WAIWIRI STREAM:
SOURCES OF POOR WATER QUALITY AND IMPACTS ON THE COASTAL ENVIRONMENT

Manaaki Taha Moana

MTM Report No. 9
October 2012

WAIWIRI STREAM: SOURCES OF POOR WATER QUALITY AND IMPACTS ON THE COASTAL ENVIRONMENT

CRAIG ALLEN, JIM SINNER, JONATHAN BANKS, KATI DOEHRING
CAWTHRON INSTITUTE

WITH SPECIAL THANKS TO AND SUPPORT FROM KAITIAKI OF NGĀTI KIKOPIRI, NGĀTI HIKITANGA, NGĀTI TŪKOREHE AND MUA ŪPOKO TRIBAL AUTHORITY

Manaaki Taha Moana: Enhancing Coastal Ecosystems for Iwi and Hapū

ISBN 978-0-9876535-8-1
ISSN (Print) 2230-3332
ISSN (Online) 2230-3340

Published by the Manaaki Taha Moana Research Team
Funded by the Ministry for Science and Innovation
MAUX 0907 Contract Holder: Massey University
www.mtm.ac.nz

REVIEWED BY:
James Lambie
Science Coordinator
and Maree Clark
Senior Water Quality
Scientist

Horizons Regional
Council

APPROVED FOR RELEASE BY:
MTM Science Leader
Professor Murray Patterson

ISSUE DATE: 29 October 2012

RECOMMENDED CITATION: Allen C, Sinner J, Banks J, Doehring K 2012. Waiwiri Stream: Sources of Poor Water Quality and Impacts on the Coastal Environment. Manaaki Taha Moana Research Report No.9. Cawthron Report No. 2240. 48 p. plus appendices.

Mihi

Te ngākau pūaroha ki ngā ōhākī
‘E kore koe e ngaro- te kākano i ruia mai i Rangiātea Puritia! Puritia! Puritia!

E ngā atua Māori, mō ōu whakaaro pai mā a tātou, tēnā koutou.

E ngā mana, e ngā reo, e ngā iwi o te motu, tēnā koutou.
E ngā matāwaka, whītiki! Whītiki! Whītiki!
Te hunga ora ki te hunga ora, te hunga mate ki te hunga mate.

E kui mā, e koro mā a Ngāti Hikitanga, a Ngāti Kikopiri hoki, i te taha a te Mua Ūpoko Tribal Authority, kia koutou kua ū mai nei ki tēnei mahi nui, ki te atawhai, ki te manaaki i ngā taonga o te takiwā nei a Muhunoa, i tukua mai e ngā tūpuna, tēnā koutou.

E whaea mā, e matua mā, e ngā whānaunga katoa, e hoa mā, e kohikohi ana, e mahi tonu ana me te kaupapa nui mō Te Reo o Te Taiao, tēnā koutou.

Ko te tūmanako kia whakawhānuitia i ōu mātou tirohanga i roto i te whakatakotoranga kaupapa nei.

Nō reira, tēnā koutou, tēnā koutou, tēnā koutou katoa.

Published by the Manaaki Taha Moana Research Team
MAUX 0907 Contract Holder:
Massey University
Palmerston North
New Zealand

EXECUTIVE SUMMARY

In close collaboration with local tangata whenua , Manaaki Taha Moana (MTM) selected the poor water quality in the Waiwiri Stream as a priority for investigation. MTM is a six-year research programme, funded by the Ministry of Business Innovation & Employment, which aims to assist iwi, hapū and whānau to maintain and enhance coastal ecosystems of cultural significance.

Revered in recent memory by kaumātua as an abundant food resource, the coastal foreshore adjacent to the mouth of the Waiwiri Stream once provided local hapū and kaitiaki with a plentiful supply of shellfish, including toheroa. This is no longer the case today. Anecdotal evidence suggests that the stream has suffered severe ecological degradation in the past 35 years, reflecting the cumulative effects of loss of riparian vegetation, sedimentation, and increased nutrient and faecal loading.

Waiwiri Stream is in many ways typical of lowland streams in the case study area. It flows out of a shallow dune lake through land that has been highly modified for pastoral agriculture and, in some cases, for forestry and residential development. Pastoral land use is known to lead to such effects in lowland rivers around New Zealand, and is therefore one of the probable causes in the Waiwiri Stream. However, mandated kaitiaki have also expressed concern about the possible contribution of human faecal matter from 'The Pot', an artificial pond built on an area of elevated sand dunes approximately 300 m from the stream. The unlined pond receives secondary treated effluent via a pipe from the Levin Wastewater Treatment Plant. From The Pot, effluent either seeps into groundwater or is spray-irrigated onto surrounding pine forest at a rate of up to 20,000 m^3 per day. Effluent will also disperse via evaporation.

This report attempts to assess the influence of two land use practices on water quality in the Waiwiri catchment: pastoral land use and human effluent input from The Pot. It looks for evidence of a longitudinal decline in water quality by first interpreting historical data, before narrowing the focus to look for the presence and likely source of faecal contaminants. Historical water quality data from the catchment were assessed with reference to national and regionally specific water quality guidelines, which assess the risk posed to either aquatic ecosystems or human health (*e.g.* ANZECC 2000).

Historical data indicates that Waiwiri Stream is in a poor state of health, with total phosphorus, ammoniacal nitrogen, total nitrogen, dissolved reactive phosphorus, carbonaceous biological oxygen demand and faecal coliforms all above guideline values. Between Lake Waiwiri and the coastal mouth of Waiwiri Stream there is a longitudinal decline in some water quality parameters (*i.e.* total coliforms, nitrate and total dissolved solids). Since these parameters are not source specific, the decline may be due to pastoral land use, human effluent input from The Pot, or avian sources.

Microbial source tracking (MST) was used to link faecal contamination with host organisms to identify the dominant source of faecal contamination and determine if human faecal matter enters the stream. From a cultural perspective, any faecal matter (particularly human) anywhere in the stream is offensive regardless of whether there is ‘longitudinal decline’. The inability to manaaki (care for) guests with healthy, local delicacies at marae is a grave loss of mana or standing.

Non-host specific MST results indicate substantial faecal contamination in the stream as well as in shellfish collected at the mouth. High concentrations of ruminant faecal marker and the persistent presence of bovine faecal markers indicate that the dominant source of faecal contamination in the Waiwiri Stream is manure from cows. Ruminant marker concentrations were high at almost all stream sampling sites, but the highest densities were found in the stream, close to the point where it leaves the lake. Human markers were present in two of the 42 water tests and none of the six shellfish tests. These were found in water from a tributary that enters the stream from land surrounding The Pot. This indicates that water containing traces of human faecal matter, enters the Waiwiri Stream at this point. However, the evidence suggests that, relative to other sources, human sources are likely to be a minor contributor to faecal contamination in the stream.

Recommendations for restoration include:

- riparian fencing and planting
- improved management of effluent irrigation to land surrounding The Pot
- improvements to non-compliant agricultural practices
- continued management of populations of Canadian geese around the lake
- resumption of groundwater quality monitoring around The Pot.

This study has been carried out under the assumption that the health of shellfish populations at the stream mouth reflects water quality in the stream. It would be timely to investigate this further to see if shellfish abundance is affected by water quality in lowland streams and/or emergent groundwater.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

GLOSSARY

Term	Definition
ANZECC	Australia and New Zealand Environment and Conservation Council
cfu	Colony forming units
cm	Centimetre
DO	Dissolved oxygen
DRP	Dissolved reactive phosphorus
km	Kilometre
m	Metre or Metres
m^3/s	Cubic metres per second
MfE	Ministry for the Environment
mg/L	Milligrams per Litre (parts per million)
mL	Millilitre
mm	millimetres
MPN	Most probable number
N	Nitrogen
NIWA	National Institute of Water and Atmospheric Science
NO_3	Nitrate
NTU	Nephelometric turbidity unit
TN	Total nitrogen
TP	Total phosphorus
hapū	a number of related whānau groups; regarded as subtribe
iwi	In contemporary times it is important to note that separating whānau, hapū and iwi (tribe) has resulted in the creation of a hierarchical structure with iwi at the top, for ease of communication with government agencies, and to simplify policy making. *www.teara.govt.nz*
kaitiaki	Environmental guardian, protector
kaumātua	elders
mahinga kai	traditional food gathering places
mana	authority, respect, prestige
pā	fortified village
rohe	boundary, tribal area
tangata whenua	people of the land
taonga	Treasure
turangawaewae	Place where one has rights of residence and belonging through kinship and whakapapa.
urupā	cemetery
wāhi tapu	sacred place; areas ritualistically set aside from common usage
whānau	extended family, family group; whānau are part of hapū and iwi

1. INTRODUCTION

1.1. Background to the Manaaki Taha Moana (MTM) Project

This report is one in a series of reports and other outputs from the research programme "Enhancing Coastal Ecosystems for Iwi: Manaaki Taha Moana" (MAUX0907), funded by the Ministry of Business Innovation and Employment (including what was previously known as the Foundation for Research Science and Technology). Readers should refer to the MTM website for on-going updates: www.mtm.ac.nz.

Manaaki Taha Moana (MTM) is a six-year programme, running from October 2009 to September 2015, which aims to assist iwi to maintain and enhance coastal ecosystems of cultural significance. Research is conducted primarily in two areas; Tauranga moana and the Horowhenua coast. The Horowhenua case study area is the rohe of Ngāti Raukawa ki te Tonga (and other iwi affiliates including Ngāti Tūkorehe, Ngāti Wehiwehi and neighbouring tribe, Muaūpoko) which includes the stretch of coast between the Waitohu and Hokio Streams.

This programme builds on "Ecosystem Services Benefits in Terrestrial Ecosystems for Iwi" (MAUX0502), Massey's previous research with Ngāti Raukawa in the lower North Island.

1.1.1. MTM research team

A number of organisations are contracted to deliver the research:

- Te Manaaki Awanui Trust (previously Te Manaaki Taiao Trust and Waka Taiao Ltd); with the Tauranga moana case study
- Te Reo a Taiao Ngāti Raukawa Environmental Resource Unit (Taiao Raukawa) and Dr Huhana Smith; with the Horowhenua coast case study
- Waka Digital Ltd
- Cawthron Institute
- Massey University.

The research team also engages with local communities and end–users through a variety of means. More about the research programme can be found on the MTM programme website http://www.mtm.ac.nz.

1.1.2. MTM objectives

The central research question of MTM is, "How can we best enhance and restore the value and resilience of coastal ecosystems and their services, so that this makes a positive contribution to iwi and hapū identity, survival and welfare in the case study regions?" Thus, our research aims to restore and enhance coastal ecosystems and their services of importance to iwi and hapū, through a better knowledge of these ecosystems and the degradation processes that affect them.

We utilise both western science and mātauranga Māori knowledge to assist iwi, hapū and whānau groups along the coast to evaluate and define preferred options for enhancing/restoring coastal ecosystems. This evaluation of options will also be assisted by the development of innovative Information Technology and decision support tools (such as, for example, simulation modelling, interactive mapping, 3-D depiction, real-time monitoring) by Waka Digital Ltd. Action plans will be produced for improving coastal ecosystems in each rohe.

1.2. How this report fits into the broader MTM programme

The initial research activities for the first phase of MTM focussed on 'Building Up a Knowledge Base of Coastal Ecosystems and their Services', in both case study regions. In summary, we engaged in:

- Undertaking an ecological stocktake of what is already known about the state of coastal ecosystems in each rohe, including both Mātauranga Māori and western science knowledge.
- Creating a mediated model of Tauranga Harbour and the inter-relationships between the various factors that contribute to its health.
- Developing some information technology (IT) tools to help us capture and utilise this critical knowledge and information to bring about restoration to coastal ecosystems.

Collectively, these components helped inform the selection of case studies for more in-depth study and tool development in the current stage of MTM. Outputs from these research activities can be found at: http://www.mtm.ac.nz/knowledge_centre-publications.php

The culmination of the above activities helped inform our research team about what knowledge gaps exist regarding the state of the coastal ecosystems and their services in our case study areas, and what the most critical areas are for on-going investigation. Based on the conclusions of these stocktake exercises, in close collaboration with local tangata whenua, we are undertaking detailed case study research in both Tauranga Moana and the Horowhenua coast. This report details an investigation of sources of contaminants in Waiwiri Stream in the Horowhenua case study.

1.3. Background to Waiwiri Stream study

A major issue for tangata whenua in the coastal Horowhenua is a lack of mahinga kai: the inability to harvest from places that were once abundant food sources. The degradation and depletion of various coastal species, and the pollution of waterways that help to sustain them, has had significant negative impact on the wellbeing and mana of local iwi and hapū. Iwi are particularly interested in the restoration of coastal shellfish fisheries and the systems that maintain their health.

In close collaboration with local tangata whenua, identifying sources of poor water quality in Waiwiri Stream was selected as a priority for the MTM programme. Waiwiri Stream is in many ways typical of lowland streams in the case study area. It flows out of one of the shallow dune lakes through land that has been highly modified for pastoral agriculture and, in some cases, for forestry and residential development (Figure 1). However, it is also situated close to a wastewater disposal site, which has raised other concerns for iwi, as discussed below.

Figure 1. View of the Waiwiri Stream with access for grazing cattle (foreground) and the dunes that surround 'The Pot' (background).

Revered in recent memory by kaumātua and resource gathering kaitiaki as an abundant food resource, the coastal foreshore adjacent to the mouth of the Waiwiri Stream once provided local iwi and hapū with a plentiful supply of shellfish, including toheroa (pers. comm. Tipene Perawiti, local kaumātua, 2011). This is no longer the case.

This anecdotal evidence suggests that the stream has suffered severe ecological degradation in the past 35 years, reflecting the cumulative effects of loss of riparian vegetation, sedimentation, and increased nutrient and faecal loading. Agricultural land use is known to lead to such effects in lowland rivers around New Zealand (Parkyn & Wilcock 2004) and is therefore one of the likely causes in the Waiwiri Stream. Iwi have also expressed concern about the possible contribution of human faecal matter from 'The Pot'; part of Horowhenua District Council's Levin Wastewater Treatment Plant since 1986.

1.4. Aim of the study

This report assesses the influence of two land use practices on water quality in the Waiwiri catchment: pastoral land use and land disposal of human effluent from The Pot. It looks for evidence of a longitudinal decline in water quality (*i.e*. the progression downstream) by first interpreting historical data, and then by narrowing the focus to look for the presence and likely source of faecal contaminants. The research questions were:

- What do historical water quality data and reports show for the Waiwiri catchment and is there a longitudinal decline in water quality from Lake Waiwiri to the sea?
- Is there faecal contamination in the stream and if so, what is the likely source of contamination?
- Is there faecal contamination in shellfish harvested from areas around the stream mouth and if so, what is the likely source of contamination?

Ultimately, the aim of Manaaki Taha Moana is to rehabilitate habitat in the Waiwiri Stream to enable tangata whenua to once again realise the high cultural value of seasonal harvest of kai moana (specifically toheroa, tuatua and kahitua) and freshwater species such as tuna (eel).

1.5. Location and physical environment

The Waiwiri Stream is approximately 85 km north of Wellington on the west coast of the North Island (Figure 2). The soft bottomed stream features a low gradient single thread channel. It flows westward from Lake Waiwiri (more commonly known as Lake

Papaitonga), near Levin, for approximately 6 km to its coastal outlet just north of the Ōhau River mouth.

Land use in the 1,500 hectare Waiwiri catchment is dominated by high–producing exotic grassland (74%), associated mostly with dairy and beef farming. Pine forest covers approximately 13% of the catchment and native vegetation approximately 6%. The remaining 7% is mostly covered by lakes and coastal sand (Ministry for the Environment 2002).

The stream runs through an elongated coastal zone known as the Foxton Ecological District, which is characterised by sand dune country spanning approximately 1,100 km^2 (Ravine 1992). "The parabolic and transgressive dune field that extends from Paekakariki to Patea is the largest in New Zealand, extending approximately 200 km north to south and 18 km wide at its widest point (at Rangiotu)" (Hesp 2001).

The mean annual rainfall at Manakau, 7 km south of Lake Waiwiri, is 1,216 mm based on data for the period 1975-2011 (NIWA 2012a).

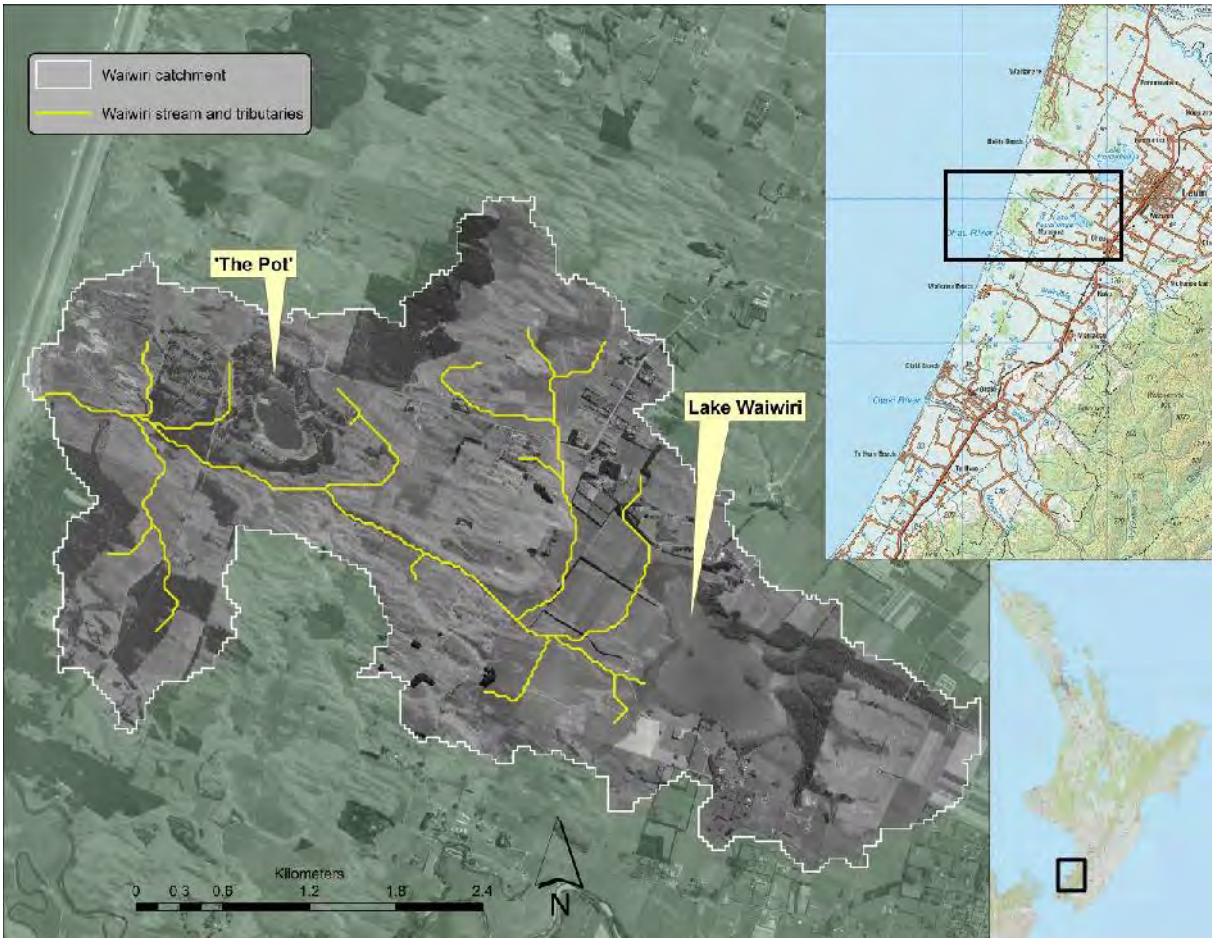


Figure 2. Location of Waiwiri Stream, 'The Pot', and Lake Waiwiri.

1.6. Significance of land and waters within the Waiwiri catchment

To Māori, tribal identity and the wellbeing of iwi, hapū and whānau are inextricably intertwined with the natural environment through cultural places, landforms, natural resources and taonga species (Cooper & Brooking 2002; Smith 2007). Traditionally, any ecosystems with particular species and associated habitat qualities were likely to have taonga status in the customary Māori landscape. "A swamp or coastal foreshore ecosystem that possessed such qualities, or a river ecosystem, or a forest, could be considered, with the people it sustained, to be a living being and be termed a 'taonga' (Park 2001)."

"Important Māori expressions of belonging or turangawaewae continue to emphasise ancestral connections and inter-generational responsibilities for lands, rivers, wetlands, healing springs and freshwater springs…" (Treadwell and Associates 2009).

On many occasions the lake and surrounding land was the scene of great warfare and bloodshed, particularly for Mua Ūpoko iwi. As a result, the lake (Figure 3) and stream have great mana and are home to highly significant wāhi tapu and pā sites that have high cultural and spiritual significance (pers. comm. Robert Warrington, Mua Ūpoko Tribal Authority, 21 July 2012; Treadwell & Associates 2009).

Lake Waiwiri, designated a regionally significant lake in Horizon's 'One Plan', is located within Papaitonga Scenic Reserve. The reserve is administered by the Department of Conservation (DOC) and is one of the oldest scenic reserves in New Zealand. Spanning 135 ha, the reserve contains the only intact wetland to dry terrace forest sequence in the Wellington and Horowhenua districts (Treadwell & Associates 2009). Forest surrounding the lake is typical of that which formerly covered the broader coastal plain. Rare wetland forest associations such as kahikatea / pukatea / tawa and pukatea / tawa / swamp maire can be found. The area provides habitat for a wide range of waterfowl, swamp and forest birds and is one of the largest regional habitats for the endangered New Zealand native land snail, *Powelliphanta* (Treadwell and Associates 2009). Among other native fish species, there have been recorded sightings of brown mudfish (*Neochanna apoda)* and longfin eel, (*Anguilla dieffenbachii)* as recently as 2008 (NIWA 2012b). Both of these species have a threat classification of 'Declining' (Allibone *et al.* 2009). The area is also home to the rare leafless mistletoe, *Korthalsella salicornioides*.

A report by James & Joy (2009), produced for Horizons Regional Council (the Manawatu/Wanganui regional authority), identified the Waiwiri as one of three coastal outlet streams and associated lakes/wetlands in the Horowhenua region that would most benefit from riparian restoration and improvements to fish passage. The survey looked at physical habitat quality (as distinct from water quality, which was not measured) and restoration potential in 22 streams. It recommended the remediation of the stream be prioritised, especially factors relating to fish passage (such as the presence of two perched culverts in the stream preventing fish passage) and habitat quality above potential barriers (such as the quantity, quality and diversity of in-stream and riparian habitat) (James & Joy 2009). The two barriers identified are just downstream from the lake outlet, and DOC is currently considering options for replacing these structures to improve fish passage (pers. comm. Jason Roxburgh, Manawatu/Rangitikei Area Manager, DOC, 7 August 2012).

Figure 3. This dairy effluent pond (foreground) is located on an elevated piece of land approximately fifty metres from the wetland that surrounds Lake Waiwiri. The island in the distance is wāhi tapu. At the time this photo was taken there was effluent flowing over a low point in the pond's bund and overland into the wetland.

2. REVIEW OF PREVIOUS WATER QUALITY DATA

This section reviews previous water quality reports and data from the Waiwiri catchment. It provides a historical context for decline issues and highlights which pollutants and other indicators have been found to breach national and regional water quality guidelines. The information is summarised with reference to the presence or absence of a longitudinal decline in water quality down the Waiwiri Stream, and what this implies with respect to the influence of pastoral land use and The Pot.

2.1. History and background

Prior to 1887, lands within the Horowhenua region were still in Māori ownership and much of the land in the Waiwiri area was predominantly in its natural state (Horizons Regional Council 2003). As land was sold, the extensive lowland and valley forests were logged and the river flats were cleared of vegetation to make way for farming. In 1914, the area under bush was only one quarter what it had been in 1890 and by 1963, 92% of the land had been cleared (Park 2001). Trees were felled and burnt and the ashes sown in English varieties of perennial plant species for pasture *e.g.* cocksfoot, clover.

The earliest water quality measurements in Lake Waiwiri were in 1950 and 1976 and included pH, dissolved oxygen and nutrients (Section 2.2).

In 1986, Horowhenua District Council (HDC) built an effluent treatment pond (commonly referred to as 'The Pot') on land adjacent to the Waiwiri Stream (Figure 2). The Pot is a 7.7 ha artificial pond built on an area of elevated sand dunes approximately 300 m from the stream. Resource consent conditions stipulate that the unlined pond can receive up to 20,000 m^3 of treated effluent each day, via a pipe from the Levin Wastewater Treatment Plant. However, existing infrastructure limits this to 10,000 m^3 per day, and the actual daily average is 6,184 m^3 per day (pers. comm. Wally Potts, HDC, 16 October 2012). Whilst some of the effluent will evaporate, most of it either soaks into shallow groundwater or is spray irrigated onto approximately 50 ha of surrounding pine forest when weather and soil conditions are suitable (Cowie 1998). Resource consent conditions also stipulate that the land surrounding The Pot can receive up to 10,000 m^3 of digested sludge each year from the Levin Wastewater Treatment Plant. However, for the past two years the average annual sludge volume deposited at The Pot was 728 m^3 (pers. comm. Wally Potts, HDC, 16 October 2012).

Definition of run-off

Run-off is the process that occurs following rainfall (or irrigation) where water moves from land into streams and open water such as lakes and wetlands (Freeze & Cherry 1979). There are two main types of run-off; overland flow and interflow. Both are likely to occur in the Waiwiri catchment due to soil types.

Overland flow occurs when either the rate of rainfall exceeds the infiltration rate of the soil or when the soil is saturated so excess water cannot infiltrate down (Davie 2004). Overland flow is particularly important in lowland areas such as pasture developed on drained wetland, where peat soils are often close to saturation.

Interflow is water that travels laterally or horizontally through the soil during or immediately after precipitation (Ward & Elliot 1995). It is not well defined but can be described as either:

- *Through-flow* - lateral flow of water through soil in unsaturated conditions.
- *Subsurface storm flow* - lateral flow of water through soil in saturated conditions.
- *Translatory flow* - lateral flow of 'old' water in soil, pushed out by the freshly precipitated water.

According to HDC's 2009 Asset Management Plan, "the current rate of (effluent) application exceeds the original design parameters of this soil and additional areas need to be developed to receive irrigant" (Horowhenua District Council 2009). The nature of the soil surrounding The Pot is such that overland flow is unlikely to occur, even when saturated (pers. comm. Hamish Lowe, 12 October 2012). Instead, irrigated effluent will infiltrate into the soil and be transported downwards under gravity. The effluent will travel through the soil as interflow until it reaches a surface water body, such as an open drain. Bacteria and particles are likely to be filtered by the soil, though the extent of filtering will depend on soil structure and flow paths.

Surface ponding may occur in areas where there is insufficient drainage, bringing "potential adverse effects to coastal lakes and watercourses such as Waiwiri Stream" (Cowie 1998). HDC's resource consent (No. 6610) for discharge to land states that "the discharge of sludge and effluent onto land shall not result in run-off beyond the boundary of the EDS (effluent disposal site)" (Cowie 1998). It is not clear if Cowie defines the term 'run-off' as overland flow plus interflow, as defined above, or overland flow only. Both the resource consent and the Asset Management Plan (2009) state that the current rate of application exceeds the original design parameters of the soil and note that HDC has indicated an interest in expanding the discharge area. Additional land has been purchased and plans are being developed for irrigation expansion (pers. comm. Wally Potts, HDC, 16 October 2012).

In order for HDC to meet the conditions of Resource Consent 6610, wastewater needs to be processed through secondary treatment. Based on current industry standards, secondary treatment describes the process of biologically converting the non-settleable organic solids (light suspended and dissolved) of the wastewater into more stable and settleable biological solids (NZWERF 2002). Horizons Regional Council is satisfied that the wastewater meets this requirement prior to it leaving the Levin Wastewater Treatment Plant (pers. comm. Robert Rose, Horizons Regional Council Environmental Protection Officer, 27 August 2012).

During construction of The Pot in 1986, drains were dug and a pumping station was installed to lower the groundwater level and transport excess water from low lying areas of the EDS to Waiwiri Stream (Harding 1986).The purpose of the drains was to mitigate surface ponding in the EDS, as groundwater was expected to rise as a result of building The Pot. “Because of the clearances and the permeability of the sand, there will be no direct run-off of treated effluent into the drains” (Harding 1986). As with Cowie, it is not clear if Harding includes interflow when using the term, ‘run-off’.

Today, however, with greater volumes of effluent and a well-documented need to increase the irrigated area, it is possible that the application of effluent is at a rate that facilitates indirect discharge of secondary treated effluent into the drains surrounding The Pot via interflow. As effluent moves through the soil matrix it will undergo an unknown degree of filtering, hence providing some cleansing before it reaches surface water bodies. It is not known what quantity of nutrients or microbial contaminants remains in the water by the time it reaches the edge of the EDS. Three drains were found flowing from the EDS into Waiwiri Stream during fieldwork (Figure 4 and 15).

Regular monitoring of groundwater from five shallow bores installed in surrounding land was required as a condition of HDC’s original consent for The Pot. Monitoring of groundwater level, pH, iron and nutrients took place between 1986 and1996. Monitoring of groundwater quality ceased from 1996, so that only groundwater level was recorded and reported on by engineering consultants, MWH (2007). In 2011 HDC declined a request for site access to The Pot and the bores to assess present day water quality.

Stream monitoring did not commence until 1999, when MWH consultants were engaged by HDC to undertake bi-annual water quality monitoring in an attempt to measure the impact of The Pot on Waiwiri Stream. Water quality sampling was conducted upstream and downstream of The Pot, as well as in The Pot itself between 1999 and 2011. Parameters measured included pH, suspended solids, carbonaceous biological oxygen demand, ammoniacal nitrogen, nitrate, total coliforms, iron, and dissolved reactive phosphorus. This monitoring is on–going as part of HDC's resource consent for The Pot.

Two other water quality surveys have been carried out on Waiwiri Stream. These surveys, part of Horizons Regional Council's State of the Environment (SOE) monitoring, measured water quality in the stream at the outlet of Lake Waiwiri (in 2008 and 2010), as well as near the stream's coastal outlet (in 2008 only) (pers. comm. Maree Clark, water quality scientist, Horizons Regional Council, 1 April 2011). Parameters measured included pH, dissolved oxygen, conductivity, temperature, *Escherichia coli (E. coli)*, black disc, turbidity, dissolved reactive phosphorus, ammoniacal nitrogen, total dissolved phosphorus, total phosphorus, total nitrogen, total oxidised nitrogen, nitrate, nitrite, arsenic, calcium carbonate, bicarbonate, iron, calcium, chloride, potassium, magnesium, manganese, sodium, sulphate and total dissolved solids (Horizons Regioinal Council 2011b).

Figure 4. A drain outflow diverting surface water, from land irrigated with treated effluent, into the Waiwiri Stream.

2.2. Lake Waiwiri

The source of the Waiwiri Stream is Lake Waiwiri (Papaitonga). Assessing water quality at the lake provides an indication of the 'starting condition' of the stream, as a basis for assessing longitudinal decline.

Water quality guidelines in New Zealand are set by regional councils, following recommended national guidelines (*e.g.* ANZECC 2000; Appendix 1). Regionally specific guidelines are also used in some situations.

Graphs showing the most relevant historical water quality data for Lake Waiwiri are provided in Appendix 5. Water quality measurements taken in 1976 indicated that the lake had elevated concentrations of total phosphorus, with median concentrations exceeding recommended guidelines for ecosystem protection by three times (Table 1; ANZECC 2000). The pH level was also very high. Recent measurements of these parameters (2008 and 2010) showed that the median concentration of total phosphorus exceeded the recommended guideline for ecosystem protection by 32 times. Ammoniacal nitrogen was also above the recommended guideline for the Papaitonga catchment. Nitrate concentrations were mostly within the guideline limits for all datasets. Paired t-tests showed that water samples taken in 2008 and 2010 have significantly higher total phosphorus, ammoniacal nitrogen, nitrate and conductivity compared with samples taken in 1976 and significantly lower pH and dissolved oxygen (Table 1). Finally, in 2008 and 2010, pH was 6.8, marginally below the recommend range of 7.0 to 8.5 for ecosystem protection. This compares with measurements from 1976 that indicates pH in the lake was much higher (9.3). The pH varies considerably on a daily and seasonal basis due to changes in photosynthesis in aquatic plants, so this difference is likely to be of little significance.

Table 1. Selected Lake Waiwiri water quality survey results for 1950, 1976, 2008 and 2010. Orange shading with bold text highlights values that exceeded water quality standards as indicated on bottom row. Green shading indicates a statistical difference between the historical and recent data. Graphs for these and other parameters can be viewed in Appendix 5. Data supplied by Horizons Regional Council.

	pH		**Total phosphorus (mg/L)**		**Dissolved oxygen (mg/L)**		**Nitrate (mg/L)**		**Ammoniacal nitrogen (mg/L)**		**Conductivity (uS/cm)**	
Year	**1950 & 1976**	**2008 & 2010**	**1976**	**2008 & 2010**	**1976**	**2008 & 2010**	**1976**	**2008 & 2010**	**1976**	**2008 & 2010**	**1976**	**2008 & 2010**
Maximum	**10.25**	7.44	**0.46**	**10.12**	19.4	9.82	0.24	**2.07**	0.15	**1.77**	308	867
Median	**9.3**	**6.81**	**0.09**	**1.07**	13	**4.4**	0.04	0.38	0.1	**0.53**	278	380
Minimum	7.6	**6.44**	**0.05**	**0.18**	6.8	**1.1**	0.01	0.01	0.08	0.07	230	269
Paired t-test result	**Higher in 1950/1976** *T = 11.29* *d.f. = 26* *P = 0.000*		**Lower in 1976** *T = -3.33* *d.f. = 25* *P = 0.003*		**Higher in 1976** *T = 7.32* *d.f. = 24* *P = 0.000*		**Lower in 1976** *T = -3.33* *d.f. = 25* *P = 0.002*		**Lower in 1976** *T = -3.63* *d.f. = 25* *P = 0.001*		**Lower in 1976** *T = -3.03* *d.f. = 23* *P = 0.005*	
Guideline value	**Between 7.0–8.5** Ecosystem protection (Horizons Regional Council 2011a and ANZECC 2000)		**<0.033** Ecosystem protection (ANZECC 2000)		***>6.5 mg/L*** Ecosystem protection (ANZECC 1992)		***Upper limit <1.7*** 95% Ecosystem protection (Hickey & Martin 2009)		**<0.4** Ecosystem protection for Papaitonga (Horizons Regional Council 2011a and ANZECC 2000)		***No guideline***	

Notes:

T is the test statistic

d.f. is the degrees of freedom (n-1)

P is the probability of obtaining a test statistic at least as extreme as that observed, assuming both samples are from the same population (*i.e.* if there is a statically significant difference between datasets, *P* will be less than 0.05, at 95% confidence).

2.3. Waiwiri Stream

Water quality data collected 2008-2010 and 1999-2011 indicated that the Waiwiri Stream is in a poor state of health (Table 2 and Table 3, respectively). Some of the notable readings include:

- High concentrations of total nitrogen in 2008 (six times higher than recommended guidelines; ANZECC 2000).
- High concentrations of ammoniacal nitrogen between 1999 and 2011 (15 times higher than recommended guidelines; ANZECC 2000).

- High concentrations of dissolved reactive phosphorus between 1999 and 2011 (16 times higher than the proposed 'One Plan' guideline value for the Ōhau River[1]).
- High faecal coliform count between 1999 and 2011 (three times higher than recommended contact recreation guidelines; ANZECC 2000).
- Consistently high concentrations of total phosphorus in 1976, 2008 and 2010 (32 times higher than recommended ecosystem protection guidelines (Table 1; ANZECC 2000)).
- High carbonaceous biological oxygen demand between 1999 and 2011 (usually above proposed standards set in Horizons, 'One Plan').

Graphs showing the most relevant historical water quality data for the Waiwiri Stream are provided in Appendices 3 (1999-2011) and 4 (2008). Total phosphorus concentrations significantly decreased from the lake outlet to the stream mouth at the beach (Table 2). This downstream 'improvement' of water quality is likely to be due to dissolved phosphates binding to suspended sediment particles or phosphates already attached to sediment particles suspended in the water column, which then settle on the stream bed in low velocity areas. In addition, some of the dissolved phosphate fraction of total phosphorus will be taken up by plants living in the stream.

Stream monitoring between 1999 and 2011 (Table 3) revealed very high faecal coliform counts, with concentrations up to 74 times higher than recommended contact recreation guidelines (ANZECC 2000). When compared with modelled predictions of median faecal coliform concentrations in New Zealand rivers (Unwin *et al.* 2010), the observed medians (405 and 430 FC/100mL; Table 3) were approximately 1.5 times that predicted for all rivers in the Horowhenua district[2] (259 FC/100 mL), which includes both upland and lowland rivers (pers. comm. Martin Unwin, NIWA, 29 October 2012). Faecal coliform concentrations in the Waiwiri were predicted to be the 5th highest of 48 named Horowhenua streams. *E. coli* counts were lower at the upper (lake) end of the stream than they were at the lower (beach) end, where they surpassed contact recreation guidelines (Table 2; Ministry for the Environment and Ministry of Health 2003).

At 95% confidence, the parameters that exhibited a longitudinal decline were total coliforms, total dissolved solids and nitrate.

Coliform organisms are used as indicators of water pollution. Coliforms are commonly found in water, soil and vegetation but are present in large numbers in the faeces of warm-blooded animals. While coliforms are themselves not normally the cause of serious illness, they are tested because they are easy to culture and their presence is used to indicate that other pathogenic organisms of faecal origin may be present.

[1] The Ōhau River is the closest lowland river to the Waiwiri Stream (2.5 km south).
[2] Across 2,229 reaches found in the River Environment Classification (REC) database.

Faecal pathogens include bacteria, viruses and parasites. Faecal coliforms are more specific than total coliforms because they refer to the coliforms that live in the intestinal track of humans and many other animals.

Total dissolved solids are a measure the total amount of organic and inorganic substances dissolved in the water, including dissolved minerals, salts or metals. These can be elevated by the introduction of agricultural and residential run-off, leaching of contaminated soils, and point source water pollution from industrial and sewage treatment facilities. Monitoring total dissolved solids provides a measure of the aesthetic properties of water.

Nitrate is a nutrient essential to plant growth and when found in streams in high concentrations is one of the main contributors to eutrophication and prolific growth of periphyton species. It is also toxic to aquatic organisms in high concentrations. A major source of nitrate in New Zealand streams is from the effluent of livestock in areas associated with intensive agricultural land use (Parkyn & Wilcock 2004). Nitrate can also enter the water because of poorly managed fertiliser application and leakage of untreated sewage/effluent.

The increase in total coliforms downstream from The Pot is not likely to be associated with effluent irrigation at the EDS because there was no corresponding increase in faecal coliforms. If interflow is the dominant mechanism for run-off at the EDS, then the observed increase in total dissolved solids downstream is also not likely to be associated with effluent irrigation at The Pot, particularly since turbidity measured in water from the drains was typically lower than that of Waiwiri Stream (Appendix 2). The downstream increase in nitrate, however, may be a consequence of effluent irrigation because nitrate will dissolve readily in water and is not likely to be removed due to natural filtering via interflow. The implications of the increase in total coliforms, total dissolved solids and nitrate downstream from The Pot are discussed further in Section 2.4.

Table 2. Selected water quality data collected in the Waiwiri Stream at the beach and lake end by Horizons in 2008. Orange shading with bold text highlights values that exceed water quality standards as indicated on bottom row. Green shading highlights the comparisons where water quality at the beach was significantly different to that at the lake. The sampling locations for the 'beach' and 'lake' sites are near the stream's coastal outlet (40°37'40.57"S, 175°10'17.34"E) and near the outlet of Lake Papaitonga (40°38'40.98"S, 175°13'3.02"E). Graphs for these and other parameters can be viewed in Appendix 4. Data supplied by Horizons Regional Council.

	pH		***E. coli*** **(MPN/100 mL)**		**Total phosphorus (mg/L)**		**Total nitrogen (mg/L)**		**Total dissolved solids (g/m³)**	
	Beach	**Lake**	**Beach**	**Lake**	**Beach**	**Lake**	**Beach**	**Lake**	**Beach**	**Lake**
Maximum	7.90	7.44	**1000**	**1100**	**0.30**	**1.59**	**4.63**	**4.90**	460	430
Median	7.04	**6.77**	**288**	203	**0.24**	**1.07**	**3.48**	**3.82**	420	350
Minimum	**6.37**	**6.55**	83	60	**0.12**	**0.18**	**2.90**	**2.94**	320	330
Paired t-test result	**No significant difference** *T = 1.06* *d.f. = 8* *P = 0.322*		**No significant difference** *T = 0.051* *d.f. = 8* *P = 0.63*		**Lower downstream** *T = -4.08* *d.f. = 8* *P = 0.003*		**No significant difference** *T = -0.79* *d.f.= 8* *P = 0.45*		**Higher downstream** *T = 4.13* *d.f. = 8* *P = 0.003*	
Guideline value	***7.0–8.5*** Ecosystem protection (Horizons Regional Council 2011a and ANZECC 2000)		***Median: <260*** Contact recreation (Horizons Regional Council 2011a and MfE & MoH 2003)		***<0.033*** Ecosystem protection (ANZECC 2000)		***<0.614*** Ecosystem protection (ANZECC 2000)		***No guideline***	

Notes:

T is the test statistic

d.f. is the degrees of freedom (n-1)

P is the probability of obtaining a test statistic at least as extreme as that observed, assuming both samples are from the same population (*i.e.* if there is a statically significant difference between datasets, *P* will be less than 0.05, at 95% confidence).

Table 3. Summary of water quality measurments taken in Waiwiri Stream by HDC between 1999 and 2011. Orange shading with bold text highlights values that exceed water quality standards as indicated on bottom row. Green shading highlights the comparisons where water quality upstream was significantly different to that downstream. The sampling location for the 'downstream' site is just below the downstream-most drain coming in from 'The Pot' (40°37'46.28"S, 175°10'40.19"E); and for the 'upstream' site is just upstream from a drain located on the eastern side of The Pot (40°38'1.02"S, 175°11'34.29"E). Graphs for these and other parameters can be viewed in Appendix 3. Data supplied by Horizons Regional Council.

	pH		**Suspended solids (mg/L)**		**CBOD (mg/L)**		**Ammoniacal nitrogen (mg/L)**		**Nitrate (mg/L)**		**Total coliforms (per 100 mL)**		**Faecal coliforms (per 100 mL)**		**Iron (mg/L)**		**DRP (mg/l)**	
	U/S	**D/S**	**U/S**	**D/S**	**U/S**	**D/S**	**U/S**	**D/S**	**U/S**	**D/S**	**U/S**	**D/S**	**U/S**	**D/S**	**U/S**	**D/S**	**U/S**	**D/S**
Maximum	7.6	7.4	100	616	**6.7**	**15**	**1.6**	**1.43**	**3**	**2.6**	35,700	40,500	**11,120**	**8,400**	95.2	27.8	**2.3**	**1.68**
Median	**6.8**	**6.9**	20.5	17	**2.5**	**2.1**	**0.29**	**0.29**	0.67	1.58	4,840	7,240	**405**	**430**	2.51	2.1	**0.18**	**0.14**
Minimum	**6.1**	**6.1**	6	1.3	0.8	0.2	0	0	0	0.36	80	104	32	44	0.09	0.1	**0.03**	**0.04**
Paired t-test result	**Higher D/S** *T = -4.23* *d.f. = 54* *P = 0.000*		**No difference** *T = 1.06* *d.f. = 53* *P = 0.29*		**No difference** *T = 0.72* *d.f. = 53* *P = 0.475*		**No difference** *T = 1.24* *d.f. = 53* *P = 0.218*		**More D/S** *T = -8.48* *d.f. = 53* *P = 0.000*		**More D/S** *T = -2.43* *d.f. = 53* *P = 0.018*		**No difference** *T = 0.25* *d.f. = 53* *P = 0.8*		**No difference** *T = 1.24* *d.f. = 47* *P = 0.21*		**Less D/S** *T = 3.25* *d.f. = 47* *P = 0.002*	
Guideline value / reference	***7.0–8.5*** Ecosystem protection, (Horizons Regional Council 2011a and ANZECC 2000)		***No guideline***		***<2*** Ecosystem protection (Horizons Regional Council 2011)		***<0.02*** Ecosystem protection (ANZECC 2000)		***<1.7*** Ecosystem protection (Hickey & Martin 2009)		***No guideline***		***Median <150*** Ecosystem protection (ANZECC 2000)		***No guideline***		***<0.015*** Ecosystem protection Horizons Regional Council 2011a and ANZECC 2000)	

Notes:

U/S = upstream from The Pot; D/S is downstream from The Pot

T is the test statistic

d.f. is the degrees of freedom (n-1)

P is the probability of obtaining a test statistic at least as extreme as that observed, assuming both samples are from the same population (*i.e.* if there is a statically significant difference between datasets, *P* will be less than 0.05, at 95% confidence)

CBOD is carbonaceous biological oxygen demand

DRP is dissolved reactive phosphorus.

2.4. The Pot

To investigate whether inflow from land surrounding The Pot affects downstream water quality of Waiwiri Stream, effluent pond water quality (Table 4) was compared to water quality upstream and downstream of The Pot (Table 3).

As noted in Section 2.3, total coliforms, total dissolved solids and nitrate measured upstream and downstream of The Pot indicated a longitudinal decline in water quality. Measurements taken from The Pot by HDC show concentrations of total coliforms are considerably higher than in the stream (median is approximately 70 times greater). However, this does not imply that The Pot contributes to the longitudinal decline, since the data show no significant change in faecal coliforms downstream of The Pot (Table 3). Total coliforms include sixteen species of bacteria that are found in soil, vegetation, animal waste and human sewage, whereas faecal coliforms are six species of bacteria that are specific to animal (including human) waste. The most likely source of faecal contamination of the Waiwiri stream is discussed in detail in Section 3.

Whilst concentrations of nitrate are low in The Pot relative to the stream, ammoniacal nitrogen is considerably higher (median is approximately 100 times greater). If effluent moves between The Pot and the stream via interflow through the soil (as discussed in Section 2.1), ammoniacal nitrogen will be converted to nitrate through the process of nitrification. This would explain the increase of nitrate in the stream below The Pot. Further sampling would be required to verify this.

Table 4. Summary of water quality measurments taken in 'The Pot' between 1999 and 2007 (MWH 2007).

	pH	Suspended solids (mg/L)	CBOD* (mg/L)	Ammoniacal nitrogen (mg/L)	Nitrate (mg/L)	Total coliforms (per 100 mL)	*E. coli* (per 100 mL)	Dissolved oxygen (mg/L)
Maximum	9.1	308	116	52	1.8	1,500,000	304,000	19
90th percentile	8	50.2	28.3	34	1.0	801,000	124,400	10.4
70th percentile	7.6	30	17.8	31.5	0.7	528,000	48,000	5.6
Median	7.4	20.8	13.6	29	0.6	342,000	24,000	3.2
30th percentile	7.2	14	10	25.3	0.5	202,500	8,400	2.1
10th percentile	7.1	6.8	6.4	17.3	0.4	92,500	2,000	1
Minimum	6.8	0.8	3	12	0.3	5000	1,000	0

* CBOD is carbonaceous biological oxygen demand.

2.5. Groundwater surrounding The Pot

Guidelines for groundwater quality are not subject to the same aquatic ecosystem protection guidelines that apply to surface water systems (*i.e.* ANZECC 2000).

Instead, groundwater is tested using aesthetic and health related guidelines for drinking water, published by the Ministry of Health (Ministry of Health, 2005).

Shallow groundwater in land surrounding The Pot flows approximately towards the southwest (Cowie 1998), therefore bore A (Figure 5) can be used as a ‘control’ for exploring The Pot’s influence on groundwater quality. Groundwater quality data collected from five bores surrounding The Pot between 1986 and 1996 showed no clear trend in spatial variation amongst the bores for all measured parameters (Table 5).

Bore A, which is located east of The Pot, had significantly higher iron concentrations than the other bores, but this could be due to natural variation. Groundwater of the Horowhenua / Kapiti coastal plain, of which the Waiwiri catchment is a part of, is known to be high in iron, high in ammonia, and low in pH (pers. comm. Wally Potts, HDC, 12 October 2012, citing (GNS 2010)).

There is a gap in the understanding of the subsurface fate of treated effluent at The Pot because current groundwater monitoring does not adequately assess the quantity and quality of groundwater, flow direction, and effluent attenuation. HDC is currently developing a more comprehensive groundwater monitoring regime which will address these matters (pers. comm. Wally Potts, HDC, 12 October 2012).

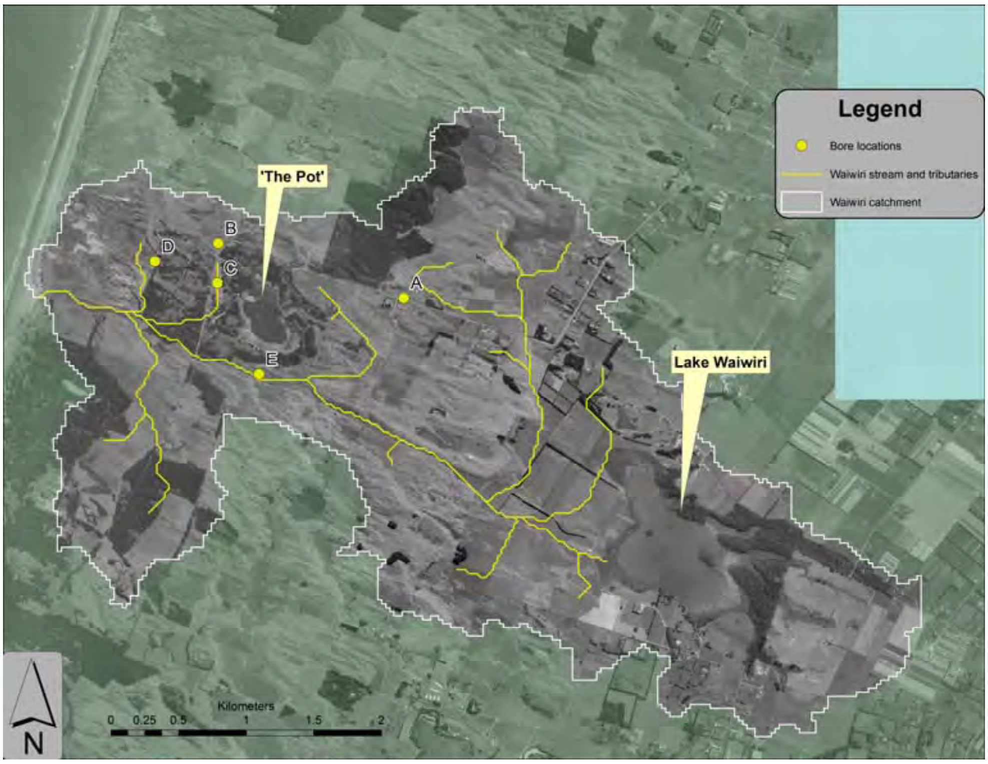


Figure 5. Location of Horowhenua District Council (HDC) bores (A-E) used to monitoring groundwater quality and level. Data supplied by Horizons Regional Council.

Table 5. Summary of water quality measurments taken from bores surrounding 'The Pot' between 1986 and 1996. Orange shading with bold text highlights values that exceed water quality standards (bottom row). Green boxes highlight the comparisons where water quality in bore A (the control) was significantly different (S/D) to other bores (bores B-E). Data supplied by Horizons Regional Council.

	Iron (mg/L)					pH					Nitrate (mg/L)					Ammonium (NH4) (mg/L)				
Bore	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Max	**46**	**0.4**	**9.9**	**33.0**	**32.0**	6.8	7.4	7.5	7.4	7.2	**103.6**	**45.2**	**27.9**	8.9	9.7	**5.1**	0.1	**1.5**	**3.9**	**2.1**
Median	**33**	0.1	**2.4**	**10.0**	**11.1**	6.2	6.66	6.92	6.85	6.72	1.8	9.7	2.7	0.5	0.4	0.6	0.0	0.1	1.1	0.6
Min	**20**	0.0	0.1	**1.0**	**1.2**	5.9	6.4	6.6	6.6	6.5	0.2	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.2
Paired t-test (to test if bore is different to bore A)	**Control** (used paired t-test, two sample assuming equal variance)	**S/D** ***A>B*** *T = 63.9 df=167 P(2) =0.00*	**S/D** ***A>C*** *T=62.4 df=181 P(2) =0.00*	**S/D** ***A>D*** T=27.5 df=174 P(2) =0.00	**S/D** ***A>E*** T=28.1 df=181 P(2) =0.00	**Control** (used paired t-test, two sample for means)	**S/D** ***A<B*** *T = -2.1 df =42 P(2) =0.04*	**S/D** ***A<C*** *T=-3.6 df=42 P(2) =0.00*	**S/D** ***A<D*** T=-3.11 df=42 P(2) =0.00	**S/D** ***A<E*** T=-2.51 df=42 P(2) =0.02	**Control** (used paired t-test, two sample assuming equal variance)	**No S/D** ***A=B*** *T = 0.11 df=76 P(2) =0.9*	**No S/D** ***A=C*** *T=0.79 df= 48 P(2) =0.43*	**No S/D** ***A=D*** T=1.47 df=28 P(2) =0.15	**No S/D** ***A=E*** T=1.8 df=36 P(2) =0.08	**Control** (used paired t-test, two sample assuming equal variance)	**S/D** ***A>B*** *T = 6.36 df =141 P(2) =0.00*	**S/D** ***A>C*** *T=8.65 df= 198 P(2) =0.00*	**S/D** ***A<D*** T=-3.95 df=196 P(2) =0.00	**No S/D** ***A=E*** T=1.82 df=203 P(2) =0.07
Guideline value	**<0.2mg/L** Aesthetic guideline (Ministry of Health 2005)					**No guideline**					**<11.3mg/L** Health related guideline (Ministry of Health 2005)					**<1.5 mg/L** Aesthetic guideline (Ministry of Health 2005)				

Note:
S/D=significantly different

2.6. Summary of historical data

Water quality data indicate that Lake Waiwiri and Waiwiri Stream are in a poor state of health. In 2008 / 2010, Lake Waiwiri had high concentrations of total phosphorus and ammoniacal nitrogen, both of which were outside recommended guidelines for ecosystem protection. The pH and dissolved oxygen levels were also outside recommended guidelines, but these parameters are known to vary diurnally and seasonally, so one-off measurements are of limited value. All parameters indicate a decline in lake water quality since measurements taken in 1976 (Table 1).

Similarly, nutrients measured in 2008 and 2010 in Waiwiri Stream were higher than those recommended by ecosystem protection guidelines (total nitrogen, total phosphorus, ammoniacal nitrogen, dissolved reactive phosphorus and carbonaceous biological oxygen demand). Median *E. Coli* counts in the stream were higher than guidelines for contact recreation, and faecal coliforms concentrations were up to 72 times higher than the recommended guideline for ecosystem protection. When compared with modelled predictions of median faecal coliform concentrations in New Zealand rivers (Unwin *et al.* 2010), the observed medians (405 and 430 FC/100mL; Table 3) were approximately 1.5 times that predicted for all rivers in the Horowhenua district[3] (259 FC/100 mL), which includes both upland and lowland rivers (pers. comm. Martin Unwin, NIWA, 29 October 2012). Faecal coliform concentrations in the Waiwiri were predicted to be the 5th highest of 48 named Horowhenua streams.

Parameters that showed a longitudinal decline in water quality were total coliforms, nitrate and total dissolved solids. Whilst it is possible that water from three drains that enter the Waiwiri Stream from land surrounding The Pot contributes to this decline, it is not likely in the case of total coliforms and total dissolved solids. Nitrate, however, may become concentrated in run-off from The Pot due to the irrigation of effluent high in ammoniacal nitrogen. None of the above parameters are source specific; hence the observed decline may be due to pastoral land use or some other source. Section 3 uses source-specific methodology to assess the likely influence of pastoral land use, The Pot, and other sources on water quality in Waiwiri Stream.

Measurements of groundwater quality show no clear trend in spatial variation of iron, ammonium and nitrate, relative to the location of The Pot.

[3] Across 2,229 reaches found in the River Environment Classification (REC) database

3. MICROBIAL SOURCE TRACKING ANALYSIS

This section examines possible sources of the faecal contamination indicated by the high faecal coliforms concentrations outlined in Section 2. The analysis is summarised with reference to the presence or absence of a longitudinal decline in water quality down the Waiwiri Stream, and what this implies with respect to the influence of pastoral land use and The Pot.

3.1. Introduction

Microbiological water quality guidelines for managing shellfish harvest are based on faecal indicator bacteria (FIB) such as *Escherichia coli* (*E.coli*). However, it is widely acknowledged in scientific literature that the use of FIB as a surrogate for pathogen risk is problematic since these organisms can persist in the environment (Byappanahalli *et al.* 2003; Byappanahalli MN *et al.* 2006), have only limited direct significance for human health and provide no information on the source(s) of contamination (Souza *et al.* 1999; Kirs & Cornelisen 2011; Cornelisen *et al.* 2012).

Microbial Source Tracking (MST) offers a solution to this problem. Water and shellfish samples are tested for the presence of bacterial genetic markers from the Order Bacteroidales (Cornelisen *et al.* 2012). The markers include a universal bacteriodales marker (UBac) that serves as an overall measure of faecal contamination but is not host-specific, a marker specific to humans (HBac), a marker associated with ruminant animals (RBac) such as sheep and cows, and a bovine marker (BBac) specific to cows.

Representatives of Bacteroidales have been suggested as alternative indicators to faecal indicator bacteria such as E. coli since the 1960s (Cornelisen *et al.* 2012). Concentrations of Bacteroidales bacteria greatly exceed those of E. coli and, more importantly, members of this Order are obligate anaerobes so it is highly unlikely they would find suitable conditions to replicate in the environment, i.e. they are likely to originate only from recent run-off from animal sources. The prevalence of Bacteroidales markers within a water sample can, therefore, provide some indication as to whether contamination is associated with fresh inputs.

Marker specificity relates to the cross-reactivity between markers and non-target organisms, such as possums and rabbits (*i.e.* if specificity is low then there is a greater chance of non-target organisms causing ‘false positives’ for the presence of target organisms). Cornelisen *et al.* (2011) showed that the selected markers were strongly associated with their target organisms; where specificity to human, ruminant and bovine markers was 88%, 81% and 97% respectively. The probability of contamination from non-target organisms using these markers is likely to be very low.

Marker sensitivity relates to how effective the marker is at identifying the presence of the target organism (*i.e.* if sensitivity is low then not all contamination from the target organism will be identified by the markers, possibly causing 'false negatives'). Cornelisen *et al.* (2011) showed that universal and ruminant markers are highly sensitive, detecting 97% and 96% of host populations respectively. The human and bovine markers were less sensitive, detecting the presence of faecal markers in 62% and 72% of samples known to contain faecal matter, respectively.

Due to the high sensitivity of the RBac marker, results can be interpreted quantitatively so that relative concentrations can be compared at various sites. Conversely, the low sensitivity of HBac and BBac markers means that these are most reliably interpreted via their presence or absence. However since HBac and BBac have low sensitivity, if present then they can be assumed to be present in abundance (Cornelisen *et al.* 2012).

To explore the spatial distribution and likely source of faecal contamination in the Waiwiri Stream, MST analyses were carried out on water samples collected at 14 locations between Lake Waiwiri and the stream's coastal outlet (Figure 6). Three samples were taken from Lake Waiwiri (white markers); seven from Waiwiri Stream (below major tributaries where appropriate) (blue markers); and four from tributaries (green markers). Tributaries B, C, and D, are drains that collect run-off from the land surrounding The Pot. Water sampling was carried out on three separate occasions, two of which followed moderate to heavy rainfall (September and October 2011). The rainfall volume for the hours prior to sampling is given in Appendix 6.

To help assess water quality, turbidity, pH and temperature data were also collected at each water site (results in Appendix 2), and all samples were tested for *E. coli*. Turbidity is a measure of the suspended sediments found in water, which relates to the visibility and amount of light reaching aquatic plants. Some fish and shellfish species are better able to cope with turbid waters than others. Water pH is a measure of how acidic or basic it is. Most fish can tolerate a pH range of between 5.0 and 9.0. The 'target' pH range as set in Horizon's 'One Plan' for the Waiwiri (Papaitonga) catchment is 7-8.5. More than half of the measurements taken during this study were below this range. Fish have optimum water temperature requirements for their various life stages and temperature variations may influence fish migration behaviour. Also, toxicity may become a problem when warm water is combined with other water quality stressors, such as low dissolved oxygen.

Tuatua (*Paphies subtriangulata),* a bivalve shellfish commonly consumed in New Zealand, were also sampled at three locations close to the stream's coastal outlet (Figure 6, red markers) and analysed for the presence of faecal contamination. Sampling took place on two occasions, one of which followed moderate to heavy rainfall (July 2012). Whilst MST methodology for testing shellfish is still being developed, the ability to test using MST has great potential because filter feeding shellfish concentrate microorganisms, whereas faecal contaminants measured from water samples can be greatly diluted and could go undetected (Kirs & Cornelisen 2011).

There is a potential bias in the results due to the fact that sampling was limited to winter and spring, with a focus on collecting water after heavy rainfall events. We did this because we were trying to identify faecal marker 'hot spots' so that stream restoration efforts could be prioritised. Heavy rainfall is likely to facilitate overland flow on low lying land situated where the water table is close to the surface. In particular, this will tend to mobilise faeces from ruminant animals in paddocks formed on drained wetlands more so than human effluent around The Pot, since the effluent disposal site (EDS) features high drainage soils that are not likely to facilitate overland flow. Effluent is sprayed at a higher rate during summer (pers. comm. Wally Potts, HDC, 12 October 2012). Human markers may have been more evident if sampling was done during an extended dry period (i.e. summer) when there is less dilution. Additional sampling would be required to determine whether this is the case.

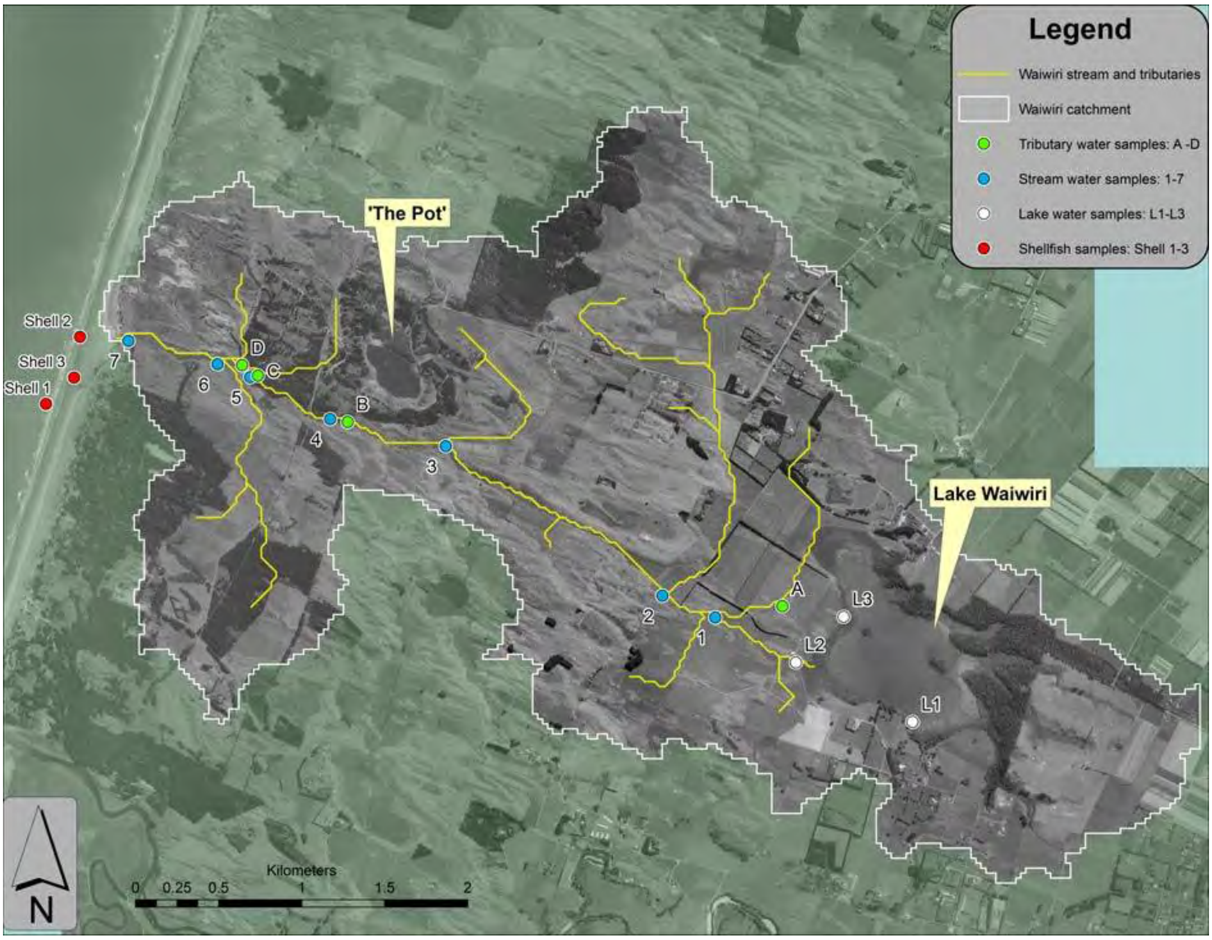


Figure 6. Locations of water and shellfish sample sites used for microbial source tracking (MST) analysis.

3.2. General indicators of faecal contamination and water quality

E. coli concentrations from water samples taken from the stream following moderate to heavy rainfall (September and October 2011) were higher than the recommended 'acceptable' guideline for contact recreation (<260 cfu/100mL, Appendix 1) and the acceptable standard for stock drinking water (<1,000 cfu/100mL) (ANZECC & ARMCANZ 2000; Ministry of Health 2005) (Figure 8). Concentrations at all stream sites during September and October were much higher than the maximum recorded in the 2008 water quality survey (1,100 cfu/100mL). *E. coli* and UBac concentrations from water samples were generally higher following rainfall.

Lake site L1 and tributary site A (Figure 7) had the highest *E. coli* concentrations of all water sampling sites (Figure 8). The high concentration at L1 coincides with one of the highest universal marker (UBac) concentrations at the same site on the same day (Figure 9), indicating a high level of faecal contamination. Site L1 is the only obvious grassy flat area situated immediately beside the lake, and at the time of sampling there were obvious signs that birds had been using the land. Tributary site A is an unfenced drain that runs through pasture situated on drained wetland close to the lake (Figure 7). Pasture in this area was saturated at the time of sampling. Turbidity was also comparitively high at tributary site A (Appendix 2). The implications of this are discussed further in Section 3.3.

E. coli and UBac concentrations in water from drains that enter the Waiwiri Stream from The Pot (Tributary sites B, C, and D) were relatively low.

Figure 7. Tributary site A is a ditch that drains pasture on low lying land, close to Lake Waiwiri. This tributary had the second highest *E. coli* and universal bacteriodale (UBac) concentrations of all sites.

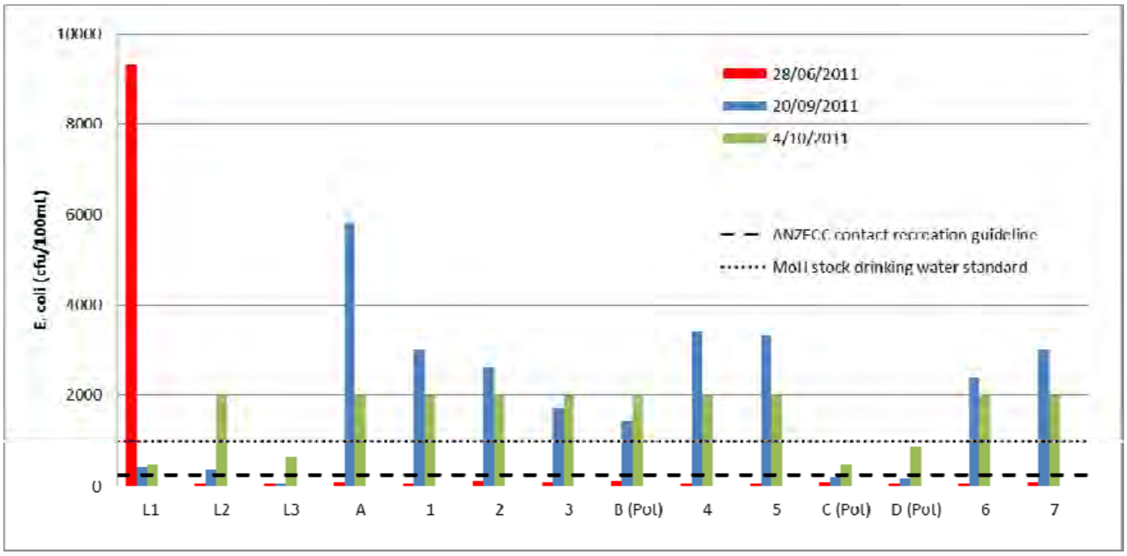


Figure 8. *E. coli* concentration (cfu/100 mL) in water on the three sampling occasions. Due to a change in lab procedures, *E coli* sample processing in October 2011 limited the counts to 2,000 cfu/100 mL. Note that data are presented longitudinally, from the lake (left) to the stream's coastal mouth (right).

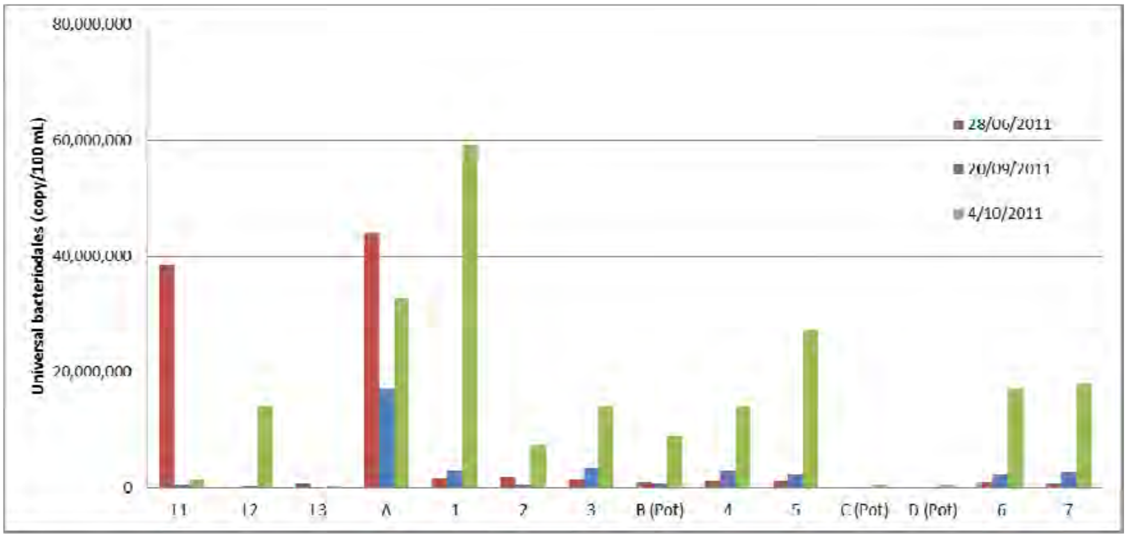


Figure 9. Concentration of universal bacteriodale (UBac) markers from Lake Waiwiri (L1-L3) to the sea (7) over three sampling occasions. Note that data are presented longitudinally, from the lake (left) to the stream's coastal mouth (right).

E. coli concentrations from shellfish harvested following moderate to heavy rainfall in July 2012 were 790 MPN/100 mL (Shell sites 1 and 3), and 2,400 MPN/100 mL (Shell site 2). All were above the upper limit recommended for human consumption, 230 MPN/100g (NZMOH 1995). *E coli* concentrations were not measured in shellfish harvested in June 2011. Following rainfall, UBac concentrations from shellfish at sites Shell 1 and 3 were much higher than concentrations found in shellfish after dry weather (Figure 10). Shell site 3, which was situated within the plume emanating from the Waiwiri Stream, had the highest concentrations of UBac marker for both sampling occasions.

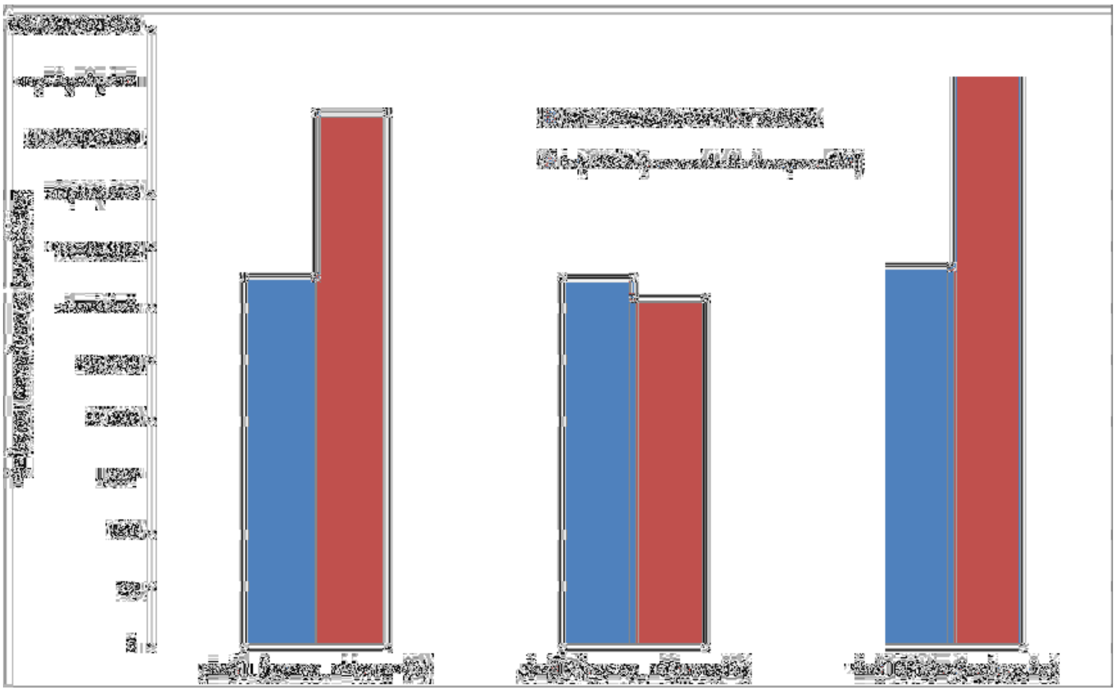


Figure 10. Concentration of universal bacteriodale (UBac) markers found in shellfish at the mouth of the Waiwiri Stream.

3.3. Host specific markers from water samples

Microbial source tracking showed that the faecal contamination of Waiwiri Stream originated predominantly from ruminants and bovines. Table 6 and Figure 11 summarise the presence or absence of bacteriodale markers measured in water over three separate sampling events. Of the host-specific markers, the ruminant bacteriodales marker (RBac) was the most abundant, found in 32 of the 42 water samples. Bovine (BBac) and human (HBac) markers were found in 18 and 2 of the water samples, respectively. The greater abundance of RBac markers is due to their higher sensitivity and abundance in host organisms.

Table 6. Presence and absence of detectable concentrations of *E. coli* and bacteriodale markers in water samples collected during three sampling events. Note that data are presented spatially, from the lake (left) to the stream's coastal mouth (right).

	L1	L2	L3	A	1	2	3	B (Pot)	4	5	C (Pot)	D (Pot)	6	7
***E. coli* (>2000)**	X--	--X	---	-XX	-XX	-XX	--X	--X	-XX	-XX	---	---	-XX	-XX
Universal	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
Ruminant	XX-	X--	---	X--	XXX	X--	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
Bovine	--X	---	---	--X	XXX	--X	-XX	-X-	XXX	-XX	---	---	-XX	-XX
Human	---	---	---	---	---	---	---	-(X)X	---	---	---	---	---	---

Notes:
X Present in June 2011
X Present in September 2011
X Present in October 2011
(X) Trace presence
\- Not Present

Cornelisen *et al* (2011) also show that, unlike BBac and HBac markers, RBac markers can be used in a quantitative manner to assess the potential faecal contribution from ruminants at a given site. Stream site 1 had the highest overall total concentration of ruminant marker – 2.5 times greater than the next highest location, stream site 5 (Figure 12). Ruminant marker concentrations remained relatively high at almost all sites downstream of stream site 1, with the exception of stream site 2 and the tributaries that drain the land surrounding The Pot (B, C, and D). Markers were present in greatest concentration following rainfall (September and October). Stream site 1 is located at the confluence of two streams, both of which drain from the western side of Lake Waiwiri (Figure 13). Upstream from this site there are multiple points where stock can access the water via open drains, such as that found at tributary site A (Figure 10). Stock access points along the Waiwiri Stream were identified during fieldwork (Figure 17) and are discussed in more detail in Section 4.

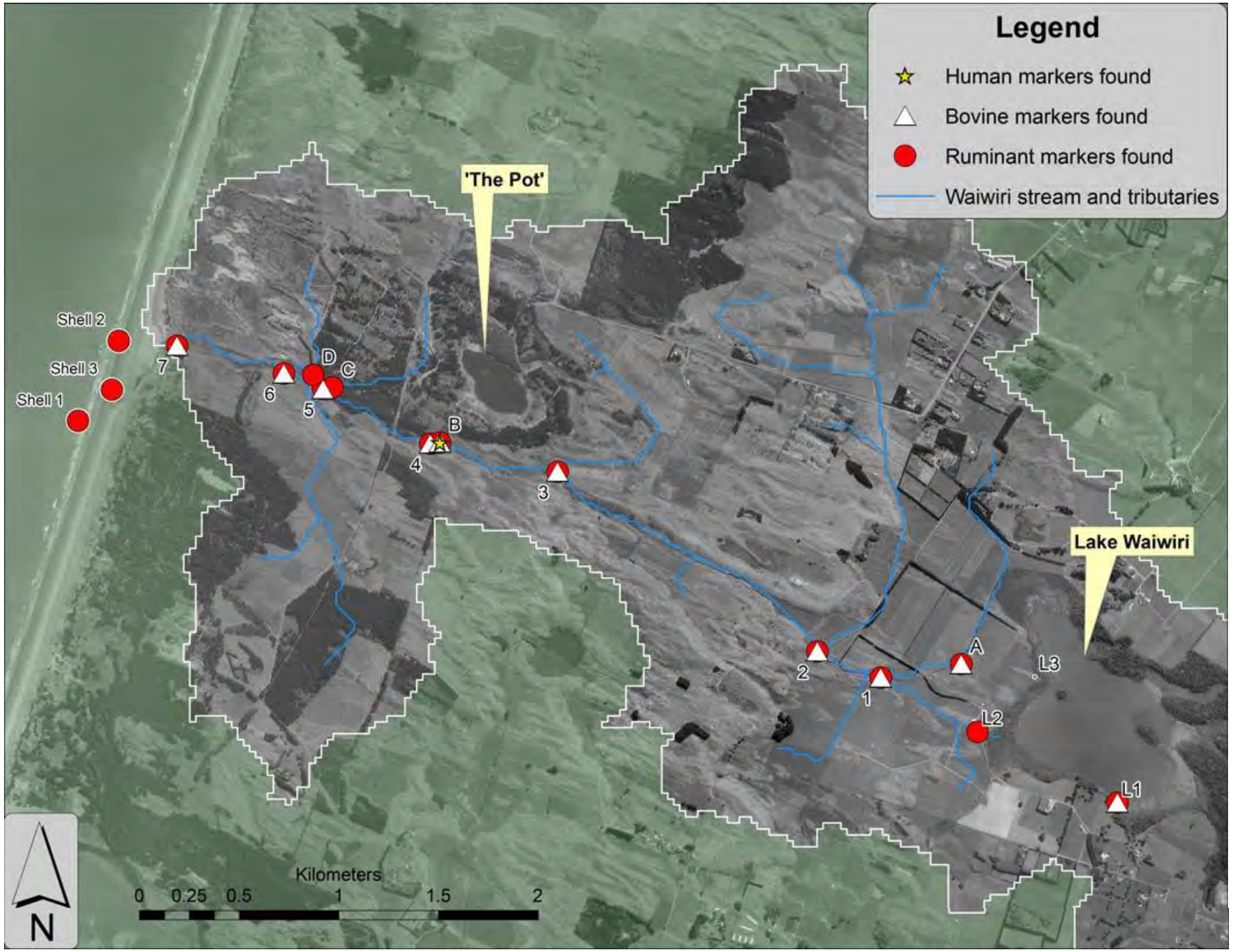


Figure 11. Presence of detectable concentrations of ruminant, bovine and human faecal markers over three sampling occasions at Lake Waiwiri and Waiwiri Stream. Note that only one symbol is shown if a marker is present more than once at the same site.

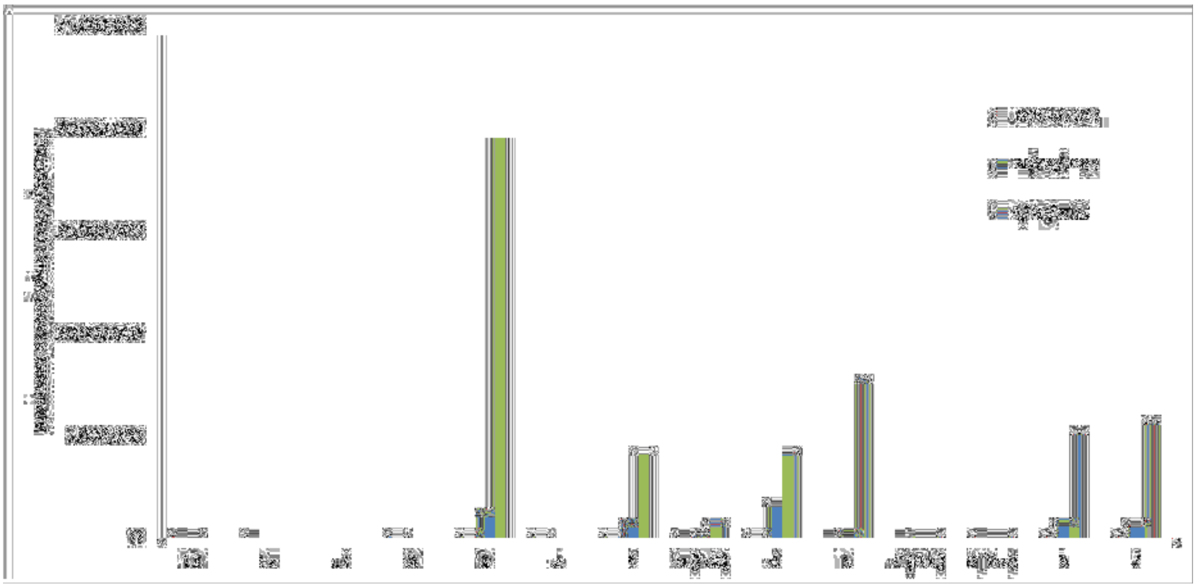


Figure 12. Concentrations for ruminant bacteriodale (RBac) markers from Lake Waiwiri (L1-L3) to the sea (7) over three sampling occasions. Note that data are presented longitudinally, from the lake (left) to the stream's coastal mouth (right).

Figure 13. Looking upstream (towards northern branch) at stream site 1. Water containing the highest ruminant faecal marker concentrations was collected here.

Due to their low sensitivity, BBac and HBac markers do not provide a good quantitative measure of abundance. However, simple presence/absence of these markers provides a good indication of contamination, since due to their high specificity, their presence (in concentrations greater than a reliable detection limit) indicates that faecal matter from the target-organism is present and likely to be abundant (Cornelisen *et al.* 2012). The fact that bovine markers have been detected in 15 of the 21 water samples taken from the stream, indicates that their presence is abundant. In contrast, only one of the nine lake water samples and two of the 12 tributary water samples contained BBac. The presence and spatial distribution of BBac followed a similar pattern to that of the RBac markers presented in Figure 12.

MST methodology developed in New Zealand has adopted the use of reliable detection limits, which is the concentration below which the quantity of markers is not sufficient to ascertain its presence beyond reasonable doubt (Shanks *et al.* 2009; Cornelisen *et al.* 2012). Using a reliable detection limit of 10 copies per reaction, human markers were found in two of the 42 water tests. Of the two positive results, both emanate from tributary site B (Figures 14 and 15), which flows in from irrigated land surrounding The Pot. The fact that human markers have been detected at this location indicates that their presence was likely to have been abundant when the water was sampled.

Human markers were found in more than two samples but most of these were not above the reliable detection limit (Figure 14). Therefore whilst human faecal matter enters the Waiwiri Stream via tributary site B, there is no conclusive evidence of a presence (in excess of the reliable detection limit) downstream from this point. This may be because the concentration of human markers is diluted with water from the Waiwiri, and so is no longer present above the detection limit. Both of the positive human marker results were found in water samples that were taken following significant rainfall events. No human markers were found in tributary sites C and D, which also emanate from the EDS.

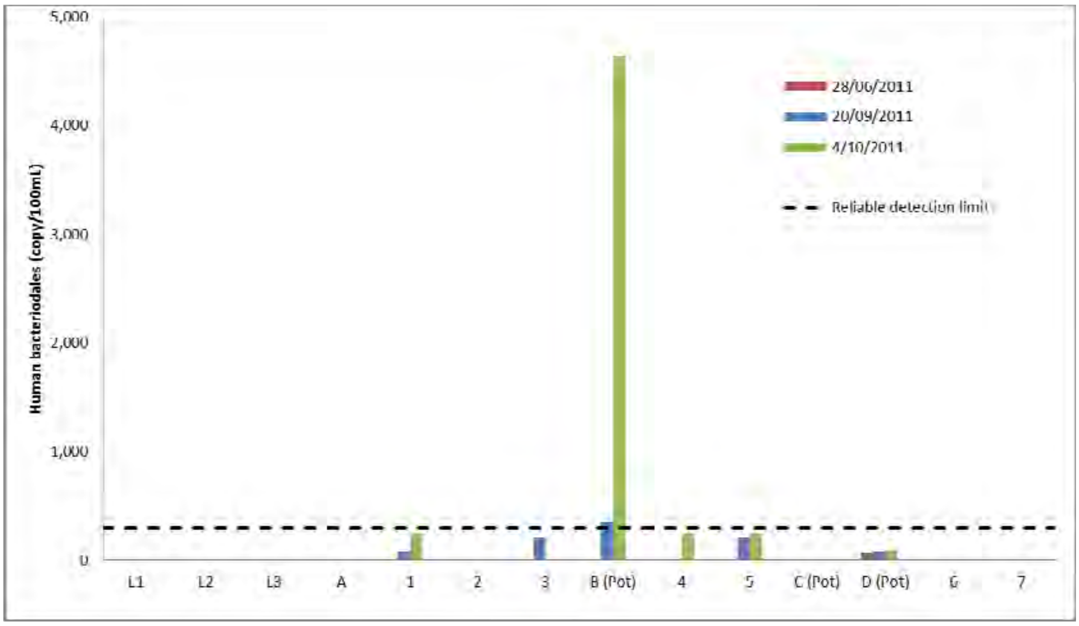


Figure 14. Concentrations for human bacteriodale (HBac) markers from Lake Waiwiri (L1-L3) to the sea (7) over three sampling occasions. Note that data are presented longitudinally, from the lake (left) to the stream's coastal mouth (right).

Figure 15. Tributary site B, the first drain that directs excess surface flow from irrigated land surrounding 'The Pot' (background) into Waiwiri Stream (foreground). Human faecal markers were present in two of the three water samples taken from this site.

Of the total concentration of UBac markers detected across all sites, nearly half (43%) were found in samples taken from, or close to, Lake Waiwiri (*i.e.* Lake sites, L1, L2, L3 and tributary site A), indicating high faecal contamination in this area (Figure 9). Conversely, human, ruminant and bovine markers were sparse at the same sites, suggesting that there is likely to be some other source of faecal contamination in this area. Birds, such as Canadian geese and black swans, are known to populate the lake in high numbers (pers. comm. Nathan Murray, Lake Waiwiri farmer, June 2011), and may contribute significantly to faecal contamination at these sites. However, the presence of BBac markers in tributary site A implies that there is likely to be an abundance of bovine faecal matter at this site. This is not surprising since this is an unfenced drain running through low lying pasture. As noted in Section 3.2, this site had the second highest concentrations of *E coli* and UBac faecal marker.

3.4. Host specific markers from shellfish samples

Microbial source tracking showed that the faecal contamination of shellfish harvested from the mouth of Waiwiri Stream originated predominantly from ruminant animals (Table 7). Using a reliable detection limit of >10 copies per reaction, no human or bovine markers were found in any of the samples. Shellfish site 3, which is located in the brackish-water plume that emanates from the Waiwiri Stream, contained ruminant markers in both sampling events. Higher concentrations of ruminant markers were found at all shellfish sites following moderate to heavy rainfall in July 2012 (Figure 16).

Table 7. Presence/absence of host specific microbial source tracking (MST) markers in shellfish samples collected from the mouth of Waiwiri Stream.

	Shell 1		Shell 2		Shell 3	
E. coli >2000	ND	-	ND	X	ND	-
Universal	X	X	X	X	X	X
Ruminant	-	X	-	X	X	X
Bovine	-	-	-	-	-	-
Human	-	-	-	-	-	-

Notes:
X Present in June 2011
X Present in July 2012
\- Not Present
ND No data

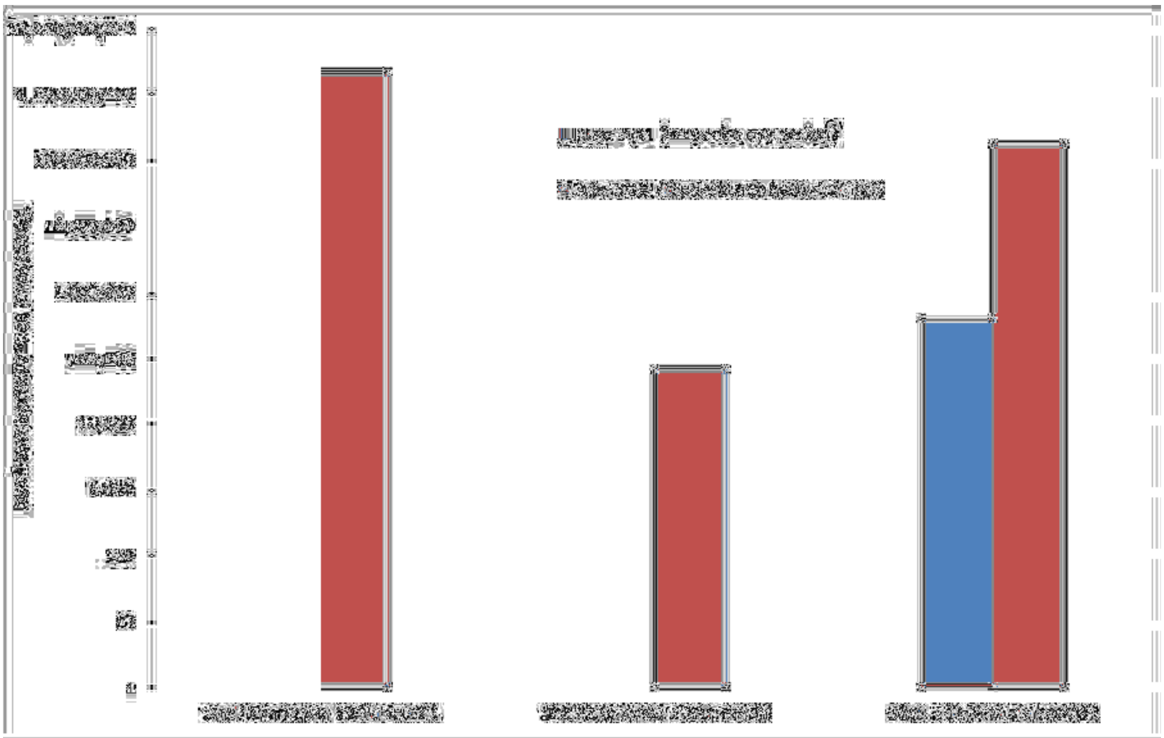


Figure 16. Concentrations for ruminant bacteriodale (RBac) markers in shellfish collect from the mouth of the Waiwiri Stream.

3.5. Summary of microbial source tracking results

High concentrations of ruminant faecal marker and the frequent presence of bovine faecal marker indicate that the dominant source of faecal contamination in the Waiwiri Stream is manure from cows. The highest concentrations of ruminant markers were found at stream site 1.

Assuming a reliable detection limit of >10 copies per reaction, human markers were found in two of the 42 water tests and none of the six shellfish tests. The two positive results from tributary site B provide evidence that water containing human faecal matter enters the Waiwiri Stream from land surrounding The Pot.

Tributary site A had the second highest *E. coli* and universal faecal marker concentrations. The presence of bovine markers at this site indicates a likely abundance of cow faeces, although very high concentrations of universal markers suggests that there may be some other source of faecal contamination. Canadian geese are a likely source, as they are known to populate the lake in significant numbers.

3.6. Discussion and recommendations

This report assesses the influence of two land use practices on water quality in the Waiwiri catchment: pastoral land use and land disposal of human effluent from The Pot. It looks for evidence of a longitudinal decline in water quality by first interpreting historical data, before narrowing the focus to look for the presence and likely source of faecal contaminants.

The research questions were:

- What do historical water quality data and reports show for the Waiwiri catchment and is there a longitudinal decline along the stream?
- Is there faecal contamination in the stream and, if so, what is the likely source of contamination?
- Is there faecal contamination in shellfish harvested from areas around the stream mouth and, if so, what is the likely source of contamination?

3.7. Historical water quality data

In Section 2, water quality data were assessed with reference to national and regionally specific water quality guidelines, which consider the risk posed to either aquatic ecosystems or human health for contact recreation (*e.g.* ANZECC 2000).

Table 8 summarizes the poor water quality found at various locations in the catchment and notes the likely source(s). To answer our first research question, historical water quality data indicate that Lake Waiwiri and Waiwiri Stream are in a poor state of health. In 2008 and 2010, Lake Waiwiri had high concentrations of total phosphorus and ammoniacal nitrogen, both of which were outside recommended guidelines for ecosystem protection. Similarly, the stream contained nutrients with median concentrations that were higher than those recommended by ecosystem protection guidelines (total nitrogen, ammoniacal nitrogen, dissolved reactive phosphorus, total phosphorus and carbonaceous biological oxygen demand). Median *E. Coli* counts in the stream were higher than guidelines for contact recreation, and faecal coliforms concentrations were up to 74 times higher than the recommended guideline for ecosystem protection. When compared with modelled predictions of median faecal coliform concentrations in New Zealand rivers (Unwin *et al.* 2010), the observed medians (405 and 430 FC/100mL; Table 3) were approximately 1.5 times that predicted for all rivers in the Horowhenua district[4] (259 FC/100 mL), which includes both upland and lowland rivers (pers. comm. Martin Unwin, NIWA, 29 October 2012).

[4] Across 2,229 reaches found in the River Environment Classification (REC) database

Faecal coliform concentrations in the Waiwiri were predicted to be the 5th highest of 48 named Horowhenua streams.

Evidence summarised in Section 2 confirms that there is a longitudinal decline in some water quality parameters (*i.e.* total coliforms, nitrate and TDS). Since these parameters are not source specific, the decline may be due to either pastoral land use, effluent disposal at The Pot or avian sources. Microbial source tracking (Section 3) uses source-specific methodology to help resolve the question posed by this finding.

Historical measurements show that in 2008 and 2010 pH was low relative to ecosystem protection guidelines for the catchment (7.0 to 8.5) in both the stream (6.9) and the lake (6.8). This compares with measurements from 1976, which indicate pH in the lake was much higher (9.3).

3.8. Microbial source tracking

Microbial source tracking helps to clarify the likely source of decline as indicated by the historical water quality data (see summary,

Table 8). To answer our second and third research questions, MST analyses show that whilst there is a small amount of human faecal matter entering the stream from The Pot, the dominant source of faecal contamination is cow faeces. No human or bovine markers were found in shellfish harvested from the stream mouth. However, most of the water and shellfish samples contained high concentrations of faecal markers specific to ruminant animals, which include cattle, sheep, deer and goat, particularly following heavy rainfall.

The fact that no human or bovine markers were found in shellfish does not mean that they were not there, as both of these markers have low sensitivity (62 and 72% respectively) (Cornelisen *et al.* 2012). If sensitivity is low, then not all contamination from the target organism will be identified by the markers possibly causing 'false negatives'. Also, following exposure to water contaminated with faecal indicating bacteria, once back in clean water, shellfish are known to depurate within a few days[5], depending on the feeding rate (pers. comm. Dr Paul Gillespie, Coastal and Estuarine Scientist, Cawthron Institute, 24 August 2012). It is possible that the shellfish used in this study depurated some of the faecal material prior to testing.

[5] 'Depuration' is the process that occurs in shellfish where FIB loads are reduced. As shellfish feed, the flow through the gut cleans it out, so the rate of depuration depends on the feeding rate.

From a cultural perspective, any faecal matter and especially any human faecal matter anywhere in the stream is offensive regardless of whether there is 'longitudinal decline'. The inability to manaaki (care for) guests with healthy, local delicacies at marae is a grave loss of mana or standing.

Table 8. Summary of historical water quality data and microbial source tracking analyses.

Water quality indicator	**Location**	**Likely source**
High nutrients (TP, TN and ammoniacal nitrogen) Low pH High conductivity	Lake Waiwiri	Pastoral land use Birds – Canadian geese and black swan
High nutrients (TP, TN, DRP, CBOD, ammoniacal nitrogen) High *E. coli* counts High faecal coliforms	Throughout Waiwiri Stream	Pastoral land use
Total coliforms, TDS and nitrate; higher downstream from The Pot than upstream	Waiwiri Stream, downstream from The Pot	Pastoral land use Human effluent disposal at The Pot (likely nitrate only)
High concentrations of ruminant faecal markers and the frequent presence of bovine faecal markers	Throughout Waiwiri Stream, excluding the lake and tributaries Stream site 1 had the highest concentration followed by stream sites 5, 7, 6, 4, 3, and 2	Pastoral land use
Human faecal markers present	Found in tributary site B, which enters Waiwiri Stream from The Pot.	Human effluent disposal at The Pot
Abundant universal faecal markers that do not correspond with ruminant, bovine or human markers. Also the high *E. coli* counts	Tributary site A, beside lake Waiwiri	Birds – Canadian geese and black swan

Notes:
TP = Total phosphorus
TN = Total nitrogen
DRP = Dissolved reactive phosphorus
CBOD = carbonaceous biological oxygen demand
TDS = Total dissolved solids.

3.9. Pastoral land use

During 2011 fieldwork, MTM kaitiaki noted the locations along the Waiwiri mainstem at which either livestock could enter the stream or where unfenced tributaries join the mainstem from surrounding farmland (Figure 17). Tributaries were included if water could be seen in the bed. However, no depth or width measurements were taken and there was no way of knowing if the tributaries were permanently flowing or ephemeral. The 2003 Clean Streams Accord requires the exclusion of dairy cattle from permanent waterways wider than 1m and deeper than 30cm. Regardless whether they are permanent or ephemeral, the sites shown in Figure 17 should be investigated for future fencing and planting. There are likely to be more locations of a similar nature in some of the larger tributaries, so some reconnaissance exploration is required to help prioritise riparian restoration efforts.

The benefits for water quality provided by riparian buffers in areas dominated by pastoral land use are well known (Wenger 1999; Parkyn 2004). The minimum buffer width necessary for such benefits is less clear, but best estimates range between 10-30 m (Parkyn 2004). Following advice from Amy Hawcroft, an ecologist for the Department of Conservation, Horizons recommends a 20 m buffer width (Hawcroft 2011). Given the cultural significance of Waiwiri Stream and the inherent ecological values of Papaitonga Reserve, a strong case can be made for maximising the extent of this corridor, although loss of pasture must also be considered. Small, low lying tributaries, such as tributary site A, are likely to contribute significantly to ruminant/bovine faecal contamination in the main stem. If fencing of these tributaries is not practical or too expensive then a smaller fenced area surrounding a constructed wetland would provide some level of filtering before the water enters the stream.

It is important to consult with farm managers regarding riparian restoration to assess and prioritise fencing and planting options. It may not be necessary to apply a blanket strategy regarding buffer width to achieve similar results, as doing this may unnecessarily retire highly productive land. Whilst Horizons Regional Council recommends a 20 m buffer this is not a requirement and the actual width is up to the landowner.

The Waiwiri (Papaitonga) catchment is one of several in the region that are now part of a Horizons Regional Council policy initiative; the ‘Farmer Applied Resource Management Strategy’ (FARM). Established to help manage nutrient run-off within ‘problem’ catchments, FARM will require ‘intensive farms’ to get resource consent. As part of the consent they will be required to prepare a FARM Strategy, which includes a nutrient management plan.

There is one dairy effluent pond in the catchment where a small amount of effluent was observed overflowing into the wetland surrounding Lake Waiwiri. Effluent from this pond is likely to contribute to elevated nutrient levels and microbial contamination in the wetland and possibly the lake.

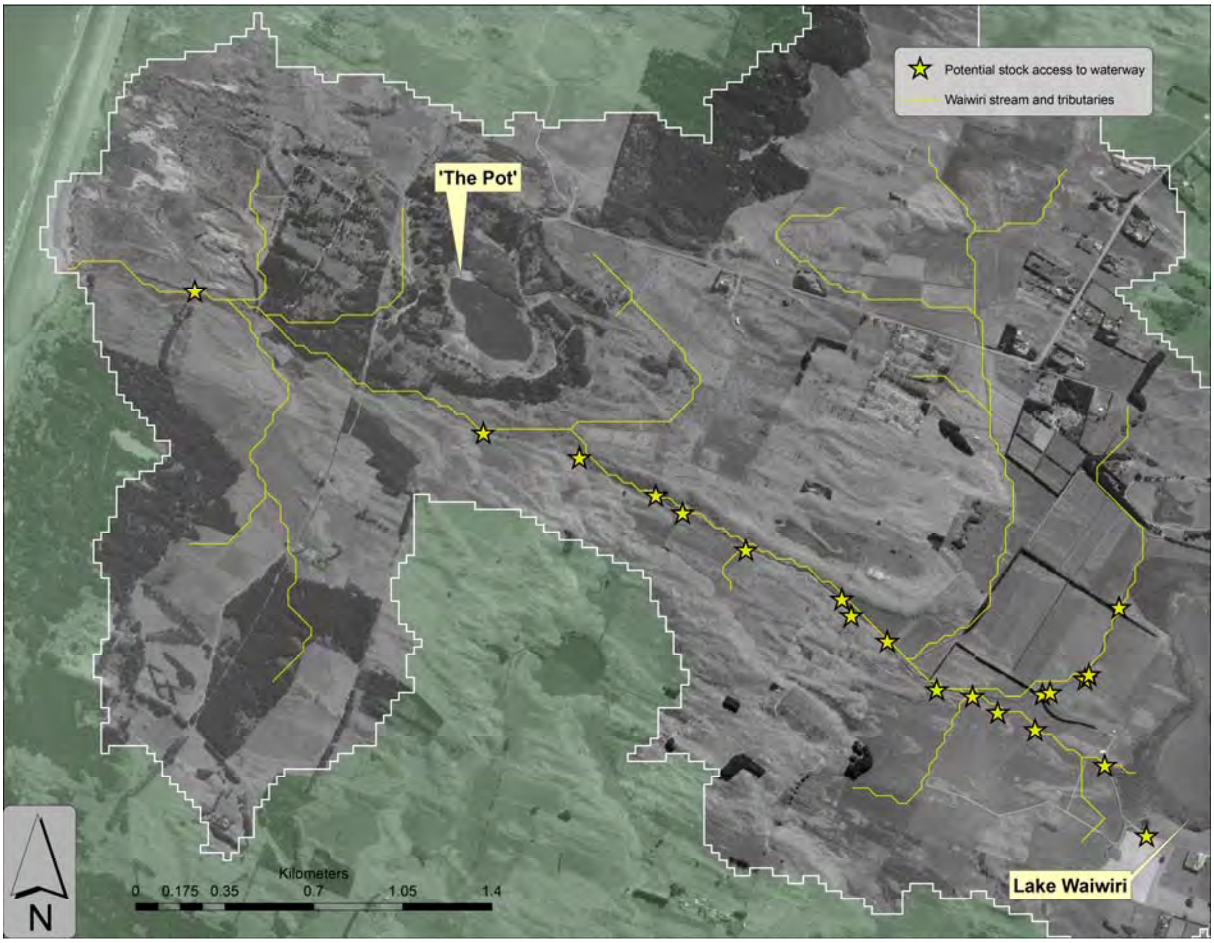


Figure 17. Known locations where either livestock can enter the stream, or unfenced tributaries join the mainstem from surrounding farmland (see text for details).

3.10. The Pot

Microbial Source Tracking results indicate that human faecal matter enters the Waiwiri Stream via Tributary B; a drain that crosses land surrounding The Pot that is irrigated with secondary treated effluent. HDC's resource consent stipulates that "the discharge of sludge and effluent onto land shall not result in run-off beyond the boundary of the effluent disposal site". To mitigate potential flow into the stream, effluent from The Pot should be irrigated only whilst soils are unsaturated. Soil moisture and drain flow monitoring would be an easy way to identify times when effluent can and cannot be irrigated, though this assumes that there is sufficient storage available in The Pot to postpone irrigation when soils are saturated. To avoid a situation where there is insufficient storage in The Pot when soils are saturated, HDC could proceed with plans to increase the irrigated area. Tertiary treatment of water from the drains may provide another solution. Constructed wetlands are commonly used in New Zealand for tertiary treatment of wastewater. These could be constructed on-site, in low-lying areas surrounding The Pot so that existing drains can be diverted to run through wetland vegetation before discharging to the stream. However, constructed wetlands might lead to a net increase in faecal coliforms from local fauna (e.g. birds) associated with wetland habitat (pers. comm. Hamish Lowe 12 October 2012).

HDC has consent to discharge secondary treated wastewater at a rate of up to 20,000 m^3/day onto and into land surrounding The Pot, as well as up to 10,000 m^3/year of digested sludge onto the land[6]. These activities could affect the quality of groundwater flowing west from the effluent disposal site (EDS). It is possible that as groundwater emerges on the coastal foreshore, it introduces toxic constituents (trace metals and ammonia), nutrients (nitrate and ammoniacal nitrogen) and bacteriological contaminants (viruses, protozoans and pathogens) from the EDS to shellfish populations. For unknown reasons, groundwater quality monitoring ceased in 1996. When designing the MST study, Cawthron had planned to test groundwater surrounding the pot using the five existing monitoring wells. When approached, HDC declined a request for access to the site. The consequence of this is a gap in the understanding of the subsurface fate of treated effluent from the EDS.

Since shellfish populate the coastal foreshore approximately 1 km from The Pot, assessing groundwater quality will assist in monitoring the environmental impact of The Pot. Therefore we recommend that groundwater quality monitoring be resumed and expanded to include groundwater that emerges on the coastal foreshore, above the low tide mark, as well as tissue samples from shellfish.

Testing for trace metals commonly associated with digested sludge and wastewater is advised. These include zinc, copper, arsenic, chromium, nickel, lead, mercury and cadmium. A recommended sampling protocol is outside the scope of this report, but a ‘one off’ assessment may be sufficient to indicate whether on-going monitoring is warranted and, if so, which metals should be targeted. In addition to trace metals, nitrate, ammonia, pH, faecal coliforms and *E. coli* should also be assessed. Further MST sampling at these sites would also be useful to identify the sources of any bacterial contamination.

3.11. Lake Waiwiri

Assessing water quality at the lake provides an indication of the ‘starting condition’ of the stream. As discussed, both the lake and the stream contained high nutrient concentrations in 2008 and 2010. In 2008 there was significantly more total

[6] The actual discharge averages 6,184 m^3/day of effluent and 728 m^3/year of digested sludge (pers. comm. Wally Potts, HDC, 16 October 2012).

phosphorus in the stream near the lake than near the beach, but no difference in total nitrogen, *E. coli* and pH (Table 2). However, results from the MST analysis (Section 3.2) indicate that *E. coli* and universal bacteriodale concentrations are generally lower[7] in the lake than in the stream (Figures 8 and 9).

3.12. Birds

High concentrations of *E. coli* and universal faecal markers at tributary site A are most likely to be the result of contamination from both cows and bird faeces. Site A is one of about half a dozen drains in the area that run through low lying pasture close to the lake, some of which are accessible to grazing cattle. Two of the three water samples taken from site A had concentrations of *E. coli* higher than the guideline value for stock drinking water (ANZECC 1992). Left unfenced, these drains pose a threat to the health of livestock as well as aquatic values downstream.

It is understood that one of the landowners bordering the lake has managed populations of Canadian geese in the past (pers. comm. Jason Roxburgh, Manawatu/Rangitikei Area Manager, DOC, 8 August 2012). Annual culls of this nature will benefit aquatic ecosystems by reducing the amount of faecal matter entering the lake and stream.

3.13. Other impacts

Using heavy machinery on riparian areas is not conducive to riparian restoration. In August 2012 'mechanical cleaning' was carried out on sections of the Waiwiri that had been fenced and planted the year before by the Horizons' Environmental Management Group. Aimed at mitigating flood hazard, the excavations are estimated to have destroyed or badly affected some 25% of the plantings (pers. comm. Horizons' Operations Group via Huhana Smith, 11 October 2012). The work was carried out by Horizons' Operations Group under Consent 100431. Following concerns raised by kaitiaki and landowners, damaged areas were re-planted in September 2012 by members of the Waiwiri kaitiaki group, Horizons' Environmental Management Group, Operations Group and independent contractors who did the original cleaning.

Work of this nature not only smothers riparian plantings but has a detrimental effect on riparian soils and stream ecology. Using an excavator on the riparian strip will compact the soil, reducing the capacity for infiltration, thereby limiting one of the most important intended functions of the strip. Mechanically removing material from the stream bed destroys marginal and in–stream habitat, affecting species known to

[7] In seven of the nine lake water samples.

reside in the stream such as whitebait and kokopu. It also mobilises fine sediments from the bed and bank which may smother significantly more habitat downstream. Also, resident microbial populations may be liberated from bed sediments, which would have a detrimental effect on shellfish harvesting downstream.

The riparian operation occurred due to inadequate communication between two groups within Horizons Regional Council. Since the incident it has been clarified by Horizons that the Waiwiri Stream is to be managed as an approved drainage scheme by Operations, and that the cleaning will take place every 5-7 years. A stream management plan is to be written based on a verbal agreement that the northern side will be fenced and planted whilst the southern side is to remain accessible by digger for cleaning (pers. comm. Horizons Regional Council, via Huhana Smith, 11 October 2012).

However, the best option for ecological restoration on the Waiwiri Stream is to fence and plant as much riparian area as possible, and to discontinue the use of heavy machinery inside this area.

3.14. Recommendations

- In light of the above discussion (Section 4.6), this report still recommends complete fencing and planting projects along the Waiwiri mainstem and significant tributaries. This will require a preliminary inspection of tributaries to see which are most suitable for the creation of riparian buffers, as well as discussions with farm managers.
- Fence smaller tributaries closer to the confluence and construct wetlands to filter run-off before the tributary water enters the stream.
- Address effluent discharge(s) from dairy farms that flow directly into surface waters within the catchment.
- Consider regular culling of waterfowl such as Canadian geese and black swan in and around Lake Waiwiri to reduce the amount of bird faecal matter in the catchment.
- Fence drains in low-lying pasture on the western side of the lake.
- Consider seasonally or permanently retiring low–lying pasture on the western side of the lake to reduce faecal and nitrate contamination on saturated soils.
- Improve management of treated effluent irrigation at The Pot, so that overland run-off and interflow are mitigated. Monitoring soil moisture and drain flow would help minimise this until plans for increasing the irrigated land area are realised. Consider constructing wetlands for the purpose of tertiary treatment.

- Resume groundwater quality and shellfish tissue monitoring west of The Pot to assess the potential threat from trace metals, microbial contaminants, pH and ammonia to shellfish and shellfish consumption.

This study has been carried out under the assumption that the health of shellfish populations at the stream mouth reflects water quality in the stream. Investigating the validity of this assumption provides an opportunity for further research to see if shellfish presence and abundance are affected by water quality in lowland streams and/or emergent groundwater.

Finally, Lake Waiwiri and Waiwiri Stream are recognised as an 'Outstanding Natural Feature or Landscape' (Boffa Miskell Ltd 2011), and restoration initiatives in Waiwiri Stream are already underway. In a report to Horizons Regional Council, James & Joy (2009) identified Waiwiri Stream as one of three in the region that would most benefit from riparian restoration and restoration of fish passage. Following these recommendations (and as outlined in Section 4.6), HRC have funded the fencing and planting project for riparian buffers along the mainstem as far upstream as stream site 2 (Figure 6). Also, the Department of Conservation (DOC) purchase of lake-side pasture on the north western side of the lake is a precursor to prospective ecological restoration initiatives.

The next step is to obtain support from the key players (iwi, landowners, leaseholders and local government), identify sources of funding and prioritise funding needs. This report provides a timely impetus for a restoration project that has already gained the support of Horizons Regional Council and DOC.

4. ACKNOWLEDGEMENTS

MTM would like to thank the following individuals and organisations for their assistance and support in this project:

Iwi/Hapū/ Organisation or Individual	Including
Mua Ūpoko Tribal Authority	Robert Warrington Kerehi Wi Warena Apikaira Maria Wi Warena Marokopa Wiremu-Matakatea
Ngāti Kikopiri,Ngāti Hikitanga of Muhunoa	Rob Kuiti Hape Royal Larry Parr
Kaitiaki for Ngāti Kikopiri,Ngāti Hikitanga and the MTM project	Tipene (Sonny) Perawhiti
Ngāti Tūkorehe of Kuku	
Taiao Raukawa Environmental Resource Unit	
MTM project	Dr Huhana Smith, Research Leader Māori Moira Poutama, Research Assistant Aroha Spinks, Researcher
Nga Whenua Rahui	Richard Anderson, Rangimarkus Heke
Tipene Hoskins	
Kaitiaki for Ngāti Tūkorehe Ngāti Wehiwehi and the MTM project	Paul Ransfield
Kaitiaki for Ngāti Tūkorehe	Isha Heke Toby Lawton, Customary Fisheries Patrick Seymour, Customary Fisheries
Horizons Regional Council	Lisa Duffy - Consents planner James Lambie – Science co-ordinator Robert Rose – Environmental protection officer Maree Clarke – Senior scientist water quality
Horowhenua District Council	Wally Potts – Community assets manager Hamish Low – Wastewater consultant
Nathan Murray, Levin	
Brendan and Debbie Faith, Te Horo	
Paul Cockrell, Porotawhao	
Brian and Pauline May, Muhunoa, Ōhau	
Malcolm and Betty Bryant, Muhunoa, Ōhau	
Donald Bryant, Muhunoa, Ōhau	
Tony Ryan, Ōhau	
Department of Conservation, Palmerston North	
Forest and Bird, Horowhenua Branch	Joan Leckie
School of Architecture and Design, Victoria University, Wellington	Jamie MacFarlane Associate Professor Penny Allan & the 2012 Masters students involved with the Waiwiri

5. REFERENCES

Allibone R, David B, Hitchmough R, Jellyman D, Ling N, Ravenscroft P, Waters J 2009. Conservation status of New Zealand freshwater fish, 2009. New Zealand Journal of Marine and Freshwater Research 44 (4): 271-287.

ANZECC 1992. In Australian water quality guidelines for fresh and marine waters. Australian & New Zealand Environment & Conservation Council.

ANZECC, ARMCANZ 2000. In Australian and New Zealand guidelines for fresh and marine water quality. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

Boffa Miskell Ltd 2011. Outstanding Natural Landscapes and Features Review. Report No. BML Reference W10046.

Byappanahalli M, Fowler M, Shively D, Whitman R 2003. Ubiquity and persistence of Escherichia coli in a Midwestern coastal stream. Applied and Environmental Microbiology 69 (8): 4549-4555.

Byappanahalli MN, Whitman RL, Shively DA, Ting WTE, Tseng CC, MB N 2006. Seasonal persistence and population characteristics of Escherichia coli and enterococci in deep backshore sand of two freshwater beaches. Journal of Water and Health 4: 313-320.

Cooper R, Brooking R 2002. Ways through complexities. In: Kawharu M ed. Whenua managing our resources. Reed Publishing Ltd, Auckland.

Cornelisen C, Kirs M, Gilpin B, Scholes P 2012. Microbial Source Tracking (MST) Tools For Water Quality Monitoring. Prepared for Regional Councils and the Coastal Special Interest Group. Cawthron Report No. 2047. 22 p.

Cowie B 1998. Decision on an application for Resource Consent. Levin. Report No. 1/3/HDC MJM:SMH.

Davie T 2004. Soil water, run-off and streamflow generation. In: Mosely JHP ed. Freshwaters of New Zealand New Zealand Hydrological Society, Christchurch.

Freeze R, Cherry JA 1979. Groundwater. Englewood Cliffs: Prentice Hall Inc.

GNS 2010. Horowhenua Water Resources: Water Budget and Groundwater-Surface Water Interaction.

Harding JRG 1986. Letter to Manawatu Catchment Board: Levin Effluent Disposal Scheme. Beca Carter Hollings and Ferner Ltd. pp 607409.0 JRGH:hln.

Hawcroft A 2011. Biodiversity and Forestry: Setback for SOS aquatic and other rivers. In One Plan Mediation: notes by Amy Hawcroft, 14 June 2011.

Hesp PA 2001. The Manawatu Dunefield: Environmental Change and Human Impacts. New Zealand Geographer 57 (2): 33-40.

Hickey CW, Martin ML 2009. A review of nitrate toxicity to freshwater aquatic species. NIWA client report HAM2009-099. Prepared for Environment Canterbury.

Horizons Regioinal Council 2011a. Proposed 'One Plan'. In Schedule D, Part 3.

Horizons Regioinal Council 2011b. Waiwiri at Papaitonga and Beach (unpublished data). Horizons Regioinal Council, ed., Palmerston North.

Horizons Regional Council 2011. Proposed 'One Plan'. Retrieved July 2011, from http://www.horizons.govt.nz/about-us/publications/about-us-publications/one-plan-publications-and-reports/proposed-one-plan/

Horowhenua District Council 2009. Asset management plans: Waste Water AMP August 2009 Levin. pp 78-80; Appendix 10.

James A, Joy M 2009. Prioritisation for restoration of out-flow stream habitat of coastal wetlands on the west coast of the Manawatu-Wanganui region. Horizons Regional Council.

Kirs M, Cornelisen C 2011. MST Technology For Shellfish; Final Report. Prepared for Seafood Innovations Ltd. Cawthron Report No. 2002. 36 p.

Ministry for the Environment 2002. The New Zealand Land Cover Database (LCDB) 2.

Ministry for the Environment and Ministry of Health 2003. Microbial Water Quality Guidelines for Marine and Freshwater Recreational Areas. In Microbial Water Quality Guidelines for Marine and Freshwater Recreational Areas.

Ministry of Health 2005. Guidelines for Drinking-water Quality Management for New Zealand 2005. Second edition. Ministry of Health, Wellington.

MWH 2007. Horowhenua District Council: Levin Sewage Treatment Plant and the Pot Monitoring Report 2006-2007. Cawthron Report No. Z1116504.

NIWA 2012a. National climate database. Retrieved July 2012, from http://cliflo.niwa.co.nz/

NIWA 2012b. New Zealand Freshwater Fish Database. National Institute of Water & Atmospheric Research, Accessed 25.10.2012.

NZMOH 1995. Microbiological reference criteria for food. New Zealand Ministry of Health, ed. Version 2.0.

NZWERF 2002. New Zealand Municipal Wastewater Monitoring Guideline. New Zealand Water Environment Research Foundation, ed. D. E. Ray, Wellington.

Park G 2001. Effective exclusion? An exploratory overview of Crown actions and Māori responses concerning the indigenous flora and fauna, 1912-1983. Waitangi Tribunal, Wellington.

Parkyn S 2004. Review of Riparian Buffer Zone Effectiveness. Prepared for Ministry of Agriculture and Forestry. 37 p.

Parkyn S, Wilcock B 2004. Impacts of agricultural landuse. In: Harding J, Mosley P, Pearson C, Sorrell B ed. Freshwaters of New Zealand. New Zealand Hydrological Society. Pp 34.1.

Ravine DA 1992. Foxton Ecological District: Survey for the Protected Natural Areas Programme. Department of Conservation, ed., Wanganui. pp 204-206.

Saffran K, Cash K, Hallard K, Neary B, Wright R 2001. Canadian water quality guidelines for the protection of aquatic life CCME Quality Index 1.0 User's Manual. Prepared for Canadian Council of Ministers of the Environment. 1-5 p.

Shanks OC, Kelty CA, Sivaganesan M, Varma M, Haugland RA 2009. Quantitative PCR for Genetic Markers of Human Fecal Pollution Applied and Environmental Microbiology 75 (17): 5507.

Smith SM 2007. Hei Whenua Ora ki Te Hakari: Hapū and iwi approaches for reinstating valued ecosystems of cultural landscape. In Māori Studies. Massey University, Palmerston North.

Souza V, Rocha M, Valera A, Eguiarte LE 1999. Genetic structure of natural populations of Escherichia coli in wild hosts on different continents. Applied and Environmental Microbiology 65 (8): 3373-3385.

Treadwell and Associates 2009. Assessment of the outstanding landscapes and natural features of the Horowhenua district. Prepared for Horowhenua District Council.

Unwin M, Snelder TH, Booker D, Ballantine DJ, Lessard JL 2010. Modelling water quality in New Zealand rivers from catchment-scale physical, hydrological and land-cover descriptors using random forest models. NIWA, ed. Report No. CHC2010-037.

Ward, Elliot WJ 1995. Environmental Hydrology. CRC Press.

Wenger S 1999. A review of the scientific literature on riparian buffer width, extent and vegetation. Prepared for Office of Public Service and Outreach, Institute of Ecology, University of Georgia.

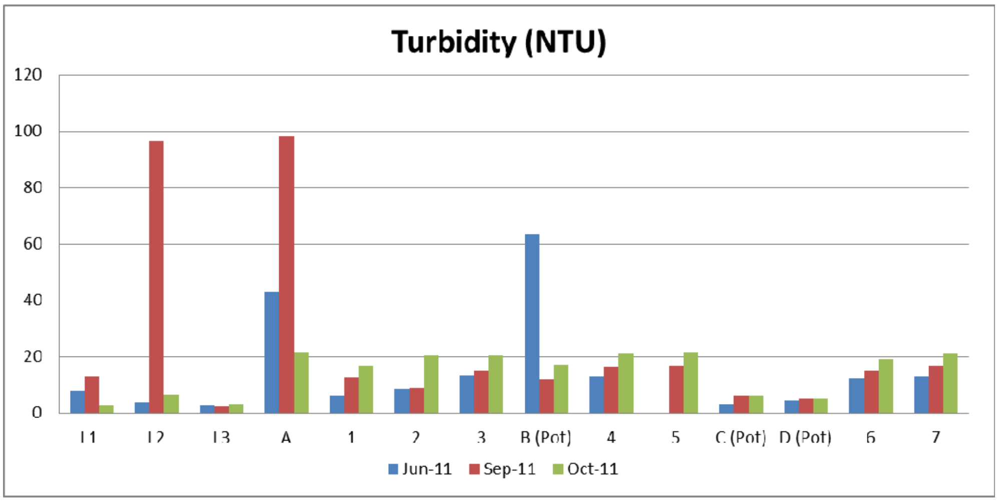
6. APPENDICES

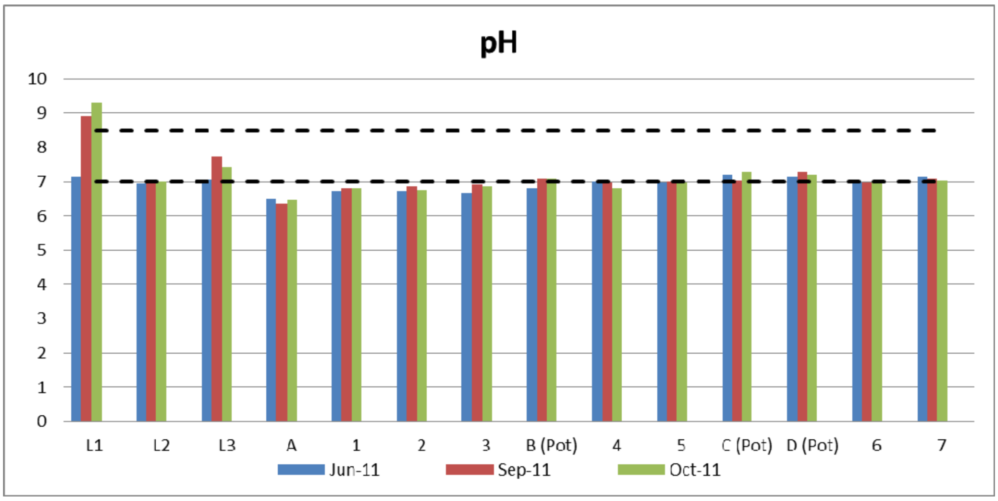
Appendix 1. Guideline water quality values for protection of river ecosystems, aesthetics, and human health.

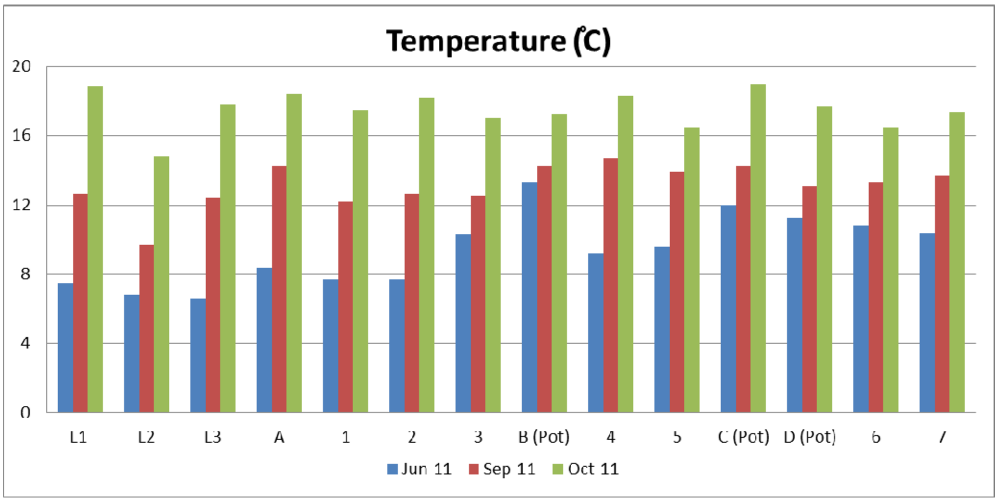
Parameter	Guideline acceptable value	Purpose of standard or guideline	Reference
Dissolved oxygen (DO)	>60% saturation	'Target' for aquatic ecosystem protection specific to Lake Papaitonga catchment	(ANZECC & ARMCANZ 2000; Horizons Regional Council 2011)
	>80% saturation or >6.5 mg/L	Aquatic ecosystem protection	(ANZECC 1992)
pH	7.0–8.5	'Target' for aquatic ecosystem protection specific to Lake Papaitonga catchment	(ANZECC & ARMCANZ 2000; Horizons Regioinal Council 2011a)
	6.5–8.5	Contact recreation (NZ natural range)	(ANZECC & ARMCANZ 2000; Saffran *et al.* 2001)
	5–9	Aquatic ecosystem protection	(Saffran *et al.* 2001)
Turbidity	<5.6 NTU for lowland rivers	Contact recreation	(ANZECC & ARMCANZ 2000)
Ammoniacal nitrogen (NH_4-N)	<0.4 g/m^3 (0.4mg/L) and max 2.1 g/m^3	'Target' for aquatic ecosystem protection specific to Lake Papaitonga catchment	(ANZECC & ARMCANZ 2000; Horizons Regioinal Council 2011a)
	<0.02 mg/L	Aquatic ecosystem protection (for lowland rivers)	(ANZECC & ARMCANZ 2000)
Total nitrogen (TN)	<0.614 mg/L	Aquatic ecosystem protection	(ANZECC & ARMCANZ 2000)
Nitrate (NO_3-N)	<1.7 mg/L	Aquatic ecosystem protection (Toxicity for average species at 95% protection)	(Hickey & Martin 2009)
Dissolved reactive phosphorus (DRP)	<0.015 mg/L	'Target' for aquatic ecosystem protection specific to Lake Papaitonga catchment	(ANZECC & ARMCANZ 2000; Horizons Regioinal Council 2011a)
	<0.01 mg/L	Aquatic ecosystem protection	(ANZECC & ARMCANZ 2000)
Total phosphorus (TP)	<0.033 mg/L	Aquatic ecosystem protection	(ANZECC & ARMCANZ 2000)
Carbonaceous biological oxygen demand (CBOD)	<2 mg/L	Aquatic ecosystem protection (specific for the lower Ōhau River)	(ANZECC & ARMCANZ 2000; Horizons Regioinal Council 2011a)
Soluble carbonaceous biological oxygen demand (scBOD)	<2 g/m^3	'Target' for aquatic ecosystem protection specific to Lake Papaitonga catchment	(ANZECC & ARMCANZ 2000; Horizons Regioinal Council 2011a)
E. coli	<260 cfu/100mL	Contact recreation	(ANZECC & ARMCANZ 2000; Horizons Regioinal Council 2011a)
	150 cfu/100mL	Contact recreation (median)	MfE & MoH (2003)
	<260 cfu/100 mL	Contact recreation ***'Acceptable'***	
	260-550 cfu/100 mL	Contact recreation	

Parameter	Guideline acceptable value	Purpose of standard or guideline	Reference
		'Alert'	
	>550 cfu/100 mL	Contact recreation ***'Action'***	
	<1000 cfu/100 mL	Acceptable stock drinking water (median)	(ANZECC 1992)
Faecal coliforms	<150 per 100mL	Aquatic ecosystem protection (median)	(ANZECC & ARMCANZ 2000)
Particulate organic matter (POM)	<5 g/m^3	'Target' for aquatic ecosystem protection specific to Lake Papaitonga catchment	(ANZECC & ARMCANZ 2000; Horizons Regional Council 2011)
Periphyton	<200 mg/m^2 chl-*a*		
Soluble inorganic nitrogen (SIN)	<0.167 g/m^3		
Temperature	<24°C		

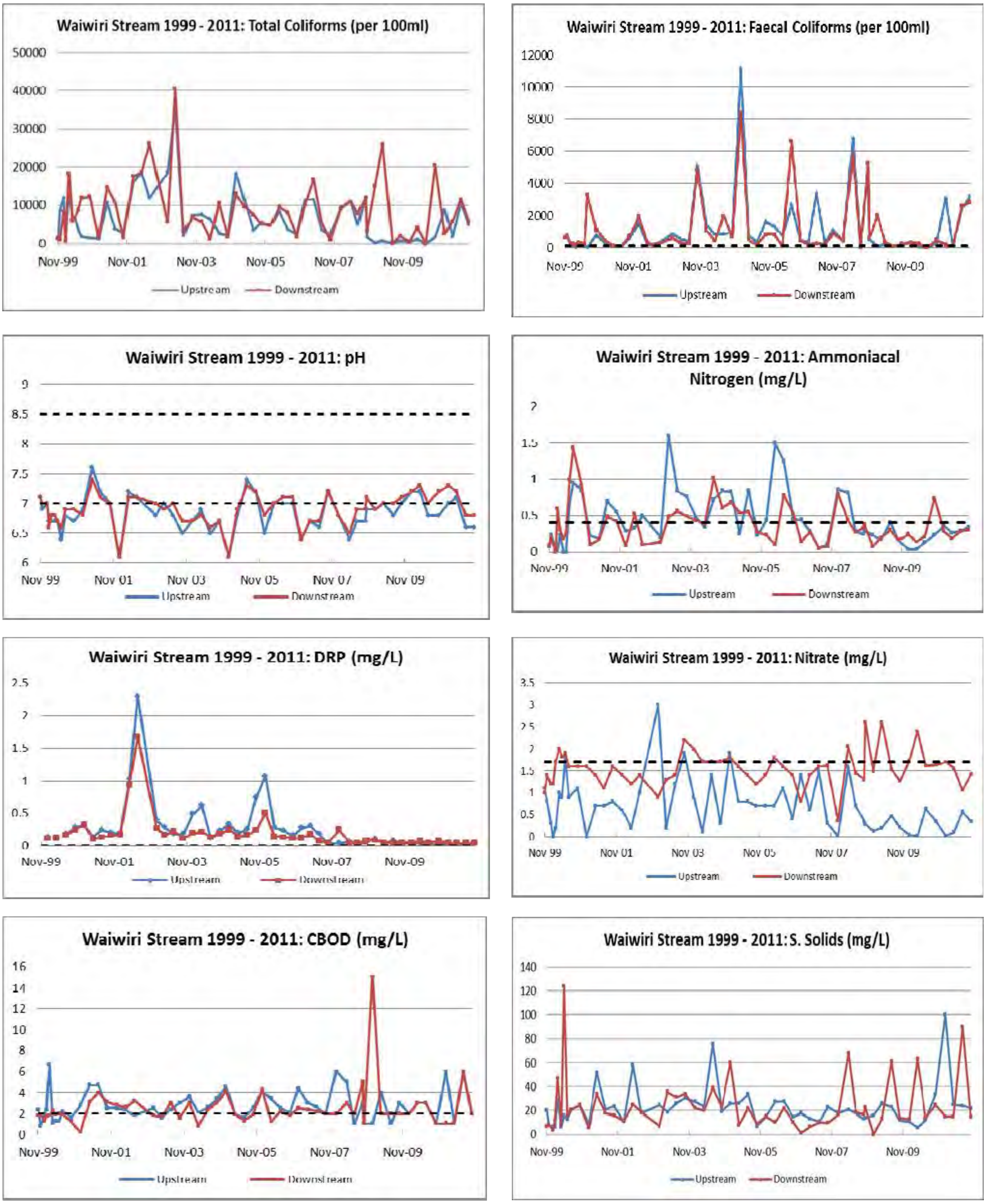
Appendix 2. Turbidity, pH and temperature of water from the lake and stream on the three sampling occasions in 2011. Dashed lines represent the most relevant guideline values as indicated in Appendix 1.



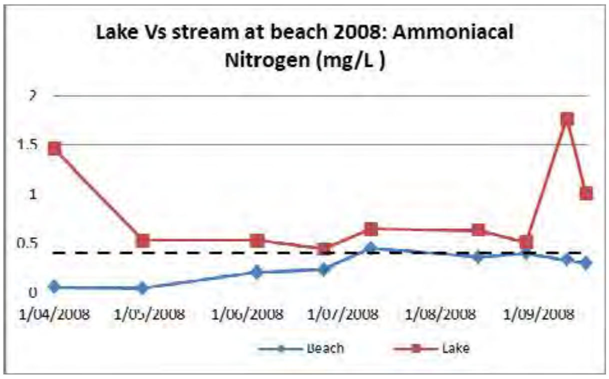


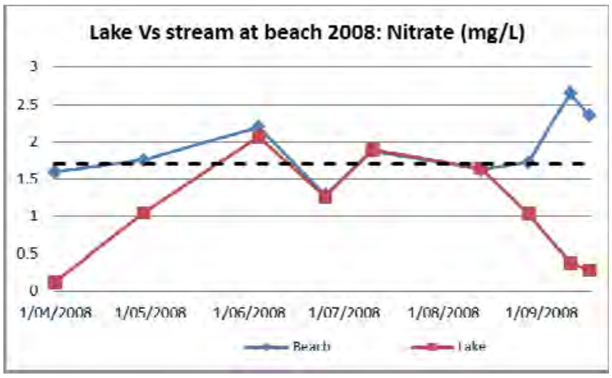


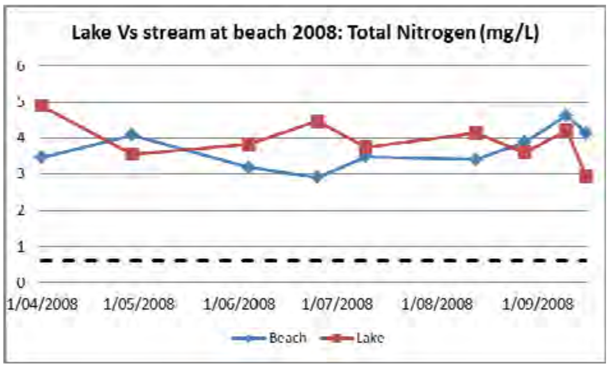
Appendix 3. Water quality in Waiwiri Stream: immediately upstream and downstream of 'The Pot' effluent disposal site, 1999-2011. Dashed lines represent the most relevant guideline values as indicated in Appendix 1. Data supplied by Horizons Regional Council.

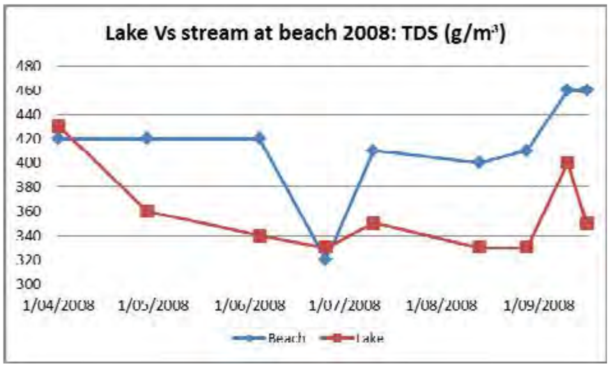


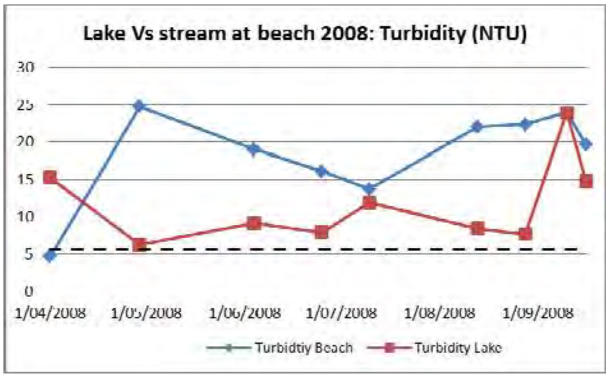
Appendix 4. Water quality in Waiwiri Stream: at the beach and lake end, 2008. Dashed lines represent the most relevant guideline values as indicated in Appendix 1. Data supplied by Horizons Regional Council.

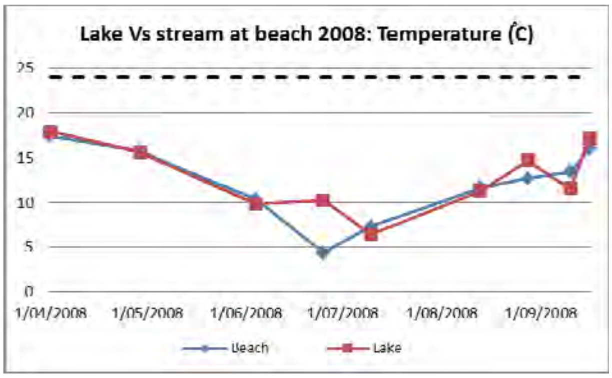


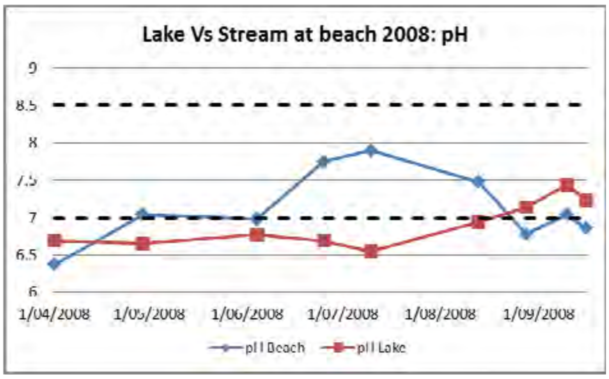


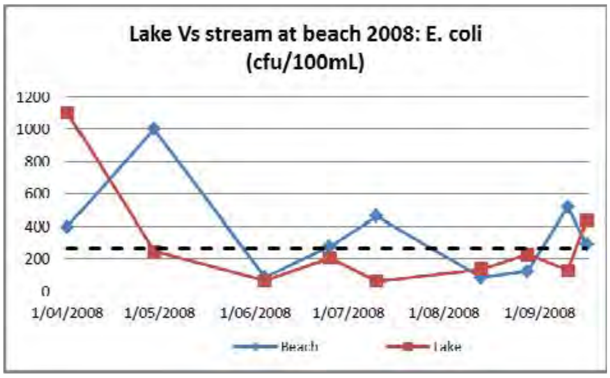


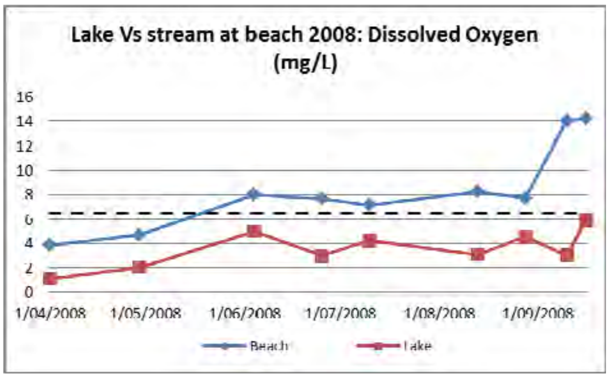


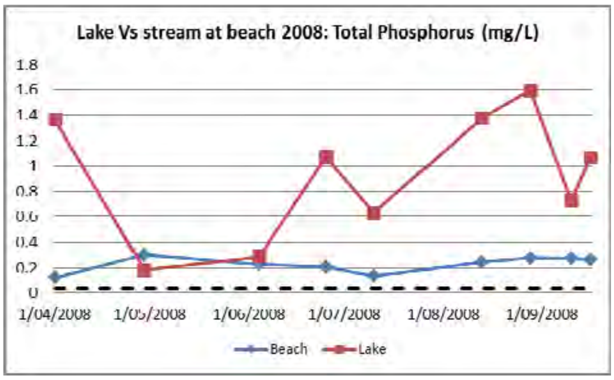


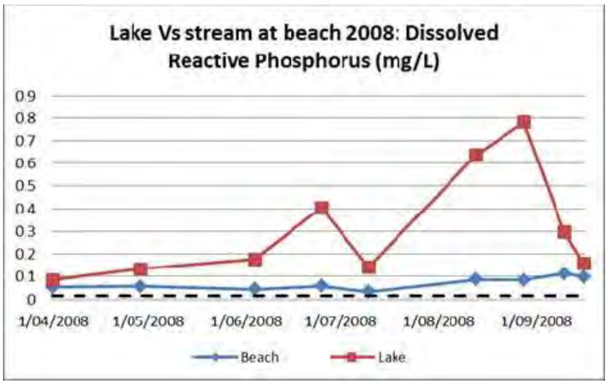




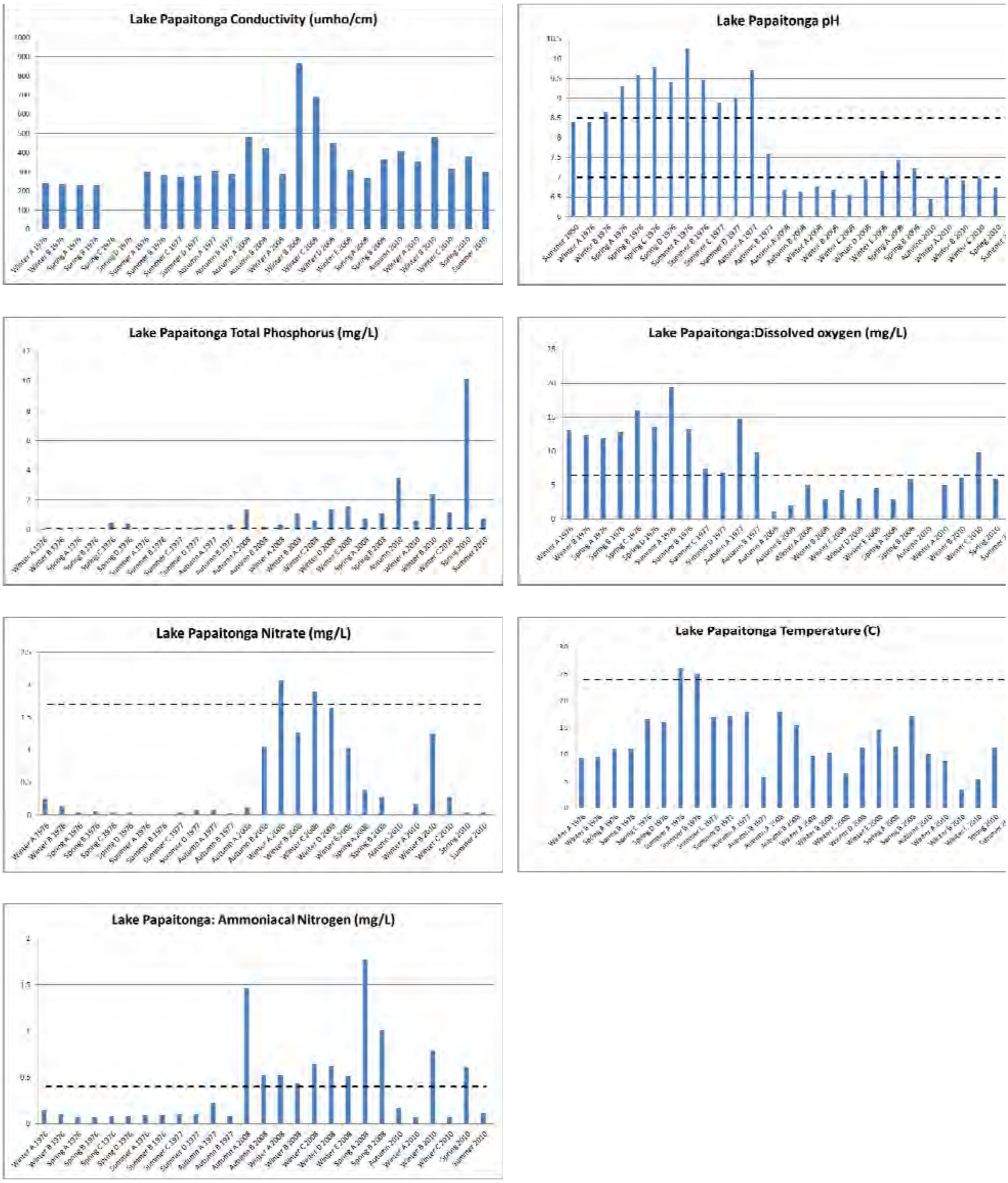



Lake Vs stream at beach 2008: Dissolved Oxygen (mg/L)
16
14
12
10
8
6
4
2
0
1/04/2008
1/05/2008
1/06/2008
1/07/2008
1/08/2008
1/09/2008
Beach
Lake


Lake Vs stream at beach 2008: Total Phosphorus (mg/L)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1/04/2008
1/05/2008
1/06/2008
1/07/2008
1/08/2008
1/09/2008
Beach
Lake


Lake Vs stream at beach 2008: Dissolved Reactive Phosphorus (mg/L)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1/04/2008
1/05/2008
1/06/2008
1/07/2008
1/08/2008
1/09/2008
Beach
Lake

Appendix 5. Water quality in Lake Papaitonga (1976/77) and the uppermost reach of Waiwiri Stream (2008/2010): Dashed lines represent the most relevant guideline values as indicated in Appendix 1. Data supplied by Horizons Regional Council.



Appendix 6. Rainfall taken at Horizons Waitarere Forest Climate Station prior to MST water sampling events.

	Sample 1	Sample 2	Sample 3
Date	28 June 2011	20 Sept 2011	4 Oct 2011
Time	0930–1400	1100–1500	1100–1500
Conditions	Fine, no wind	Fine, no wind	Fine, no wind
Rainfall – prev 6–hr	0 mm	0 mm	1.6 mm
prev 12–hr	0 mm	0 mm	4.4 mm
prev 24–hr	0 mm	20.4 mm	31 mm
prev 72–hr	2 mm	26.4	32.4 mm
Manakau Stream flood peak		4.08 m^3/s at 22.15 on 19 September 2011	4.01 m^3/s at 2200 on 3 October 2011