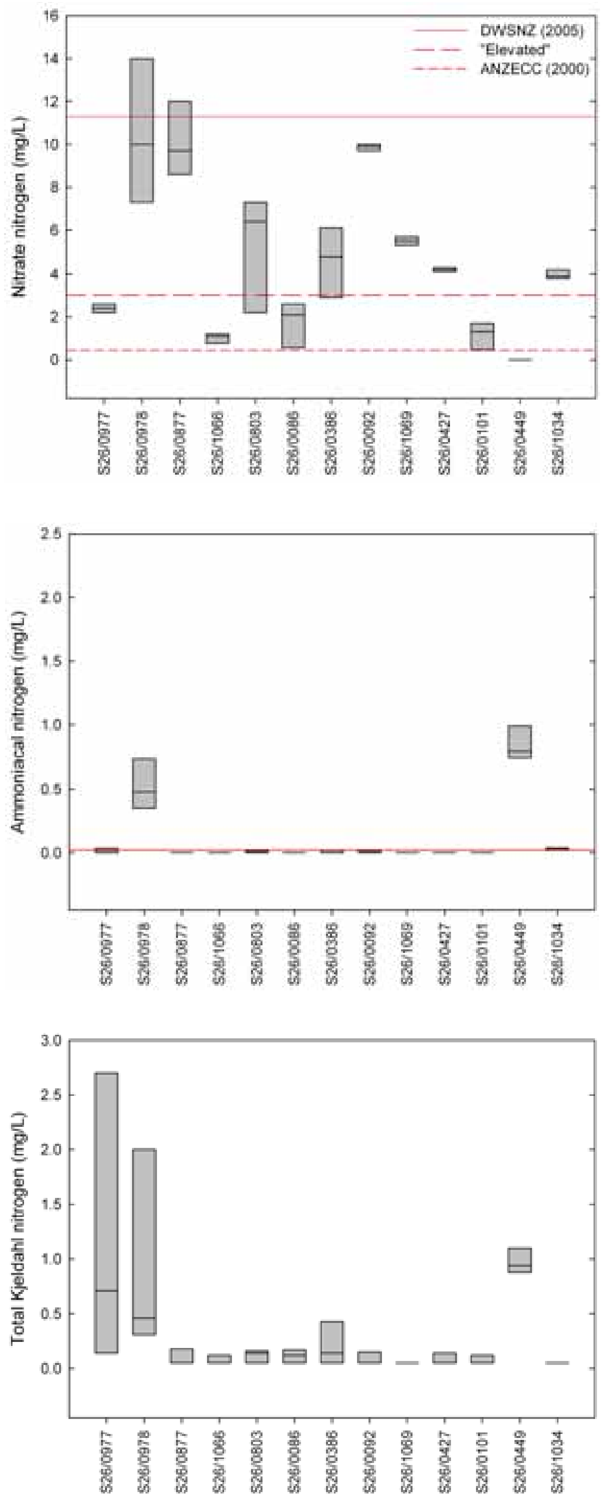

Figure 5.4: Box-and-whisker plots of nitrate-nitrogen, ammoniacal nitrogen and TKN concentrations in groundwater samples collected from 13 bores in the Mangatarere catchment at two-monthly intervals over October 2008 to October 2009 (*n*=7). The three lines indicate in the first plot represent the DWSNZ (2005) MAV, the “elevated” nitrate nitrogen threshold and the ANZECC (2000) trigger value for nitrite-nitrate nitrogen in lowland streams.

Median concentrations of TKN ranged from <0.1 mg/L to 0.94 mg/L. The highest TKN concentrations were found in samples from bores S26/0449 (1.2 mg/L), S26/0978 (2.3 mg/L) and S26/0977 (7.4 mg/L) (Table 5.2, Figure 5.4).

Total nitrogen concentrations (as medians) ranged from 0.95 mg/L to 10 mg/L (Table 5.2), with the highest concentrations measured in the same bores that had the highest nitrate concentrations: S26/0092 (11 mg/L), S26/0877 (14 mg/L) and S26/0978 (17 mg/L). Bores S26/0877 and S26/0978 are located downgradient of Reid's piggery and bore S26/0092 is located on a dairy farm. Median total nitrogen concentrations were above the ANZECC (2000) trigger value for lowland streams (0.614 mg/L) in all 13 bores.

There were clear seasonal patterns in nitrate and total nitrogen concentrations in seven of the 13 bores (S26/0086, S26/0092, S26/0101, S26/0386, S26/0427, S26/0978, and S26/0803); similar to TOC, concentrations were greatest from June to November (winter/spring) and lowest from December to May (summer/autumn), mirroring seasonal changes in groundwater levels in these bores (Figure 5.5). In contrast, nitrate and total nitrogen concentrations were lowest in bore S26/0877 from June to November and highest from January to May. Sample results from bore S26/0449 demonstrated a similar pattern, with greater concentrations of ammonia, TKN and total nitrogen observed from January to May and lower concentrations observed from June to November.

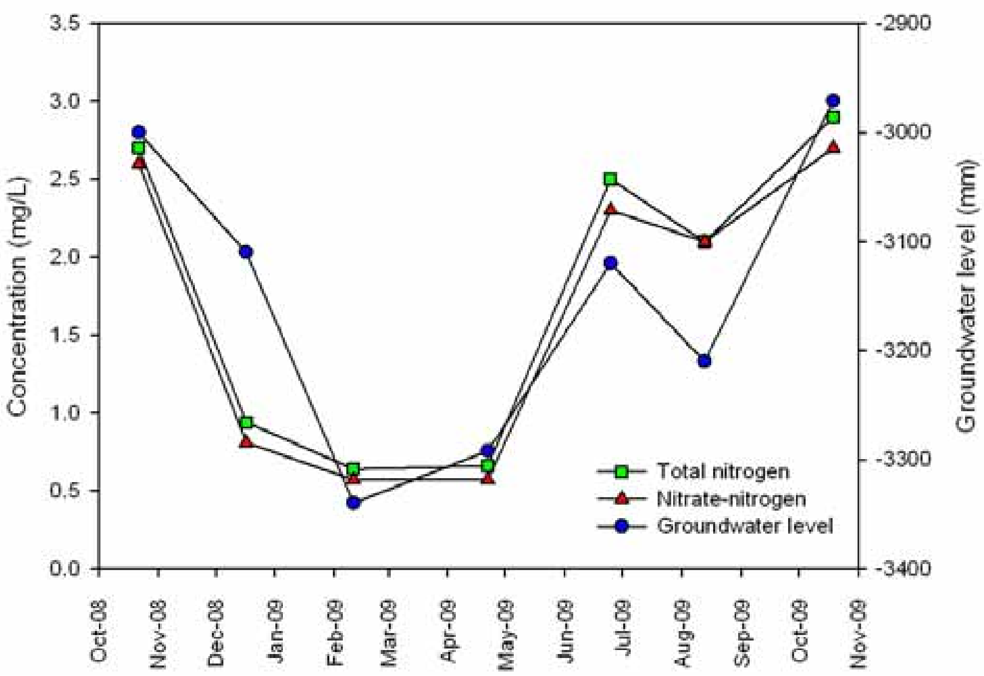

Figure 5.5: Nitrate nitrogen and total nitrogen concentrations (left axis) and groundwater levels (right axis) in bore S26/0086 in the Mangatarere catchment, based on seven sampling occasions over October 2008 to October 2009

A weak seasonal pattern was seen in nitrate concentrations in bore S26/0977, with greater concentrations observed in winter and lower concentrations observed in summer. A seasonal pattern may have also been present for total nitrogen, with greater concentrations observed in summer. However, the greater summer concentrations also coincided with the higher turbidity measurements which were due to the poor bore development at this site. No seasonal patterns were observed for nitrogen species measured from groundwater samples from bores S26/1034, S26/1066 and S26/1069.

Median DRP concentrations ranged from 0.002 mg/L to 1.7 mg/L (Figure 5.6), with the highest concentration of 1.9 mg/L measured in a sample from bore S26/0449 (Table 5.2). Median concentrations of DRP were above the ANZECC (2000) trigger value for lowland streams (0.01 mg/L) in eight of the 13 bores.

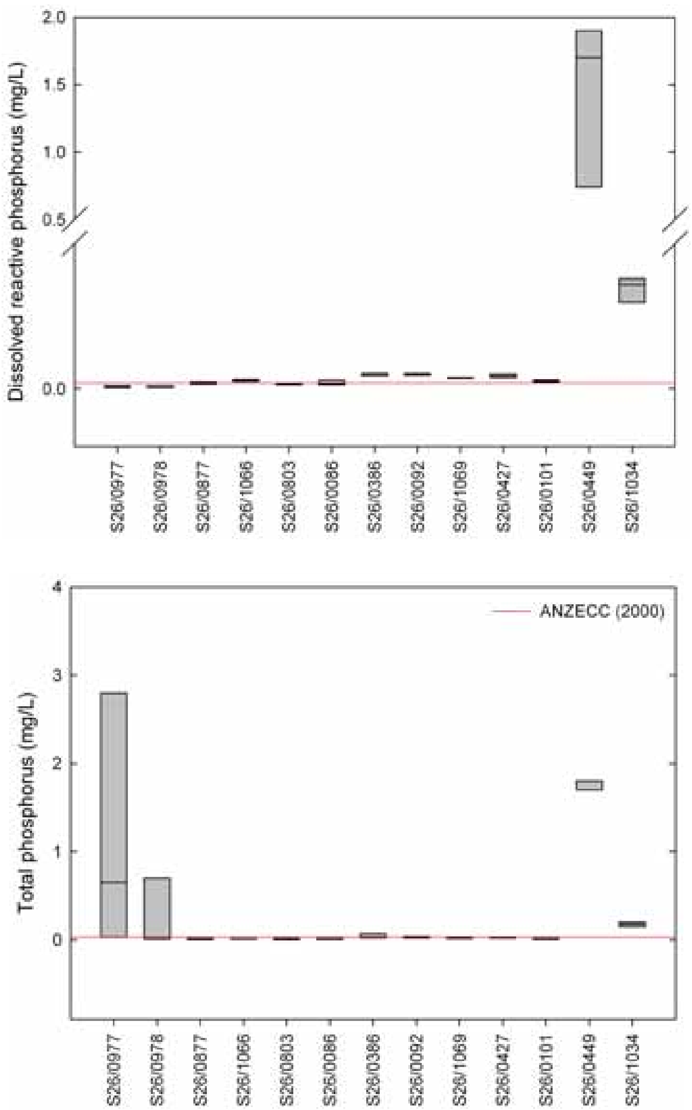

Figure 5.6: Box-and-whisker plots of dissolved reactive phosphorus (top) and total phosphorus (bottom) concentrations in groundwater samples collected from 13 bores sampled in the Mangatarere catchment at two-monthly intervals October 2008 to October 2009 (*n*=7). The red lines indicate the ANZECC (2000) trigger value for lowland streams.

Median total phosphorus concentrations ranged from 0.008 mg/L to 1.8 mg/L, with most bores recording a median concentration below 0.1 mg/L. The exceptions were bores S26/0449, S26/0977 and S26/1034 (Table 5.2, Figure 5.6). The highest total phosphorus concentrations were recorded in samples from bores S26/0978 (1.5 mg/L), S26/0449 (2 mg/L) and S26/0977 (12 mg/L). Median concentrations of total phosphorus were above the ANZECC (2000) trigger value for lowland streams (0.033 mg/L) in three of the 13 bores (S26/0449, S26/0977 and S26/01034).

Total phosphorus results from the two piggery bores were also plotted against turbidity measurements recorded in water samples from these bores. Figure 5.7 indicates when turbidity is high, total phosphorus concentrations are also high. This was confirmed by a Spearman Rank correlation test (r=0.89 and 0.99 for bores S26/0978 and S26/977 respectively, p<0.001 for both tests).

Unlike nitrate concentrations, no obvious seasonal patterns in DRP or total phosphorus concentrations were observed during the investigation period.

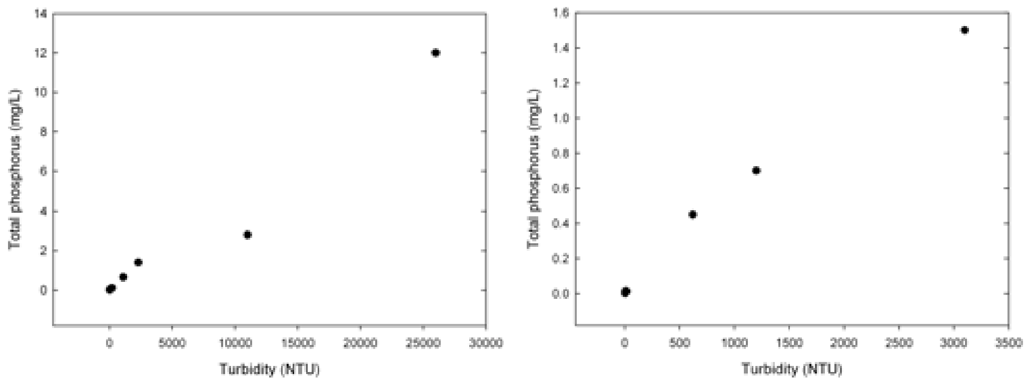

Figure 5.7: Comparison of turbidity and total phosphorus concentrations in groundwater samples collected on seven sampling occasions from bores S26/0977 (left) and S26/0978 (right) sampled in the Mangatarere catchment from October 2008 to October 2009

5.4.3 Major ions

Median dissolved concentrations of major ions are presented in Table 5.3. Bore S26/0978 recorded the greatest median concentrations for total hardness (82 mg/L), dissolved calcium (19 mg/L), magnesium (8.2 mg/L), sodium (19 mg/L) and chloride (20 mg/L), while bore S26/0082 recorded the greatest median concentration of potassium (2.9 mg/L) and bore S26/0449 had the greatest median concentrations of bicarbonate (76 mg/L) and fluoride (0.12 mg/L).

In general, median concentrations of major ions tended to be greatest in bores S26/0978, S26/0449, S26/0977, S26/0877, S26/1034 and S26/0092 (Table 5.3). The higher ion concentrations in these bores were consistent with the greatest median nutrient, dissolved metal and conductivity concentrations. Three of these bores (S26/0977, S26/0978 and S26/0877) are located on Reid's piggery, although bore S26/0977 is classified as a "control bore" upgradient of the piggery. Bores S26/0449 and S26/1034 are thought to be drawing older groundwater which may have had more rock-water interaction. Bore S26/0092 is located in an area of dairy farming.

Table 5.3: Summary of major ion concentrations in groundwater samples collected from 13 bores in the Mangatarere catchment over October 2008 to October 2009 (*n*=3). Guideline values (DWSNZ 2005) are listed where applicable.

Variable	DWSNZ		S26/0086	S26/0092	S26/0101	S26/0386	S26/0427	S26/0449	S26/0803	S26/0877	S26/0977	S26/0978	S26/1034	S26/1066	S26/1069
Dissolved calcium (mg/L)		Median	5.2	12	8.1	17	7.3	14	12	13	12	19	12	5.7	12
		Min	5.1	11	6.8	13	7	13	8.1	12	11	16	11	4.9	12
		Max	5.9	13	9.1	19	7.7	16	14	14	12	24	12	6.3	13
Dissolved magnesium (mg/L)		Median	2.2	5.4	2.9	5	3.7	5.5	3.7	6.3	6	8.2	5.1	1.8	5.1
		Min	2.1	4.6	2.3	3.6	3.5	5	2.7	5.7	5.8	6.8	5	1.6	4.9
		Max	2.4	5.6	3.1	5.1	3.7	6.5	4.1	7	6.3	9	5.5	2	5.5
Dissolved potassium (mg/L)		Median	2.9	2.6	1.9	1.4	1.1	2.4	1.7	1.8	1.2	1.8	1.1	2	1.1
		Min	2.9	2.4	1.9	1.4	0.97	2	1.6	1.7	1.1	1.7	1	1.9	1.1
		Max	3.2	2.6	2	1.6	1.3	3.1	1.8	2	1.2	1.8	1.1	2.6	1.2
Dissolved sodium (mg/L)		Median	12	13	9.7	9.8	11	18	9	12	14	19	18	7.6	15
	200[1]	Min	11	11	9.7	8.2	10	16	8.8	12	14	19	18	7.1	14
		Max	12	14	10	9.9	11	19	9.1	14	17	20	19	8.2	16
Chloride (mg/L)		Median	15	16	13	12	12	17	13	17	12	20	15	10	15
	250[1]	Min	12	15	12	11	12	17	11	16	11	19	14	10	14
		Max	22	17	13	15	12	18	18	18	13	23	15	11	15
Sulphate (mg/L)		Median	5.9	17	11	16	9.4	6.3	15	12	7.9	6.6	8.1	4.5	19
		Min	3.6	16	8.8	11	9.3	3.8	12	11	7.7	6.3	7.2	4.2	19
	250[1]	Max	7.3	19	12	17	9.5	6.6	17	13	9.1	7	8.4	4.9	20
Fluoride (mg/L)		Median	0.025	0.071	0.072	0.078	0.12	0.19	0.052	0.059	0.096	0.12	0.17	0.054	0.12
	1.5[2]	Min	<0.05	0.057	0.072	0.059	0.09	0.16	0.052	0.058	0.082	<0.05	0.16	0.052	0.11
		Max	0.08	0.076	0.1	0.1	0.13	0.2	0.053	0.076	0.12	0.13	0.18	0.076	0.13
Bicarbonate (mg/L at 25°C)		Median	22	13	32	46	24	100	18	22	70	76	65	28	38
		Min	15	11	26	40	21	93	16	21	68	72	60	21	36
		Max	29	13	34	51	28	110	19	26	87	76	66	29	39
Total hardness (mg/L $CaCO_3$)		Median	22	53	32	64	33	58	45	58	54	82	50	22	50
		Min	21	47	27	48	33	53	31	54	51	69	49	19	50
		Max	25	56	36	69	34	67	52	65	57	96	53	24	54

[1] Guideline Value for aesthetic determinands.

[2] Maximum Acceptable Value for inorganic determinands of health significance.

5.4.4 Heavy metals and metalloids

Dissolved metal results are summarised in Table 5.4. Dissolved arsenic was only found in samples from one bore (S26/0449), located in an area where older groundwater is upwelling into the shallow aquifer. Because the result from the first sampling event was double the DWSNZ (2005) MAV (0.01 mg/L), arsenic was analysed in all six subsequent samples collected from this bore. Groundwater samples were also collected from two other nearby bores (sampled in addition to the 13 investigation bores); two from bore S26/0968 and one from bore S26/0372. Both samples from bore S26/0968 (located approximately 200 m west of bore S26/0449) were found to contain arsenic concentrations just above the MAV (0.011 mg/L and 0.012 mg/L). No arsenic was detected in the groundwater sample collected from bore S26/0372 (located approximately 275 m east of bore S26/0449) (Appendix 4).

Dissolved iron was detected on 18 occasions in seven bores. On eight of these sampling occasions, dissolved iron concentrations were above the DWSNZ (2005) GV (0.2 mg/L) in three bores (S26/0449, S26/0977 and S26/1034). The maximum dissolved iron concentration was 7.6 mg/L in bore S26/0449; concentrations of dissolved iron in all other bores were generally below 0.05 mg/L (Table 5.4).

Dissolved manganese was detected on 35 occasions in 12 of the 13 bores sampled. However, only groundwater samples from two bores (S26/0449 and S26/0978) contained concentrations above the DWSNZ (2005) MAV of 0.4 mg/L. This occurred on one sampling occasion (1.6 mg L and 0.63 mg/L for bores S26/0449 and S26/0978 respectively).

Dissolved concentrations of boron, aluminium, copper, lead, nickel and zinc were detected in samples from some bores but all concentrations were below their respective DWSNZ (2005) MAV or GV (Table 5.3). Cadmium was only detected at a low concentration on one occasion in a sample from bore S26/0386 while chromium was not detected in any samples (Appendix 4).

Table 5.4: Summary of selected metal and metalloids concentrations in groundwater samples collected from 13 bores in the Mangatarere catchment over October 2008 to October 2009 (*n*=1-3). Guideline values (DWSNZ and ANZECC) are listed where applicable.

Variable	DWSNZ		S26/0086	S26/0092	S26/0101	S26/0386	S26/0427	S26/0449	S26/0803	S26/0877	S26/0977	S26/0978	S26/1034	S26/1066	S26/1069
Dissolved aluminium (mg/L)	0.1[1]	Median	0.014	0.02	0.0015	0.009	0.004	0.0015	0.026	0.021	0.0015	0.0015	0.0015	0.004	0.0015
		Min	0.011	0.016	<0.003	<0.003	<0.003	<0.003	0.014	0.019	<0.003	<0.003	<0.003	0.0036	<0.003
		Max	0.017	0.021	0.0015	0.037	0.0077	0.0015	0.026	0.023	0.0015	0.0015	0.0015	0.0044	0.0015
Dissolved arsenic (mg/L)	0.01[1]	Median	0.0005	0.0005	0.0005	0.0005	0.0005	0.0255	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
		Min	<0.001	<0.001	<0.001	<0.001	<0.001	0.011	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
		Max	0.0005	0.0005	0.0005	0.0005	0.0005	0.029	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Dissolved boron (mg/L)	1.4[1]	Median	0.017	0.015	0.014	0.029	0.012	0.029	0.013	0.016	0.018	0.018	0.021	0.014	0.015
		Min	0.017	0.013	0.013	0.027	0.011	0.028	0.012	0.016	0.017	0.018	0.02	0.013	0.014
		Max	0.021	0.018	0.018	0.029	0.014	0.037	0.018	0.022	0.024	0.023	0.024	0.018	0.018
Dissolved copper (mg/L)	2[1]		0.0015	0.0035	0.0028	0.013	0.0013	<0.0005	0.0016	0.010	<0.0005	<0.0005	<0.0005	0.0009	<0.0005
Dissolved iron (mg/L)	0.2[2]	Median	0.01	0.01	0.01	0.01	0.01	6.5	0.01	0.033	0.46	0.033	0.50	0.026	0.028
		Min	<0.02	<0.02	<0.02	<0.02	<0.02	5.9	<0.02	<0.02	<0.02	<0.02	0.41	<0.02	0.025
		Max	0.01	0.01	0.01	0.024	0.01	7.6	0.01	0.034	0.49	0.057	0.58	0.05	0.065
Dissolved lead (mg/L)	0.01[1]		<0.0001	0.00011	0.00025	0.00016	<0.0001	<0.0001	0.00023	0.00034	<0.0001	<0.0001	0.00015	0.00026	<0.0001
Dissolved manganese (mg/L)	0.4[1]	Median	0.0031	0.0051	0.00025	0.00065	0.0026	1.3	0.0029	0.0078	0.21	0.34	0.24	0.002	0.0073
		Min	0.0025	0.0041	<0.0005	<0.0005	0.0011	1.2	0.002	0.0073	0.18	0.2	0.24	0.0013	0.004
		Max	0.0042	0.0066	0.00025	0.0037	0.0043	1.6	0.0031	0.0082	0.27	0.63	0.29	0.0035	0.0073
Dissolved nickel (mg/L)	0.02[1]		0.001	0.0012	0.00093	0.0038	<0.0005	<0.0005	0.0012	0.00056	<0.0005	0.00073	0.00051	0.00059	<0.0005
Dissolved zinc (mg/L)	1.5[2]		0.007	0.004	0.004	0.006	0.002	<0.001	0.002	0.009	<0.001	<0.001	0.004	0.074	0.002

[1] Maximum Acceptable Value for inorganic determinands of health significance.

[2] Guideline Value for aesthetic determinands.

5.5 Discussion

The monitoring results clearly indicate that groundwater quality in the Mangatarere catchment is impacted by intensive land use. Of the 13 bores sampled bi-monthly between October 2008 and October 2009, the groundwater in those located in areas of agriculture and near consented discharges to land tended to have the highest nutrient, metal and major ion concentrations. In particular, groundwater samples from bores S26/0978, S26/0877, S26/0803, S26/0092, S26/1069, S26/0427 and S26/1034 all consistently recorded concentrations of nitrate above the "elevated" (natural background) threshold of 3 mg/L (Figure 5.8).

The Beef Creek subcatchment appears to be most impacted by elevated nitrate concentrations in groundwater (bores S26/0386, S26/0427 and S26/1069); this may reflect the high proportion of land used for dairy (44%) and drystock (29%) farming. The Enaki subcatchment has similar land use and is also considerably impacted by nitrate contamination (bores S26/0092 and S26/0803). A "highly elevated" median nitrate concentration of 9.9 mg/L was recorded in groundwater samples collected from bore S26/0092.

Several bores located in areas of agriculture recorded relatively low nitrate concentrations (<3 mg/L): S26/1066 near Andersons Line, S26/0086 in the Kaipaitangata subcatchment and S26/0101 in the lower reaches of the Enaki subcatchment. All three of these bores are shallow and located close to streams, where a direct hydraulic connection is expected. Therefore, at times these bores may draw up water from these streams while recharging stream flow at other times. Depending on a number of factors including season and land management practices, groundwater may be contributing to or diluting soluble nutrient concentrations in surface waters.

Stockwater bore S26/0449 located towards the bottom of Beef Creek and Matarawa Road also recorded relatively low nitrate concentrations. However, concentrations of ammonia, total phosphorus, DRP and TKN were elevated in samples from this bore. Hydrochemical clustering analysis undertaken using groundwater and surface water quality data for the Wairarapa Valley (Daughney et al. 2009) suggests that this is probably due to older, "evolved" groundwater upwelling in this area; sulphate concentrations in this bore were relatively low and bicarbonate and sodium concentrations relatively high compared to those in other bores sampled.

Like bore S26/0092, median nitrate concentrations in bores S26/0978 and S26/0877 were "highly elevated" (Figure 5.8). In addition, nitrate concentrations in these bores exceeded the DWSNZ (2005) MAV (11.3 mg/L) on two sampling occasions; concentrations on the remaining five sampling occasions were consistently above 3 mg/L. Concentrations of ammonia and nitrite detected in bore S26/0978 were also among some of the highest measured. These bores are located downgradient of Reid's piggery and, when the results from these bores are compared against the piggery's upgradient "control" bore, it appears that piggery and dairy effluent disposal is having a noticeable effect on nitrate concentrations in groundwater downgradient of the piggery. This is demonstrated graphically in Figure 5.9 and assessed statistically using the Wilcoxon Signed Rank test. The test results (Table 5.6) confirm that during the 12-month monitoring period, median NNN and total nitrogen concentrations in both downgradient bores were significantly higher than their respective concentrations in the upgradient control bore.

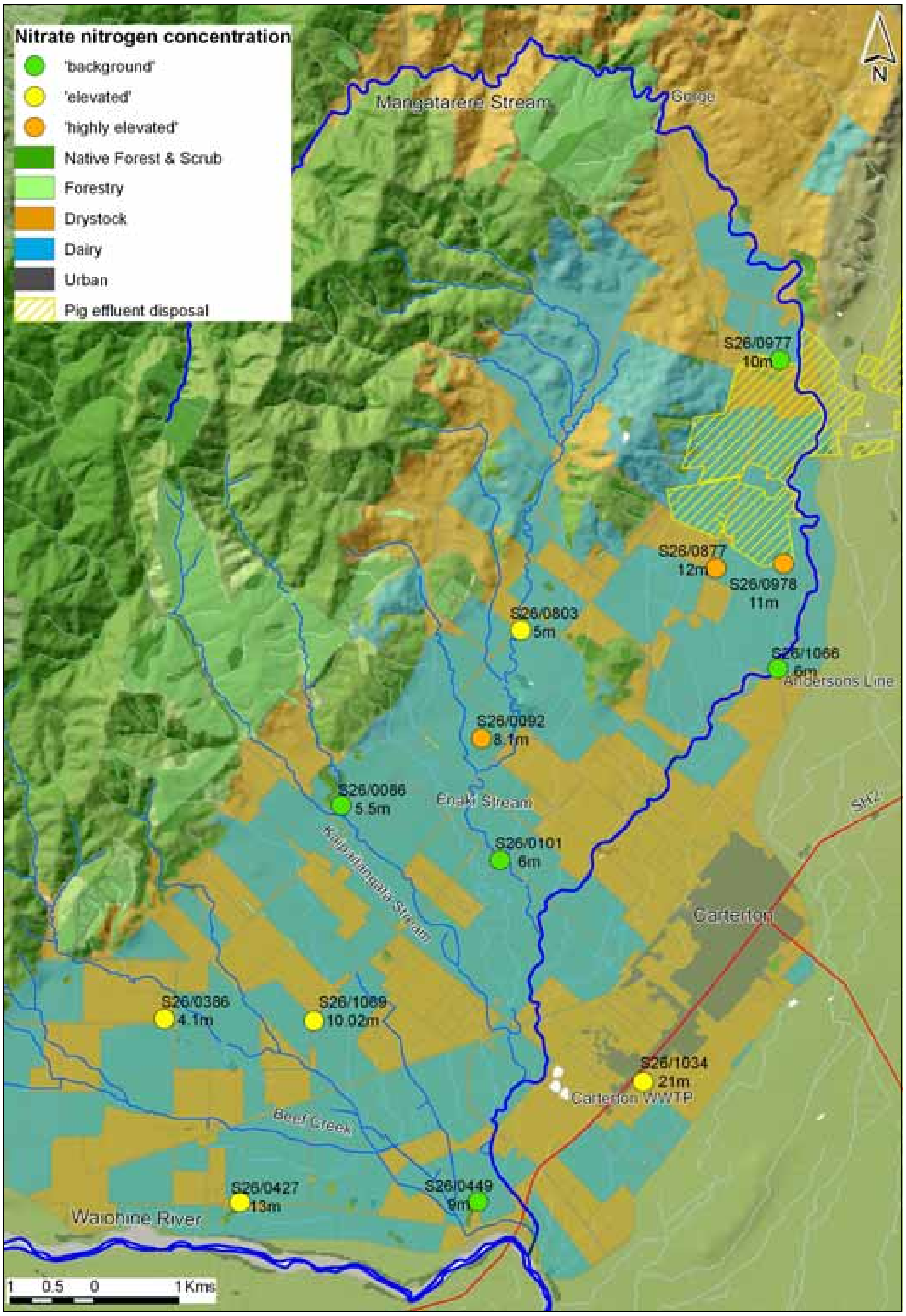

Figure 5.8: Median nitrate-nitrogen concentrations recorded in 13 groundwater bores in the Mangatarere catchment, based on seven sampling occasions over October 2008 to October 2009. Predominant land use is also shown.

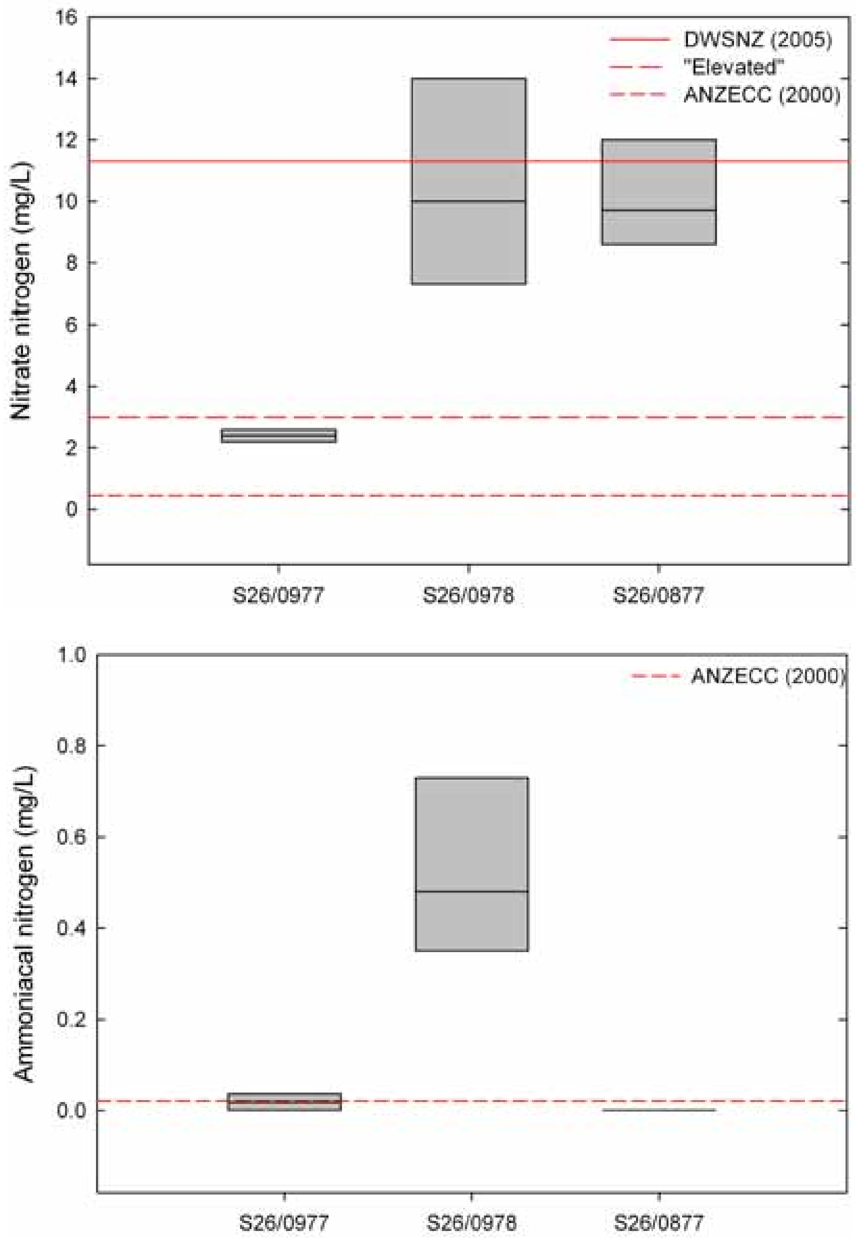

Figure 5.9: Box-and-whisker plots of nitrate-nitrogen (top) and ammoniacal nitrogen concentrations in groundwater upgradient (bore S26/0977) and downgradient (bores S26/0978 and S26/0877) of Reid's piggery, based on seven sampling occasions over October 2008 to October 2009

Conversely, Table 5.6 shows that the median total phosphorus concentration during the monitoring period was significantly higher in the upgradient bore. This is likely to be related to soil-bound phosphorus being present in the bore water. As noted in Section 5.4.1, the upgradient bore was poorly developed; as a result the water in the bore was very turbid during part of the monitoring period, which coincided with the highest total phosphorus concentrations (refer Figure 5.7). The organic matter in the soil may also explain the higher median TKN and TOC concentrations recorded in this bore.

Table 5.6: Summary of Wilcoxon Signed Rank test results comparing the median concentrations of selected water quality variables in groundwater samples from bore S26/0977 located upgradient of Reid's piggery with the median concentrations recorded in samples from downgradient bores S26/0978 and S26/0877. The test results are based on seven samples collected bi-monthly from October 2008 to October 2009. Values in bold font indicate a median concentration that is significantly higher (p<0.05) than the upgradient median concentration.

Variable	Upgradient bore	Downgradient bores			
	S26/0977	S26/0978		S26/0877	
	Median	Median	*p*-value	Median	*p*-value
Nitrite-nitrate nitrogen (mg/L)	2.4	10	0.016	9.7	0.016
Ammoniacal nitrogen (mg/L)	0.018	0.48	0.016	0.001	0.125
Total Kjeldahl nitrogen (mg/L)	0.71	0.46	0.938	0.05	0.063
Total nitrogen (mg/L)	2.9	10	0.031	9.9	0.016
Dissolved reactive phosphorus (mg/L)	0.004	0.002	0.999	0.010	0.016
Total phosphorus (mg/L)	0.650	0.015	0.999	0.018	0.031
Total organic carbon (mg/L)	1.8	2.5	0.469	1.1	0.016
E. coli (cfu/100mL)	<2	<1	0.999	<1	0.25

The piezometric surface in Section 2.3 (Figure 2.4) suggests that the nitrate-enriched groundwater downgradient of the piggery will flow in a south to south-westerly direction along the permeable river gravels and enter the Mangatarere Stream at some point downstream of Andersons Line (where the stream starts to gain flow from groundwater). This enriched groundwater input can be seen in the stream in Figure 4.4 (Section 4.4.3) and is discussed further in Section 9. The implications of observed seasonal patterns in groundwater quality are also discussed in Section 9; low concentrations of major ions in a number of shallow groundwater bores indicate groundwater recharge is primarily from rainfall (Daughney et al. 2009), with nitrate concentrations highest in winter, coinciding with groundwater levels nearer to the ground's surface. During this time there is a greater likelihood – especially where intensive land use occurs – of groundwater intercepting effluent applied to land leaching through the soil column, transporting high concentrations of nutrients (especially nitrate) to hydraulically connected surface waters.

E. coli bacteria were detected on one or more sampling occasions in 11 of the 13 bores. The highest count was in bore S26/0386 (320,000 cfu/100mL), a large diameter concrete well, 5 m deep. It is not known why *E. coli* counts are so high in this bore but the bore is not used for potable supply because of this contamination. Elevated counts of *E. coli* in bores S26/0427 and S26/0803 are likely to be due to a lack of borehead protection and isolation from stock; bore caps were regularly found lying next to the bore (not on the borehead). Bore S26/1034 also recorded elevated *E. coli* counts; the reason for this is unclear but it is possible that a disused septic tank nearby may be having some influence.

Iron was present above the DWSNZ (2005) MAV in samples from three bores: S26/0449, S26/0977 and S26/1034. Manganese was also present in concentrations above the DWSNZ (2005) MAV in two of these bores (S26/0449 and S26/0977). Bores S26/0449 and S26/1034 are thought to draw on an older groundwater source. However, bore S26/0977 is the control bore upgradient of Reid's piggery; the reason for the elevated iron and manganese concentrations in this bore is unclear but may be related to sediment found in this bore.

Dissolved arsenic concentrations in samples from bore S26/0449 were double the DWSNZ (2005) MAV (0.01 mg/L) on six sampling occasions. It is thought that arsenic is occurring naturally in the groundwater at this location; as noted previously, the groundwater in this bore is reduced (median dissolved oxygen concentration of just 0.09 mg/L) and arsenic is able to dissolve out of the surrounding rock under reducing conditions. Arsenic was also present in groundwater from a nearby potable bore (S26/0968) and soil sampling elsewhere on the property also identified contamination (refer Section 6.4). Median dissolved concentrations of other metals were below the DWSNZ (2005) MAV or GV.

Overall, the 13-month groundwater quality sampling programme confirms that intensive land use in the Mangatarere catchment is having a measurable impact on water quality in the shallow unconfined aquifer. The implications of this for hydraulically connected surface waters are discussed in Section 9.

6. Soil quality

6.1 Sampling sites and frequency

As no current State of the Environment (SoE) soil quality monitoring sites are located in the Mangatarere catchment, very little was known about the quality of the catchment's soils. Therefore, new monitoring sites were established and sampled on one occasion in spring 2009, specifically for this investigation.

Sixteen sampling sites were randomly selected throughout the catchment on various soil types and land uses to gain an understanding of the impacts different land uses were having on soil quality (Figure 6.1, Appendix 1). One of the sites (PM011) was located in the Fensham Reserve native forest to represent background (unimpacted) soil conditions.

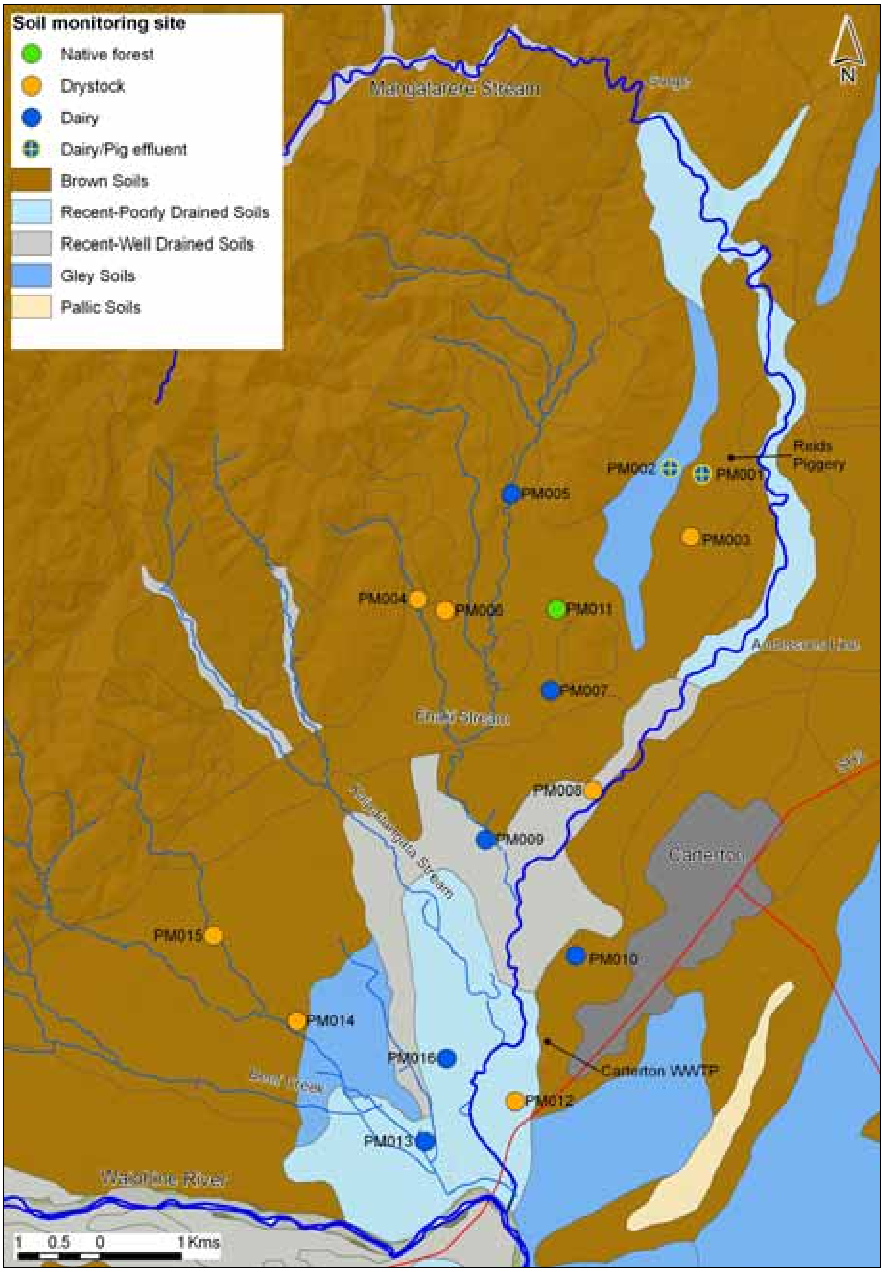

Figure 6.1: Soil quality sites sampled in the Mangatarere catchment on one occasion during spring 2009

6.2 Sampling methods and sample analysis

The soil sampling methods employed were consistent with the SoE monitoring methods, which are derived from "The 500 Soils Project", a national soil quality programme that Greater Wellington was part of until it ended in 2001. However, because the sites hadn't been sampled previously it was important to establish the soil type of the site, and ensure samples were taken from soil representative of the site.

Once a proposed sampling site was located, a walkover of the site was undertaken to ensure that a 40-50 m transect covering the same soil type could be used. To confirm the soil across a transect was generally the same several holes were dug with an auger (Figure 6.2). When the soil type surrounding the site was established an appropriate 50 m transect line was laid out. As well as collecting samples from each site, a pit was dug at each side exposing the soil profile, which was then characterised by Scott Fraser, a pedologist from Landcare Research (Figure 6.2). A photograph and full description of each of the site's soil profiles are presented in Appendix 1.

Figure 6.2: Scott Fraser (Landcare Research, left) using an auger to dig small cores to find an area of consistent soil type to sample at site PM006 and (right) soil profile at site PM013 consisting of silt loam topsoil, mottled silt loam to clay loam subsoil and an underlying compacted ironstone layer impeding drainage.

At each sampling site soil cores (2.5 cm in diameter to a depth of 10 cm) were taken every 2 m along the transect using a soil corer. The 25 individual cores were combined and mixed into a single composite sample for analysis to determine the organic resources, acidity, fertility of the soil and concentrations of various trace elements. Three undisturbed soil samples were also obtained from each site at 15, 30 and 45 m intervals along the transect by pressing steel ring liners 10 cm in width and 7.5 cm in depth into the soil surface. The 3 intact ring samples were collected to establish the physical properties (bulk density and macroporosity) of the soil. The laboratory's soil analysis methods can be found in Appendix 2; a summary of the soil properties analysed is provided in Table 6.1.

Table 6.1: Soil properties assessed in one-off Mangatarere catchment soil samples

Soil property	Indicator	Soil quality information
Physical condition	Bulk density	Soil compaction
	Macroporosity	Soil compaction and degree of aeration
Organic resources	Total carbon (C) content	Organic matter carbon content
	Total nitrogen (N) content	Organic matter nitrogen content
	Mineralisable N	Organic nitrogen potentially available for plant uptake and activity of soil organisms
Acidity	Soil pH	Soil acidity
Fertility	Olsen P	Plant-available phosphate
Trace elements	Concentrations of total recoverable trace elements (As, Cd, Cr, Cu, Ni, Pb and Zn)	Accumulation of trace elements

6.3 Data interpretation and analysis

The soil properties themselves do not measure soil quality, rather soil quality is a value judgement about how suitable a soil is for its particular land use. A group of New Zealand experts in soil science developed soil response curves for each of the soil properties, and established critical values or optimal ranges for the assessment of soil quality for the predominant soil orders under a number of different land uses (Appendix 3). These critical values and optimal ranges are used to assess soil quality (Hill & Sparling 2009).

In the absence of any New Zealand guidelines for trace element concentrations in agricultural soils, the trace element concentrations in this report were compared against the soil limits presented in the New Zealand Water and Wastes Association (NZWWA 2003) ‘Guidelines for the Safe Application of Biosolids to Land in New Zealand’ (referred to as the biosolids guidelines). While guidelines containing soil contaminant values like the biosolids guidelines have been written for a specific activity (biosolids application), the values are generally transferrable to other activities that share similar hazardous substances (MAF 2008). For example, the biosolids guidelines have been used by some regional councils to measure and assess cadmium present in soils as a result of phosphate fertiliser application rather than the application of biosolids (MAF 2008).

6.4 Soil quality results

The majority of the 16 soil quality sampling sites were found to be in good condition, with six sites meeting all the soil quality criteria, and just four sites having more than one soil quality indicator outside the target (optimal) range (Tables 6.2 and 6.3). However, nearly half the sites were found to have low macroporosity values (indicating soil compaction), while high concentrations of total nitrogen were found at some other sites. These findings mirror previous results from the monitoring of soils at drystock and dairy farms throughout the Greater Wellington region in Sorensen (2008) and Sorensen (2009). The full results of the soil quality monitoring can be found in Appendix 4.

Table 6.2: Physical and chemical results for Mangatarere soil samples collected in spring 2009. Values in bold are outside the optimal range for the site's specific soil order and land use.

Site No.*	Soil pH	Total C %	Total N %	C:N ratio	Mineralisable N mg/kg	Olsen P mg/kg	P retention %	Bulk Density T/m³	Macro Porosity (@-10kPa) % v/v
PM001 (Dai)	6.35	8.37	0.71	11.9	178	103	46 (Medium)	0.82	10.23
PM002 (Dai)	6.38	5.23	0.48	11.0	144	99	25 (Low)	0.91	7.93
PM003 (Dry)	6.18	9.21	0.78	11.8	176	39		0.84	3.43
PM004 (Dry)	6.09	7.60	0.59	12.8	229	19	57 (Medium)	0.70	12.63
PM005 (Dai)	5.49	6.66	0.55	12.1	169	36		0.92	9.27
PM006 (Dry)	5.73	8.08	0.69	11.7	200	12	66 (Medium)	0.82	9.97
PM007 (Dai)	5.88	6.67	0.56	11.9	152	17		0.97	5.90
PM008 (Dry)	5.52	10.5	0.91	11.5	224	56		0.86	11.33
PM009 (Dai)	6.11	3.77	0.37	10.3	78	39	23 (Low)	1.03	6.27
PM010 (Dai)	6.34	7.98	0.72	11.0	181	74		0.89	5.43
PM011 (Nat)	5.75	8.22	0.58	14.3	140	24		0.94	18.37
PM012 (Dry)	6.01	3.53	0.33	10.7	108	24		1.23	4.07
PM013 (Dai)	5.52	6.63	0.60	11.1	148	59		1.03	2.60
PM014 (Dry)	6.56	4.73	0.43	11.0	131	34		1.08	1.83
PM015 (Dry)	5.81	5.76	0.52	11.1	180	32	45 (Medium)	0.93	5.77
PM016 (Dai)	6.46	3.56	0.34	10.5	94	44		1.34	7.33

* Dai = Dairy, Dry = Drystock, Nat = Native Forest

Bulk density and macroporosity are both measures of soil compaction, and are important physical properties of a soil. Although samples from all of the sites had optimal bulk density values, their macroporosity levels were generally low, with seven sites below the lower limit of the optimal range (Figure 6.3), indicating that some soils are compact. Macroporosity values ranged from 1.83 at site PM014 to 18.37 at site PM011. Out of the seven sites that exceeded the lower limit for macroporosity, four were drystock sites, and the other three were dairy sites. The native forest site had a significantly higher macroporosity value than the other pasture sites.

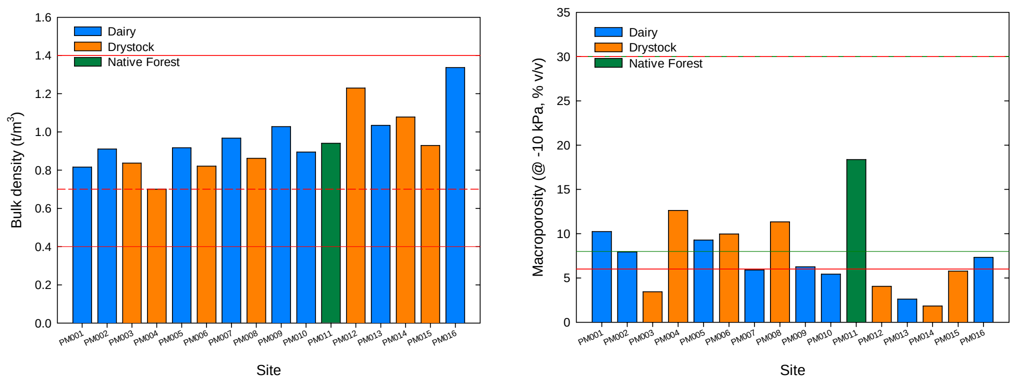

Figure 6.3: Bulk density and macroporosity values for Mangatarere soil quality sites sampled in spring 2009. The area between the red lines represents the optimal range for pasture sites* and the green lines represent the optimal range for forestry sites.

* The lower threshold values for bulk density are 0.4 for pallic and recent soils, and 0.7 for other soils.

The soil pH of all of the 16 sites sampled was within the optimal range, ranging from 5.49 to 6.56, and the total carbon contents of the 16 sites sampled were also found to be within the optimal range (Figure 6.4).

Total nitrogen concentrations ranged from 0.33 to 0.91% w/w (Figure 6.4). Four sites (two dairy and two drystock) had total nitrogen contents greater than the optimal range. Mineralisable nitrogen concentrations, which give a measure of how much organic nitrogen is potentially available for plant uptake, and the activity of the soil organisms (Hill & Sparling 2009), were within the optimal range at all of the sites sampled.

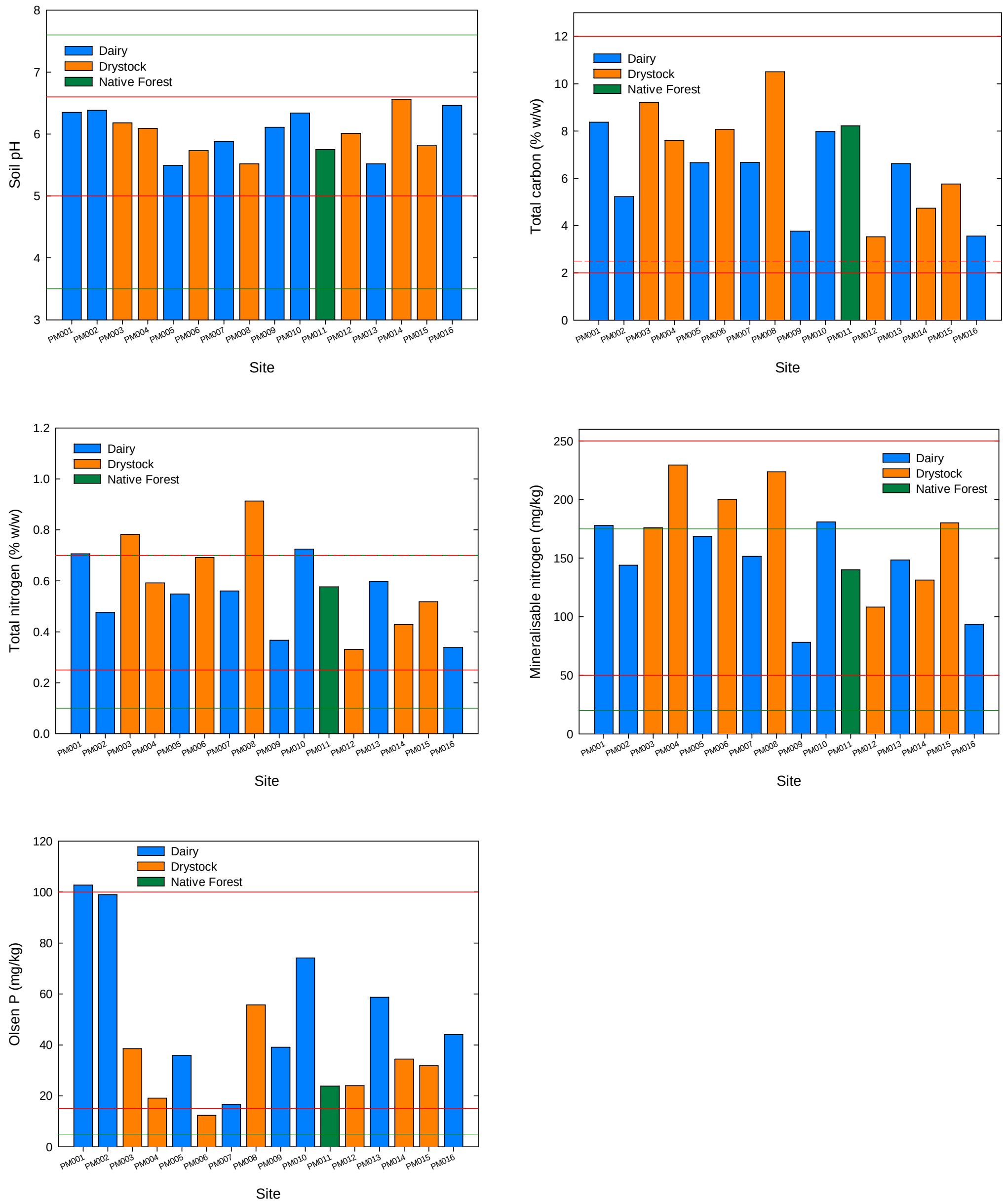

Figure 6.4: Selected chemical properties for Mangatarere soil quality sites sampled in spring 2009. The area between the red lines represents the optimal range for pasture sites*, the green lines represent the optimal range for forestry sites.

* The lower threshold values for total carbon are 2 for recent soils and 2.5 for the other soil orders.

Olsen P concentrations were variable throughout the 16 sites. Site PM001 exceeded the upper limit of the target range with 103 mg/kg Olsen P, while PM006 was outside the lower limit with just 12 mg/kg Olsen P. PM011 contained an unusually high Olsen P concentration (for a native forest site) of 24 mg/kg, which suggests there could have been some fertiliser drift from adjacent paddocks (Fraser[24], pers. comm. 2010). P-retention was measured at six of the 16 sites to gain an understanding of the different P-retention values for the major soil types in the catchment. P-retention will change little with change in management as it is essentially a property of the clay mineralogy of the soil (McLeod[25], pers. comm. 2009). Values of P-retention ranged from 23% (low) to 66% (medium) throughout the catchment. Sites PM001 and PM002 contained the highest Olsen P concentrations, and also contained low-medium P-retention values.

Concentrations of trace elements (total recoverable) measured at all the 16 sites are presented in Table 6.3. Generally concentrations of the trace elements were below the NZWWA (2003) guideline values, with the exception of the sample from site PM013, which contained an elevated concentration of arsenic. In comparison to the other sites, site PM013 also contained elevated concentrations of nickel, lead and zinc. As noted in Section 5.4.4, groundwater samples taken from bores in the general vicinity also contained elevated arsenic concentrations.

Although all cadmium results were well below guideline levels, compared with the native forest site (PM011), concentrations were elevated in all samples (Figure 6.5).

Table 6.3: Trace element concentrations (total recoverable) in Mangatarere catchment soil samples collected in spring 2009. The concentration in bold font exceeds the NZWWA (2003) recommended guideline value.

Site No.	Arsenic (As) mg/kg	Cadmium (Cd) mg/kg	Chromium (Cr) mg/kg	Copper (Cu) mg/kg	Nickel (Ni) mg/kg	Lead (Pb) mg/kg	Zinc (Zn) mg/kg
PM001	4.1	0.31	17	36	15	9.6	110
PM002	2.2	0.21	12	21	11	5.8	71
PM003	4.4	0.51	17	11	15	9.4	80
PM004	3.6	0.22	17	9.5	13	7.5	57
PM005	<2.0	0.26	13	8.4	12	8.1	60
PM006	3.6	0.25	19	10	14	8.3	59
PM007	<2.0	0.27	14	5.8	8.6	6	51
PM008	3	0.39	16	10	12	9.7	88
PM009	2.7	0.33	17	13	13	11	63
PM010	3	0.49	17	9	22	8.6	74
PM011	3	<0.10	16	12	15	9.3	68
PM012	3.4	0.29	20	11	17	13	74
PM013	28	0.25	26	23	29	19	100
PM014	<2.0	0.23	14	3.9	7.2	6.1	32
PM015	3.6	0.37	16	11	16	8.7	77
PM016	2.9	0.32	21	20	13	13	86

24 Scott Fraser, Soil Scientist, Landcare Research

25 Malcolm McLeod, Soil Scientist, Landcare Research

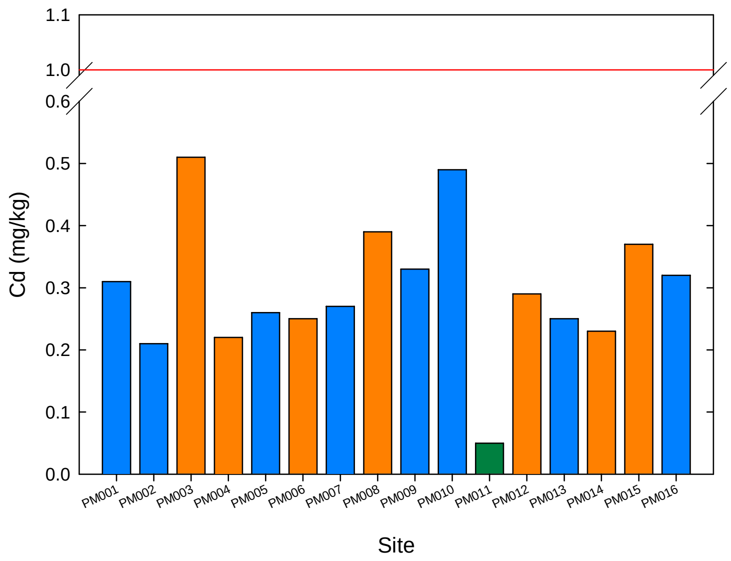

Figure 6.5: Total recoverable cadmium concentrations in Mangatarere catchment soil samples collected in spring 2009. The NZWWA (2003) recommended guideline value is also shown.

6.5 Discussion

The results of the one-off soil quality sampling in the Mangatarere catchment found the soils to generally be in good condition, with six sites meeting all the soil quality criteria and just four of the 16 sites having more than one soil quality indicator outside of the recommended target range (Figure 6.6). The primary concern was compaction, and to a lesser extent elevated concentrations of nutrients, findings consistent with soil quality monitoring undertaken at various dairy and drystock farms throughout the region as part of Greater Wellington's soil quality monitoring programme.

Low macroporosity appears to be related to soil type and soil drainage properties rather than land use as there appears to be no significant difference in macroporosity values between dairy and drystock sites. In seven cases, macroporosity values were low, indicating soil compaction may be an issue catchment-wide, but particularly in the more poorly drained soils throughout the lower end of the Mangatarere catchment and the Beef Creek subcatchment. Borrie and Webb (2006) state that poorly drained soils perch water and are prone to compaction under stock and wheel traffic when wet. Low macroporosity and associated soil compaction increases the risk of potential flow-on impacts for water quality in drains and streams. As a result of reduced infiltration, under wet conditions these soils are susceptible to surface ponding, which promotes greater sediment and nutrient runoff from the land; evidence of such ponding was seen in the lower reaches of the Beef Creek subcatchment following heavy rain in early June 2010 (Figure 6.7). Low macroporosity also has adverse effects on plant growth, creating a poor root environment which restricts air access and nitrogen-fixation by clover roots (Hill & Sparling 2009).

Samples from four of the 16 sites had high total nitrogen concentrations, with no significant difference in concentrations between dairy and drystock sites. Pasture has a high demand for nitrogen, and when pasture is growing vigorously, it takes up available nitrogen in the soil (Borrie & Webb 2006).

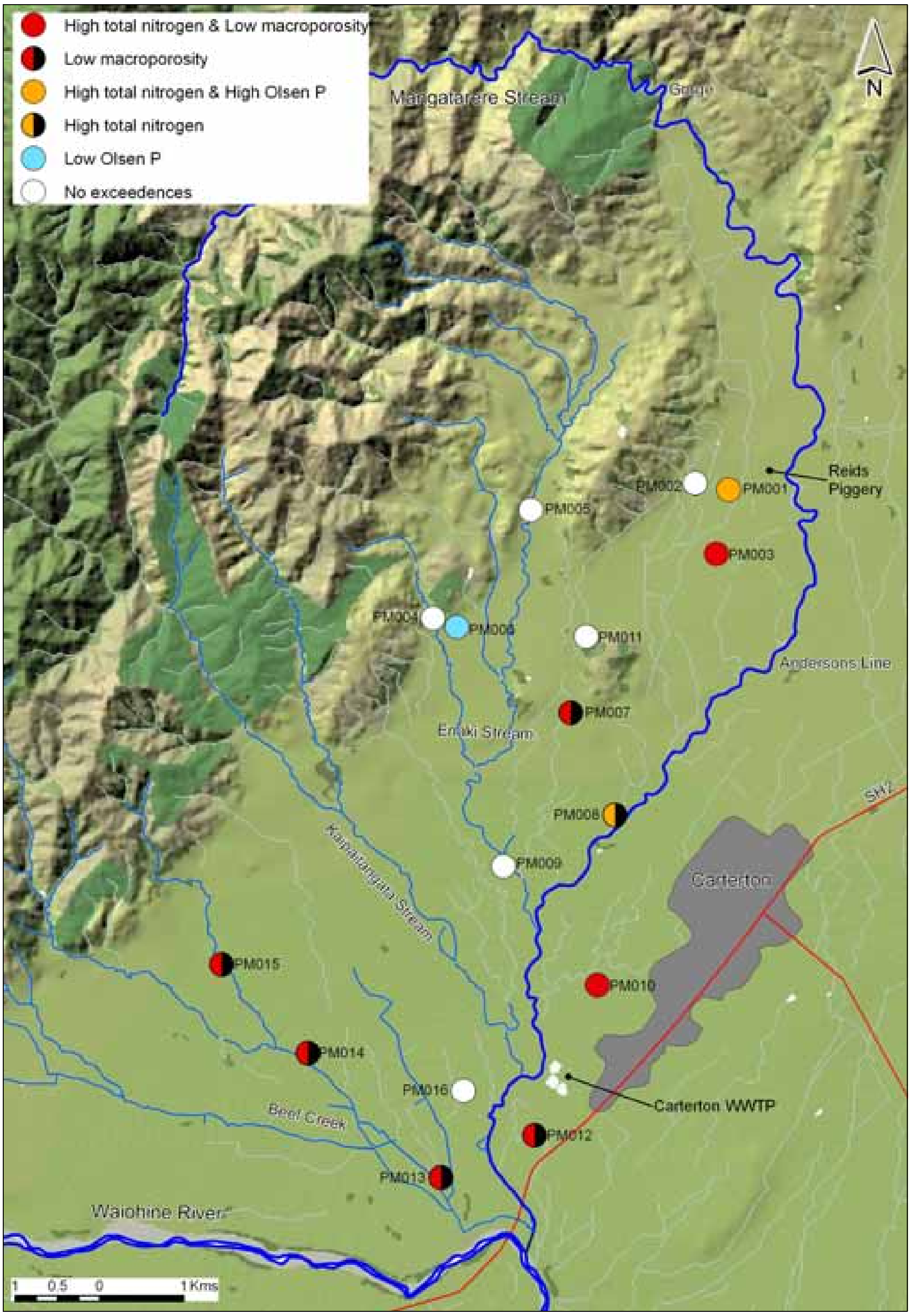

Figure 6.6: Summary of compliance with recommended soil quality criteria for 16 soil quality sites sampled in the Mangatarere catchment during spring 2009

However, when nitrogen concentrations in the soil are greater than what can be up taken by plants, nitrogen can leach through the soil profile. Nitrogen is commonly added to pastoral soils through fertilisers, application of effluent (piggery and dairy) and urine patches. Nitrogen in urine patches alone is commonly deposited at a rate of between 800 and 1,000 kg/N/ha, and on a typical dairy farm urine patches will occupy about 30% of the grazed area over a year (Borrie & Webb 2006). Therefore, the addition of fertilisers and effluent on grazed pastures needs to be carefully managed along with stocking rates to minimise the increased risk of nitrogen leaching through the soil profile.

Figure 6.7: Surface ponding in the lower Beef Creek catchment following heavy rainfall in early June 2010 (left) and runoff from a ploughed paddock flowing towards Beef Creek upstream of Matarawa Road

Only one of the sites exceeded the upper limit of the optimal range for Olsen P. Despite this, a Mann Whitney Rank Sum Test showed that Olsen P concentrations were significantly greater (p=0.04) in samples from dairy sites than samples from drystock sites, which may reflect greater application of phosphate fertiliser on dairy farm sites. The two sites with the highest Olsen P concentrations (PM001 and PM002) are dairy sites which also receive piggery effluent. Borrie and Webb (2006) reported that previously measured Olsen P values from soils that receive piggery effluent (near these sites) contained high to very high Olsen P values, indicating that significant accumulation of phosphorus has occurred under historical management. High Olsen P concentrations present a significant risk of phosphorus loss through runoff and leaching (McDowell & Condron 2004).

One of the most important properties related to phosphorus leaching potential is phosphate retention (Borrie & Webb 2006). P-retention tests revealed that site PM001 has low P-retention (25%) and site PM002 medium P-retention (46%); this indicates that excess phosphorus applied to these soils (particularly site PM001) could leach into underlying groundwater. The relationship between soil phosphorus accumulation (Olsen P) and the soil's adsorption capacity (P retention) was quantified by McDowell and Condron (2004). They derived formulae to estimate dissolved reactive phosphorus (DRP) concentrations in overland (runoff) and subsurface (leaching) flow based on Olsen P and P retention data for 44 soils in New Zealand[26]. Their formula for loss through runoff is:

$$\textit{Runoff DRP concentration (mg/L)} = 0.024 \times (P_{Olsen}/P_{Retention}) + 0.024$$

Their formula for loss through leaching (below 30 cm soil depth) is:

$$\textit{Leachate DRP concentration (mg/L)} = 0.069 \times (P_{Olsen}/P_{Retention}) + 0.007$$

Although none of the soils in McDowell and Condron (2004) are representative of the Mangatarere catchment, the above formulae provide a useful tool to

[26] McDowell and Condron (2004) note that additional work is still required to determine the degree that the relationships change under the range of rainfall intensities possible in the New Zealand environment, and different scales in the field. Furthermore, the relationship is only applicable for pasture soils that have not been recently grazed (<10–15 days since grazing), since dung may significantly increase P loss. This work should, therefore, be considered as still evolving.

estimate potential phosphorus losses through runoff and leaching from soils in the catchment (Table 6.4).

Table 6.4: Estimated dissolved reactive phosphorus (DRP) concentrations in runoff and leachate at sites where Olsen P and P retention was analysed using the formulae from McDowell and Condron (2004)

Site No.	Land use	Olsen P mg/kg	P retention %	Runoff DRP mg/L	Leachate DRP mg/L
PM001	Dairy	103	46	0.077	0.160
PM002	Dairy	99	25	0.120	0.284
PM004	Drystock	19	57	0.032	0.030
PM006	Drystock	12	66	0.029	0.020
PM009	Dairy	39	23	0.065	0.126
PM015	Drystock	32	45	0.041	0.056

The results presented in Table 6.4 show that estimates of DRP concentrations in both runoff and leachate are variable depending on the amount of phosphorus accumulated in the soil (Olsen P) and the soil's ability to adsorb the phosphorus (P-retention). DRP concentration estimates in both runoff and leachate are particularly high at sites PM001, PM002 and PM009 (all dairy). The ANZECC (2000) trigger value for DRP concentrations in lowland streams is 0.01 mg/L.

The soil sample from site PM013 towards the bottom of the Beef Creek subcatchment contained an elevated concentration of arsenic. Sampling of the groundwater from several shallow bores in the general area also revealed elevated arsenic concentrations in the groundwater, suggesting that the source of the arsenic is likely to be natural and not a result of site-specific contamination (refer Section 5.5).

Elevated concentrations of cadmium in soil samples from all sites except the site in Fensham Reserve may reflect the application of phosphate fertilisers. Phosphate fertilisers such as superphosphate are produced from phosphate rock, which contains several trace element impurities such as cadmium at concentrations well above their crustal averages (Kim & Taylor 2009). Therefore, soils on which phosphate fertilisers have been applied generally contain elevated concentrations of cadmium which has accumulated over time. Previous SoE soil quality monitoring undertaken in the Wellington region to date has shown cadmium concentrations tend to be higher in agricultural soils compared with native forest soils (Croucher 2005).

Lastly, the soil investigation also identified an exception to the soil map presented in Figure 2.5 (Section 2.4) that was based on Heine (1975). Sampling at site PM015 in the middle reaches of the Beef Creek subcatchment indicates that poorly-drained gley soils may cover a larger area of the lower half catchment than illustrated in Figure 2.5. A previous soil investigation undertaken by Webb (2006) also found that the floodplain of the middle section of the Mangatarere Stream shown as being a poorly-drained recent soil in Figure 2.5, should be shown as a well drained recent soil. These findings highlight the importance of verifying soil types in the field rather than relying solely on existing maps.

7. State of the environment monitoring – temporal trends

As outlined in Sections 4.1 and 5.1, Greater Wellington has long-term State of the Environment (SoE) surface water quality and groundwater quality monitoring sites located within the Mangatarere catchment (Figure 7.1). These sites are sampled monthly and quarterly respectively. This section presents a summary of temporal trend analysis of long-term water quality data from each of these sites.

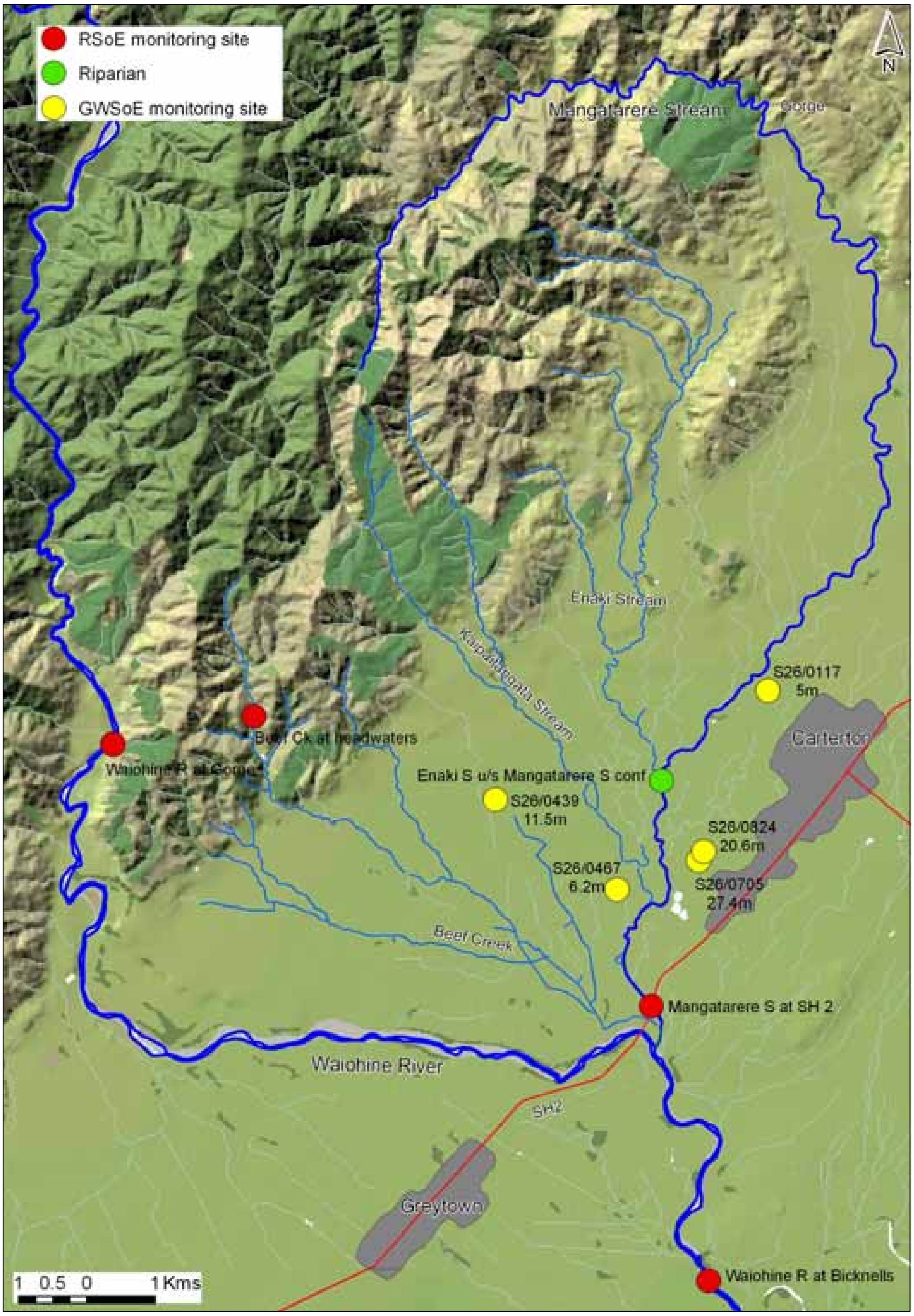

Figure 7.1: Long-term state of the environment river (RSoE) and groundwater (GWSoE) monitoring sites in the Mangatarere catchment. The long-term Enaki Stream riparian rehabilitation monitoring site is also shown.

7.1 Trend analysis methods

7.1.1 Surface water quality

Temporal trends in water quality at Greater Wellington's long-term RSoE and riparian rehabilitation monitoring programme sites were analysed using NIWA's Time Trends software (Version 3.1, 2010). The time period analysed was from September 2003 to August 2009 inclusive; although records date back to 1998 for some sites, not all variables were monitored from this time and there was a significant change in laboratory analysis for some variables from September 2003.

Where a data-set for a variable comprised a large number (>30%) of values below the analytical detection limit, trend analysis was not carried out as any results were deemed to be of limited reliability (Scarsbrook & McBride 2007). This excluded trend analysis for the following variables at the following sites:

- Ammoniacal nitrogen (ammonia) – the Waiohine River sites at the Gorge and Bicknells; and
- Total nitrogen, dissolved reactive phosphorus (DRP) and total phosphorus – the Waiohine River at Gorge.

Data-sets for all other variables at all other sites had less than 10% of values below the analytical detection limit. In these latter cases, where a value was recorded as below the detection limit, this value was replaced with one half the value of the detection limit before performing trend analyses (Scarsbrook & McBride 2007).

Trend analysis firstly involved analysing the data for seasonality. Twelve seasons (i.e., monthly) were examined using the Kruskal-Wallis One Way Analysis of Variance test. If 12 seasons were not evident in the data (i.e., $p \geq 0.05$), four seasons (of three months starting from January) were analysed. If no seasonality for either 12 or four seasons were evident in the data, trend analysis was carried out using a Mann-Kendall test. Where seasonality was evident, trend analysis was carried out using a Seasonal Kendall test with the appropriate number of seasons (i.e., 12 or four).

Trend analyses (both Seasonal Kendall and Mann-Kendall) were carried out on both raw and flow-adjusted data from most sites; only raw data were used for Beef Creek at Headwaters (flows could not be estimated for this site). Flow adjustment was performed in the Time Trends software using LOWESS (Locally Weighted Scatterplot Smoothing) with a 30% span. See Appendix 5 for further information on flow estimation and adjustment.

A trend was deemed statistically significant if the *p*-value was less than 0.05. The Sen Slope estimator was used to represent the direction and magnitude of the trend. The Sen Slope estimator was divided by the raw data median to provide a relative rate of change. As per Scarsbrook (2006), a relative rate of change threshold of 1% per annum was set to denote a trend that may be "meaningful" (although note that Scarsbrook (2006) recognises this 1%

threshold is totally arbitrary and thresholds above 1% may still not be environmentally significant).

Linear trends in macroinvertebrate metrics for the long-term monitoring sites were examined using non-parametric Spearman Rank correlations (in Sigmaplot Version 11.0). Correlations were considered significant when *p*-values were less than 0.05.

7.1.2 Groundwater quality

Trend analysis was performed on groundwater sample results from the five GWSoE monitoring bores located in the Mangatarere catchment using NIWA Time trends software (Version 3.1, 2010). The time period for trend analysis varied between sites; the commencement of water quality monitoring in these bores ranged from 1998 to 2005, and extended to December 2009.

Similar to the analysis of surface water quality data, trend analysis was not carried out where a data-set for a variable comprised more than 30% of values below the analytical detection limit. This excluded the analysis of trends in faecal coliforms, *E. coli,* nitrite-nitrogen, ammonia and iron concentrations for all five GWSoE bores. Bromide data from bore S26/0117 were also excluded from trend analysis.

Where a data-set for a variable contained between 10 and 30% of values below the analytical detection limit, statistical analysis was carried out using the NADA (Non-detects and Data Analysis) for R Package which contains S-language implementations of the methods described by Helsel (2005). The Arkritas-Theil-Sen (ATS) line is plotted on a graph and tested to see if the ATS slope is significantly different from zero ($p<0.05$). This is also the test for whether or not Kendall's Tau is significantly different from zero.

All other trend analysis was conducted by examining variables for two and four seasons (i.e., bi-annually and quarterly) using Mann-Whitney and Kruskal-Wallis tests respectively. Statistically significant differences (i.e., $p<0.05$) were confirmed between four seasons for the variables DRP (bore S26/0439), calcium (bores S26/0467), and temperature (bores S26/0705 and S26/0824). Therefore, a Seasonal-Kendall test based on four seasons was used on these data-sets. Where water quality data didn't indicate any seasonal trends, the Mann-Kendall test was used to identify statistically significant trends. In addition to statistical significance, the relative rate of change was assessed. Daughney[27] (pers. comm. 2009) suggests that in groundwater a relative rate of change in a water quality variable greater than 5% per annum is probably due to human activity and may be environmentally significant.

7.2 Temporal trends in long-term SoE monitoring data

7.2.1 Surface water quality

Meaningful trends (i.e., statistically significant ($p<0.05$) and with a rate of change greater than 1% per annum) in flow-adjusted water quality data for the

[27] Dr Chris Daughney, GNS Science

long-term surface water quality monitoring sites are summarised in Table 7.1; full details of trend analyses for all sites and variables are provided in Appendix 5, including the results of trend analysis on raw water quality data.

Table 7.1: Summary of meaningful (i.e., statistically significant and a rate of change >1%/year) temporal trends in flow-adjusted water quality data from long-term SoE surface water monitoring sites (sampled monthly from September 2003 to August 2009) using the Mann-Kendall or Seasonal-Kendall test. Median values in bold font do not comply with guideline values.

Site and variable	*n*	Median	Trend test	Median Annual Sen Slope (rate of change in units/year)	*p*-value	Increasing/ decreasing trend	Rate of change (%/year)
Waiohine R at Gorge							
pH	70	7.48	Mann-Kendall	-0.10	<0.001	Decreasing	1.3
Turbidity (NTU)	71	0.89	Mann-Kendall	-0.08	0.043	Decreasing *(improvement)*	9.3
Waiohine R at Bicknells							
Dissolved oxygen (% saturation)	72	98.0	Mann-Kendall	-1.57	0.003	Decreasing *deterioration)*	1.6
Turbidity (NTU)	72	2.92	Mann-Kendall	-0.48	0.012	Decreasing *(improvement)*	16.4
Visual clarity (m)	72	1.21	Mann-Kendall	0.18	0.014	Increasing *(improvement)*	15.2
Mangatarere S at SH 2							
Water temperature (°C)	72	14.2	Seasonal Kendall	-0.15	0.004	Decreasing *(improvement)*	1.1
Visual clarity (m)	70	1.65	Seasonal Kendall	0.16	0.016	Increasing *(improvement)*	9.9
Ammoniacal nitrogen (mg/L)	72	0.085	Seasonal Kendall	0.005	0.020	Increasing *(deterioration)*	5.8
Dissolved reactive phosphorus (mg/L)	72	0.080	Seasonal Kendall	0.006	0.011	Increasing *deterioration)*	8.1
Total phosphorus (mg/L)	72	0.105	Seasonal Kendall	0.009	0.015	Increasing *deterioration)*	8.2
E. coli (cfu/100 mL)	72	110	Mann-Kendall	-24	0.023	Decreasing *(improvement)*	22.1

No meaningful trends were found in the six years of data analysed for the Enaki Stream upstream of the Mangatarere confluence (Greater Wellington's riparian rehabilitation monitoring site) nor Beef Creek at Headwaters. Small decreases in pH (0.10 pH units/year) and turbidity (0.04 NTU/year) were observed in the Waiohine River at Gorge site. The Waiohine River at Bicknells also showed a small decrease in turbidity (0.48 NTU/year) and this was reflected in a corresponding increase in visual clarity (0.18 m/year). A small decrease in dissolved oxygen (percent saturation) was also present at this site.

Decreasing water temperature (0.15°C/year) and *E. coli* bacteria counts (24 cfu/100 mL/year) were observed in the Mangatarere Stream at SH 2, as well as increasing visual clarity (0.16 m/year). In contrast, increasing concentrations of DRP (0.006 mg/L/year; Figure 7.2), total phosphorus (0.009 mg/L/year) and ammonia (0.005 mg/L/year; Figure 7.3) at this site indicate a deterioration in water quality in terms of nutrient concentrations. In the case of DRP and total phosphorus, the rates of increase were significant in both raw and flow-adjusted data.

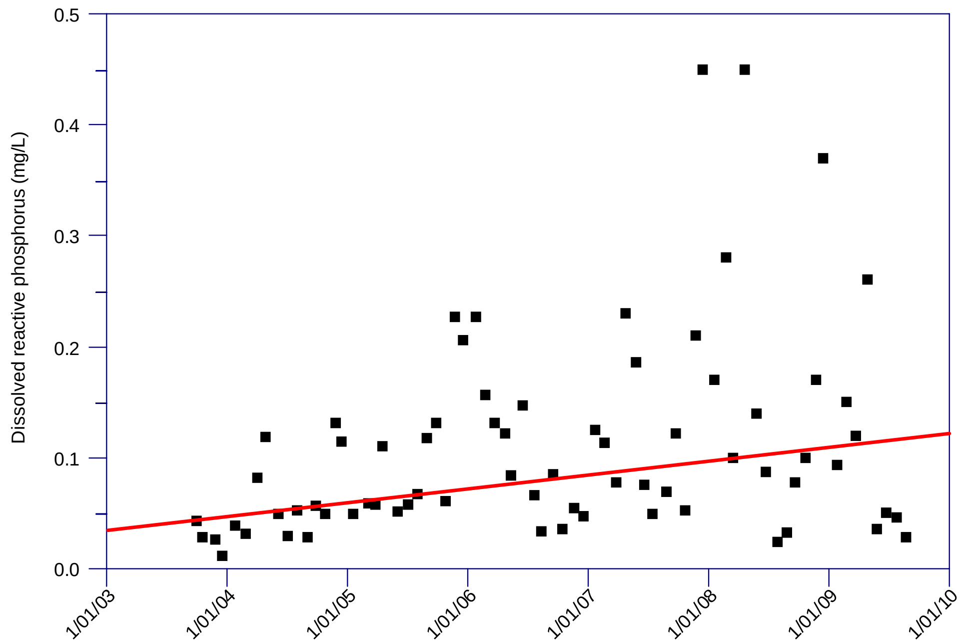

Figure 7.2: Dissolved reactive phosphorus concentrations in water samples from the Mangatarere Stream at SH 2, based on monthly testing over September 2003 to August 2009 (*n*=72). The solid line represents the overall trend (Seasonal Kendall Sen slope) in the raw data.

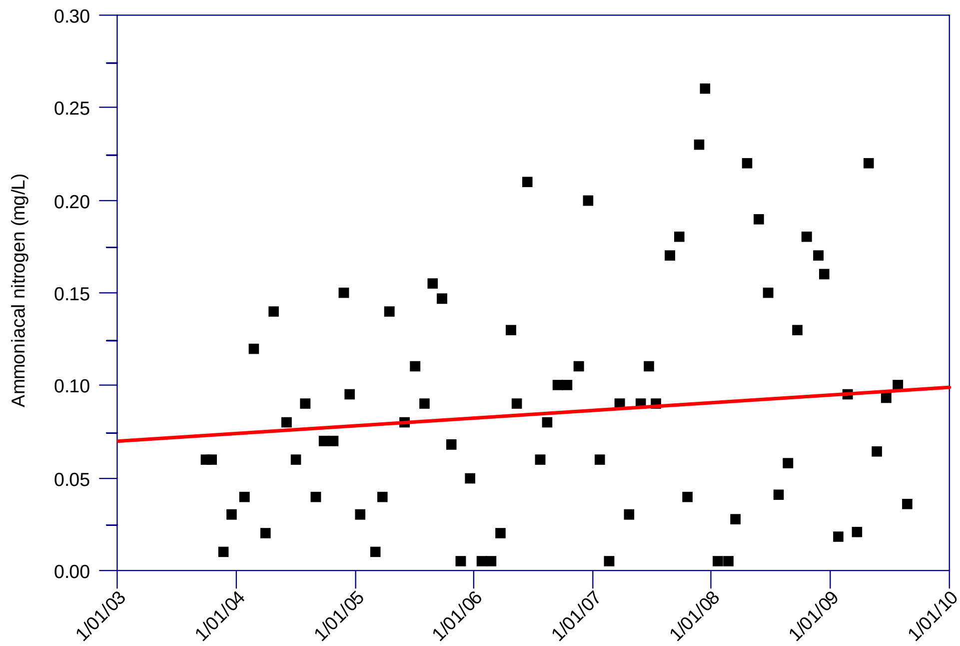

Figure 7.3: Ammoniacal nitrogen concentrations in water samples from the Mangatarere Stream at SH 2, based on monthly testing over September 2003 to August 2009 (*n*=72). The solid line represents the overall trend (Seasonal Kendall Sen slope) in the raw data.

7.2.2 Macroinvertebrate health

Spearman Rank Correlations showed a statistically significant (p=0.033) decline in mean MCI scores over 2004 to 2009 at Greater Wellington's RSoE monitoring site on the Mangatarere Stream at SH 2 (Figure 7.4). Over this period, mean MCI scores dropped from a quality classification (from Stark & Maxted 2007) of "good" to "fair". No significant trends were present in the three other metrics analysed (QMCI, %EPT (taxa) and %EPT (individuals), although mean QMCI values did also decrease over time. Full details of analyses can be found in Appendix 5. The only other statistically significant trend in metric scores for the long-term sites examined was an increase in EPT taxa at the Beef Creek at Headwaters site from 60% in 2004 to 80% in 2009. Based on MCI scores, this site has consistently been classed as "excellent".

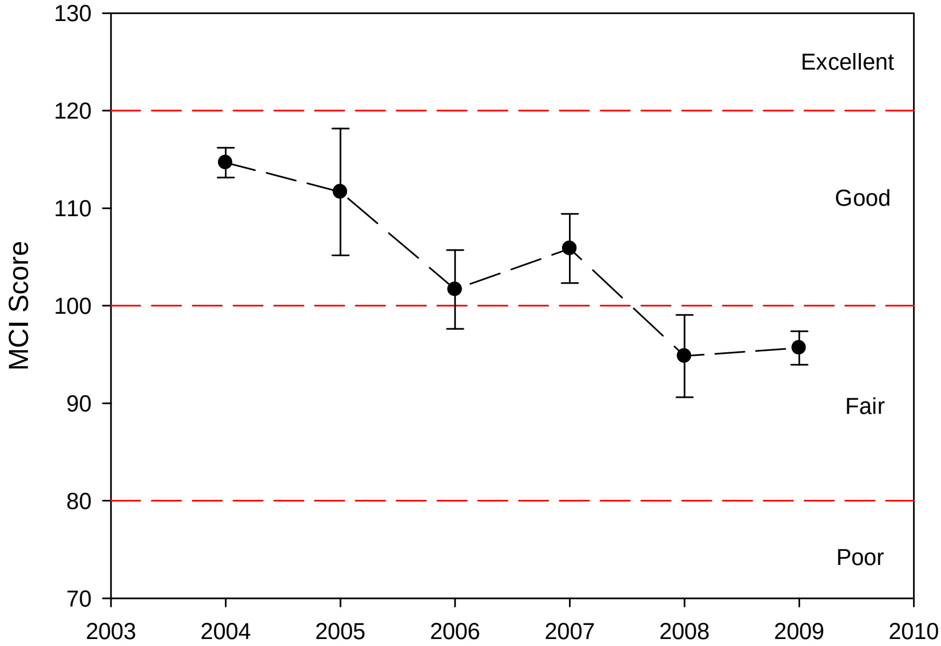

Figure 7.4: Mean MCI values (+/-1 standard deviation) for the Mangatarere Stream at SH 2 from 2004 to 2009, based on three replicate macroinvertebrate samples collected annually during the summer months. The red dashed lines indicate community health quality thresholds from Stark and Maxted (2007).

7.2.3 Groundwater quality

Meaningful trends (i.e., statistically significant (p<0.05) and with a rate of change greater than 5% per annum) in groundwater quality data for five long-term SoE monitoring bores are summarised in Table 7.2; full details of trend analyses for all sites and variables are provided in Appendix 5. As noted in Section 7.1.2, the time period for trend analysis varied between sites; the commencement of monitoring in the bores ranged from 1998 to 2005, and extended to December 2009.

A number of trends were deemed statistically significant (see Appendix 5), but in many cases, these trends were small in magnitude and not likely to be environmentally meaningful. Most of the meaningful trends related to decreasing metal concentrations (Table 7.2). Decreasing trends in nitrate and

Table 7.2: Summary of meaningful (i.e., statistically significant and a rate of change >5%/year) temporal trends in groundwater quality data from five SoE bores (sampled quarterly) using the Mann-Kendall Kendall test and Sen's slope estimator

Bore	Variable	Trend period	*n*	Min	Median	Max	Median Annual Sen Slope	*p*-value	Trend type	Rate of change (%/year)
S26/0824 (20.6 m deep)	Dissolved lead (mg/L)	Oct 2003 – Dec 2009	26	<0.0001	0.0003	0.0014	<-0.0001	<0.0001	Decrease	13.0
	Dissolved manganese (mg/L)	Oct 2003 – Dec 2009	26	0.00089	0.00155	0.01	-0.0002	<0.0001	Decrease	15.6
	Dissolved zinc (mg/L)	Oct 2003 – Dec 2009	26	0.001	0.005	1.64	-0.0025	0.0358	Decrease	49.7
	Fluoride (mg/L)	Oct 2003 – Dec 2009	26	0.089	0.12	0.2	-0.0080	0.0160	Decrease	6.7
S26/0705 (27.4 m deep)	Dissolved lead (mg/L)	Oct 2003 – Dec 2009	26	<0.0001	0.0003	0.0012	-0.0001	<0.0001	Decrease	11.7
	Dissolved manganese (mg/L)	Oct 2003 – Dec 2009	26	0.00025	0.00078	0.0067	-0.0002	<0.0001	Decrease	20.2
	Dissolved zinc (mg/L)	Oct 2003 – Dec 2009	26	0.0012	0.014	1.41	-0.0072	<0.0001	Decrease	51.1
	Dissolved oxygen (mg/L)	Oct 2003 – Dec 2009	26	0.32	0.805	1.78	0.1039	0.0005	Increase	12.9
S26/0467 (6.2 m deep)	Nitrate nitrogen (mg/L)	Jan 2005 – Dec 2009	21	1.2	2.2	4.14	-0.2970	0.0234	Decrease	13.5
	Nitrite-nitrate nitrogen (mg/L)	Jan 2005 – Dec 2009	21	1.2	2.2	4.14	-0.2970	0.0234	Decrease	13.5
S26/0439 (11.5 m deep)	Dissolved manganese (mg/L)	Jan 2005 – Dec 2009	21	0.00067	0.0015	0.0056	-0.0002	0.0484	Decrease	15.0
S26/0117 (5 m deep)	Dissolved lead (mg/L)	Jan 2005 – Dec 2009	21	<0.0001	0.0001	0.00078	0.0001	0.0378	Increase	13.6

NNN concentrations were also found in one bore, S26/0467 (rate of change 13.5% for both variables, Figure 7.5). No statistically significant or environmentally meaningful increasing trends were detected for nutrients.

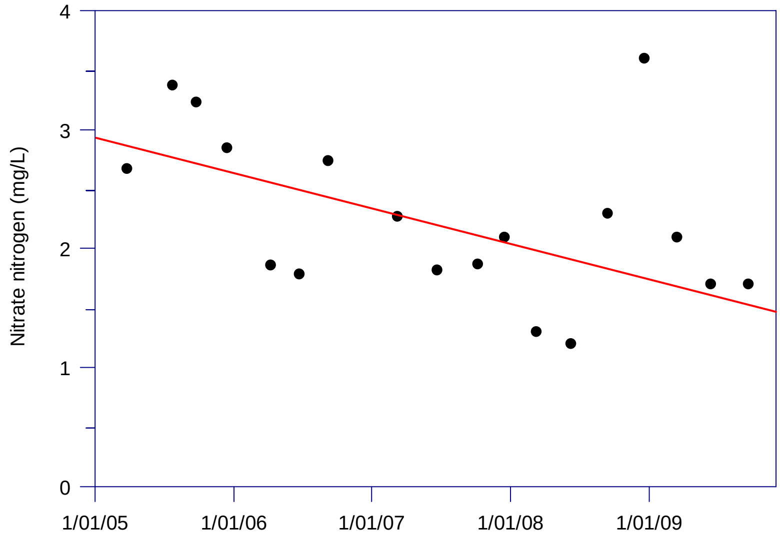

Figure 7.5: Nitrate nitrogen concentrations recorded in GWSoE bore S26/0467 sampled quarterly from January 2005 to December 2009 (n=21). The red line indicates the Mann-Kendall slope trend line.

In addition to assessing temporal changes in groundwater quality, temporal changes in water levels were also assessed for the two GWSoE bores where groundwater level information has been collected (S26/0467 and S26/0439). No trends were evident but data from both bores exhibited a clear seasonal pattern (Figure 7.6); groundwater levels were higher during winter and lower in summer. A Kruskal-Wallis test confirmed seasonality in bore S26/0467 (p=0.021) with four major seasons identified (February to April, May to July, August to October and November to January), while a Mann-Whitney test confirmed seasonality in bore S26/0439 (p=0.021) with two major seasons identified (June-November and December to May).

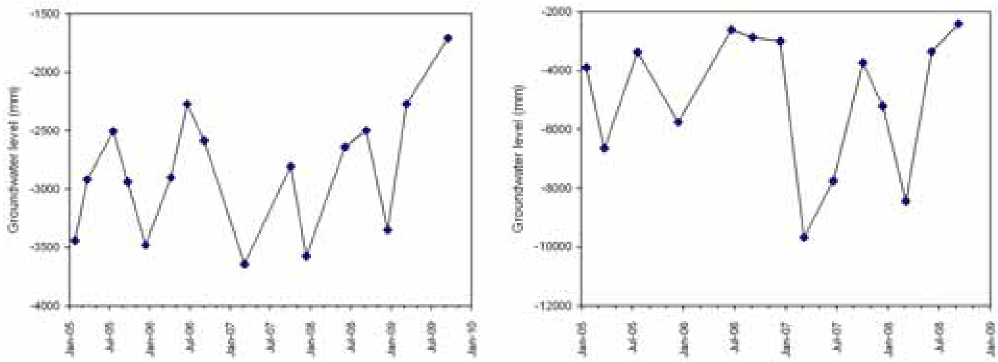

Figure 7.6: Groundwater levels measured at quarterly intervals in GWSoE bores S26/0467 (left) and S26/0439 (right) between January 2005 and December 2009

7.3 Discussion

Analysis of water quality data collected monthly from Greater Wellington's RSoE monitoring sites over September 2003 to August 2009 identified statistically significant and meaningful improvements in some optical water properties in the Waiohine River. The improvements were particularly apparent at the Bicknells site, where visual clarity increased by 0.18 m/year. The reason for this improvement is not known but it is important to note that the median clarity measurement for the six-year trend period was just 1.21 m, well below the MfE (1994) contact recreation standard of 1.6 m.

Analysis of SoE water quality data for the Mangatarere Stream at SH 2 also identified a statistically significant and meaningful increase in visual clarity over September 2003 to August 2009, as well as decreasing temperature and *E. coli* bacteria counts (i.e., improvements in water quality). It is possible that improvements in wastewater treatment at the Carterton WWTP since 2003 may be contributing to these trends, especially in terms of the decreasing *E. coli* counts (refer Section 2.7.4). However, the WWTP discharge is likely to also be responsible for the increasing trends in DRP, total phosphorus and ammonia concentrations (5.8–8.2% per year) because the discharge is the major source of ammonia and DRP upstream of SH 2 (refer Section 4.6.1). Unfortunately this is difficult to demonstrate because CDC lacks a reliable long-term data-set for wastewater flows discharged into the Mangatarere Stream (refer Section 8.2).

A statistically significant decline was also evident in mean MCI scores for the Mangatarere Stream at SH 2 over 2004 to 2009. Although there were no obvious trends in periphyton cover or biomass (chlorophyll *a*) during this period which might have explained this decline, the lowest MCI scores were recorded in early 2008 and 2009 coinciding with the highest periphyton biomass concentrations (243 mg/m^2 and 143 mg/m^2 as chlorophyll *a* respectively).

Analysis of long-term groundwater quality data identified a number of statistically significant trends in contaminant concentrations over time. Some of these trends were also considered meaningful, although generally the existing median concentrations were low (below guideline values), suggesting that the observed trends are not likely to result in any significant environmental consequence. In addition, the data record for three of the five bores was limited, with monitoring in these bores only commencing in 2005. Generally a period of 10 years is recognised as being the minimum to ensure robust temporal trend analysis of water quality data collected at quarterly intervals (Stansfield[28], pers. comm. 2010). Therefore, while there was no indication of increasing trends in nutrient concentrations in any of the five SoE bores (rather an indication of decreasing nitrate concentrations in bore S26/0467), it is probably still too early to confirm the presence of any trends in groundwater quality.

[28] Brett Stansfield, Water Quality Scientist, Hawke's Bay Regional Council.

8. Resource consent monitoring

Both Reid's piggery and Carterton District Council (CDC) are required to undertake regular surface water and groundwater quality monitoring at sites within the Mangatarere catchment in accordance with the conditions of their respective resource consents (refer Section 2.7). Reid's piggery also undertakes annual soil quality sampling. The results of this monitoring are summarised here[29], together with information from recent dairy farm compliance inspections undertaken by Greater Wellington environmental regulation staff.

8.1 Reid's piggery

Reid's piggery is required to undertake monthly water quality sampling at five surface water sites in the Mangatarere catchment (Figure 8.1): Farm Drain at Chester Road (within Reid's Piggery) and in the Mangatarere Stream at Valley Road, "Piggery Ford", Andersons Line and Belvedere Road. The results of monitoring over the period June 2007 to March 2010 are summarised in Table 8.1.

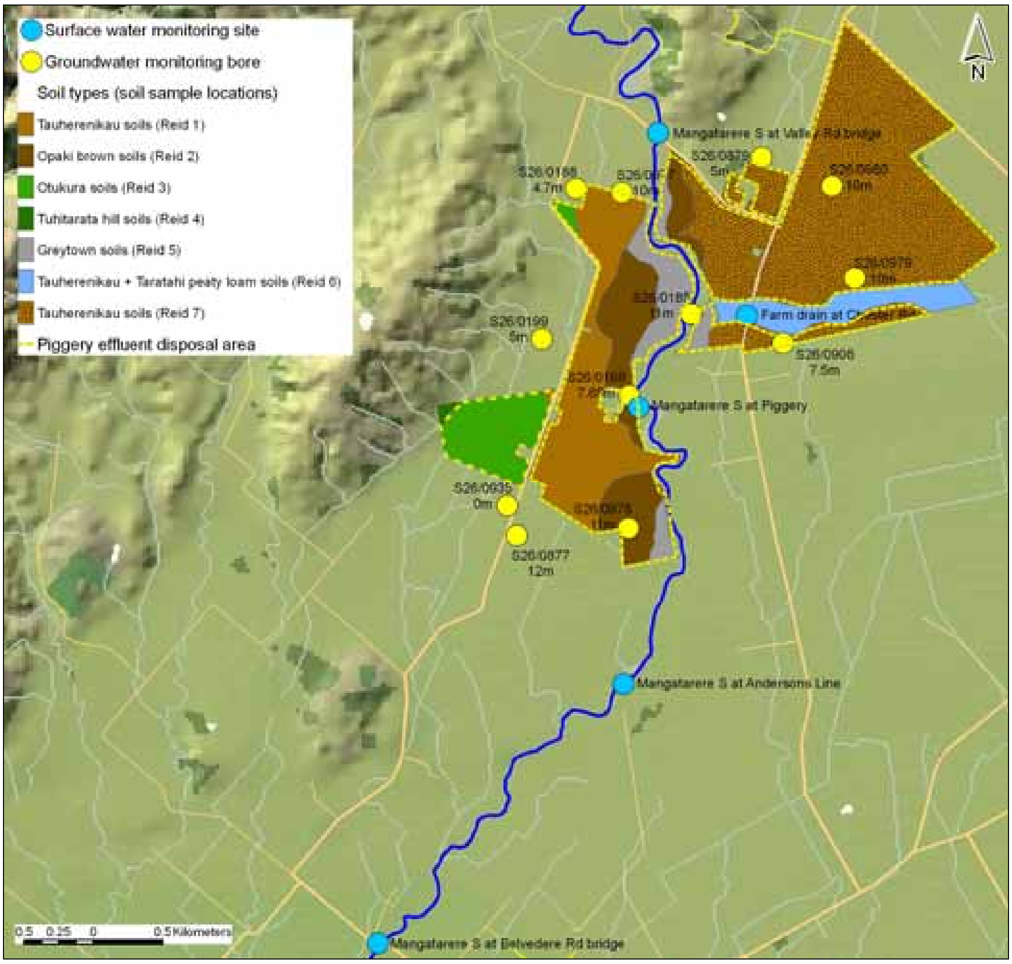

Figure 8.1: Surface water, groundwater and soil quality sites monitored by Reid's piggery in relation to their treated piggery wastewater discharges to land at Haringa Road in the middle reaches of Mangatarere catchment. Note that in the there are dairy farms operating within the land disposal area (i.e., both piggery and dairyshed effluent is discharged to land (refer Figure 2.6)).

29 For the purposes of calculating median values, any data reported as less than the detection limit were replaced by values one-half of the detection limit.

Table 8.1: Median concentrations of selected water quality variables in surface waters, based on monthly sampling by Reid's piggery from June 2007 to March 2010, in accordance with Discharge Permit WAR050090 (*n*=34). Median nutrient values in bold font exceed guideline values.

Site	Nitrite-nitrate nitrogen (mg/L)		Ammoniacal nitrogen (mg/L)		Dissolved reactive phosphorus (mg/L)		*E. coli* (cfu/100 mL)	
	Median	Range	Median	Range	Median	Range	Median	Range
Farm Drain at Chester Rd	2.69	0.371–12.6	0.050	<0.01–1.22	0.023	0.008–0.291	570	36–18,000
Mang. S at Valley Rd Br	0.13	0.006–0.50	0.005	<0.01–0.12	0.009	<0.004–0.134	165	24–2,400
Mang. S at Piggery Ford	0.48	0.082–3.21	0.005	<0.01–0.20	0.014	0.006–0.086	200	36–5,200
Mang. S at Anders Line	0.52	0.132–5.25	0.005	<0.01–0.05	0.013	0.007–0.041	110	23–1,200
Mang. S at Belvedere Rd	1.06	0.411–2.16	0.005	<0.01–0.02	0.014	0.007–0.115	175	19–1,900

Reid's dissolved nutrient monitoring results for the Mangatarere Stream are similar to those recorded in Greater Wellington's 12-months of sampling (refer Table 4.2, Section 4.4.3 and Figures 9.2 and 9.4, Section 9.3). Median nitrite-nitrate nitrogen (NNN) concentrations increase with distance downstream from Valley Road (located upgradient of the piggery but downstream of Greater Wellington's Gorge site) to Belvedere Road, with concentrations highest in winter. Table 8.1 shows a marked increase in median NNN concentrations between Valley Road and "Piggery Ford", indicating a clear impact on the stream within the piggery wastewater application area. Median NNN concentrations also increase markedly between Andersons Line and Belvedere Road, which is consistent with nitrate-enriched groundwater entering the stream between these sites.

Median dissolved reactive phosphorus (DRP) concentrations are elevated at all sites monitored by Reid's except Valley Road, with Wilson (2009) finding no obvious relationship with stream flow or rainfall. A comparison with Greater Wellington's sampling results (refer Table 4.2, Section 4.4.3) indicates some differences in DRP concentrations in stream samples collected by Greater Wellington and Reid's (samples were collected on different days), although both data-sets demonstrate a steady increase in DRP concentrations downstream of the Gorge to Andersons Line. Further downstream at SH 2, below the Carterton WWTP discharge, DRP concentrations jump significantly to a median (for September 2008-August 2009) of 0.097 mg/L (refer Figure 4.6, Section 4.4.3).

Farm Drain at Chester Road – which discharges to the Mangatarere Stream at "Piggery Ford" (Figure 8.1) – consistently has poor water quality; ammoniacal nitrogen and *E. coli* concentrations in some spot samples from this site are high enough to suggest that at times the drain has received effluent of some sort, either through surface runoff or subsurface seepage. Wilson (2009) concurs that the drain shows evidence of groundwater discharge, particularly in winter when groundwater levels are high. Wilson (2009) also notes that the soils in the vicinity of Farm Drain are poorly drained, with potentially low oxygen levels;

this could be expected to contribute to the elevated ammoniacal and nitrite-nitrogen concentrations recorded in water samples from the drain.

Wilson (2009) suggests that the contamination in Farm Drain comes from dairy effluent (piggery effluent is not discharged to land in the vicinity of the drain). He also notes the presence of two dairy farms operating downgradient of Reid's piggery and suggests that these are likely to be affecting nutrient and *E. coli* concentrations in the Mangatarere Stream at Andersons Line and Belvedere Road. Farm Drain will impact on water quality in the Mangatarere Stream at "Piggery Ford" although during winter it is also likely that the stream gains flow from shallow groundwater underneath the piggery site.

Reid's piggery also undertakes quarterly groundwater quality monitoring in 10 bores in the Mangatarere catchment (Figure 8.1). Three of these bores (S26/0188, S26/0977 and S26/0879) are located upgradient of the piggery and serve as "control" bores, while the remainder are located within and downgradient of the piggery site. Sample results for selected water quality variables monitored over the period June 2004 to March 2010 are summarised in Table 8.2. Note that the length of monitoring record varies between bores and for different water quality variables[30].

Monitoring to date indicates that the highest nitrate nitrogen (nitrate) concentrations are present in bores S26/0935 and S26/0877 located downgradient of the piggery effluent application area on the western side of the Mangatarere Stream. Concentrations in these bores regularly exceed the DWSNZ (2005) MAV of 11.3 mg/L and median values were either at or just below the DWSNZ (2005) MAV (Figure 8.2). While this provides strong evidence of effluent application at the piggery impacting on groundwater quality, nitrate results from one upgradient bore (S26/0188, median 5.62 mg/L) suggest agricultural land use upgradient of the piggery contributes to some level of nitrate contamination before groundwater flows under the piggery site. This requires further investigation; the bore in question is actually a large diameter well that may not have been purged sufficiently of standing water prior to sample collection.

Elevated nitrate concentrations (median 5.27 mg/L) have also been recorded in bore S26/0169 ("piggery well"), located adjacent to the Mangatarere Stream; at times concentrations in this bore exceed the DWSNZ (2005) MAV. Median nitrate concentrations in the other bores are much lower, ranging from 0.18 mg/L to 2.60 mg/L (Table 8.2).

Median concentrations of nitrite nitrogen (nitrite)[31] and ammoniacal nitrogen (ammonia) were generally below analytical detection limits (<0.002 mg/L and <0.01 mg/L respectively) in most samples from most bores. However, maximum ammonia concentrations of 4.52 mg/L and 3.33 mg/L were recorded in samples from bores S26/0977 and S26/0978 respectively. In addition, maximum nitrite concentrations were above the DWSNZ (2005) MAV of 0.06 mg/L in bores S26/0169 (0.104 mg/L) and S26/0978 (0.083 mg/L).

30 Bores S26/0977, S26/0978, S26/0979 and S26/0980 were not installed at the time Discharge Permit WAR050090 commenced. As a result, bores S26/0188 and S26/0877 were monitored in place of bores S26/0977 and S26/0978 respectively until March 2008. Also, initially, samples were not tested for all of the variables specified in the conditions of the permit.

31 Analytical laboratory detection limits for nitrite nitrogen changed from <0.005 mg/L to <0.002 mg/L in 2008.

Table 8.2: Summary of groundwater quality data collected by Reid's piggery from 12 bores sampled quarterly over different time periods between June 2004 and March 2010. Only 10 bores are required to be sampled under Discharge Permit WAR050090[1].

Variable		(upgradient of piggery)					Groundwater bore					(downgradient of piggery)	
		S26/0188	S26/0977	S26/0879	S26/0980	S26/0199	S26/0185	S26/0979	S26/0908	S26/0169	S26/0935	S26/0978	S26/0877
Conductivity (µS/cm)	Median	169	179	140	275	254	85.5	117	90	151	210	238	199
	Min	153	147	18	197	185	79	110	83	15.3	174	163	179
	Max	186	197	213	328	282	119	126	92	257	274	287	236
	n	15	9	32	10	4	10	10	4	33	9	9	13
Nitrite nitrogen (mg/L)	Median	0.0025	0.016	0.0025	0.001	0.002	0.001	0.001	0.001	0.0025	0.001	0.01	0.0025
	Min	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
	Max	0.0025	0.029	0.011	0.006	0.006	0.007	0.001	0.001	0.104	0.001	0.083	0.0025
	n	17	10	33	10	4	11	10	5	34	9	10	15
Nitrate nitrogen (mg/L)	Median	5.62	1.27	0.545	0.695	0.6	0.19	2.595	1.41	5.27	11.3	0.71	10.3
	Min	0.02	0.92	0.08	<0.01	0.22	0.1	1.79	1.23	2.2	9.07	<0.01	0.01
	Max	7.24	2.3	7.14	2.24	0.79	0.52	4.36	2.85	15.4	16.6	11.2	12.5
	n	17	10	33	10	4	11	10	5	34	9	10	15
Ammoniacal nitrogen (mg/L)	Median	0.005	0.075	0.005	0.005	0.05	0.005	0.005	0.005	0.005	0.005	0.725	0.005
	Min	<0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.13	<0.01
	Max	0.06	4.52	0.07	0.5	0.08	0.62	0.62	0.02	0.04	0.005	3.33	0.04
	n	16	10	33	10	4	11	11	5	34	9	10	14
Dissolved reactive phosphorus (mg/L)	Median	0.009	0.0135	0.015	0.014	0.0075	0.015	0.0155	0.018	0.031	0.019	0.005	0.007
	Min	0.005	0.006	0.005	0.006	<0.005	0.01	0.006	0.005	0.022	0.015	<0.005	0.004
	Max	0.012	1.4	0.022	0.307	0.01	0.02	0.035	0.028	0.038	0.038	0.531	0.01
	n	3	10	14	10	4	10	10	5	14	9	10	3
E. coli (cfu/100 mL)	Median	2	2	5	2	102	11	2	90	7	12	18	5
	Min	<2	<1	<1	<2	16	3	<1	<1	<1	<1	<1	<1
	Max	98	2,500	84	8	1,000	126	20	92	700	210	55,000	16
	n	16	10	33	10	4	11	10	3	34	9	10	13
Faecal coliforms (cfu/100 mL)	Median	3	2	2	2	6	12	2	2	2	12	2	2
	Min	2	<1	<1	<2	6	3	<1	<1	<1	<1	<1	<1
	Max	3	6,100	84	14	6.2	126	42	2	500	210	64,000	4
	n	2	9	14	10	4	11	10	5	15	9	9	2

[1] Bores S26/0977, S26/0978, S26/0979 and S26/0980 were not installed when Discharge Permit WAR050090 commenced. As a result, bores S26/0188 and S26/0877 were monitored in place of bores S26/0977 and S26/0978 respectively until March 2008.

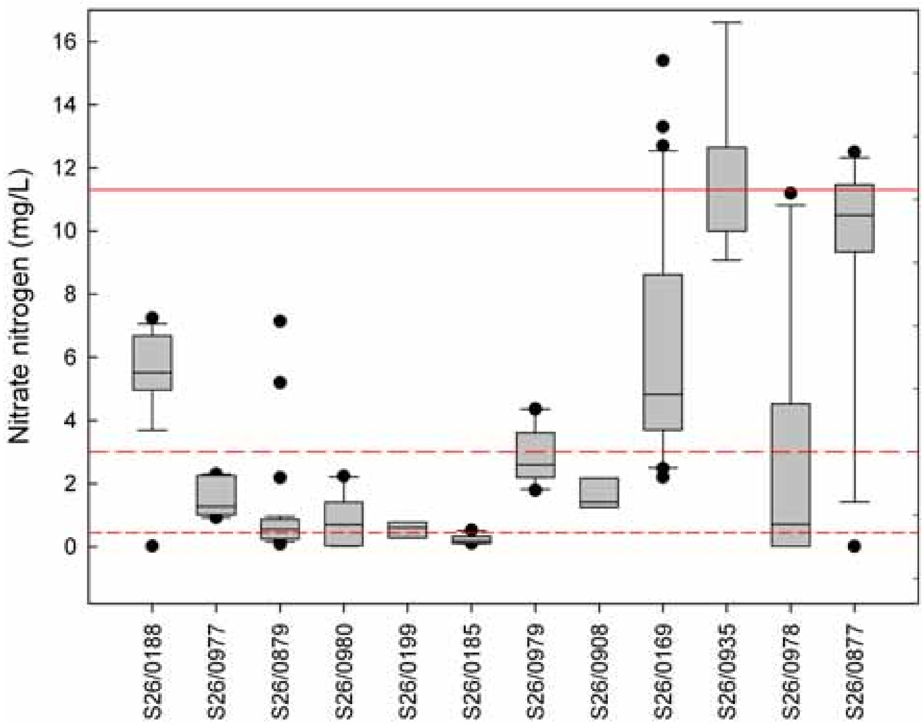

Figure 8.2: Box-and-whisker plots summarising nitrate nitrogen concentrations in groundwater bores sampled quarterly by Reid's piggery from June 2004 to March 2010, in accordance with Discharge Permit WAR050090. The solid red line represents the DWSNZ (2005) MAV and the dashed red lines represent the "elevated" nitrate nitrogen threshold (3 mg/L) and the ANZECC (2000) trigger value for nitrite-nitrate nitrogen in lowland streams (0.444 mg/L).

Median DRP concentrations ranged from 0.005 mg/L (bore S26/0978) to 0.031 mg/L (bore S26/0169). The highest individual DRP results were found in samples from bores S26/0977 (1.4 mg/L), S26/0978 (0.531 mg/L), and S26/0980 (0.307 mg/L) (Figure 8.3). As noted in Section 5.4.1, the first two of these bores were re-developed in June 2009 because it was thought poor bore construction was affecting the integrity of groundwater sample results (sediment-laden water). Samples from bores S26/0979 and S26/0980 were also sediment-laden and so these bores were redeveloped at the same time.

Faecal indicator bacteria have been found in one or more samples from all monitoring bores (Table 8.2). The highest individual *E. coli* counts were recorded in samples from bores S26/0978, S26/0977 and S26/0199 (55,000 cfu/100 mL, 2,500 cfu/100 mL and 1,000 cfu/100 mL respectively).

Wilson (2009) comments that the low pH in bores S26/0935, S26/0877 and S26/0169 on the western side of the Mangatarere Stream suggests groundwater at these sites is being influenced by the breakdown of organic matter. This could be expected given piggery and dairyshed effluent is applied to land upgradient of these bores. While nutrient leaching is cited as the likely reason for the elevated DRP concentrations in the piggery bore (S26/0169), and is thought to explain much of the elevated nitrate present in bores S26/0935 and S26/0877, Wilson (2009) suggests that some of the nitrate contamination present in these latter bores may also be due to an upgradient septic tank and soakage pits. This requires further investigation.

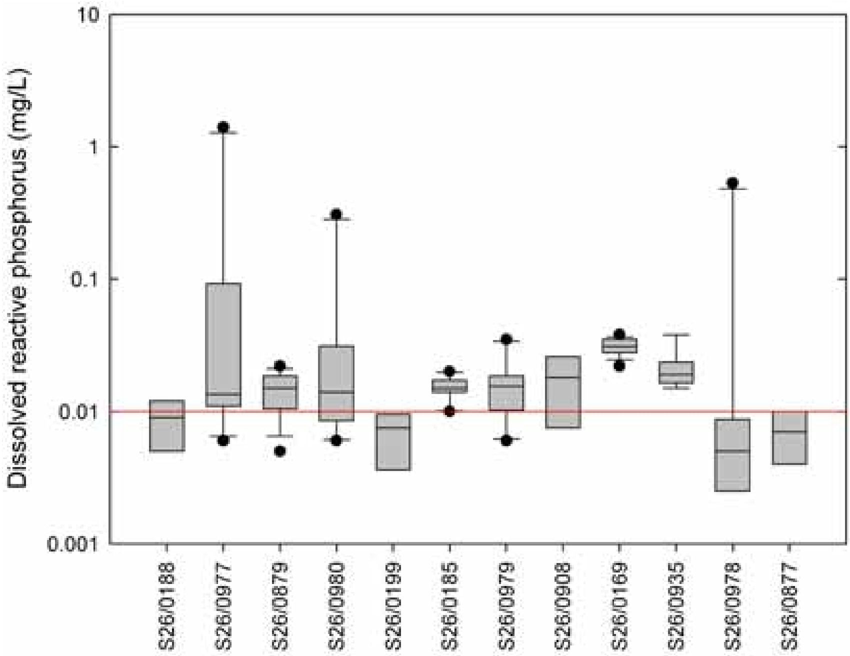

Figure 8.3: Box-and-whisker plots summarising dissolved reactive phosphorus concentrations in groundwater bores sampled quarterly by Reid's piggery from June 2004 to March 2010, in accordance with Discharge Permit WAR050090. The horizontal solid line indicates the ANZECC (2000) trigger value for lowland streams. Note the logarithmic scale.

Wilson (2009) demonstrates a positive relationship between rainfall and groundwater nitrate concentrations on and downgradient of Reid's piggery. A similar relationship was seen with *E. coli* counts. The relationship between rainfall and DRP concentrations is less clear; a positive relationship was seen between stream flow and DRP, with concentrations highest during summer and lowest in winter. Overall, the monitoring record for most bores is still too short to confidently determine some of these relationships and to determine if nutrient concentrations are increasing or decreasing over time.

In addition to surface and groundwater quality monitoring, Reid's piggery is required to undertake annual soil quality testing across the seven soil types where piggery effluent is applied. The 2009 results and the results of a background assessment of soils that have not had effluent applied (also undertaken in 2009) are summarised in Table 8.3.

The soil quality monitoring results indicate soils which have received piggery effluent contain elevated concentrations of total nitrogen and Olsen P. The increase in Olsen P concentrations as a result of continued piggery effluent application is particularly evident, with Olsen P concentrations ranging from 21–141 mg/kg at the monitoring sites compared to 9–38 mg/kg at the background soil sites. While bulk density was not measured (not a consent requirement), when applying a bulk density of 0.86 T/m^3 (average bulk density of sites PM001 and PM002, which are sites located on Reid's as part of the investigation) to the mineralisable nitrogen concentrations to get a concentration by mass, mineralisable nitrogen is also elevated with some sites exceeding the upper limit of the optimal range of 250 mg/kg. P-retention values were found to be between 20 (low) and 46 (medium) across the whole site.

Table 8.3: Summary of Reid's piggery 2009 annual soil quality monitoring results and 2009 background soil assessment. Values in bold are outside the optimal range for the site's specific soil order and land use (see Appendix 3).

Sample name	Soil pH	Total C (%)	Total N (%)	C:N ratio	Mineralisable N[1] (kg/ha)	Olsen P (mg/kg)	P retention (%)
Reid 1 A	5.8	9.26	0.82	11	369	141	38
Reid 2 A	6.3	5.52	0.56	10	289	103	31
Reid 3 A	6.2	8.15	0.73	11	325	82	40
Reid 4 A	5.8	6.21	0.50	12	293	21	40
Reid 5 A	6.1	3.72	0.36	10	277	41	20
Reid 6 A	5.8	15.74	1.32	12	322	110	41
Reid 7 A	6.0	10.26	0.88	12	285	74	46
Carter 106[2]	5.5	8.45	0.62	14	–	9	–
W Atkinsons 76b[2]	5.7	5.28	0.47	11	–	30	–
Smiths 75b[2]	5.4	7.44	0.65	11	–	38	–
Waynes Boundary 01[2]	5.8	4.59	0.46	10	–	24	–
Coopers Hill 41aH[2]	5.4	6.44	0.51	13	–	9	–
Cloutman 75b[2]	5.6	9.86	0.79	13	–	23	–
Quinn 75b[2]	5.3	11.35	0.74	15	–	15	–

[1] Mineralisable nitrogen is expressed as a volume (kg/ha) rather than a mass (mg/kg) because bulk density was not measured so comparisons can not be made to optimal range values.

[2] Background soil assessment site.

The concentrations of total nitrogen and Olsen P found in soil samples from site Reid 6 are amongst the highest found in all samples. The soils in this location (adjacent to Farm Drain) are Tauherenikau and Taratahi peaty loam which are boggy when wet, prone to water logging and ponding, and have a water table close to the surface. For this reason, irrigation with piggery wastewater is restricted on these soils. However, piggery wastewater was applied on these soils historically and there is no restriction on dairy effluent application in this area.

8.2 Carterton wastewater treatment plant

In addition to regular monitoring of wastewater quality and flows, the resource consents for the Carterton WWTP discharges to the Mangatarere Stream and land adjacent to Dalefield Road require CDC to undertake regular monitoring of surface water quality (Figure 8.4). Discharge Permit WAR950148 requires monthly, year-round sampling immediately upstream and approximately 80 m downstream of the point of direct discharge to the Mangatarere Stream. Discharge Permit WAR060211 also requires monthly sampling, from December to April inclusive, at four sites on the Mangatarere Stream (upstream of Dalefield Road, upstream of the Kaipaitangata Stream confluence, and 40 m and 500 m downstream of the Kaipaitangata Stream confluence) and one site on the Kaipaitangata Stream (above the Mangatarere Stream confluence). Stream sampling under permit WAR060211 is designed to measure seepage into surface water from the land application area during summer.

Discharge Permit 950148 also requires biannual monitoring of macroinvertebrate health upstream and downstream of the discharge (undertaken in March and November each year) and monthly groundwater quality sampling in six bores Figure 8.4).

Figure 8.4: Surface water and groundwater quality sites monitored by CDC in relation to their treated wastewater discharges to land and water at Dalefield Road in the lower Mangatarere catchment

Table 8.4 presents a summary of wastewater quality and physico-chemical and microbiological water quality upstream and downstream of the point of discharge to the Mangatarere Stream. Daily contaminant loads in the discharge have also been estimated from wastewater inflows to the WWTP; it is not possible to accurately calculate the loads because the daily volumes of wastewater discharged to the stream have not been monitored to date[32].

The data in Table 8.4 show that the wastewater discharge is having a measurable impact on nutrient concentrations in the Mangatarere Stream; for the March 2006 to February 2010 period there was a 43-fold increase in the median ammoniacal nitrogen (ammonia) downstream compared with upstream, and over a six-fold increase in the median DRP concentration downstream compared with upstream[33]. Wilcoxon Signed Rank Tests confirmed that these higher median nutrient concentrations downstream, together with higher median *E. coli* and turbidity values downstream, were statistically significant (p<0.05). Water temperature was the only variable with upstream and downstream median values that were not significantly different from one other.

Despite an incomplete monitoring record for Discharge Permit WAR060211[34], sampling undertaken during the summer months confirms that the Carterton

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32 Discharge Permit 950148 requires both wastewater inflows and treated wastewater volumes discharged to the stream to be recorded on a daily basis. Only data for inflows are available and there have been notable periods of questionable data (Andy Duncan, Consultant Engineer to CDC, pers. comm. 2010).

33 The ratios of the increases are inconsistent with what is expected. It was noted during data analysis that some soluble nitrogen species have been reported at higher concentrations than total nitrogen, indicating a sampling or analytical reporting error.

34 Stream sampling is required on five occasions per year but generally only four rounds of sampling have been undertaken. In addition, sampling of six groundwater bores is required at monthly intervals but only four bores (LF8, LF9, TP3 and MT5) have been monitored regularly.

Table 8.4: Carterton WWTP effluent quality and daily contaminant loads, and water quality upstream and downstream of the discharge to Mangatarere Stream, based on monthly sampling by CDC over March 2006 to February 2010 (*n*=40-46 for most variables, except water temperature). Contaminant loads have been conservatively calculated based on median effluent contaminant concentrations and an estimated median daily discharge volume[1] of 2,720 m^3/day.

Variable	CDC WWTP Discharge					Upstream			Downstream		
	Median	Min	95th %-ile	Max	Load (kg/day)	Median	Min	Max	Median	Min	Max
TSS (mg/L)	50	12	325	851	134.63	-	-	-	-	-	-
BOD_5 (mg/L)	21	6	33	60	57.12	0.5	<1	3	0.5	<1	4
Nitrite-nitrate nitrogen (mg/L)	0.366	0.024	2.27	3.50	1.00	1.12	<0.005	3.42	1.15	0.457	3.46
Ammoniacal nitrogen (mg/L)	12	1.0	22.1	25.0	32.64	0.005	<0.010	0.35	0.215	0.020	2.28
Total nitrogen (mg/L)	15.4	3.77	26.3	28.0	41.89	1.27	0.490	3.09	1.74	0.690	4.34
Dissolved reactive phosphorus (mg/L)	4.56	0.46	9.96	10.7	12.40	0.017	<0.005	0.027	0.115	0.030	1.01
Total phosphorus (mg/L)	5.21	0.534	11.6	11.9	14.17	0.022	0.011	0.228	0.13	0.037	1.28
E. coli (cfu/100 mL)	1,700	50	10,500	130,000	-	180	16	2,500	285	4	3,200
Faecal coliforms (cfu/100 mL)	1,900	70	10,500	150,000	-	215	20	2,500	335	4	3,400
Turbidity (NTU)	21.5	4.44	97.7	316	-	1.09	0.2	184	2.00	0.27	186
Temperature (°C)	-	-	-	-	-	14.2	7.2	17.3	13.9	6.7	17.5

[1] Based on limited records of inflows to the WWTP (6 May 2006–28 Nov 2007 and 28 Nov 2008–18 Jun 2009, data from A. Duncan).

Table 8.5: Median concentrations of selected water quality variables in stream waters, based on monthly sampling by CDC over December to April each year in accordance with Discharge Permit WAR060211 (Dec 2006–Feb 2010, *n*=11-17 for most variables)

Site name	Dissolved oxygen (mg/L)	Conductivity (µS/cm)	Ammoniacal nitrogen (mg/L)	Nitrate nitrogen (mg/L)	Total nitrogen (mg/L)	Dissolved reactive phosphorus (mg/L)	Total phosphorus (mg/L)	*E. coli* (cfu/100 mL)
Kaipaitangata S u/s Mang. S conf.	8.8	110	0.005	0.425	0.55	0.011	0.017	180
Mangatarere S u/s Dalefield Rd Br	9.1	113	0.005	0.64	0.71	0.018	0.022	160
Mangatarere S u/s Kaipai. S conf.	8.5	130	0.310	1.185	1.64	0.151	0.172	150
Mangatarere S 40 m d/s Kaipai. S conf.	8.2	126	0.210	1.125	1.55	0.132	0.182	160
Mangatarere S 500 m d/s Kaipai. S conf.	9.3	129	0.090	1.11	1.35	0.129	0.156	140

WWTP also impacts on nutrient concentrations in the Mangatarere Stream when treated wastewater is discharged to land. As shown in Table 8.5, median ammonia and DRP concentrations are clearly higher in the Mangatarere Stream adjacent to the WWTP wetlands and remain elevated (relative to concentrations upstream at Dalefield Road), even after mixing with the "cleaner" waters from the Kaipaitangata Stream[35]. Piezometric contours presented in NZET (2007) indicate that the saturated groundwater flow direction under the oxidation ponds, wetlands and adjacent land application area is in a west-south west direction towards the Mangatarere Stream, confirming that the impact in the stream is due to nutrient-rich seepage from underneath the unlined oxidation ponds and wetland cells (and possibly some leachate from the adjacent closed landfill). According to NZET (2007), this seepage flow discharges into the Mangatarere Stream over an approximately 300 m front.

Ammonia concentrations recorded in groundwater samples taken monthly over March 2006 to February 2010 from monitoring bore TP3 (3 m deep) located between the wetland and the stream ranged from 5.03 to 20.7 mg/L (Table 8.6). These concentrations mirror concentrations in the wastewater discharge and may explain the slightly lower median dissolved oxygen concentrations in the Mangatarere Stream at and below seepage entry; nitrifying bacteria converting ammonia to nitrate consume oxygen in the process. On one occasion in February 2008, an ammonia concentration of 2.38 mg/L was recorded in the Mangatarere Stream above the Kaipaitangata Stream confluence; this concentration would be toxic to aquatic life in most streams but the pH at the time was slightly acidic (6.6), meaning that the concentration fell slightly below the ANZECC (2000) toxicity trigger value (95% protection level).

It is difficult to determine if seepage/leachate from the Carterton WWTP and the adjacent landfill area is also entering the Mangatarere Stream to the south of the oxidation ponds. This is because a new monitoring bore installed immediately south of the oxidation ponds has only been sampled on a handful of occasions. The other relevant monitoring bore (MT5) is located quite a long distance south and its integrity has been compromised by stock access and poor borehead protection. Sample results for all groundwater bores monitored by CDC also reveal very high concentrations of suspended solids (Table 8.5), suggesting that the bores have either been poorly developed or groundwater has been sampled without adequate purging. For this reason, caution should be exercised in using the data from these monitoring bores. It is also noted that in the case of Landfill bores 8 and 9, nitrate has been regularly reported at higher concentrations than total nitrogen, indicating either a sampling or analytical reporting error that needs further investigation.

In terms of biological monitoring results, biannual macroinvertebrate surveys in the Mangatarere Stream have consistently reported significant reductions in MCI, QMCI and EPT metrics downstream of the discharge relative to the upstream monitoring site (Figure 8.5), with the impacts most pronounced in the summer low flow surveys when higher periphyton cover is present downstream (e.g., Coffey 2009, Coffey 2008). Although the upstream site was intended to

[35] Although "cleaner" – and classified as "excellent" 1.2 km upstream at Dalefield Road (see Section 4.6.1) – CDC's summer monitoring results indicate nutrient concentrations in the Kaipaitangata Stream are elevated at the confluence with the Mangatarere Stream – a drain entering the stream near the sampling point may account for this and local groundwater may also be having some impact.

Table 8.6: Summary data for selected water quality variables in six groundwater bores monitored by CDC from March 2006 to February 2010, in accordance with Discharge Permit WAR060211[1]. Note that the ratio of nitrogen species concentrations for bores 8 and 9 appear questionable.

Bore		Conductivity at 25`C (µS/cm)	pH	Turbidity (NTU)	Total suspended solids (mg/L)	BOD_5 (mg/L)	Nitrate nitrogen (mg/L)	Ammoniacal nitrogen (mg/L)	Total nitrogen (mg/L)	Dissolved reactive phosphorus (mg/L)	Total phosphorus (mg/L)	*E. coli* (cfu/100 mL)
Landfill Bore 8	Median	16.8	5.7	7.54	13	0.5	6.66	0.005	5.95	0.027	0.048	2
	Min	13.4	5.1	0.19	<5	<1	5.05	<0.01	4.52	0.020	0.024	<1
	Max	26.5	6.1	375	464	1.5	12.5	17.5	12.2	3.61	0.509	64,000
	n	45	45	45	45	45	45	44	45	45	45	45
Landfill Bore 9	Median	25.1	5.8	12.4	37	0.5	6.55	0.005	6.06	0.120	0.162	12
	Min	16.4	5.3	0.41	<5	<1	0.94	<0.01	1.24	0.021	0.040	<4
	Max	41.6	6.3	228	576	1	14	0.04	13.3	0.258	0.680	65,000
	n	47	47	47	47	47	47	47	47	47	47	46
TP3	Median	53.1	6.4	16.9	28	4	0.13	13.5	14.8	4.12	6.505	44
	Min	23.1	5.8	3.57	<6	1	<0.01	5.03	6.18	0.293	0.554	<4
	Max	77.3	7.0	73.7	128	25	4.77	20.7	20.4	8.29	10	7,300
	n	46	46	46	46	46	45	46	46	46	46	46
MT5	Median	28	6.1	91.6	208	2	0.60	0.125	1.93	0.012	0.187	14
	Min	23.7	5.6	5.09	9	<1	0.01	<0.01	0.67	<0.005	0.031	<4
	Max	34.6	6.7	416	990	33	7.58	1.33[2]	8.28	0.901	1.16	41,000
	n	44	44	44	44	42	42	44	44	43	44	44
MT6	Median	48.1	6.1	–	1,320	11	1.93	2.15	10.5	0.046	0.503	750
	Min	39.5	5.6	–	8	1	<0.01	0.11	5.41	0.011	0.073	65
	Max	55.7	6.2	–	32,200	22	26.9	5.13	27.7	0.097	24.7	4,100
	n	4	4	–	3	3	4	4	4	4	4	4
Wetland bore	Median	49.1	6.4	–	19	3	0.19	5.36	7.36	1.95	2.7	190
	Min	40.5	6.1	–	<6	3	<0.01	3.83	5.45	1.03	1.6	110
	Max	66.0	6.7	–	1,110	32	0.80	9.65	10.6	4.41	6.1	3,700
	n	10	10	–	9	9	10	10	10	10	10	10

[1] Bore MT6 and the wetland bore have not been sampled at the required frequency (monthly).
[2] This is the second highest value – a concentration of 84.1 mg/L was recorded in March 2006 but was dismissed as being erroneous.

be a control site, its location below Dalefield Road suggests that it may itself be impacted to some degree from nutrient-enriched groundwater from the land application area. The location and suitability of this upstream "control" site may require further investigation. Spearman Rank correlations did not identify any significant trends in the upstream or downstream invertebrate metrics (2000-2010 period). This is in contrast to Greater Wellington's SoE site further downstream at SH 2 which showed a decreasing trend in MCI scores since 2004 (refer Section 7.2.2.).

Note: S = Summer, 4 = 2004, 6 = 2006, 7= 2007, 8 = 2008, 9 = 2009. U = upstream, D = downstream.

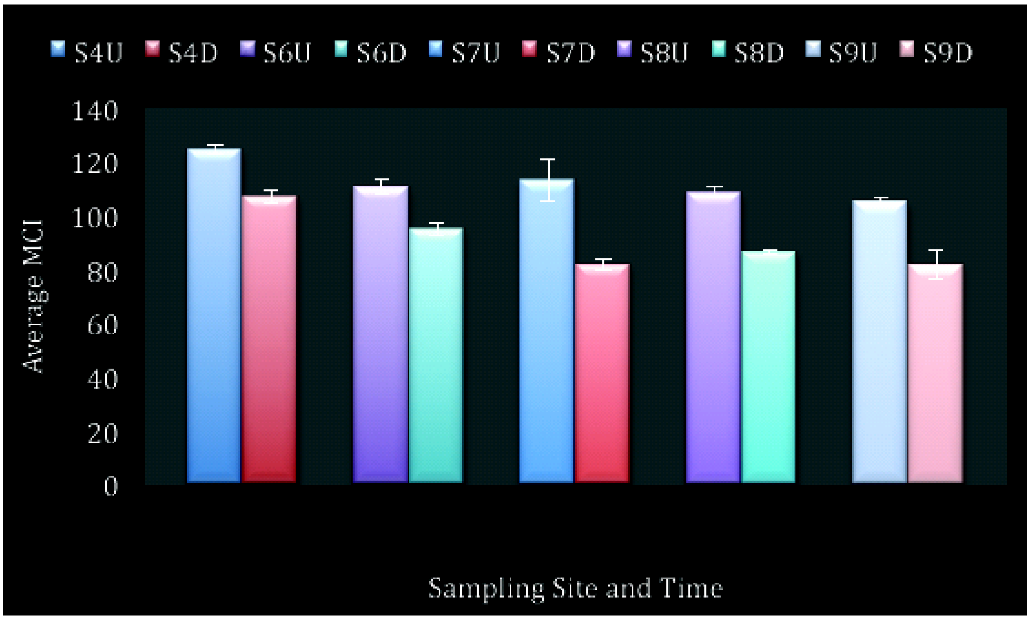

Figure 8.5: Mean (average) Macroinvertebrate Community Index (MCI) scores at sampling sites upstream and downstream of the Carterton WWTP, based on annual summer surveys from 2004 to 2009 inclusive
(Source: Coffey 2009, p.6)

8.3 Dairyshed discharge compliance inspections

Greater Wellington inspects dairy farms across the Wellington region to assess farmer compliance with the conditions of resource consents for dairyshed discharges to land. Prior to the 2009/10 milking season, compliance inspections were undertaken on a semi-regular basis; farms with a history of non-compliance were visited annually while fully complying farming operations were inspected once every three years. Inspections of all farms increased to an annual frequency from July 2009 due to increased levels of non-compliance observed during three-yearly inspections. Inspections assess whether or not the effluent disposal area and method and rate of effluent application comply with discharge permit specifications, and look for evidence of effluent ponding or runoff to surface water. Additional information sought in includes dairy herd size, contingency plans for effluent in the event of wet weather or mechanical failure (e.g., effluent storage) and whether winter milking takes place. Discharges from feedpads, underpasses and raceways are also assessed.

A summary of recent compliance inspection grades awarded to dairy farms with active resource consents (discharge permits) in the Mangatarere catchment is provided in Figure 8.6. In 2006/07 there were 39 active permits, nine of which were surrendered or transferred (or had expired) by 2009/10, leaving 30 active permits. Compliance inspections indicate that of the dairy farms physically inspected between June 2006 and May 2009, most did not comply with some aspect of the conditions of their discharge permits. The compliance record was better during the 2009/10 season when all dairy farms with active discharge permits were visited. Of the 30 permits monitored in 2009/10, there was only one incidence of non-compliance where a farm exceeded their authorised number of stock by 240 cows. This farm had recently merged with a neighbouring farm and taken on part of its herd.

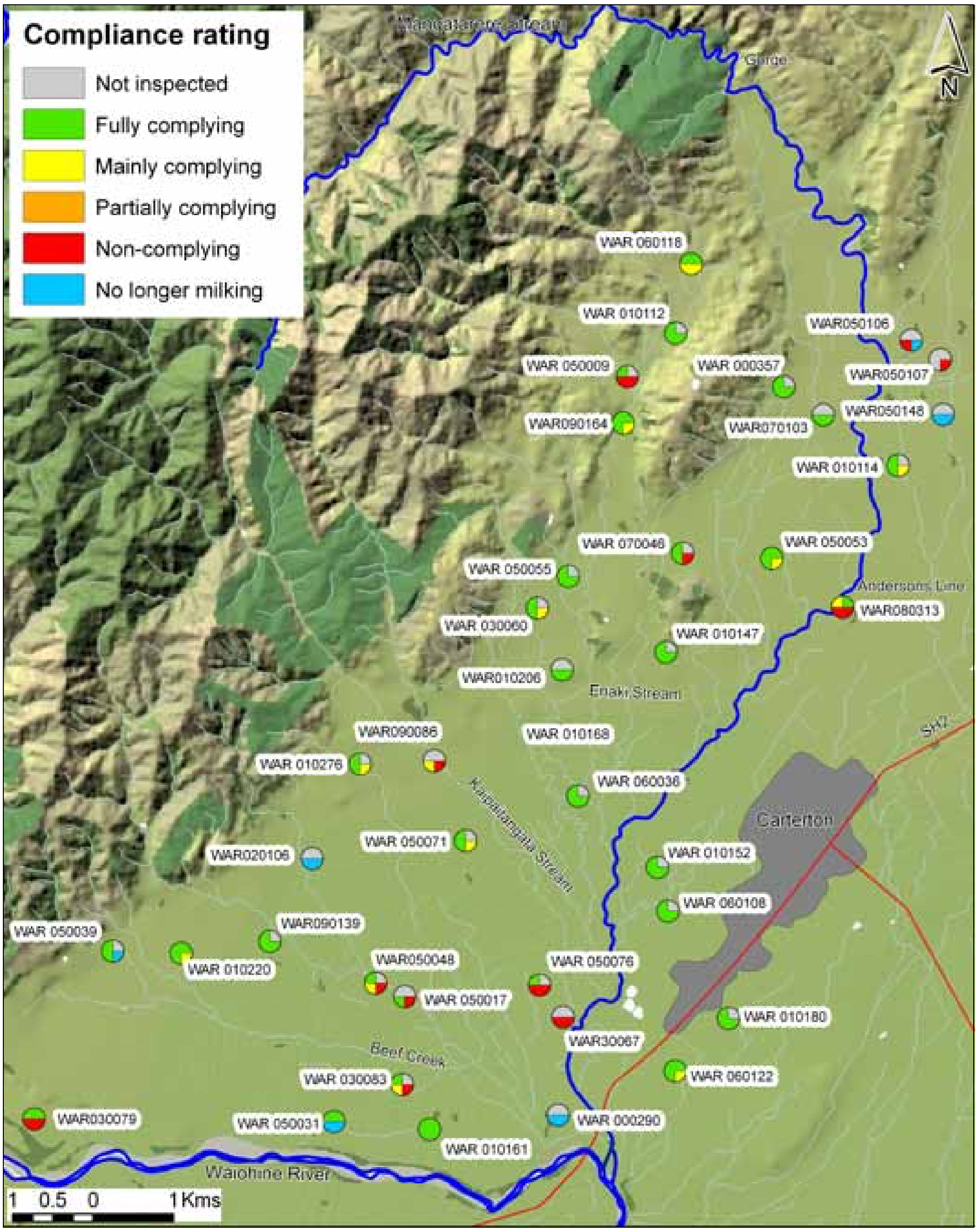

Figure 8.6: Compliance grades awarded to the holders of dairyshed discharge permits exercised in the Mangatarere catchment over four consecutive seasons from June 2006 to June 2010

According to the inspection reports, the most common causes of non-compliance with consent conditions were:

- Faulty or broken equipment (such as travelling irrigators, sumps, irrigation pipes) used for effluent disposal, and inappropriate effluent management practices (e.g., disposal of effluent through open-ended pipes), that could result in the spilling, ponding or overflowing of effluent to surface water;
- Cow numbers above the authorised number, suggesting that the effluent disposal area was not large enough to cater for the additional effluent that needed to be irrigated;
- Evidence of over-application of effluent to pasture (i.e., application rates higher than the hydraulic capacity of the underlying soil;
- Unsealed feed pads with potential for leaching of nutrients (or leaching from solid waste purged from sump pits); and
- The irrigation of effluent within 20 metres of a stream or other water body.

  Although not a factor in the compliance grade (i.e., not a consent condition), inspections over the last two years also noted:

- 24 cases where the compliance officer noted no current form of deferred effluent storage (holding pond) to prevent application of effluent to land in wet conditions; and
- 28 cases where rainwater from shed roofs was being directed into the effluent management system, resulting in a greater volume of effluent to be applied to land.

8.4 Summary

The results of resource consent monitoring in relation to Reid's piggery and the Carterton WWTP (and landfill) indicate that wastewater discharges associated with these activities are having measurable environmental effects in the Mangatarere catchment. Dairyshed compliance inspections also indicate clear potential for adverse environmental effects. This is discussed further in Section 9.

9. Synthesis – key findings

This section draws on the findings from the 13-month surface water, groundwater and soil quality investigation (Sections 4-6), temporal trend analysis (Section 7) and resource consent monitoring (Section 8) to revisit the three main objectives of the Mangatarere catchment investigation. As outlined in Section 3.2.1, these objectives were to determine the state of surface water quality throughout the catchment, assess changes in water quality over time and identify likely contaminant (principally nutrient) sources. Limitations of the study and knowledge gaps are also presented in this section.

9.1 Surface water quality state

The results of surface water quality sampling over September 2008 to August 2009 indicate a clear decline in water quality with distance down the Mangatarere Stream. Water quality is “excellent” at the Gorge but is rated only “fair” at all main stem sites further downstream due to median dissolved nutrient concentrations exceeding ANZECC (2000) thresholds for aquatic ecosystems and median *E. coli* counts exceeding the ANZECC (2000) stockwater benchmark. Water quality is “poor” at two of the three monitoring sites in the Enaki subcatchment and in the Beef Creek at SH 2; these sites have elevated nutrient and *E. coli* concentrations and poor water clarity. The Kaipaitangata Stream at Dalefield Road was the only monitoring site below the Gorge with a water quality classification of “excellent”, although this site is subject to low dissolved oxygen concentrations at times during summer.

Water temperatures above 19ºC were measured in some parts of the catchment during summer, with potential to cause stress to aquatic life. This was particularly the case in the Mangatarere Stream at Andersons Line where stream flow is lost to groundwater. Elevated water temperatures are likely to be a more widespread problem as well, particularly given the lack of riparian vegetation cover throughout much of the catchment.

Overall, Beef Creek at SH 2 had the poorest water quality of the monitoring sites located on the three main tributary streams. This site recorded the highest conductivity, suspended sediment, total organic carbon (TOC) and nutrient concentrations. The Enaki Stream recorded the highest *E. coli* counts, regularly exceeding both ANZECC (2000) stockwater and MfE/MoH (2003) contact recreation guidelines. Nine of the eleven surface water quality monitoring sites recorded *E. coli* counts above the MfE/MoH (2003) action guideline (550 cfu/100 mL) at times, including sites on the Mangatarere Stream where contact recreation occurs (e.g., Belvedere Road). Stock access was a contributing factor to elevated *E. coli* counts at a number of sites, with dairy cows observed in the water at two sites in the Enaki subcatchment and beef cows observed at the stream’s edge at several other sites.

Dissolved inorganic nitrogen (DIN) and total nitrogen concentrations increased down the Enaki Stream. However, the lowest median TOC, *E. coli*, dissolved reactive phosphorus (DRP) and total phosphorus concentrations in this subcatchment were actually recorded at the most downstream site where Greater Wellington’s riparian rehabilitation programme was established back in 2001. Optical water quality properties (e.g., visual clarity) were also better at this site.

Although groundwater inputs and upstream periphyton communities are probably influencing instream nutrient concentrations (see Section 9.3), with stock excluded from the area adjacent to and upstream of this site, and well established plantings in place along both stream banks, it appears that riparian rehabilitation is resulting in some noticeable improvements in the stream environment at this site. The biological sampling results support this; periphyton cover did not exceed nuisance thresholds at this site on any sampling occasion and macroinvertebrate metrics were generally higher at this site than at the two upstream sites. Perrie (2008) describes in detail the benefits of riparian rehabilitation in the Enaki catchment.

The high water quality observed in the lower reaches of the Kaipaitangata Stream probably reflects the large proportion of its catchment under forest or scrub cover (73%). Groundwater inputs are also expected to influence water quality in the lower reaches.

In terms of the ecological monitoring results, three sampling sites exceeded the 30% nuisance threshold for filamentous periphyton cover on four or more sampling occasions, with the Hinau Stream at Hinau Gully Road exceeding this threshold seven times. In addition, the two most downstream sites located on the Mangatarere Stream (at Dalefield Road and SH 2), along with the Kaipaitangata Stream at Dalefield Road, all exceeded periphyton biomass guidelines indicating that prolific periphyton growth at these sites may be having a negative impact on benthic biodiversity. This is supported by the invertebrate metrics; both MCI scores and % EPT taxa values tended to be lower at the sites with high algal biomass.

Aquatic invertebrate health typically reflected water quality; a general deterioration in metric scores was seen with distance down the catchment (Figure 9.1). Scores ranged from “excellent” at headwater sites (including State of the Environment (SoE) site Beef Creek at Headwaters) and the Mangatarere Stream at Gorge to “good” at most mid catchment sites – as well as the Mangatarere Stream at Dalefield Road – to “fair” at SH 2 below the Carterton Wastewater Treatment Plant (WWTP) discharge. Beef Creek at SH 2 recorded the poorest invertebrate health which is a reflection of the poor quality of the habitat at this site (channelised and dominated by macrophytes) as much as poor water quality. Figure 9.1 also demonstrates a decline in invertebrate health downstream in the Waiohine River, from “excellent” at the Gorge SoE site to “good” at Bicknells, approximately 4 km downstream of the Mangatarere Stream confluence. While a number of factors are likely to account for this decline, the Mangatarere Stream is the largest tributary of the Waiohine River and does have an impact on water quality in the river.

9.1.1 Implications for aquatic life

Elevated dissolved nutrient concentrations, as well as periods of low or stable stream flow and a general lack of riparian vegetation, are contributing to nuisance periphyton growth and degraded invertebrate health, particularly in the lower reaches of the Mangatarere Stream below the Carterton WWTP. However, impacts on stream health are also evident higher up the catchment and appear to reflect more than degraded water quality. A lack of flow in streams and degraded instream habitat (e.g., as a result of direct stock access and a lack of riparian vegetation at some sites) appear to be significant factors.

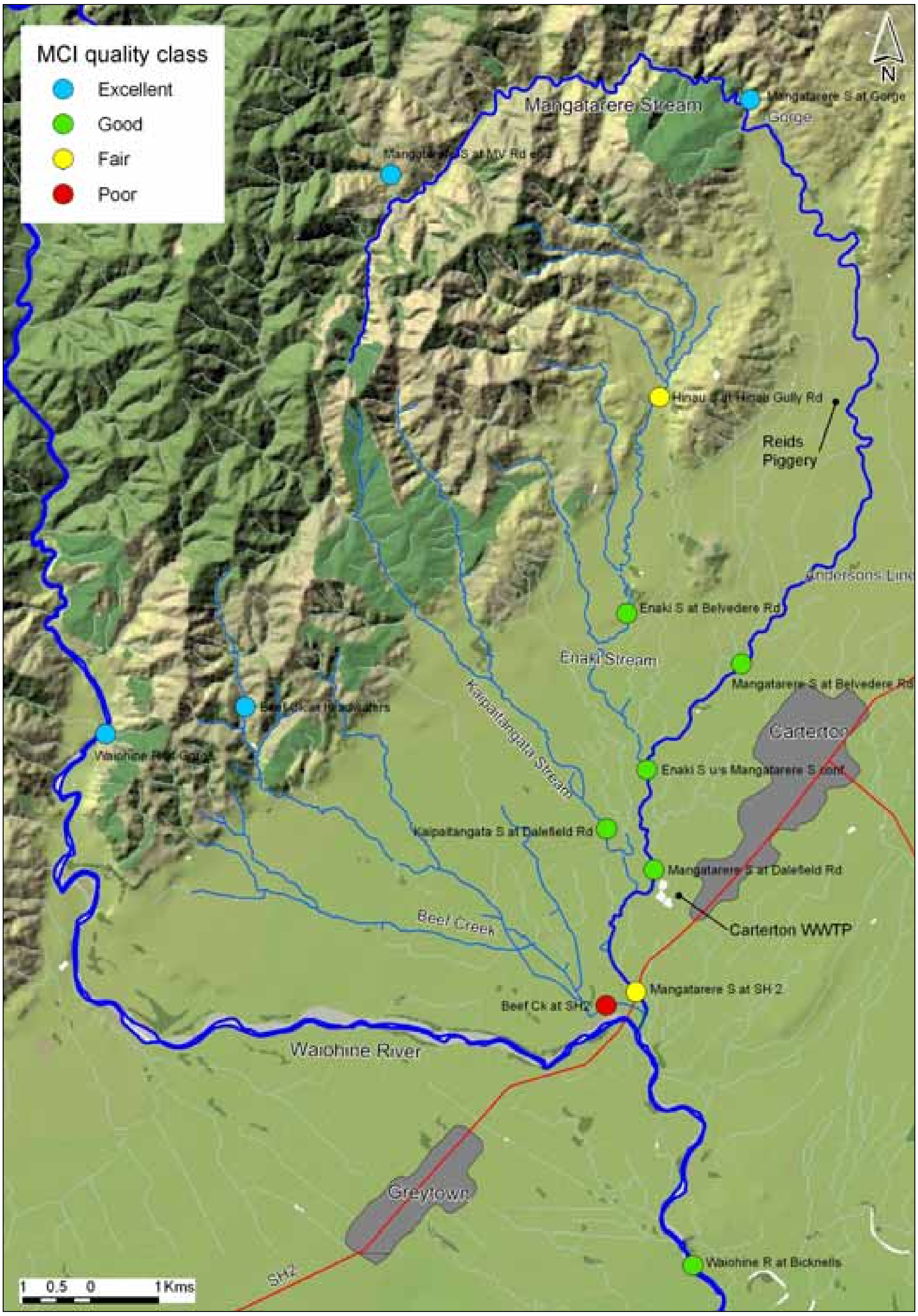

Figure 9.1: MCI scores for surface water sites in the Mangatarere catchment sampled during February 2009, along with scores for samples collected from Greater Wellington's SoE sites on Beef Creek (headwaters) and the Waiohine River (also sampled in summer 2009)

Low stream flows and the drying of some stream reaches are likely to be exerting a strong influence over the health and diversity of the aquatic ecosystem. Low flows threaten instream ecological values by:

- reducing the total amount of aquatic habitat available;
- reducing water quality through less dilution of contaminants, increased water temperatures and an associated reduction in dissolved oxygen concentrations; and
- encouraging instream siltation and periphyton growth which in turn can reduce habitat quality (e.g., smothering of streambed gravels favoured by trout for spawning and native fish for refuge).

Although the complete drying of some stream reaches (e.g., Mangatarere Stream at Andersons Line) during parts of summer is considered "natural", it is highly likely that both surface water and groundwater abstraction are increasing the frequency and duration of low flows and periods when stream reaches are dry. As noted in Section 2.7.1, the Mangatarere Stream's water is fully allocated. Given that this classification has been made without taking into account all groundwater takes with a direct or partial connection to the stream, nor the volume of water taken through Greater Wellington's Regional Freshwater Plan (WRC 1999) permitted activity rule[36], it is likely that the cumulative effects of surface water and groundwater abstraction on the Mangatarere Stream are significant.

While dry stream reaches are often seen as having little or no aquatic value, this is not always the case. Groundwater-fed pools commonly remain throughout the dry reaches of the Mangatarere Stream (and its tributaries) and, based on observations made during this investigation (and over the last few years), these pools often support both invertebrates and fish. As such, these pools can provide an important refuge for aquatic animals and aid the rapid recolonisation of previously dry reaches once stream flow returns (Davey & Kelly 2007).

Although fish monitoring did not form part of the catchment investigation, from existing NZ Freshwater Fish Database records and recent fishing in the wider Waiohine River catchment, it appears that some migratory fish species (e.g., redfin bullies) are largely absent from the headwaters of Mangatarere Stream and its tributaries. This is despite these species being relatively common in the headwaters of other tributaries of the Waiohine River. The effects of degraded water quality – together with habitat degradation and low stream flows – on the presence/absence of migratory fish species in the Mangatarere catchment requires further investigation. The effects of other potential stressors – notably habitat degradation (e.g., alteration of the substrate as a result of increased periphyton, damage through stock access or instream channel works) and low stream flows – also need consideration, from both a native fishery and trout spawning point of view.

[36] Greater Wellington's Wairarapa groundwater resource investigation estimated that a total of 1,300 m^3/day of groundwater (from about 300 bores) may be taken in the Mangatarere area as a permitted activity (Gyopari, pers. comm. 2010). This is equivalent to more than 75% of Carterton District Council's consented take from one of its potable supply bores for Carterton township.

9.2 Temporal trends

Analysis of temporal trends was limited to five surface water quality and five groundwater quality sites that form part of Greater Wellington's SoE monitoring network. Of these sites, the Mangatarere Stream at SH 2 demonstrated the most changes in water quality over time. Based on monthly data collected from September 2003 to August 2009, statistically significant and meaningful decreases in water temperature and *E. coli* counts were evident. These changes, together with an increase in visual clarity over the same period, represent improvements in water quality at this site. However, these improvements were countered by increasing DRP, total phosphorus and ammoniacal nitrogen concentrations over 2003 to 2009, along with a decline in macroinvertebrate health (in terms of mean MCI scores). The reason for the changes in water quality at the SH 2 site are unclear but are probably related to the Carterton WWTP discharge given it is the only major point source upstream of SH 2. However, as noted in Section 7.3, this is difficult to verify because Carterton District Council lacks a reliable long-term data-set for wastewater flows discharged into the Mangatarere Stream.

9.3 Nutrient loads and sources

9.3.1 Nitrogen

The catchment investigation indicated that at most sites on the Mangatarere Stream and sites on the lower reaches of the three main tributaries, the majority of the nitrogen load was present in the dissolved (soluble) form, principally as nitrate nitrogen (nitrate). This is not surprising, particularly given the lower reaches of all tributary streams and the Mangatarere Stream have a direct connection with the underlying unconfined shallow groundwater aquifer (refer Sections 2.2–2.3). Water sampling in several bores intercepting this aquifer and in surface waters demonstrated elevated nitrate concentrations, with the highest concentrations in both groundwater and streams occurring in the winter months when groundwater levels were closer to the soil surface and more likely to intercept land drainage. This indicates a 'flushing' of nitrogen from saturated soils through into the underlying groundwater and into hydraulically connected streams.

Median DIN concentrations increase steadily with distance down the main stem of the Mangatarere Stream (Figure 9.2). Based on the September 2008–August 2009 sampling period, the contribution to the total mean DIN load that exits the Mangatarere Stream into the Waiohine River increases from just over 2% at the Gorge to 14% at Andersons Line, 25% at Belvedere Road, 44% at Dalefield Road and 67% at SH 2 (Figure 9.3). The remaining 33% of the DIN load is attributed to the Beef Creek subcatchment which drains into the Mangatarere Stream just downstream of SH 2.

Reid's piggery resource consent monitoring data indicate a marked increase in median DIN concentrations between Valley Road and "Piggery Ford" (located between the Gorge and Andersons Line, Figure 9.2), indicating a clear impact on the Mangatarere Stream within the piggery wastewater application area. The marked increase in DIN concentrations and loads in the Mangatarere Stream below Andersons Line (observed at the Belvedere Road site, Figure 9.2) is consistent with expected inputs from nitrate-enriched shallow groundwater. The application of piggery (and dairyshed) wastewater to land at Haringa Road is contributing to this groundwater and stream contamination; Reid's piggery monitoring results indicate nitrate concentrations immediately downgradient of land application areas regularly exceed the DWSNZ (2005) MAV of 11.3 mg/L). Wilson (2009 and 2010) suggests that two dairy farms located downgradient of the piggery may also be having some impact. Compliance inspections to date suggest this is likely, particularly at Andersons Line (refer Figure 8.6, Section 8.3) where in September 2009 field staff observed washdown from a cow race running onto a gravel beach adjacent to the stream.

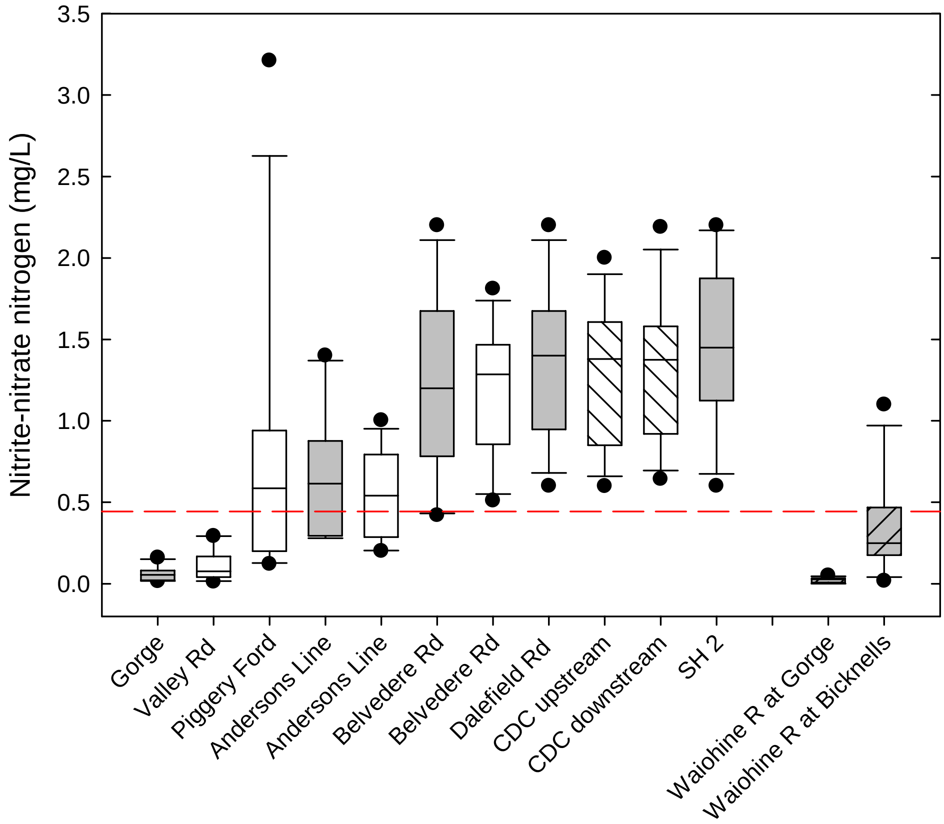

Figure 9.2: Box-and-whisker plots summarising nitrite-nitrate nitrogen (NNN, the major component of DIN) concentrations at various monitoring locations down the Mangatarere Stream, based on monthly sampling (on different days) by Greater Wellington (grey boxes), Reid's piggery (white boxes) and Carterton District Council (hashed white boxes) over September 2008 to August 2009 (*n*=12). The NNN concentrations for Greater Wellington's two Waiohine River SoE monitoring sites are also shown for comparison. The horizontal red dashed line indicates the ANZECC (2000) trigger value for lowland streams.

Further down the catchment, the Carterton WWTP also contributes a significant DIN load into the Mangatarere Stream (mostly as ammonia), both through direct discharge and through seepage from the oxidation ponds, wetland cells and land application area adjacent to the stream. However, this contribution is only significant at lower stream flows; based on the mean of the six highest stream flow sampling occasions, the WWTP discharge was estimated to contribute less than 20% of the total DIN load into the lower Mangatarere Stream. This indicates that non-point (diffuse) sources from Reid's piggery and agriculture upstream (which comprises over 50% of the land use in the catchment) make up the majority of the total DIN stream load at higher flows. Beef Creek also contributes a significant amount of DIN at higher stream flows. These findings highlight the importance of managing both point and non-point sources of nitrogen in the catchment. In terms of managing the latter, stocking rates is a particularly important factor, especially on dairy farms where as much as 95% of nitrate is generated from urine patches (Edmeades[37] 2010).

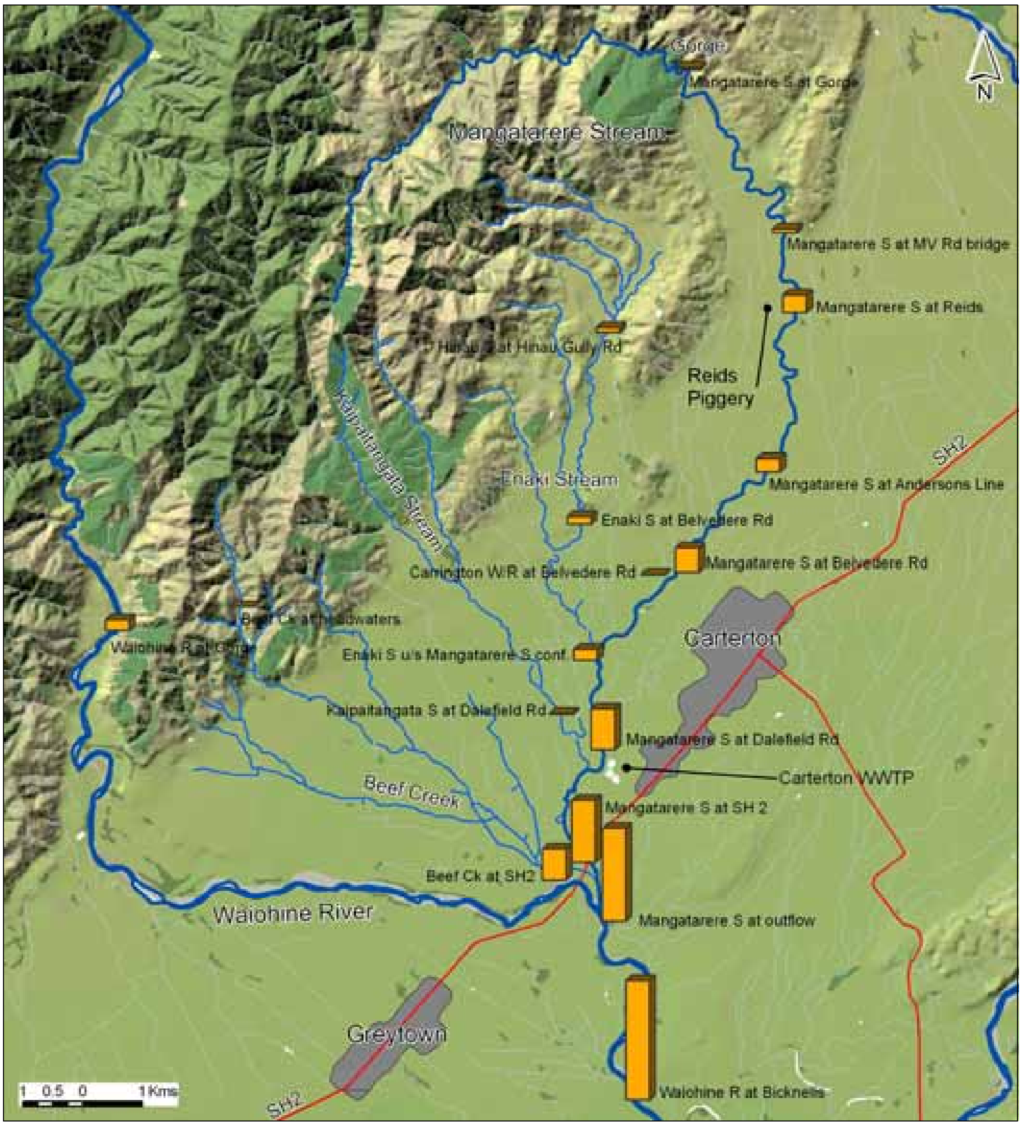

Figure 9.3: Mean daily dissolved inorganic nitrogen (DIN) loads for surface water quality sites in the Mangatarere catchment sampled monthly from September 2008 to August 2009 inclusive, including estimated mean loads for the same period at SoE sites on Beef Creek and the Waiohine River, and two sites on the Mangatarere Stream monitored by Reid's piggery[38] (sampled on a different day). The height of each coloured bar is proportional to the DIN load present.

[37] Dr Doug Edmeades, Soil Scientist and Managing Director of AcKnowledge – speaking on Radio NZ – "Dairying: the dosh or the dirt", 1 February 2010.

[38] DIN (and DRP) loads at Reid's piggery monitoring sites were calculated from the mean of individual loads that were estimated for each of Reid's monthly stream sampling events using stream flow at the Gorge on the day of sampling less 150 L/s to account for the Carrington Water Race abstraction and stream flow lost to groundwater.

Based on the 12-month sampling period, the mean DIN load from the intensively farmed Beef Creek subcatchment is very significant; 33% compared with 11.8% for the Enaki subcatchment (Figure 9.3), even though the latter is similar in area and land-use composition (refer Section 2.5). The higher DIN load contribution from Beef Creek reflects both higher nitrate concentrations (median 2.15 mg/L) and higher flows in this creek (refer Table 4.3, Section 4.4.2). Shallow groundwater intercepting agricultural land drainage is likely to be contributing the majority of the DIN to Beef Creek, although, as discussed in Section 9.3.2, phosphorus concentration data suggest surface water inputs from overland flow into drainage channels may also be significant.

Figures 9.2 and 9.3 indicate that the Mangatarere Stream contributes a significant amount of DIN to the Waiohine River below the SH 2 confluence. It is difficult to accurately quantify the contribution during the 12-month sampling period because the Waiohine River sites were sampled on a different day and the Bicknells SoE monitoring site is located 4 km downstream of the confluence.

9.3.2 Phosphorus

In contrast with nitrogen, the catchment investigation indicated that at most surface water sites, less than half of the phosphorus load is present in the soluble form. In the case of the Carrington Water Race at Belvedere Road, just one third of the mean phosphorus load was present in the form of DRP. This suggests that a significant amount of sediment-bound phosphorus is present in the race. The most likely source of this phosphorus is streambank sediment as a result of stock damage and/or erosion during high flows (a water race is not required to be fenced). Stock access is also likely to account for high proportions of particulate phosphorus at some other sites, notably the Hinau Stream and Enaki Stream at Belvedere Road. Dairy cows were observed in the stream at both of these sites which resulted in a number of other impacts on water quality, including reduced clarity and elevated *E. coli* bacteria counts.

Overland flow (surface runoff) is another likely source of sediment-bound phosphorus at some sites. This is likely to be particularly significant in the Beef Creek subcatchment where compacted and poor draining soils in the lower reaches have led to the construction of drainage channels to carry away excess surface runoff from farmland to the creek.

In contrast with DIN, median DRP concentrations increase only gradually with distance down the main stem of the Mangatarere Stream, until Dalefield Road (Figure 9.4). Based on the September 2008–August 2009 investigation period, the contribution to the total mean DRP load exiting the Mangatarere Stream into the Waiohine River increases from just over 3% of the load at the Gorge to nearly 16% by Dalefield Road and 86% at SH 2 (Figure 9.5). This indicates that the Carterton WWTP discharge was responsible for as much as 70% of the DRP load that entered the Mangatarere Stream (the Kaipaitangata Stream input just above the discharge is negligible). The actual contribution varies with stream flow; based on the six lowest stream flow sampling occasions during the reporting period, the mean contribution was estimated to be as high as 90%.

The remaining 14% of the DRP load (based on mean figures for the 12-month sampling period) exiting the Mangatarere Stream catchment is attributed to the Beef Creek subcatchment (Figure 9.5). The contribution from this subcatchment – as with the contributions from the other subcatchments – varied with flow, from a mean of 6.4% under the six lowest stream flow sampling occasions to a mean of 17.1% under the six highest flows. The Mangatarere Stream at Dalefield Road exhibited a similar pattern, highlighting that non-point sources of DRP make a significant contribution to total instream loads during wet weather and high stream flows.

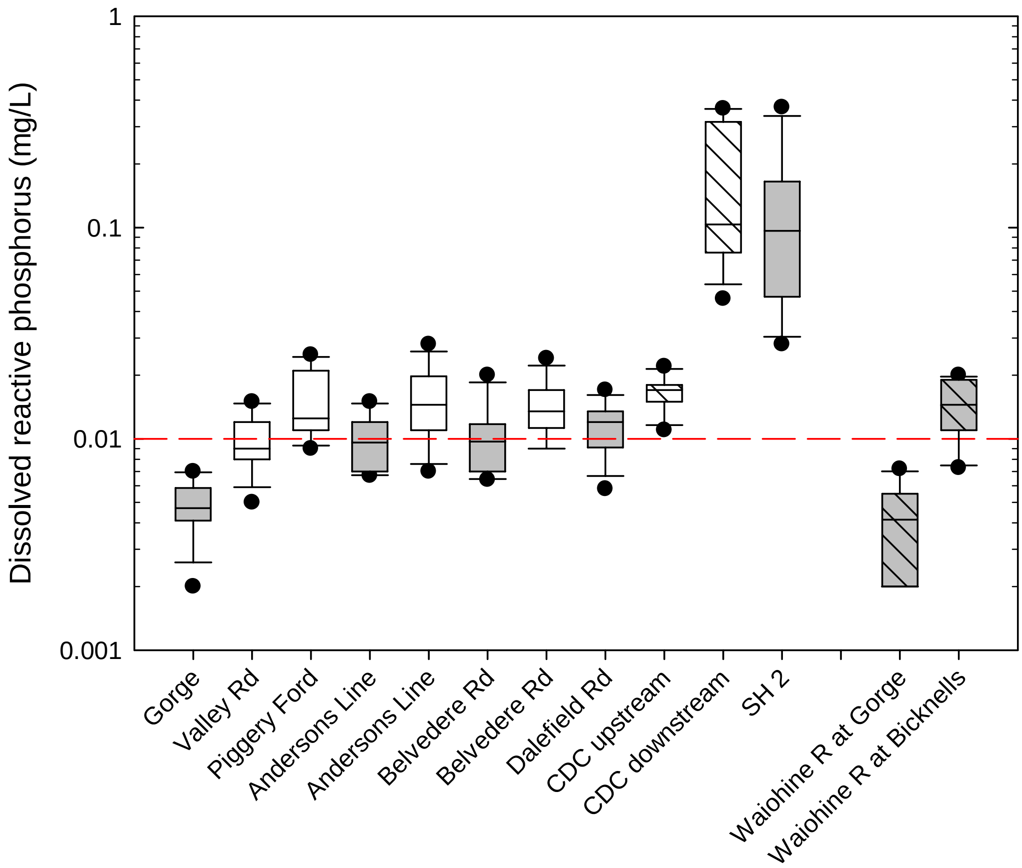

Figure 9.4: Box-and-whisker plots summarising dissolved reactive phosphorus (DRP) concentrations at various monitoring locations down the Mangatarere Stream, based on monthly sampling (on different days) by Greater Wellington (grey boxes), Reid's piggery (white boxes) and Carterton District Council (hashed white boxes) over September 2008 to August 2009 (*n*=12). The DRP concentrations for Greater Wellington's two Waiohine River SoE monitoring sites are also shown for comparison. The horizontal red dashed line indicates the ANZECC (2000) trigger value for lowland streams. Note the logarithmic scale.

Figures 9.4 and 9.5 indicate that the Mangatarere Stream contributes a significant amount of DRP to the Waiohine River below the SH 2 confluence. For the reasons noted in Section 9.3.1, it is difficult to accurately quantify the contribution during the 12-month sampling period.

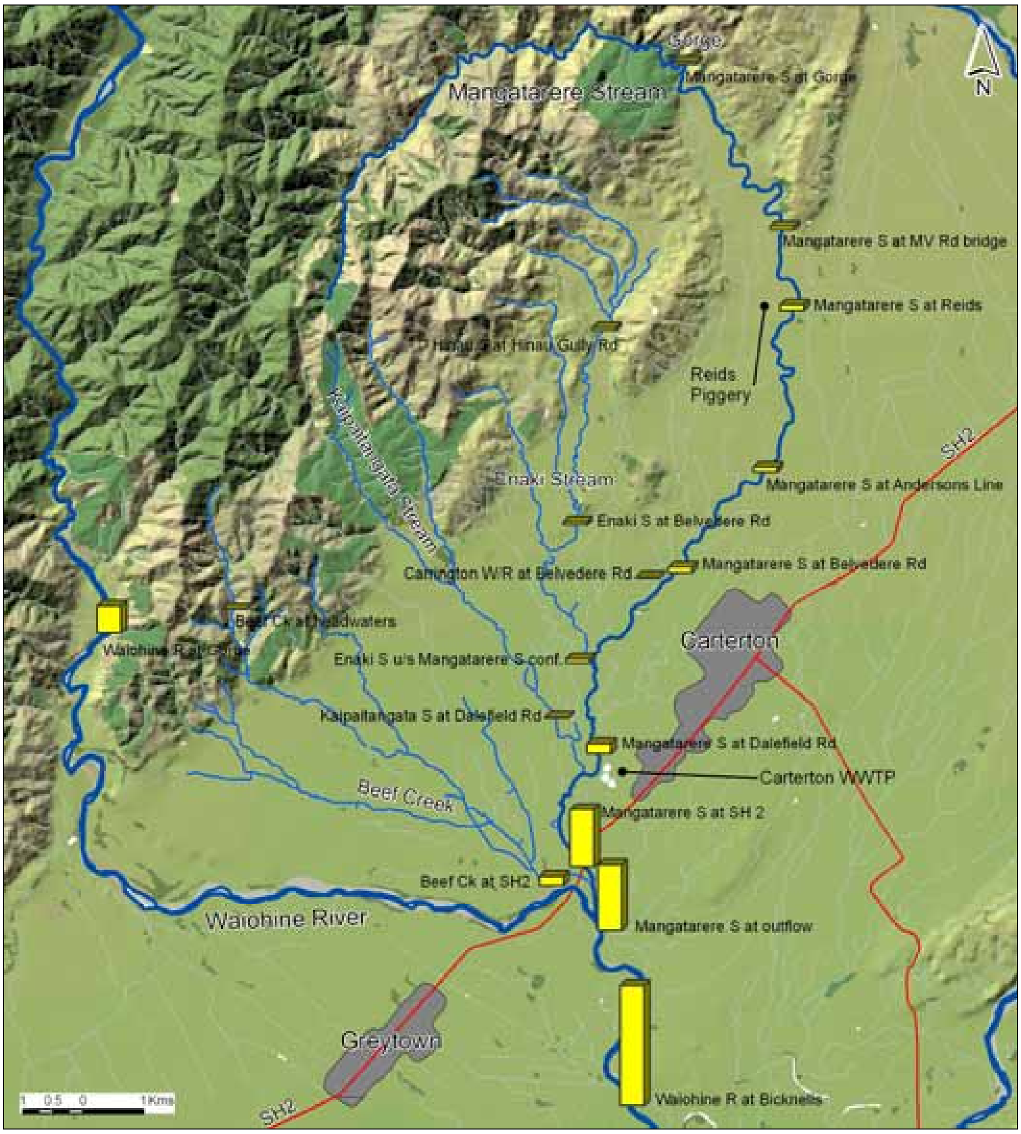

Figure 9.5: Mean daily dissolved reactive phosphorus (DRP) loads for surface water quality sites in the Mangatarere catchment sampled monthly from September 2008 to August 2009 inclusive, including estimated mean loads for the same period at SoE sites on Beef Creek and the Waiohine River, and two sites on the Mangatarere Stream monitored by Reid's piggery (sampled on a different day). The height of each coloured bar is proportional to the DIN load present.

In comparison with the Beef Creek subcatchment, the contribution to the total DRP (and DIN) load exiting the Mangatarere Stream from the Enaki and Kaipaitangata subcatchments is very small (Figure 9.5). This reflects smaller flows in these streams as well as lower instream concentrations which in turn may in part be due to dilution from 'cleaner' groundwater inputs. The influence of groundwater entering the lower Kaipaitangata Stream is evident in the water temperatures recorded at this site; despite no riparian shade and low flows, spot measurements at Dalefield Road never exceeded 16ºC.

The exact source of the DRP load present in the Mangatarere Stream upstream of the Carterton WWTP at Dalefield Road (mean of 15.5%) is unclear. Based on some Olsen-P soil concentrations soil P-retention values, the application of wastewater to land at Reid's piggery is possibly a significant, although unquantified at this stage, contributor. However, DRP inputs from agricultural sources above Dalefield Road, notably dairying, will also be contributing, particularly given DRP results from the Beef Creek subcatchment further downstream (where the source can only be agricultural; dairying and/or drystock).

Greater Wellington's most recent (2009/10) inspections of dairy farms in the Mangatarere catchment indicate a very high level of compliance with conditions for dairyshed effluent disposal to land. While this is encouraging, compliance was lower in the preceding few years, with evidence on some farms of inappropriate effluent application (e.g., ponding of effluent or effluent application too close to water bodies) and overstocking. Moreover, recent inspections have revealed that the majority (24) of the 30 discharge permits currently exercised in the catchment are exercised without any deferred storage. The implications of this are significant; without any form of deferred storage, once the capacity of the effluent sump is reached, dairyshed effluent has to be applied to land, regardless of soil or weather conditions. This means that even when soils are fully saturated during periods of heavy or prolonged rainfall, effluent is still applied. The potential for surface runoff to streams is likely to be high, particularly in the Beef Creek subcatchment which has poorly drained and compacted soils. In addition, almost all of the farms inspected were directing stormwater from the dairysheds into their effluent collection systems which increases the volume of effluent that has to be applied to land.

9.3.3 Nutrient management

Based on the 12-months of surface water quality sampling results, it appears that phosphorus-limited conditions tend to dominate in the Mangatarere catchment, with some sites in the Enaki subcatchment possibly switching between phosphorus and nitrogen-limited conditions depending on seasons/flows. Co-limited conditions likely exist in the upper reaches (e.g., the Mangatarere Stream at Gorge) and in the lower reaches of the Mangatarere Stream and Beef Creek highly elevated concentrations of both DIN and DRP at these sites mean that neither nutrient is likely to be limiting periphyton growth. Overall, this suggests that management of phosphorus alone – also the likely limiting nutrient at low flows downstream in the Waiohine River[39] (such as through a reduction or removal of the Carterton WWTP discharge), may not adequately control instream periphyton biomass under all stream flow conditions. Wilcock et al. (2007) note the importance of managing both phosphorus and nitrogen inputs within a catchment due to the influence of antecedent water quality on periphyton growth[40], the interconnectivity of waterways within subcatchments and catchments, and the need to protect downstream receiving environments.

The investigation has also clearly demonstrated that there is a need to manage both point and diffuse sources of nitrogen and phosphorus. The latter clearly contribute the majority of the nutrient loading under higher stream flows.

[39] Based on SoE monitoring results for the same 12-month period, September 2008–August 2009.

[40] Lengthy exposure to elevated nutrient concentrations preceding a major flood event is likely to give rise to vigorous periphyton growth that will respond more quickly than if it had grown in low-nutrient waters (Wilcock et al. 2007).

9.4 Limitations and knowledge gaps

A significant amount of knowledge about the Mangatarere catchment has been gained as a result of the targeted 13-month investigation, analysing long-term SoE water quality monitoring data and reviewing resource consent monitoring information. However, there are also a number of limitations and knowledge gaps. These are outlined below.

- The investigation period was limited to 13-months (largely to accommodate financial and staff resources), which only enabled water quality to be assessed across one set of seasons. Ideally, several years of data would be collected, particularly given that more recent dairyshed inspections indicate a higher level of compliance with dairy discharge permits.

- There is a lack of long-term stream flow data for the catchment, including gaugings at high stream flows, which made it difficult to accurately assess trends in water quality through time and prevented calculation of meaningful annual nutrient loads, particularly in the lower catchment reaches (Note: a telemetered flow recorder was installed in the Mangatarere Stream at SH 2 in late 2009).

- Greater Wellington changed its analytical laboratory for SoE surface water sample analysis in 2006 and, although both laboratories utilised during the 2003-2009 trend reporting period (see Section 7) were IANZ-accredited and employed the same analytical methods, it is possible that some inter-lab differences may be present.

- The interactions between groundwater and surface water are not fully understood, particularly in the lower reaches of the Enaki Stream. This makes it difficult to be certain about the source and influence of nitrate-rich shallow groundwater measured in water samples from some bores. Two analytical techniques that may assist in part are age-dating water samples through analysis of tritium concentrations and groundwater source capture zone analysis currently being investigated by GNS. (Note: surface water samples were taken from the Mangatarere Stream at SH 2 and the bottom of the three main tributaries for tritium testing in early 2010 – the results are not yet available).

- There is a lack of up-to-date land use and quality soil information for the catchment (a region-wide issue), which made it difficult to assess land use change/intensification over time and the ability of soil to hold water and retain nutrients.

- There is a notable lack of local or farm-scale information (both current and historical) about soil types and land management practices, including stocking rates and regimes (e.g., overwintering), the extent and effectiveness of channel and bank protection (e.g., riparian buffers), nutrient and effluent management (e.g., fertiliser types and application rates), drainage, fencing and stock crossings. The Ministry for the Environment (2009) has recommended this information is collected for national reporting of stream health under the under the Dairying and Clean Streams Accord. This information would also be useful for other types of farming.

- Some resource consent monitoring has not been carried out as required by resource consent conditions, meaning that there is a lack of data and/or a lack of quality data. This is particularly the case for the Carterton WWTP where the discharge flow record is almost non-existent and some water quality monitoring results appear to be unreliable.

- There is a lack of information about the potential environmental impacts of some consented and permitted activities undertaken in the Mangatarere catchment, notably stormwater discharges from Carterton township, instream works associated with flood protection and erosion control, and on-site wastewater discharges to land. (Note: Greater Wellington is currently funding research into the potential impacts of river channel realignment, and other flood protection practices, on river and stream ecosystems in the Wellington region).

- The potential impacts on surface water quality from discharges from the Carrington Water Race and artificial drainage networks are not well understood. Given stock have free access to much of the water race and drainage networks, the potential for impacts is likely to be high, particularly in terms of localised impacts.

- There is currently no analytical method readily available that can be used to differentiate between nutrients in piggery, dairyshed and drystock wastes. Such a method would greatly help to determine the sources of DIN and DRP upgradient of the Carterton WWTP and within the Beef Creek subcatchment.

Finally, although outside the scope of this technical investigation, it is recognised that cultural health assessments form an important part of integrated catchment monitoring and management. Where it is appropriate to do so, Greater Wellington should include a component of cultural health assessment/monitoring in future catchment investigations. Cultural health monitoring and assessments need further consideration when Greater Wellington reviews its existing Regional Monitoring Strategy.

10. Conclusions

Surface water quality is degraded in the lower Mangatarere Stream catchment, from both a regional and national perspective. This degradation generally begins in the main stem downstream of the Gorge, where the stream opens onto the more intensively farmed plains. Degradation in stream water quality is evident in the form of elevated dissolved nutrient concentrations, *E. coli* bacteria counts above guideline values for stockwater and/or contact recreation and, at some locations in the lower catchment, reduced water clarity.

Both dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP) loads increase with distance down the catchment. Based on the September 2008–August 2009 sampling period, the patterns of increase differ, with DIN loads increasing consistently with distance downstream, and DRP loads increasing significantly in the lower reaches of the catchment, primarily as a result of the Carterton WWTP discharge. The Carterton WWTP discharge also contributes DIN to the Mangatarere Stream, both directly and indirectly via seepage to groundwater from under the oxidation ponds, wetland cells and land application area adjacent to the stream. However, the DIN input is relatively minor at higher stream flows when non-point sources account for the majority of the DIN. Ecological sampling undertaken by Carterton District Council confirms that the discharge has a measurable impact on invertebrate health, particularly in the summer months when stream flows are lower.

The application of wastewater to land at Reid's piggery in the mid reaches of the catchment is having a measurable impact on soil, groundwater and stream water quality. Groundwater quality monitoring results for shallow bores sampled immediately downgradient of the piggery indicate impacts, principally in the form of elevated nitrate nitrogen concentrations, migrating off-site. This nutrient-rich groundwater enters the Mangatarere Stream at some point downstream of Andersons Line. However, the nature of the surface water/groundwater connection is not completely understood and dairying in the mid catchment reaches will also be contributing to nutrient concentrations in the shallow unconfined groundwater aquifer and hydraulically connected streams.

Beef Creek has very poor water quality and during the investigation period was found to contribute 33% and 14% of the mean DIN and DRP loads (respectively) exiting the Mangatarere Stream into the Waiohine River. This creek, which enters the Mangatarere Stream below SH 2, has a catchment that comprises both dairying and drystock farming, highlighting the impact intensive agriculture can have on water quality. As well as groundwater-sourced nutrient inputs, it is likely that surface water runoff is a significant source of the nutrient (and other contaminant) loads in the lower reaches of Beef Creek. The soils in this area are poorly drained and soil quality monitoring results indicate a high degree of compaction; such conditions are ideal for ponding and surface water runoff.

The impacts of drystock and dairy farming on nutrient loads were not quantified as pat of this investigation. However, impacts on physico-chemical and microbiological water quality were clearly present as a result of stock access at some sites, and the impacts due to surface runoff of dairyshed effluent have the potential to be very high. Despite Greater Wellington's 2009/10 inspections indicating a high level of compliance with resource consent conditions for the discharge of dairyshed effluent to land, 24 of the 30 active permits are currently exercised without any deferred storage. This means that dairyshed effluent generally has to be applied to land within a few days of being generated, regardless of soil or weather conditions.

Overall, elevated dissolved nutrient concentrations, as well as a lack of riparian vegetation cover and periods of low or stable stream flow, are contributing to nuisance periphyton growth and reduced invertebrate health, particularly in the lower reaches of the Mangatarere Stream. Long-term State of the Environment (SoE) monitoring data for the Mangatarere Stream at SH 2 indicate DRP and ammoniacal nitrogen concentrations are increasing over time, while invertebrate health appears to be declining. However, impacts on stream health are also evident further up in the catchment and appear to reflect more than just degraded water quality. A lack of flow in streams and degraded instream habitat (e.g., as a result of direct stock access and a lack of riparian vegetation at some sites) appear to be significant factors, with water temperatures in some parts of the catchment high enough to stress some sensitive aquatic life.

Although the complete drying of some stream reaches (e.g., Mangatarere Stream at Andersons Line) during summer is considered "natural", it is highly likely that both surface water and groundwater abstraction are increasing the frequency and duration of low flows and periods when stream reaches are dry. This highlights that intensive land use in the Mangatarere catchment generates multiple stressors (water abstraction, stock access and point and non-point source discharges) that cumulatively have significant impacts on stream health.

Efforts by Greater Wellington and landowners to rehabilitate the riparian margins of the lower reaches of the Enaki Stream subcatchment over the last nine years appear to be offsetting some of the adverse effects of intensive land use on stream health evident further up the catchment. However, water quality in the Enaki subcatchment remains degraded and considerably more work is needed to improve water quality and aquatic ecosystem health across the wider catchment. Removal (complete or even partial) of the Carterton WWTP discharge from the lower Mangatarere Stream would significantly reduce the existing DRP loading on the stream and related nuisance periphyton growth. However, DRP:DIN ratios in stream waters and the presence – albeit to a lesser extent – of nuisance periphyton growth upstream suggest that nitrogen inputs also need to be managed. In the case of DIN, the primary contribution is from diffuse sources, indicating that wastewater application to land and agricultural management practices need closer attention. This is especially the case in the Beef Creek subcatchment which appears to be contributing a significant amount of DIN (and DRP) relative to other parts of the catchment. This contribution was not known at the time of commencing the catchment investigation, Greater Wellington's long-term SoE site on the Mangatarere being located upstream of the Beef Creek confluence, at SH 2.

Overall, a significant amount of knowledge about the Mangatarere catchment has been gained as a result of the targeted 13-month investigation, analysis of long-term SoE water quality monitoring data and review of selected resource consent monitoring information. However, there were a number of limitations and knowledge gaps associated with the investigation. These include a lack of farm-scale information on soil types and land use and management, as well as a lack of long-term stream flow data and a good understanding of the interactions between groundwater and surface water in some of the subcatchments.

10.1 Recommendations

1. Further investigate water quality in the Beef Creek subcatchment.

2. Consider investigating surface water / groundwater connections within the subcatchments, particularly the Enaki Stream subcatchment.

3. Continue with the deployment of continuous water quality meters at selected sites in the summer, focusing on measurements of water temperature and dissolved oxygen.

4. Consider incorporating stream habitat assessments, streambed sedimentation measurements and fish surveys in future ecological monitoring in the Mangatarere catchment.

5. When analytical techniques that distinguish nutrient inputs from piggery, dairyshed and drystock wastes become available, consider undertaking nutrient source analysis to determine the relative contributions of DRP and DIN in receiving waters from these different wastes.

6. Further investigate the extent of groundwater quality degradation upgradient of piggery wastewater disposal in the mid catchment reaches.

7. Consider establishing long-term soil quality monitoring in the Mangatarere catchment.

8. Undertake more comprehensive assessments of compliance with resource consent conditions for discharge permits exercised in the catchment, particularly with respect to the standard of self-monitoring and reporting, and ensure any non-compliance is investigated and addressed.

9. Continue to undertake annual inspections of dairy farms within the Mangatarere catchment and work with farm owners and dairy industry staff to obtain farm management information that supports the assessment of land use effects on water and soil quality.

10. Continue to work with dairy industry staff to promote the introduction of deferred storage for dairyshed effluent and consider including minimum effluent storage requirements in the second generation regional plan(s).

11. Ensure that the review of surface water allocation within the Mangatarere catchment in the second generation regional plan(s) takes into account surface water interactions with groundwater.

12. Continue to actively promote riparian rehabilitation in the Mangatarere catchment, particularly along the banks of tributary streams where the effects of fencing and revegetation on instream habitat and water quality will be greatest.

13. Communicate the key findings of this investigation to iwi, and landowners and residents within the Mangatarere catchment, with the view to establishing joint Greater Wellington, iwi and community initiatives to address some of the issues raised in this report, including opportunities to improve water quality and stream health through best management practices such as riparian enhancement and bridged stock and vehicle crossings.

14. Communicate the key findings of this investigation and poor compliance with some aspects of the Dairying and Clean Streams Accord to Fonterra and invite their participation – together with other farming industry groups, Wellington Fish and Game and the Department of Conservation – in working with Greater Wellington, iwi and the wider farming and Carterton community to address some of the water quality issues raised in this report.

15. Consider, through the review of Greater Wellington's Regional Monitoring Strategy, opportunities to include a component of cultural health assessment/monitoring in future catchment investigations.

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Appendix 1: Surface water, groundwater and soil sampling sites

All grid references relate to the NZMS 260 topographical map series.

Table A1.1: Surface water quality and ecological sites sampled in the Mangatarere catchment investigation

Site: Mangatarere Stream at Road End

Easting: 2716186 Northing: 6025771

This was a reference site for the ecological sampling component of the catchment investigation (for comparison against the Gorge site). It is located in the upper catchment reaches where there is 100% indigenous forest and scrub cover (i.e., riparian cover is typically very good). Larger substrates (boulders and large cobbles) tend to dominate.

Sample collection details:

- Water samples: No
- Periphyton samples: Yes, one sample
- Macroinvertebrates: Yes, one sample

Site: Mangatarere Stream at Gorge

Easting: 2721500 Northing: 6027161

Upstream landcover at this site is dominated by indigenous forest and scrub (82%) but also comprises a dry stock (14%) and forestry component (4%). There is some minor evidence of stock access at this site and at a number of locations upstream. In the immediate area the riparian margin is relatively intact and comprises a mixture of exotic and native trees.

Greater Wellington monitors stream flow continuously at this site.

Sample collection details:

- Water samples: Yes, monthly samples
- Periphyton samples: Yes, two replicate samples
- Macroinvertebrates: Yes, three replicate samples

Site: Mangatarere Stream at Andersons Line

Easting: 2722761 Northing: 6020254

During dry years the stream at this site is known to stop flowing. This was the case in February 2009, which prevented any ecological sampling from being undertaken. The catchment upstream of the site includes native forest and scrub cover (63.9%), drystock (28.4%), dairy (4.8%) and forestry (2.9%). Riparian margins are generally lacking although there are clumps of willows in places. The streambed substrate typically comprises large and small cobbles.

Sample collection details:

- Water samples: Yes, monthly samples
- Periphyton samples: No, dry at time of sampling
- Macroinvertebrates: No, dry at time of sampling

Site: Mangatarere Stream at Belvedere Road

Easting: 2721064 Northing: 6018528

Native forest and scrub dominate land cover upstream (58.8%) while the remainder of the upstream catchment comprises drystock farming (28.2%), dairying (10.3 %) and forestry (2.7%). While undertaking the ecological sampling in February 2009, dry reaches were observed upstream of this site. Willows dominate the riparian margins and probably provide a significant amount of shade. The streambed substrate typically ranges in size from large cobbles to small gravels but is dominated by small cobbles and large gravels. Stock access was evident on some sampling occasions.

Greater Wellington monitors stream flow continuously at this site.

Sample collection details:

- Water samples: Yes, monthly samples
- Periphyton samples: Yes, one sample
- Macroinvertebrates: Yes, one sample

Site: Carrington Water Race at Belvedere Road

Easting: 2721003 Northing: 6018554

The Carrington Water Race is a gravity-fed unlined channel system which transports water from the Mangatarere Stream through various farms for stock water supply and limited irrigation. The site sampled was located at the southern end of the race close to where it discharges back into the Mangatarere Stream. The water race at this location (and in general) is unfenced (stock have free access) and has minimal riparian vegetation. There was no flow in February 2009, which prevented any ecological sampling from being undertaken.

Sample collection details:

- Water samples: Yes, monthly samples
- Periphyton samples: No, dry at time of sampling
- Macroinvertebrates: No, dry at time of sampling

Site: Hinau Stream at Hinau Gully Road

Easting: 2720136 Northing: 6022724

The Hinau Stream forms one branch of the upper reaches of the Enaki Stream. The sampling site at Hinau Gully Road has upstream land cover comprising native forest and scrub (57.1%), with a significant dairying component (31.6%). There is also some drystock farming (10.5%) and forestry (0.9%). Riparian vegetation is generally non-existent and stock have direct access to the streambed (they were observed in the stream on a number of occasions). The streambed substrate is highly variable, ranging from boulders and large cobbles down to small gravels and silt.

Sample collection details:

- Water samples: Yes, monthly samples
- Periphyton samples: Yes, two replicate samples
- Macroinvertebrates: Yes, three replicate samples

Site: Enaki Stream at Belvedere Road

Easting: 2719660 Northing: 6019455

Dairy farming is the dominant land use upstream of this site (50%), followed by drystock farming (32%). Native forest and scrub cover make up just 16.8% of the upstream catchment area and forestry 1.3%. Riparian vegetation is generally lacking and bank erosion is clearly evident. The streambed substrate ranges in size from large cobbles to small gravels. Stock have direct access to the streambed and on at least one occasion dairy cows were observed in the water upstream of the bridge.

Sample collection details:

- Water samples: Yes, monthly samples
- Periphyton samples: Yes, two replicate samples
- Macroinvertebrates: Yes, three replicate samples

Site: Enaki Stream upstream of Mangatarere Stream confluence

Easting: 2719946 Northing: 6017180

This is a long-term site located just upstream of the confluence with the Mangatarere Stream that has been monitored monthly since 2002 under Greater Wellington's riparian rehabilitation programme (see Perrie 2008 for details). During dry years, the lower reaches can be reduced to a series of pools. This was the case in February 2009 (see photo). The catchment upstream comprises mainly native forest and scrub (37.8%), dairying (39.8%) and drystock farming (20.2%). Forestry makes up a minor component (2.2%). Greater Wellington has invested significant resources over the last 9–10 years rehabilitating riparian margins along the lower reaches of the Enaki Stream. Consequently, the riparian margins are generally in much better condition here than in much of the upstream catchment and a mixture of exotic and native trees provide a reasonable amount of shade through this reach. The stream channel is moderately incised and small cobbles and large gravels dominate the substrate. This section of the stream is fenced to prevent stock access.

Sample collection details:

- Water samples: Yes, monthly samples
- Periphyton samples: Yes, two replicate samples
- Macroinvertebrates: Yes, three replicate samples

Site: Kaipaitangata Stream at Dalefield Road

Easting: 2719344 Northing: 6016248

This site is located approximately 1.2 km upstream of the Kaipaitangata Stream's confluence with the Mangatarere Stream. The upstream catchment is dominated by native forest and scrub (55.6%), followed by dairying (19.7%), forestry (18.0%) and drystock farming (6.8%). The lower reaches of this stream are known to dry up during dry summers – despite groundwater inputs – and upstream of this site during February 2009 the stream was reduced to a series of pools. There is limited riparian vegetation cover and the streambed substrate consists mainly of small cobbles. Stock have access to the stream at this site and were observed in the stream on some sampling occasions.

Sample collection details:

- Water samples: Yes, monthly samples
- Periphyton samples: Yes, one sample
- Macroinvertebrates: Yes, one sample

Site: Mangatarere Stream at Dalefield Road

Easting: 2720030 Northing: 6015680

Native forest and scrub comprise 43.5% of the upstream catchment area. Drystock and dairy farming are also significant, comprising 29.6% and 23.6% of the upstream catchment area respectively. Forestry and urban land uses are also present (3.1% and 0.2% respectively). The substrate generally consists of small cobbles and large gravels. Willows dominate where riparian plants are present and in some reaches may provide good shade. Stock have direct access to the streambed and were observed in the stream on some sampling occasions.

Sample collection details:

- Water samples: Yes, monthly samples
- Periphyton samples: Yes, two replicate samples
- Macroinvertebrates: Yes, three replicate samples

Site: Mangatarere Stream at State Highway 2

Easting: 2719797 Northing: 6013854

This is a long-term monitoring site that has been sampled under Greater Wellington's RSoE programme (see Perrie 2009 for details) since February 1997. The site is located approximately 700 m upstream of the stream's confluence with the Waiohine River. The upstream catchment comprises native forest and scrub (38.6%), dairying (27.4%), drystock farming (27.0%), forestry (5.4%) and urban land use (1.7%). Large gravels are the predominant substrate type and, with the exception of some willows, vegetated riparian margins are largely absent. There is evidence of stock access at this site.

Since late 2009 Greater Wellington has continuosly monitored stream flow at this site. Prior to that, this was maintained as a rated site with stage readings taken to estimate stream flow.

Sample collection details:

- Water samples: Yes, monthly samples
- Periphyton samples: Yes, two replicate samples
- Macroinvertebrates: Yes, three replicate samples

Site: Beef Creek at State Highway 2

Easting: 2719854 Northing: 6013611

This site is located at SH 2, approximately 200 m upstream of Beef Creek's confluence with the Mangatarere Stream (i.e., below the Mangatarere Stream at SH 2 monitoring site). Dairying occupies 44.1% of the upstream catchment, followed by drystock farming (29.1%), native forest and scrub (23.5%) and forestry (3.3%). The stream is deeply incised and highly channelised which has resulted in a reduction in hydrologic habitat diversity. The creek's substrate is variable with large and small cobbles in the swifter flowing areas. Finer substrates such as silt are more common in the slowing flowing reaches. Submerged macrophytes (e.g., *Potamogeton crispus*) generally cover 100% of the streambed. Riparian shading is virtually non-existent.

Sample collection details:

- Water samples: Yes, monthly samples
- Periphyton samples: No, due to 100% cover of submerged macrophytes
- Macroinvertebrates: Yes, one sample

Table A1.2: River State of the Environment (RSoE) sites located in the Mangatarere and Waiohine catchments

Site name	Site No.	Easting	Northing	Monitoring record dates from
Waiohine River at Gorge	RS47	2711830	6018370	November 1991
Waiohine River at Bicknells	RS48	2720633	6009820	November 1991
Beef Creek at Headwaters	RS49	2713981	6018117	September 2003
Mangatarere Stream at State Highway 2	RS50	2719797	6013854	February 1997

Table A1.3: Groundwater bores sampled in the Mangatarere catchment investigation

Site No.	Easting	Northing	Depth (m)	Groundwater zone[1]	Bore use
S26/0086	2717608	6018657	4	Matarawa	Potable, stock
S26/0092	2719280	6019455	8.1	Matarawa	Potable, stock
S26/0101	2719500	6018000	6	Matarawa	Potable, stock
S26/0386	2715500	6016100	5.55	Matarawa	Domestic
S26/0427	2716400	6013915	12	Greytown	Domestic
S26/0449	2719240	6013925	9	Hodders	Stock
S26/0803	2719746	6020746	4.9	Matarawa	Potable, dairy, stock
S26/0877	2722074	6021486	12	Matarawa	Domestic, stock
S26/0977	2722832	6023970	10	Mangatarere	Groundwater quality monitoring
S26/0978	2722879	6021541	11	Mangatarere	Groundwater quality monitoring
S26/1034	2721205	6015348	21	Carterton	Water level observation
S26/1066	2722808	6020286	6	Mangatarere	Dairy, stock
S26/1069	2717284	6016076	10	Matarawa	Disused bore
S26/1035[2]	2721205	6015348	6.72	Carterton	Water level observation
S26/0204[2]	2721220	6020300	9.70	Carterton	Potable
S26/0945[2]	2716803	6018295	22.00	Matarawa	Potable, dairy, stock
S26/0355[2]	2717300	6015400	4.00	Matarawa	Potable, dairy, stock
S26/0437[2]	2715504	6014893	16.18	Matarawa	Potable
S26/0580[2]	2720788	6013515	15.00	Matarawa	Potable, stock
S26/0164[2]	2720754	6018783	45.00	Matarawa	Potable, stock
S26/0185[2]	2723332	6023091	11.00	Mangatarere	Irrigation
S26/0372[2]	2719400	6014000	6	Hodders	Disused
S26/0968[2]	2719213	6013727	7.5	Hodders	Potable, domestic, stock

[1] As defined in the existing Regional Freshwater Plan (WRC 1999).

[2] Bores sampled on one occasion only, except bore S26/0968 which was sampled on two occasions.

Table A1.4: Groundwater State of the Environment monitoring bores in the Mangatarere catchment

Site No.	Easting	Northing	Depth (m)	Groundwater zone	Bore use
S26/0117	2721500	6018500	5.00	Mangatarere	Potable, stock
S26/0439	2717510	6016900	11.50	Matarawa	Stock
S26/0467	2719290	6015570	6.20	Hodders	Potable, stock
S26/0705	2720489	6015999	27.40	Carterton	Public Supply
S26/0824	2720564	6016101	20.60	Carterton	Public Supply

Table A1.5: Soil quality sites sampled in the Mangatarere catchment investigation. The following photographs and soil profile descriptions were provided by Scott Fraser (Landcare Research) who helped with the sampling. For an explanation of symbols and codes used, refer to the Soil Description Handbook (Milne 1995).

Site	PM001
Easting	2722248
Northing	6022353
Date Sampled	14/09/2009
Landuse	Dairy
NZ Soil Classification	Typic Firm Brown
Soil Order	Brown soil
Soil Series	Tauherenikau
Soil Type	Tauherenikau stony silt loam
Drainage Class	4 (Mod-well drained)

Older flood plain adjacent to but higher than modern floodplains of Mangatarere Stream.

Horizon	Depth	Matrix/ Colour	Texture	Stickiness	Gravel Abundance	Gravel Size	Lower Boundary	Mottles Abundance	Mottles Size	Mottles Colour	NAF	Notes
Ap	0-16	10YR3/2	z	ss	s	f-m	ind/irr				-ve	
Bw1	16-45	10YR4/6	sz	n	m	f-c	dif/irr				strong	
Bw2	45-60	10YR3/6	sz	n	m	m-c	dis/smth	f	f	5YR4/6		
C	60-	10YR4/2	gravel	n	v	m-c						

Site	PM002
Easting	2721852
Northing	6022427
Date Sampled	14/09/2009
Landuse	Dairy
NZ Soil Classification	Argillic Perch-gley Palic
Soil Order	Gley soil
Soil Series	Otukura
Soil Type	Otukura silt loam
Drainage Class	2 (Poorly drained)

Silty alluvium overlying impermeable gravels.

Horizon	Depth	Matrix/ Colour	Texture	Stickiness	Gravel Abundance	Gravel Size	Lower Boundary	Mottles Abundance	Mottles Size	Mottles Colour	NAF	Notes
Ap	0-26	10YR4/2	z	ss	vs	f-m	ind/irr	vf	vf	10YR5/6	-ve	
Bg	26-46	10YR6/2	lz	s	vs	f-m	ind/irr	f	f	10YR5/6+10YR5/4	-ve	
Btg	46-62	10YR7/3	lz	s	s	f-m	dis/smth	c	f	10YR6/6		
Cg	62-		gravel		v	m-c						

Site	PM003
Easting	2722102
Northing	6021589
Date Sampled	14/09/2009
Landuse	Drystock
NZ Soil Classification	Typic Firm Brown
Soil Order	Brown soil
Soil Series	Tauherenikau
Soil Type	Tauherenikau stony silt loam
Drainage Class	5 (Well drained)

Older flood plain adjacent to but higher than modern floodplains of Mangatarere Stream.

Horizon	Depth	Matrix/ Colour	Texture	Stickiness	Gravel Abundance	Gravel Size	Lower Boundary	Mottles Abundance	Mottles Size	Mottles Colour	NAF	Notes
Ap	0-20	10YR3/1	z	n	vs	f-m	ind/irr				-ve	
Bw1	20-55	10YR5/6	sz	ss	s	f-m	ind/irr				strong	
Bw2	55-75	10YR3/6	sz	n	s	f-c	dis/smth				strong	
C	75-		gravel	n	v	f-c						

Site	PM004
Easting	2718740
Northing	6020822
Date Sampled	14/09/2009
Landuse	Drystock
NZ Soil Classification	Typic Orthic Brown
Soil Order	Brown soil
Soil Series	Tuhitarata
Soil Type	Tuhitarata silt loam
Drainage Class	4 (Mod-well drained)

Horizon	Depth	Matrix/ Colour	Texture	Stickiness	Gravel Abundance	Gravel Size	Lower Boundary	Mottles Abundance	Mottles Size	Mottles Colour	NAF	Notes
Ap	0-15	2.5Y4/4	z	ss	vs	m	ind/smth				-ve	
AB	15-30	2.5Y5/4	zl	s	vs	m	ind/smth	c	m	2.5Y4/4	weak	mottles in AB likely to be worm castings rather than drainage related
Bw	30-75	2.5Y5/4	zl	s	vs	m	ind/smth	f	f	10YR5/6	weak	
BC	75-120		zl	s	vs	m		c	m-c	10YR5/6+10YR6/2		

Site	PM005
Easting	2719900
Northing	6022112
Date Sampled	15/09/2009
Landuse	Dairy
NZ Soil Classification	Typic Orthic Brown
Soil Order	Brown soil
Soil Series	Kohinui
Soil Type	Kohinui loam
Drainage Class	4 (Mod-well drained)

Horizon	Depth	Matrix/ Colour	Texture	Stickiness	Gravel Abundance	Gravel Size	Lower Boundary	Mottles Abundance	Mottles Size	Mottles Colour	NAF	Notes
Ap	0-20	10YR5/3	z	ss	vs	m	ind/irr				-ve	
Bw	20-50	2.5Y5/4	zl	ss	s	f-m	dis/smth				weak	
C	50-		gravel	n	vg	f-m						

Site	PM006
Easting	2719023
Northing	6020715
Date Sampled	15/09/2009
Landuse	Drystock
NZ Soil Classification	Typic Allophanic Brown
Soil Order	Brown soil
Soil Series	Kohinui
Soil Type	Kohinui loam
Drainage Class	5 (Well drained)

Horizon	Depth	Matrix/ Colour	Texture	Stickiness	Gravel Abundance	Gravel Size	Lower Boundary	Mottles Abundance	Mottles Size	Mottles Colour	NAF	Notes
Ap	0-24	10YR3/3	zl	ss			ind/smth				weak	
Bw1	24-49	10YR5/6	zl	ss			dis/smth				strong	
Bw2	49-76	10YR5/6	lz	ss			dis/smth				strong	A pedal, low BD
C	76-		gravel		vg	f-m						

Site	PM007
Easting	2720376
Northing	6019694
Date Sampled	15/09/2009
Landuse	Dairy
NZ Soil Classification	Typic Firm Brown
Soil Order	Brown soil
Soil Series	Tauherenikau
Soil Type	Tauherenikau stony silt loam
Drainage Class	3 (Imperfectly drained)

Horizon	Depth	Matrix/ Colour	Texture	Stickiness	Gravel Abundance	Gravel Size	Lower Boundary	Mottles Abundance	Mottles Size	Mottles Colour	NAF	Notes
Ap	0-11	10YR4/2	zl	ss	s		ind/wav	vf	f	5YR4/6	-ve	
Bw	11-30	10YR4/2	sz	ss	m		dis/smth	f	f	7.5YR3/6	-ve	
BC(g)	30-	10YR4/6	sandy gravel	n	vg			c	m	10YR7/6		

Site	PM008
Easting	2720899
Northing	6018474
Date Sampled	15/09/2009
Landuse	Drystock
NZ Soil Classification	Weathered Fluvial Recent
Soil Order	Recent soil
Soil Series	Opaki
Soil Type	Opaki brown stony loam
Drainage Class	5 (Well drained)

Horizon	Depth	Matrix/ Colour	Texture	Stickiness	Gravel Abundance	Gravel Size	Lower Boundary	Mottles Abundance	Mottles Size	Mottles Colour	NAF	Notes
Ap	0-8	10YR3/2	lz	n	m	f	ind/smth				mod	
AB	8-21	10YR3/2	ls	n	m	f	ind/smth				mod	
Bw	21-60	10YR3/4	ls	n	m	f	ind/wav				strong	
C	60-		gravel		vg	f-c						

Site	PM009
Easting	2719577
Northing	6017865
Date Sampled	15/09/2009
Landuse	Dairy
NZ Soil Classification	Weathered Fluvial Recent
Soil Order	Recent soil
Soil Series	Greytown
Soil Type	Greytown silt loam and sandy loam
Drainage Class	4 (Mod-well drained)

Horizon	Depth	Matrix/ Colour	Texture	Stickiness	Gravel Abundance	Gravel Size	Lower Boundary	Mottles Abundance	Mottles Size	Mottles Colour	NAF	Notes
Ap	0-13	10YR4/3	z	ss			ind/smth	Ap				-ve
Bw	13-75	10YR5/3	z	ss			ind/smth	Bw				-ve
C	75-110	10YR5/4	z	ss			dis/smth	C				
	110-		gravel	n	vg	f-c						

Site	PM010
Easting	2720690
Northing	6016448
Date Sampled	15/09/2009
Landuse	Dairy
NZ Soil Classification	Typic Allophanic Brown
Soil Order	Brown soil
Soil Series	Kohinui
Soil Type	Kohinui loam
Drainage Class	5 (Well drained)

Horizon	Depth	Matrix/ Colour	Texture	Stickiness	Gravel Abundance	Gravel Size	Lower Boundary	Mottles Abundance	Mottles Size	Mottles Colour	NAF	Notes
Ap	0-10	10YR3/2	z	ss	vs	f-m	ind/smth				mod	
AB	10-21	10YR3/3	lz	ss	s	f-m	dis/smth				mod	
Bw	21-53	10YR4/6	lz	ss	m	f-m	dis/smth				strong	
BC	53-75	2.5Y5/6	sl	ss	m	f-c	dis/smth					
C	75-		gravel	n	vg	f-c						

Site	PM011
Easting	2720557
Northing	6020602
Date Sampled	15/09/2009
Landuse	Native forest
NZ Soil Classification	Pallic Orthic Brown
Soil Order	Brown soil
Soil Series	Kohinui
Soil Type	Kohinui loam
Drainage Class	5 (Well drained)

Horizon	Depth	Matrix/ Colour	Texture	Stickiness	Gravel Abundance	Gravel Size	Lower Boundary	Mottles Abundance	Mottles Size	Mottles Colour	NAF	Notes
FH	0-3	10YR2/1					shp/smth					
Ah	3-19	10YR3/4	lz	ss			dis/smth				-ve	
Bw	19-55	10YR5/6	lz	ss			ind/smth				mod - strong	
C	55-	2.5Y5/4	zl	s							mod	

Site	PM012
Easting	2719943
Northing	6014657
Date Sampled	16/09/2009
Landuse	Drystock
NZ Soil Classification	Typic Orthic Brown
Soil Order	Brown soil
Soil Series	Greytown
Soil Type	Greytown silt loam and stony loam
Drainage Class	4 (Mod-well drained)

Horizon	Depth	Matrix/ Colour	Texture	Stickiness	Gravel Abundance	Gravel Size	Lower Boundary	Mottles Abundance	Mottles Size	Mottles Colour	NAF	Notes
Ap	0-9	10YR5/3	lz	ss			ind/smth					
AB	9-28	10YR5/4	lz	ss			dis/smth				-ve	
Bw	28-65	10YR6/4	lz	ss			ind/smth				-ve	
C	65-100	10YR5/4	lz	ss				m	f + m	10YR7/2, 7.5YR4/6		

Site	PM013
Easting	2718834
Northing	6014156
Date Sampled	16/09/2009
Landuse	Dairy
NZ Soil Classification	Ironstone Orthic Gley
Soil Order	Gley soil
Soil Series	Ahikouka
Soil Type	Ahikouka silt loam
Drainage Class	2 (Poorly drained)

Horizon	Depth	Matrix/ Colour	Texture	Stickiness	Gravel Abundance	Gravel Size	Lower Boundary	Mottles Abundance	Mottles Size	Mottles Colour	NAF	Notes
Ap	0-20	10YR4/2	lz	ss	vs	f-m	ind/smth	c	f	2.5YR4/6		
Bg1	20-44	10YR6/2	lz	s	vs	f-m	dis/smth	m	m	2.5YR3/4		
Bg2	44-49	10YR6/2	sl	n	vs	f-m	dis/smth	a	f	10R3/3		
Bfm	49-57	10R3/3					dis/smth					indurated iron pan with many black nodules
Cr	57-70	5G4/2					dis/smth					cemmented with common nodules
C	70-		gravel		vg	f-m		c	f	2.5YR4/6		

Site	PM014
Easting	2717255
Northing	6015639
Date Sampled	16/09/2009
Landuse	Drystock
NZ Soil Classification	Typic Orthic Gley
Soil Order	Gley soil
Soil Series	Moroa
Soil Type	Moroa loam and stony loam
Drainage Class	2 (Poorly drained)

Horizon	Depth	Matrix/ Colour	Texture	Stickiness	Gravel Abundance	Gravel Size	Lower Boundary	Mottles Abundance	Mottles Size	Mottles Colour	NAF	Notes
Ap	0-7	10YR5/2	lz	ss	vs	f-m	dis/smth	f	f	5YR3/3	-ve	
Bg1	7-27	10YR6/3	lz	s	vs	f-m	dis/smth	f	f	5YR3/3	-ve	
Bg2	27-37	10YR7/2	lz	s	m	f-c	dis/smth	m	m	5YR4/6		
Cg	37-	10YR7/1	gravel	n	vg	f-c		p	m	5YR3/2		beginnings of an iron pan

Site	PM015
Easting	2716229
Northing	6016692
Date Sampled	16/09/2009
Landuse	Drystock
NZ Soil Classification	Mottled Orthic Brown
Soil Order	Brown soil
Soil Series	Opaki
Soil Type	Opaki brown stony loam
Drainage Class	3 (Imperfectly drained)

Horizon	Depth	Matrix/ Colour	Texture	Stickiness	Gravel Abundance	Gravel Size	Lower Boundary	Mottles Abundance	Mottles Size	Mottles Colour	NAF	Notes
Ap	0-20	10YR4/3	lz	ss	vs	f-m	ind/smth	Ap	vf	f	5YR4/4	-ve
Bw	20-37	10YR6/6	lz	ss	vs	f-m	dis/smth	Bw	c	m	5YR5/6+10YR6/3	weak
Bw(g)	37-69	10YR6/2	zc	s	s	f-m	dis/smth	Bw(g)	a	c	10YR5/8	
Cg	69-		gravel		vg	f-m		Cg				

Site	PM016
Easting	2719100
Northing	6015184
Date Sampled	16/09/2009
Landuse	Dairy
NZ Soil Classification	Mottled Orthic Brown
Soil Order	Brown soil
Soil Series	Greytown
Soil Type	Greytown silt loam and stony loam
Drainage Class	3 (Imperfectly drained)

Horizon	Depth	Matrix/ Colour	Texture	Stickiness	Gravel Abundance	Gravel Size	Lower Boundary	Mottles Abundance	Mottles Size	Mottles Colour	NAF	Notes
Ap	0-26	10YR5/2	lz	ss	vs	f-m	ind/smth	Ap	vf	f	7.5YR5/6	-ve
Bg	26-57	10YR6/3	lz	ss	vs	f-m	dis/smth	Bg	c	m	7.5YR5/6	-ve
Bw(g)	57-120	10YR5/4	zl	s	s	f-m	ind/smth	Bw(g)	a	c	7.5YR7/1+7.5YR5/6	
C	120-		gravel		vg	f-c		C				

Appendix 2: Sampling and analytical methods

Surface water and groundwater quality

Surface water and groundwater quality sampling methods are outlined in Sections 4.2.1 and 5.2 of the report respectively. Analytical methods are summarised in Table A2.1.

Table A2.1: Surface water and groundwater analytical methods

Variable	Method	Detection limit
Temperature	Field meter –YSI 556 , WTW P4 Multiline and WTW350i Meters	0.01 ˚C
Dissolved oxygen	Field meter –YSI 556 , WTW P4 Multiline and WTW350i Meters	0.01 mg/L
Electrical conductivity	Field meter –YSI 556 , WTW P4 Multiline and WTW350i Meters	0.1 µS/cm
pH	Field meter – YSI 556 , WTW P4 Multiline and WTW350i Meters	0.01 units
Visual clarity[1]	Black disc	0.01 m
Turbidity	Analysis using a Hach 2100N, Turbidity meter. APHA 2130 B 21st ed. 2005	0.05 NTU
pH (lab)	pH meter APHA 4500-H+ B 21st ed. 2005.	0.1 pH units
Electrical conductivity (lab)	Conductivity meter, 25°C APHA 2510 B 21st ed. 2005.	0.1 mS/m, 1 µS/cm
Total alkalinity	Titration to pH 4.5 (M-alkalinity), Radiometer autotitrator. APHA 2320 B (Modified for alk <20) 21st ed. 2005.	1 mg/L as $CaCO_3$
Bicarbonate	Calculation: from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates. APHA 4500-CO2 D 21st ed. 2005.	1 mg/L at 25°C
Total suspended solids[2]	Gravimetric. APHA 2540 D 21st ed. 2005.	2 mg/L
Dissolved calcium	Filtered sample, ICP-MS APHA 3125 B 21st ed. 2005.	0.05 mg/L
Dissolved magnesium	Filtered sample, ICP-MS APHA 3125 B 21st ed. 2005.	0.02 mg/L
Total hardness	Calculation: from Dissolved Ca and Dissolved Mg APHA 2340 B 21st ed. 2005.	1 mg/L as $CaCO_3$
Dissolved sodium	Filtered sample, ICP-MS APHA 3125 B 21st ed. 2005.	0.02 mg/L
Dissolved potassium	Filtered sample, ICP-MS APHA 3125 B 21st ed. 2005.	0.05 mg/L
Ammoniacal nitrogen	Filtered sample. Phenol/hypochlorite colorimetry. Discrete Analyser. (NH_4-N = NH_4+-N + NH_3-N) APHA 4500-NH_3 F (modified from manual analysis) 21st ed. 2005.	0.01 mg/L
Total Kjeldahl nitrogen	Kjeldahl digestion, phenol/hyperclorite colorimetry (Discrete Analysis). APHA 4500-Norg C. (modified) 4500- F (modified) 21st ed. 2005	0.1 mg/L
Nitrate-N + Nitrite-N (NNN)	Total oxidised nitrogen. Automated cadmium reduction, Flow injection analyser. APHA 4500-NO3 - I (modified) 21sted. 2005.	0.002 mg/L
Nitrate-N	Calculation: (Nitrate-N + Nitrite-N) - Nitrite-N.	0.002 mg/L
Nitrite-N	Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO3 - I (modified) 21st ed. 2005.	0.002 mg/L
Dissolved inorganic nitrogen (DIN)	Calculation: NH_4-N + NO_3-N + NO_2-N.	
Total nitrogen	Calculation: TKN + Nitrate-N +Nitrite-N	0.1 mg/L
Dissolved reactive phosphorus	Filtered sample. Molybdenum blue colorimetry. Discrete Analyser. APHA 4500-P E (modified from manual analysis) 21st ed. 2005.	0.004 mg/L
Total phosphorus	Total Phosphorus digestion, ascorbic acid colorimetry. Discrete Analyser. APHA 4500-P E (modified from manual analysis) 21st ed. 2005	0.004 mg/L
Chloride	Filtered sample. Ferric thiocyanate colorimetry. Discrete Analyser. APHA 4500-Cl-E (modified from continuous-flow analysis) 21st ed. 2005.	0.5 mg/L
Fluoride	Ion selective electrode APHA 4500-F- C 21st ed. 2005.	0.05 mg/L
Sulphate	Filtered sample. Ion Chromatography. APHA 4110 B 21st ed. 2005.	0.5 mg/L
Total organic carbon (TOC)	Catalytic oxidation, IR detection, for Total C. Acidification, purging for Total Inorganic C. TOC = TC -TIC. APHA 5310 B (modified) 21st ed. 2005.	0.05 mg/L
Total anions	Calculation: sum of anions as mEquiv/L [Includes Alk, Cl, NO_xN & SO_4]	0.07 mEquiv/L
Total cations	Calculation: sum of cations as mEquiv/L [Includes Ca, Mg, Na, K, Fe, Mn, Zn & NH_4N].	0.06 mEquiv/L

Table A2.1 *cont.*: Surface water and groundwater analytical methods

Variable	Method	Detection limit
% Difference in ion balance	Calculation from Sum of Anions and Cations APHA 1030 E 21st ed. 2005.	0.1 %
E. coli	APHA 21st Ed. Method 9222 G. (tested at both Hill Laboratories and ELS)	1 cfu/100 mL
E. coli [3]	MPN count in LT Broth at 35°C for 48 hours, EC MUG Broth at 44.5°C for 24 hours. APHA 9221 B, 9221 F 21st ed. 2005.	2 MPN/100 mL
Dissolved aluminium	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.0030 mg/L
Dissolved arsenic	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.001 mg/L
Dissolved boron	Filtered sample. ICP-MS APHA 3125 B 21st ed. 2005.	0.005 mg/L
Dissolved cadmium	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.00005 mg/L
Dissolved chromium	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.0005 mg/L
Dissolved copper	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.0005 mg/L
Dissolved nickel	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.0005 mg/L
Dissolved iron	Filtered sample. ICP-MS APHA 3125 B 21st ed. 2005.	0.02 mg/L
Dissolved manganese	Filtered sample. ICP-MS APHA 3125 B 21st ed. 2005.	0.0005 mg/L
Dissolved lead	Filtered sample. ICP-MS APHA 3125 B 21st ed. 2005.	0.0001 mg/L
Dissolved zinc	Filtered sample. ICP-MS APHA 3125 B 21st ed. 2005.	0.001 mg/L

[1] Measured at surface water sites only.
[2] Tested in surface water samples only.
[3] Only used for turbid groundwater samples where membrane filtration was not possible.

Stream flow measurement

Of the eight surface water sites where gaugings were routinely undertaken to determine flow, only the Carrington Water Race at Belvedere Road could be gauged on every sampling occasion. On two sampling occasions (in May and August 2009) high flows meant that gaugings were not possible at the other sites. Therefore, in order to calculate nutrient loads for the May and August 2009 sampling events (see Section 4.4.3 of the report), flow at these sites was estimated using correlations with known flows at rated flow sites in the catchment.

Greater Wellington records flow continuously at both the Mangatarere Stream at Gorge and Mangatarere Stream at Belvedere Road. Therefore, flow records exist for May and August 2009 at these sites and were able to be used to estimate flows at two other sampling sites on the Mangatarere Stream (at Andersons Line and Dalefield Road). For the sampling site located at Andersons Line it was considered appropriate to use the flow recorded downstream at Belvedere Road as there are no major tributary inputs between these two sites and at higher flows interactions with groundwater are unlikely to be a significant factor affecting flow. For the Dalefield Road site, flow was also estimated from the continuous flow site at Belvedere Road (located upstream of Dalefield Road) and a rated flow site located downstream at SH 2, that was being established at the time of this investigation. While estimating the flow at Dalefield Road, consideration was also given to the discharges that could be occurring from significant tributaries (e.g., Enaki Stream which discharges into the Mangatarere Stream upstream of Dalefield Road). Estimated flows for the May and August 2009 sampling occasions, along with gauged or estimated flows for all other sampling occasions, are provided in Appendix 4.

No rated flow sites exist on any of the three main tributaries sampled during this investigation. Consequently, flows were estimated at these sites for the May and August 2009 sampling occasions by deriving linear correlations using existing gaugings at each site and continuous flow records from the Mangatarere Stream at Gorge (e.g., Figure A2.1). While correlations generally showed a reasonable fit between gauged flows and continuous flow measurements it is important to note that correlations were derived from a limited number of gaugings (n=10) and that all gaugings were carried out at wadeable flows. As such, the accuracy of these correlations for estimating higher flows is not known. Correlations used to estimate flows at each site are listed in Table A2.2 and the estimated flows are provided in Appendix 4.

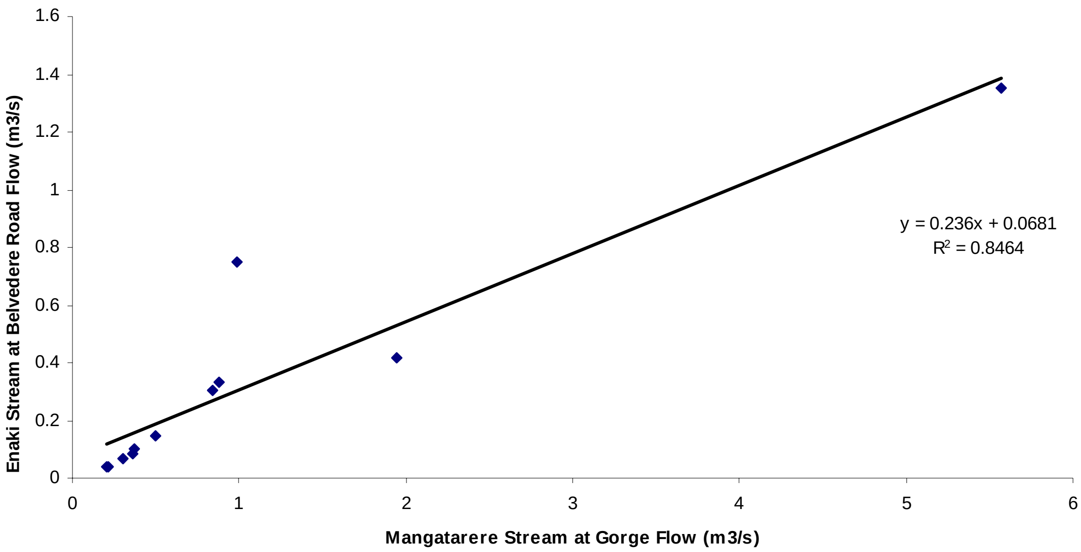

Figure A2.1: Relationship between gauged flow in the Enaki Stream at Belvedere Road and rated flow in the Mangatarere Stream at Gorge

Table A2.2: Correlations based on gaugings at each site (n=10) and rated flow in the Mangatarere Stream at Gorge

Site	Flow correlation	R^2
Hinau Stream at Hinau Gully Rd	y = 0.2196x + 0.0195	0.66
Enaki Stream at Belvedere Rd	y = 0.236x + 0.0681	0.85
Enaki Stream u/s of Mang. conf.	y = 0.4858x - 0.0863	0.85
Kaipaitangata Stream at Dalefield Rd	y = 0.1397x + 0.0437	0.48
Beef Creek at SH 2	y = 0.6757x + 0.0222	0.63

Long-term SoE surface water quality sites

Temporal trend analysis (see Section 7 of the report) involved assessment of trends in both raw and flow-adjusted water quality data. However, flow records were only available for two of the five long-term water quality sites assessed in this investigation: Waiohine River at Gorge (continuous flow recorder) and Enaki Stream upstream of the Mangatarere confluence (flow gauged at the time of sampling[42]). Very little flow information exists for the upper reaches of Beef Creek and so no there was no flow-adjustment of water quality data from the Beef Creek at Headwaters site. For both the Waiohine River at Bicknells and the Mangatarere Stream at SH 2, correlations were derived with continuous flow recorders located upstream to enable flow-adjusted temporal trend analysis. The following equations were used:

- Bicknells site: Waiohine River at Gorge flow x 1.3384 – 1.94
- SH 2 site: Mangatarere Stream at Gorge flow x 2.8513 – 0.2021.

[42] Since 2008 flow has been correlated with a continuous flow recorded located at the Mangatarere Stream at Gorge.

Periphyton sampling methods

Monthly assessment of visible streambed cover

Periphyton cover was determined by estimating the percentage of visible mats (>0.3 cm thick) and filaments (>2 cm long) present on the stream or river bed within a 20 cm diameter metal ring. Ten observations were made across the width of the stream or river, along a transect. If the stream or river was not wide enough for 10 observations, five observations were made across the width of the waterway in two locations at the site. Two transects of five observations (usually to 0.6 m depth) were also used where it was not possible to wade across more than half of the river's width.

Visible streambed assessments were typically carried out in a run, as opposed to riffle or pool-type habitats.

One-off assessment of biomass

Periphyton samples for quantitative biomass assessments (chlorophyll *a* and AFDM) were collected in February 2009 at the time of macroinvertebrate sample collection and in close proximity to macroinvertebrate sampling sites. Sampling protocols generally followed the quantitative method 1a (QM-1a outlined in the stream periphyton monitoring manual (Biggs & Kilroy 2000). However, five rocks instead of the recommended ten were assessed from each transect. Samples were collected from both riffle-type and run-type habitats. At least one sample was collected from each habitat type at each site; at six sites two replicate samples were collected from each habitat type to better quantify biomass variation at a reach scale.

Macroinvertebrate sampling methods

Macroinvertebrate samples were collected from cobbly riffle areas at or adjacent to each water sampling site in February 2009. Sampling was undertaken during a period of stable flows (i.e., at least two weeks since a flood event). Flood events were defined as flows greater than three times the median river flow.

Samples were collected with the use of a kick-net (250 um mesh size) following Protocol C1 of the national macroinvertebrate sampling protocols (Stark et al. 2001). All samples were processed in accordance with protocol P2 (Stark et al. 2001).

Soil quality

Soil sampling methods are outlined in Section 6.2 of the report. Sample analysis was undertaken at the Landcare Research soil chemistry and soil physics laboratories in Palmerston North (the exception being trace element analysis which was undertaken at Hill Laboratories in Hamilton). Where necessary, samples were stored at 4°C until analysis. Analytical methods are summarised in Table A2.3.

Table A2.3: Soil sample analytical methods

Indicator	Method
Bulk density	Measured on a sub-sampled core dried at 105°C.
Macroporosity	Determined by drainage on pressure plates at –10 kPa.
Total C content	Dry combustion method. Using air-dried, finely ground soils using a Leco 2000 CNS analyser.
Total N content	Dry combustion method. Using air-dried, finely ground soils using a Leco 2000 CNS analyser.
Mineralisable N	Waterlogged incubation method. Increase in NH_4^+ concentration was measured after incubation for 7 days at 40°C and extraction in 2M KCl.
Soil pH	Measured in water using glass electrodes and a 2.5:1 water-to-soil ratio.
Olsen P	Bicarbonate extraction method. Extracting <2 mm air dried soils for 30 mins with 0.5M $NaHCO_3$ at pH 8.5 and measuring the PO_4^{3-} concentration by the molybdenum blue method.
Trace elements	Total recoverable digestion. Nitric/hydrochloric acid digestion, USEPA 200.2.

Appendix 3: Guideline values

Table A3.1 lists the key water quality and biological variables examined in the Mangatarere catchment investigation and provides a brief explanation of their relevance from a surface water quality perspective.

Table A3.1: Key water quality and biological variables examined in the Mangatarere catchment investigation

Variable	Explanation/relevance
Water temperature	• Indicator of biological activity – temperature affects the functioning of aquatic ecosystems and the physiology of biota, including cell function, enzyme activity, bacteriological reproduction rates, and plant growth rates. • Requirement for aquatic life (e.g., temperatures >19°C can stress trout). • Influences dissolved oxygen concentrations (the higher the temperature, the lower the oxygen concentration) and can affect the toxicity of certain pollutants such as ammonia.
Dissolved oxygen (DO)	• Essential for aquatic life – concentrations less than 5 mg/L adversely affect trout and concentrations of 2-3 mg/L may result in fish kills. • Indicator of organic pollution (e.g., sewage) – DO concentrations are reduced as bacteria require oxygen to break organic matter down. • Indicator of photosynthesis (plant growth).
pH	• Protection of aquatic life – particularly high (alkaline) or low (acidic) pH levels may adversely impact on aquatic biota. Alkaline conditions may also increase the toxicity of certain pollutants such as ammonia. • Indicator of industrial discharges.
Conductivity	• Indicator of total salts/mineral content – the lower the value, the purer the water is. Wastewater/effluents therefore have higher concentrations of minerals than natural water and a large increase in the conductivity in a water body can often be traced back to wastewater discharges.
Visual clarity, turbidity and suspended solids	• Aesthetic appearance. • Aquatic life protection – differences in water clarity affect the ability of sight-feeding predators (e.g., fish, birds) to locate prey and the ability of algae to photosynthesise and hence provide food for animals further up the food chain. • Indicator of light availability for excessive plant growth. • Indicator of catchment condition, land use. • Suspended sediment in the water column can clog the gills of invertebrates and fish. • Excessive deposition of sediment on the streambed can block and seal off interstitial spaces (the spaces between cobbles/stones where most fauna live or rest), reduce water flow to the hyporheic zone (water under the streambed) where some stream animals live, degrade fish spawning habitat and encourage the growth of nuisance aquatic plants.
Total organic carbon	• Indicator of organic carbon content of a water body – provides a quick and convenient way of determining the degree of organic contamination (e.g., as a result of wastewater discharges).

Table A3.1 *cont.*: Key water quality and biological variables examined in the Mangatarere catchment investigation

Variable	Explanation/relevance
Nutrients • Nitrogen • Phosphorus	• Vital elements for aquatic plant and algal growth – may be limiting factors in plant growth when in short supply but in sufficient quantities they may also promote unsightly algal blooms and nuisance plant growth. Dissolved inorganic nutrient concentrations (ammoniacal nitrogen, nitrite-nitrate nitrogen and dissolved reactive phosphorus) are most relevant for predicting the potential for nuisance plant growth as they are the principal forms available to plants (i.e., soluble). Total nutrient concentrations are also relevant in surface waters, because particulate matter can settle out in quiescent areas and become biologically available to plants via mineralisation. • Nitrate is harmful to livestock and humans in sufficient concentrations. • Ammoniacal nitrogen comprises ammonium (NH_{4+}) and unionised ammonia (NH_3). Ammonia is rarely found in any significant amounts in natural waters and its presence most commonly indicates the presence of domestic, agricultural or industrial effluent. Ammonia is very soluble in water and can be toxic to aquatic life, especially fish. Toxicity is a function of both temperature and pH, with toxicity increasing with increasing water temperature and alkalinity.
E. coli	• Indicator of pollution with faecal matter, useful for determining the suitability of waters for contact recreation and stock drinking – presence in water may indicate the presence of harmful pathogens that can cause eye, ear, nose and throat infections, skin diseases, and gastrointestinal disorders – a number of parasites and pathogens can also be transmitted by contaminated water to livestock and affect their health. • *E. coli* is the most specific indicator of faecal contamination and is nearly always found in high numbers in the gut of humans and warm blooded animals. *E. coli* is the preferred microbiological indicator for faecal contamination and health effects in fresh waters.
Periphyton	• Periphyton is the slimy material attached to the surfaces of rocks and other bottom substrate in rivers and streams. It comprises algae, diatoms, bacteria, and fungi and plays a key role in aquatic food webs because it is the main source of food for benthic invertebrates, which in turn are an important food source for fish. • Excessive periphyton growths may block intake screens for water supply, and reduce the aesthetic, recreational and ecosystem values of rivers and streams.
Macroinvertebrates	• Macroinvertebrates are organisms that lack a backbone and are larger than 250 microns in size. Four major groups of macroinvertebrates exist: *insects* such as mayflies, caddisflies and dragonflies; *molluscs* such as snails and mussels; *crustaceans* such as freshwater shrimps and amphipods; and *oligochaetes*, aquatic worm species that live in muddy streambeds. • Different macroinvertebrate species have different tolerances to environmental factors such as dissolved oxygen, nutrients and fine sediment, such that the presence or absence of different species in an environment may indicate changes in water quality. • Macroinvertebrates indicate long-term water quality conditions compared with spot physico-chemical samples which only represent water quality at time of sampling.

Surface water quality guidelines

The physico-chemical and microbiological water quality variables and guidelines (where applicable/available) considered in the assessment of surface water quality state are outlined in Tables A3.2 and A3.3. As noted in Section 4.3.1 of the report, the ANZECC (2000) "default trigger values" for lowland aquatic ecosystems – and the trigger values for irrigation and stockwater – are intended to be compared against the *median* value from independent samples at a site. They are not legal standards and breaches of these values do not necessarily mean an adverse environmental effect would result. Rather, they can be considered "nominal thresholds" (Ballantine et al. 2010), where a breach is an 'early warning' mechanism to alert resource managers to a potential problem or emerging change that *may* warrant site-specific investigation or remedial action (ANZECC 2000).

In the case of the ANZECC (2000) toxicant trigger values (Table A3.3), it is considered appropriate to compare single sample results against these values. In this report, dissolved toxicant concentrations have been compared.

Table A3.2: Physico-chemical (excluding toxicant) and microbiological guideline values used in this report

Variable	Guideline value	Reference and purpose
Water temperature (ºC)	≤19	See text below - aquatic life
Dissolved oxygen (% saturation)	≥80	RMA 1991 Third Schedule
pH	6.5-9.0	ANZECC (1992) – aquatic ecosystems
Conductivity (µS/cm)	–	–
Visual clarity (m)	≥1.6	MfE (1994) – contact recreation
Turbidity (NTU)	≤5.6	ANZECC & ARMCANZ (2000) – aquatic ecosystems
Total organic carbon (mg/L)	–	–
Nitrite-nitrate nitrogen (mg/L)	≤0.444	ANZECC & ARMCANZ (2000) – aquatic ecosystems
Ammoniacal nitrogen (mg/L)	≤0.021	ANZECC & ARMCANZ (2000) – aquatic ecosystems
Total Kjeldahl nitrogen (mg/L)	–	–
Total nitrogen (mg/L)	≤0.614	ANZECC & ARMCANZ (2000) – aquatic ecosystems
Dissolved reactive phosphorus (mg/L)	≤0.010	ANZECC & ARMCANZ (2000) – aquatic ecosystems
Total phosphorus (mg/L)	≤0.033	ANZECC & ARMCANZ (2000) – aquatic ecosystems
E. coli (cfu/100 mL)	≤100	ANZECC & ARMCANZ (2000) – stockwater
	550	MfE/MoH (2003) – contact recreation

Key points to note in relation to the guidelines in Table A3.2:

- There are no formal guidelines for water temperature, but temperatures above 19^{o}C are likely to cause behavioural disturbance of trout, such as cessation of feeding (Hay et al. 2007) and may exclude some sensitive macroinvertebrate species such as stoneflies (Quinn and Hickey 1990). Greater Wellington's Regional Freshwater Plan (WRC 1999) has a requirement that water temperatures at fresh water sites managed for trout fishery and spawning values should not exceed 25^{o}C.

- The dissolved oxygen guideline is the "bottom line" value in the Third Schedule of the RMA 1991; the ANZECC (2000) default trigger values (98 to 105% for lowland waters) are considered overly stringent.

- The guideline range for pH is from the ANZECC (1992) water quality guidelines because the default trigger values quoted in the 2000 guidelines (pH 7.2 to 7.8 for lowland waters) are considered overly stringent.
- The MfE (1994) guideline for visual clarity is used (bathing waters) in this report; the ANZECC (2000) lowland trigger value is considered erroneous (see Milne & Perrie 2005).
- The ammoniacal nitrogen guideline used here is a typical benchmark value for lowland waterways and does not relate to the toxicity of ammonia to aquatic life (toxicity depends on water temperature and pH). Toxicity was assessed where needed (i.e., where concentrations were elevated) using the ANZECC (2000) toxicity trigger value relating to 95% species protection level and taking into account site-specific pH.

Table A3.3: ANZECC (2000) freshwater trigger values for selected toxicants in relation to protection of aquatic life (95% species protection level), stock drinking water and irrigation water. Dissolved concentrations were compared against these trigger values.

Variable	Aquatic toxicity (mg/L)	Stock drinking water (mg/L)	Irrigation water (mg/L)
Aluminium (@ pH >6.5)	0.055	5	20
Arsenic	0.013	0.5	2
Boron[1]	0.37	5	-
Cadmium	0.0002	0.01	0.05
Calcium	-	1,000	-
Chloride	-	-	175
Chromium	0.001	1	1
Copper[2]	0.0014	0.4	5
Lead	0.0034	0.1	5
Magnesium	-	2,000	-
Manganese	1.9	-	10
Nickel	0.011	1	2
Sodium	-	-	115
Sulphate	-	1,000	-
Zinc[2]	0.008	20	5

[1] Note that Fitzpatrick (2008)[43] has suggested the ANZECC (2000) trigger values for boron and zinc may be overly conservative.

[2] The stock drinking water trigger value used in this report is for sheep which are more sensitive to copper than other stock types.

Key points to note in relation to the guidelines in Table A3.3:

- The ANZECC (2000) guidelines provide a range of toxicity trigger values depending on the level of protection required. The toxicity trigger values used in this report apply to slightly to moderately disturbed (i.e., modified) systems and are expected to provide protection for 95% of the species present. Where a toxicant may occur as two "species" (e.g., arsenic (lll) or arsenic (V)) and have species-specific trigger values, the more stringent value was used to provide for protection in the 'worst case' scenario that the more toxic species is present.

[43] Fitzpatrick, M. 2008. A review of the ANZECC 2000 trigger values for zinc. In *Proceedings of the New Zealand Water & Waste Association Stormwater Conference*, Rotorua, New Zealand, 15-16 May 2008.

- Because water hardness affects the toxicity of some metals (cadmium, chromium, copper, lead, nickel and zinc), ANZECC (2000) recommends that exceedence of a trigger value should lead to the calculation of site-specific trigger values that incorporate local water hardness conditions. This was not necessary in this report as no heavy metal concentrations exceeded the trigger values in Table A3.3.

- The irrigation water guidelines in Table A3.3 refer to the ANZECC (2000) short-term trigger values (i.e., maximum concentration of contaminant that can be tolerated over a 20-year period of consistent application of irrigation water). These guidelines provide for the protection of direct toxicity to crops as well as the build-up of contaminants in surface soils. The stock drinking water guidelines set a threshold below which there is thought to be minimal risk of toxic effects.

Surface water quality index

Greater Wellington uses a water quality index (WQI) to facilitate inter-site comparisons of the state of water quality in the region's rivers and streams. The WQI is derived from the *median* values of the following six variables: visual clarity (black disc), dissolved oxygen (% saturation), dissolved reactive phosphorus, ammoniacal nitrogen, nitrite-nitrate nitrogen and *E. coli*.

The application of the WQI enables water quality at a site to be classified into one of four categories as follows:

- Excellent: median values for all 6 variables comply with guideline values
- Good: median values for 5 of the 6 variables comply with guideline values, of which dissolved oxygen is one variable that must comply
- Fair: median values for 3 or 4 of the 6 variables comply with guideline values, of which dissolved oxygen is one variable that must comply
- Poor: median values for <3 of the 6 variables comply with guideline values.

Sites with a grade of good, fair or poor represent *degraded* sites as the median value of at least one of the six key water quality variables does not comply with guideline values. The degree of degradation is relative, with good sites having the least degraded water quality and poor sites the most degraded water quality.

Periphyton guidelines

The Ministry for the Environment (MfE 2000) periphyton guidelines were used to assess streambed cover and biomass (Table A3.4).

Table A3.4: Guidelines used to assess periphyton streambed cover and biomass (MfE 2000)

Instream value/variable	Mat periphyton	Filamentous periphyton
Aesthetics/recreation		
Maximum cover of visible streambed	60% >0.3 cm thick	30% >2 cm long
Benthic biodiversity		
Maximum chlorophyll *a*	50 mg/m^2	50 mg/m^2
Trout habitat and angling		
Maximum cover of visible streambed	N/A	30% >2 cm long

Macroinvertebrate guidelines

Macroinvertebrate "guidelines" – as an indicator of macroinvertebrate community health and water quality – exist in the form of various biotic indices that have been developed over the last 10 to 20 years (Table A3.5). These indices are based on the number, type and abundance of macroinvertebrate taxa present at a monitoring site.

Table A3.5: Macroinvertebrate indices

Index	Definition	Quality class
Macroinvertebrate Community Index (MCI)	An index of sensitivity to organic pollution, based on the presence/ absence of macroinvertebrate taxa.	- Excellent: >119 - Good: 100-119 - Fair: 80-99 - Poor: <80 (Source: Stark & Maxted 2007)
Quantitative MCI (QMCI)	Similar to the MCI, but also incorporates the relative abundance of the macroinvertebrate taxa present.	- Excellent: >6 - Good: 5-6 - Fair: 4-5 - Poor: <4 (Source: Stark & Maxted 2007)
% Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa	The number of pollution-sensitive Ephemeroptera (mayfly), Plecoptera (stonefly) and Trichoptera* (caddisfly) taxa present, expressed as a percentage of total taxa richness. * excludes *Oxyethira* and *Paroxyethira* which are relatively insensitive to pollution	There are no commonly used "thresholds" for EPT although higher proportions of EPT taxa reflect "healthier" macroinvertebrate communities.

Groundwater quality guidelines

Groundwater sample results were compared against the Drinking-water Standard for New Zealand (DWSNZ 2005) maximum acceptable values (Table A3.6) and guideline values (Table A3.7). As explained in Section 5.3 of the report, nutrient concentrations and *E. coli* counts were also compared against the ANZECC (2000) lowland trigger values for aquatic ecosystems (refer Table A3.2).

Table A3.6: Drinking-water Standard for New Zealand (DWSNZ 2005) maximum acceptable values (MAVs) for selected inorganic determinands of health significance

Variable	MAV (mg/L)	Comment
Arsenic	0.01	For excess lifetime skin cancer risk of 6 x 10^{-4}. Provisional MAV (because of analytical difficulties)
Boron	1.4	WHO (2004) guideline Provisional MAV is 0.5 mg/L.
Cadmium	0.004	
Chromium	0.05	Provisional MAV. Total. Limited information on health effects
Copper	2	May affect the water's appearance, taste or odour.
Fluoride	1.5	For oral health reasons the Ministry of Health recommends that the fluoride content for drinking-water in New Zealand be in the range of 0.7-1.0 mg/L
Lead	0.01	
Manganese	0.4	May affect the water's appearance, taste or odour.
Nickel	0.02	Provisional MAV.

Table A3.6 *cont.*: Drinking-water Standard for New Zealand (DWSNZ 2005) maximum acceptable values (MAVs) for selected inorganic determinands of health significance

Variable	MAV (mg/L)	Comment
Nitrate, short-term[1]	50	Expressed in mg/L as NO_3. The sum of the ratio of the concentrations of nitrate and nitrite to each of their respective MAVs should not exceed 1 mg/L.
Nitrite, long-term	0.2	Expressed in mg/L as NO_2. Provisional MAV (long-term)
Nitrite, short-term[1]	3	Expressed in mg/L as NO_2. The sum of the ratio of the concentrations of nitrate and nitrite to each of their respective MAVs should not exceed 1 mg/L.
Escherichia coli (*E. coli*)	<1	Expressed in counts per 100 mL of sample. This is a MAV for regulatory purposes. It does not represent a dose/response relationship that can be used as the basis for determining acceptable concentrations of pathogens in drinking-water.

[1] Now short-term only. The short-term exposure MAVs for nitrate and nitrite have been established to protect against methaemoglobinaemia in bottle-fed infants.

Table A3.7: Drinking-water Standard for New Zealand (DWSNZ 2005) guideline values (GVs) for selected aesthetic determinands

Determinand	GV	Units	Comments
Aluminium	0.1	mg/L	Above this, complaints may arise due to deposition or discolouration.
Calcium			See hardness.
Chloride	250	mg/L	Taste, corrosion.
Copper	1	mg/L	Staining of laundry and sanitary ware.
Hardness (Total)	200	mg/L	High hardness causes scale deposition, scum formation. Low hardness (<100) may be more corrosive.
(Ca + Mg) as $CaCO_3$	100–300		Taste threshold.
Iron	0.2	mg/L	Staining of laundry and sanitary ware.
Magnesium			See hardness.
Manganese	0.04	mg/L	Staining of laundry.
	0.1		Taste threshold (MAV 0.4 mg/L)
pH	7.0–8.5		Should be between 7.0 and 8.0. Most waters with a low pH have a high plumbosolvency. Waters with a high pH: have a soapy taste and feel. Preferably pH <8 for effective disinfection with chlorine.
Sodium	200		Taste threshold.
Sulphate	250	mg/L	Taste threshold.
Turbidity	2.5	NTU	Appearance. For effective terminal disinfection, median turbidity <1 NTU, single sample <5 NTU.
Zinc	1.5	mg/L	Taste threshold. May affect appearance from 3 mg/L.

Soil quality guidelines

Soil quality indicator target (or optimal) ranges from Hill and Sparling (2009) are outlined in the tables below, along with guideline values for trace element concentrations in soil, adapted from NZWWA (2003)

Bulk density target ranges (t/m^3 or Mg/m^3)

	Very loose	Loose	Adequate	Compact	Very compact	
Semi-arid, Pallic and Recent soils	0.3	0.4	0.9	1.25	1.4	1.6
Allophanic soils		0.3	0.6	0.9	1.3	
Organic soils		0.2	0.4	0.6	1.0	
All other soils	0.3	0.7	0.8	1.2	1.4	1.6

Macroporosity target ranges (% @ -10 kPa)

	Very low	Low	Adequate	High	
Pastures, cropping and horticulture	0	6	10[1]	30	40
Forestry	0	8	10	30	40

Total carbon target ranges (% w/w)

	Very depleted	Depleted	Normal	Ample	
Allophanic	0.5	3	4	9	12
Semi-arid, Pallic and Recent	0	2	3	5	12
Organic	exclusion				
All other Soil Orders	0.5	2.5	3.5	7	12

Total nitrogen target ranges (% w/w)

	Very depleted	Depleted	Normal	Ample	High	
Pasture	0	0.25	0.35	0.65	0.70	1.0
Forestry	0	0.10	0.20	0.60	0.70	
Cropping and horticulture	exclusion					

Mineralisable nitrogen target ranges (mg/kg)

	Very low	Low	Adequate	Ample	High	Excessive	
Pasture	25	50	100	200	200	250	300
Forestry	5	20	40	120	150	175	200
Cropping and horticulture	5	20	100	150	150	200	225

Soil pH target ranges

	Very acid	Slightly acid	Optimal	Sub-optimal	Very alkaline	
Pastures on all soils except Organic	4	5	5.5	6.3	6.6	8.5
Pastures on Organic soils	4	4.5	5	6	7.0	
Cropping and horticulture on all soils except Organic	4	5	5.5	7.2	7.6	8.5
Cropping and horticulture on Organic soils	4	4.5	5	7	7.6	
Forestry on all soils except Organic		3.5	4	7	7.6	
Forestry on Organic soils	exclusion					

Olsen P target ranges (mg/kg)

	Very low	Low	Adequate	Ample	High	
Pasture on Sedimentary and Allophanic soils	0	15	20	50	100	200
Pasture on Pumice and Organic soils	0	15	35	60	100	200
Cropping and horticulture on Sedimentary and Allophanic soils	0	20	50	100	100	200
Cropping and horticulture on Pumice and Organic soils	0	25	60	100	100	200
Forestry on all Soil Orders	0	5	10	100	100	200

Guideline values for trace element concentrations in soil, adapted from NZWWA (2003)

Trace element	Soil limit (mg/kg)
Arsenic (As)	20
Cadmium (Cd)	1
Chromium (Cr)	600
Copper (Cu)	100
Lead (Pb)	300
Nickel (Ni)	60
Zinc (Zn)	300

Appendix 4: Surface water, groundwater and soil quality results

Refer to the CD inside the back cover of this report for tabulated analytical results of surface water, groundwater and soil quality samples collected during the catchment investigation (September 2008 to October 2009). Stream flow data and periphyton and macroinvertebrate data from one-off ecological sampling in February 2009 are also included on the CD.

Appendix 5: Surface water and groundwater temporal trend analysis

Refer to the CD inside the back cover of this report for tabulated results of temporal trend analysis performed on water quality data from Greater Wellington's long-term surface water and groundwater quality monitoring sites in the Mangatarere catchment. Macroinvertebrate trend analysis results are also included on the CD.

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