Ministry for the
Environment
Manatū Mō Te Taiao

Water Quality in Selected Dairy Farming Catchments

A baseline to support future water-quality trend assessments

New Zealand Government

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Disclaimer

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Contents

Executive Summary vii

Introduction 1

Purpose and scope of this report 1

Context for this report 1
- Dairying and water quality 2
- The Dairying and Clean Streams Accord 3
- Monitoring water quality in dairy catchments: this report 4

Methods 6

The monitored catchments 6

Data collection 8
- Land-use and farm information 8
- Water-quality data 8

Data analysis and presentation 10
- Use of guidelines 10

Data limitations and constraints 11
- Farm survey data 11
- Data scale, resolution and time lag issues 11
- Statistical constraints 12

Catchment Characteristics 14

Catchment geography, geology and hydrology 14

Land-use and farm information 15

Progress towards Accord targets 16

Water-quality Baseline 20

Presentation of data 20

Faecal contaminants 21
- Human health risk – contact recreation 23
- Stock drinking-water quality 23

Nutrients (nitrogen and phosphorus) 24
- Comparison with reference conditions and other pastoral catchments 28

Nuisance weed and algal growth 30

Stressors and toxicants 33
- Ammoniacal nitrogen 33
- Dissolved oxygen 35
- Water temperature 37
- Electrical conductivity 38

Sediments and visual quality 39

Benthic macroinvertebrates 41

Upstream vs downstream measurements 43

Observed temporal changes 45

Summary and Recommendations 47

Summary of catchment characteristics and water quality 47
- Catchment features and land use 47
- Water quality 48

Considerations for ongoing monitoring 48
- Land-use information 48
- Water-quality information 49
- Merits of the existing monitored catchments for national reporting 49
- Recommended next steps 51

References and Information Sources 54

Appendices

Appendix 1: Monitoring Catchment Details 58

Appendix 2: Water-quality Summary Data 71

Appendix 3: Regression Analyses 85

Appendix 4: Current Monitoring Programmes 86

Appendix 5: Recreational Values 89

Tables

Table 1: Monitored catchments and monitoring agencies 6
Table 2: Water-quality parameters used in this report 8
Table 3: Catchment features and land-use characteristics 17
Table 4: Catchment dairy farm information 19
Table 5: Reference values and guidelines used for interpreting *E. coli* data in Figure 3 21
Table 6: SIN:DRP ratios for each monitored dairy catchment (based on data for the most downstream site) 29
Table 7: Average MCI and QMCI scores 42
Table 8: MCI and QMCI degradation categories suggested by Wright-Stow and Winterbourn (2003) 43
Table 9: Comparison of upstream and downstream measurements 44
Table A2-A: Summary of catchment site details and data sources 71
Table A2-B: *E. coli* 72
Table A2-C: Total nitrogen 73
Table A2-D: Nitrate–nitrite nitrogen 74
Table A2-E: Soluble inorganic nitrogen (SIN) 75
Table A2-F: Total phosphorus 76
Table A2-G: Dissolved reactive phosphorus 77
Table A2-H: Ammoniacal nitrogen 78
Table A2-I: pH 79
Table A2-J: Dissolved oxygen 80
Table A2-K: Water temperature 81
Table A2-L: Electrical conductivity 82
Table A2-M: Suspended sediments 83
Table A2-N: Turbidity 84
Table A3-A: Regression analyses 85
Table A4-A: Current (2009) monitoring programme 86
Table A5-A: Recreational values of the catchment streams and downstream receiving waters 89

Figures

Figure 1: Location of Tier 1 and Tier 2 monitoring catchments in New Zealand 7

Figure 2: Comparison of annual rainfall totals during the water-quality monitoring period (grey bars) with the long-term record (black bars), Waiokura catchment 15

Figure 3: *E. coli* medians and ranges for the most downstream site for each catchment during the monitoring period 22

Figure 4: Medians (crosses) and measured ranges (min, max) for total nitrogen (top), nitrate–nitrite nitrogen (middle), and soluble inorganic nitrogen (bottom) for the most downstream site during monitoring period 25

Figure 5: Medians (crosses) and measured ranges (min, max) for total phosphorus (top), and dissolved reactive phosphorus (bottom) for the most downstream site during the monitoring period 27

Figure 6: Regression of %Dairy (left) and average annual rainfall (right) with median total nitrogen for all monitored catchments (n = 14) 28

Figure 7: Nitrogen pulses during herd crossing on a tributary of Rai River over two days in September 2001 32

Figure 8: Example of stream bed condition before (left) and after (right) herd crossing removal on a tributary stream in the Rai catchment 33

Figure 9: Medians (crosses) and ranges for ammoniacal nitrogen for the most downstream sites during the monitoring period 34

Figure 10: Medians (crosses) and ranges for dissolved oxygen for the most downstream site (unless specified otherwise) during the monitoring period 36

Figure 11: Medians and ranges for the most downstream site during the monitoring period for water temperature 37

Figure 12: Medians (crosses) and ranges for electrical conductivity for the most downstream site during the monitoring period 38

Figure 13: Medians (crosses) and ranges for the most downstream site during the monitoring period for suspended solids and turbidity 40

Figure A1-A: Toenepi Stream catchment (Tier 1), Waikato 58

Figure A1-B: Waiokura catchment (Tier 1), South Taranaki 59

Figure A1-C: Waikakahi catchment (Tier 1), South Canterbury 60

Figure A1-D: Bog Burn catchment (Tier 1), Southland 61

Figure A1-E: Inchbonnie Stream catchment (Tier 1), Westland 62

Figure A1-F: Puwera Stream catchment (Tier 2), Northland 63

Figure A1-G: Taharua River catchment (Tier 2), Hawke’s Bay 64

Figure A1-H: Mangapapa catchment (Tier 2), Manawatu 65

Figure A1-I: Enaki catchment (Tier 2), Greater Wellington 66

Figure A1-J: Powell Creek catchment (Tier 2), Tasman 67

Figure A1-K: Rai catchment (Tier 2), Marlborough 68

Figure A1-L: Rhodes and Petrie catchment (Tier 2), Canterbury 69

Figure A1-M: Washpool catchment (Tier 2), Otago 70

Executive Summary

Background and purpose

This report draws together monitoring data from 14 dairy farming catchments in New Zealand to provide a baseline of water quality (and land use) in these catchments to assist with future water-quality trend assessments.

The Dairying and Clean Streams Accord is the main driver for assembling the information provided in this report. However, Accord actions are not the only factors that influence the water-quality results presented.

The 14 monitored catchments lie in 12 of the 16 jurisdictional regions in New Zealand. They range in size from 6 km^2 to 211 km^2, generally occupy flat to rolling lowlands that are dominated by dairying, and span a range of latitudes and climatic conditions. Five of the catchments are termed Tier 1 catchments in this report in recognition of their inclusion in a Best Management Practice catchment monitoring programme that began in 2001. The remaining catchments are termed Tier 2 catchments; some are part of ongoing regional council state-of-environment monitoring programmes, while monitoring was instigated in others more recently, specifically to establish a baseline.

Baseline information is presented for a period of monitoring between 2001 and 2007, with a focus on data collected in 2006/07. Various guidelines are used to provide a context for the baseline results. However, this report does not focus on particular catchment values, nor on whether these values are being preserved or compromised.

Main results

- The majority (10) of the monitored catchments had median *Escherichia coli* concentrations that indicate higher levels of faecal contamination than the ‘average’ lowland pastoral farming catchment in New Zealand. One catchment, Taharua in Hawke’s Bay, had relatively low *Escherichia coli* concentrations, similar to those found in catchments with predominantly natural land use (ie, relatively undisturbed).
- Soluble inorganic nitrogen (nitrate–nitrite nitrogen + ammoniacal nitrogen) exceeded the guideline for the prevention of nuisance periphyton growth in all catchments except for one. In all but two of the dairy catchments, nitrate–nitrite nitrogen concentrations exceeded the medians reported for lowland pastoral catchments in New Zealand.
- Dissolved reactive phosphorus exceeded the guideline for prevention of nuisance periphyton growth in half of the catchments (seven).
- Excessive weed (macrophyte) and/or algal growth was measured or observed on occasion in seven out of nine catchments for which information was available. However, there are subjective elements to this assessment and results should be interpreted with caution. There is a need to improve the way quantitative periphyton and macrophyte data is gathered and assembled for future reports.

- Median ammoniacal nitrogen concentrations were below the concentrations at which detrimental effects on aquatic life begin to be observed in all catchments. However, two catchments had peak (spot daytime) measurements that exceeded the Australia and New Zealand Environment and Conservation Council (ANZECC) toxicant guideline, and a further two exceeded a more conservative guideline.
- Four out of 13 catchments had median turbidity levels that were at, or in excess of, ANZECC guidelines for ecosystem protection (5.6 nephelometric turbidity units (NTU)). One of the likely consequences of this is reduced visual foraging areas for native fish (with a detrimental effect on their condition). However, no fish data was available to conclude whether such sediment effects were occurring.
- Spot measurements of dissolved oxygen concentrations indicate that the requirements for supporting aquatic life were generally met in all catchments during daylight. However, continuous recorder data available for five catchments indicates that night-time excursions well below recommended guidelines occurred in four of these. Furthermore, measured daytime peaks and sags indicate large fluctuations in several other catchments, which may indicate serious depletions are occurring but are not being captured by spot measurements.
- Macroinvertebrate (aquatic insects, snails and worms) scores varied widely. Five catchments had average metric scores indicating relatively clean water or mild degradation, while five had average scores indicating moderate to severe pollution. No data was available for four catchments.
- Deterioration from upstream to downstream was found within most of the catchments for nitrate–nitrite nitrogen (eight out of 12 catchments), dissolved reactive phosphorus (six out of 10) and suspended solids (seven out of 10). *E. coli* increased in the downstream direction in half of the catchments, but decreased in the downstream direction in the other half.

Commentary

Monitoring results indicate that water quality is generally degraded in the selected dairy catchments, particularly with respect to faecal and nutrient contamination. However, the extent and pattern of degradation are variable, both within and between catchments, as is the evidence of ecological consequences (bearing in mind that many of the guidelines such as ANZECC that have been used as reference points indicate the risk of adverse consequences rather than describing actual effects). This highlights the complex and scale-dependent nature of the relationships between land use and water quality in modified catchments, and also reflects the differing underlying geology and natural stream bed conditions.

The ability to characterise some aspects of land use and water quality (including ecosystem health) for this report has been limited. For example, verified farm-scale information on the extent and effectiveness of waterway protection (both Accord waterways and smaller feeder streams) is not available for most catchments. With respect to water quality, more detailed analysis of the magnitude and frequency of extreme results using continuous recorder data (eg, the bottom of the dissolved oxygen profile, water temperature spikes), in addition to average conditions, is needed.

Recommended next steps

- It is recommended that the Ministry for the Environment coordinate a review of the catchment monitoring programmes to determine their value for ongoing inclusion in nationally focused reporting.
- The review should include consideration of capturing new or additional land-use and water-quality data and the requirements for trend detection.
- Concurrent with the above review, funding and resourcing arrangements for ongoing monitoring will need to be agreed between the relevant parties, recognising the substantial costs associated with collecting robust environmental data. This should include consideration of the interaction between the monitoring objectives of local and central government, science and research providers, and industry for each of the catchments.
- Notwithstanding the outcome of a monitoring programme review, the Ministry for the Environment expects to produce further reports on the catchments in 2012 and 2017 using this baseline report as a reference point.

Introduction

This report has been developed as part of the Ministry for the Environment's environmental reporting programme. As well as producing regular environmental reporting using a set of national environmental indicators, the programme produces a range of occasional reports – such as this one – on topical, national-scale issues. Such reporting provides quantitative information to the resource managers, policy agencies and other decision-makers who manage New Zealand's natural resources.

Purpose and scope of this report

This report draws together monitoring data from 14 dairy farming[1] catchments in New Zealand. The aim is to characterise, in a standardised way, the water quality in these catchments using the latest[2] information available from monitoring agencies. As such, this report constitutes a 'baseline' report, against which ongoing monitoring information on water quality in the same catchments can be compared in future to identify trends. If care is taken, and consideration given to other monitoring programmes (such as regional council state-of-environment monitoring), these results from the selected catchments can be extrapolated to form a broadly representative nationwide picture of water quality in dairy catchments.

If monitoring in the selected catchments continues, and in some cases intensifies, the data in this report may also be useful for future national-scale assessments of the water-quality outcomes of good practice in on-farm management on dairying land, including implementation of the Dairying and Clean Streams Accord.

There are a number of challenges to providing robust information for national reporting purposes. Although it is not within the scope of this report to determine how such challenges should be overcome, some observations about the existing monitoring programmes are made, as well as recommendations for future data analyses.

Context for this report

The degraded condition of rivers and streams in lowland catchments in New Zealand has been repeatedly described by researchers (eg, Smith et al, 1993; Davies-Colley and Nagels, 2002; Larned et al, 2004) and is recognised by the wider public (Hughey et al, 2008). The public also have a predominantly negative view of the impact of dairying on water quality (Hughey et al, 2008), and council monitoring has shown that dairying is responsible for some of the poorest water quality outside of our urban centres (eg, Perrie, 2007).

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[1] In terms of land area, dairy farming is the dominant single land-use type in 12 of the 14 catchments. In two catchments dairying is not dominant by land area but is considered to be an important determinant of overall water quality.

[2] For the purposes of this report, 'latest water quality' information refers to average water-quality information calculated using the most recent data available for each monitored catchment at the time this report was compiled: generally this means either a 2001–2006 average or a 2006/07 average. See the introduction of the 'Water-quality Baseline' section for more detail on monitoring time periods.

Although the current state of water quality in lowland catchments is well understood, it is much more difficult to make general, but definitive, statements about recent trends. Examples of deteriorations in some aspects of water quality in farmed catchments have been reported (eg, Larned et al, 2004; Scarsbrook, 2006; Parliamentary Commissioner for the Environment, 2004), as have examples of improvements (eg, Larned et al, 2004; Wilcock et al, in press). However, it is significant that Environment Waikato (2008) has recently reported a widespread deterioration in water quality in what is our most intensively farmed region.

The extent to which dairying is responsible for recent and/or continued deteriorations is difficult to quantify. It has been noted by the Parliamentary Commissioner for the Environment (2004), with reference to an earlier researcher’s findings (Larned et al, 2004), that there has been a lack of nationwide assessment of water-quality trends in relation to particular land-use types.

Dairying and water quality

Although dairying is essential to our economy, it has an impact on the natural environment, especially on our waterways (eg, Smith et al, 1993; Davies-Colley et al, 2004).[3] High-producing pastures and stock (cows), combined with high stock densities, mean that contaminant losses to fresh water are often greater per hectare of dairy land compared with other land uses. For example, dairying land occupies only 22 per cent of the land area in Waikato, but it is estimated by Environment Waikato to account for 68 per cent of nitrogen and 42 per cent of phosphorus entering the waterways of the region (Environment Waikato, 2008). And although daily faecal loads to land are broadly similar for most types of stock animal (eg, dairy cattle, beef cattle, sheep and deer), the loadings from direct deposition to water are greatest from stock crossings (Wilcock, 2006), which are typically more active on dairy farms.

Contaminants reach waterways from a combination of point and non-point (diffuse) sources. Point-source discharges in dairy catchments are mainly due to the disposal of stock effluent from farm oxidation ponds. These are generally controlled through resource consent conditions, although non-compliant discharges (direct to water) are still a concern (eg, Greater Wellington Regional Council, 2008; Environment Canterbury, 2008). The diffuse pollutants of primary concern are: nutrients from livestock wastes (including urine patches) and fertiliser run-off (eg, Monaghan et al, 2007); microbial contaminants from livestock faeces (eg, Collins et al, 2007); and sediment from eroded banks and paddocks (eg, Niyogi et al, 2007).

Actions to reduce the impacts of dairying include fencing to keep stock from waterways, riparian planting, improved control of effluent discharges, bridging and culverting of streams, wintering off stock, and adopting fertiliser management plans and nitrification inhibitors. Some of these actions have been formalised and given target measures in the Dairying and Clean Streams Accord (see next section), which applies to streams that are “wider than a stride, deeper than a redband gumboot, and permanently flowing”. Others actions are part of day-to-day council advocacy work (eg, farmer-assisted riparian planting programmes).

However, some contaminant sources and pathways, particularly diffuse ones, are notoriously difficult to manage. For example, small headwater streams can make substantial contributions to the overall pollutant loading of a stream but can also be hard to isolate from farm activities (by fencing and planting) because of their number and the extent of the drainage area.

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[3] Intensive farming, including dairying, is known to have an impact on unconfined groundwater aquifers (eg, Hayward and Hanson, 2004). However, investigating this is not within the scope of this report.

The Dairying and Clean Streams Accord

In 2003, the Dairying and Clean Streams Accord was adopted in 15 of the 16 regions in New Zealand, in effect comprising a national non-regulatory programme for the dairying sector. The Accord is centred around a number of objectives and national targets, each of which is recognised as a best practice management action on dairy farms, although there are many additional best practice management actions not covered by the Accord. (See Box 1 for more details about the Accord, its objectives and its national targets.)

Box 1: The Dairying and Clean Streams Accord

The Dairying and Clean Streams Accord (the Accord) was agreed between Fonterra Co-operative Group Ltd (which comprises over 95 per cent of New Zealand's dairy industry), the Minister for the Environment, the Minister of Agriculture, and regional authorities in May 2003. The Accord reflects a non-legally binding commitment by these parties to improve the environmental performance of dairying, and has a goal of achieving "clean healthy water in dairying areas". The parties to the Accord agreed to work together to develop practical solutions to protect and enhance water quality in dairying areas.

The Accord comprises a number of objectives and national targets, as summarised in the following table.

Accord objective	Accord national targets
Dairy cattle are excluded from streams, rivers, lakes and their banks.	Dairy cattle are excluded from 50% of streams, rivers and lakes by 2007, and from 90% by 2012.
Regular (more than twice a week) crossing-points have bridges or culverts.	50% of regular crossing-points have bridges or culverts by 2007, 90% by 2012.
Farm dairy effluent is appropriately treated and discharged.	100% of dairy farm effluent discharge complies with resource consents and regional plans immediately.
Nutrients are managed effectively to minimise losses to ground and surface water.	100% of dairy farms have in place systems to manage nutrient inputs and outputs by 2007.
Existing regionally significant or important wetlands (as defined by regional councils) are fenced and their natural water regimes are protected.	50% of regionally significant wetlands are fenced by 2005, 90% by 2007.

The Accord is operational in 15 out of the 16 regions in New Zealand. The Accord does not operate in the West Coast region, where Westland Dairy Milk Products operates. Thirteen of the 15 Accord regions have significant numbers of Fonterra dairy suppliers in their region. The two exceptions are the Gisborne District and Nelson City, which have very little dairying.

Progress towards the Accord targets set out in the table above is reported annually by the Accord partners in the Snapshot of Progress reports. Up to June 2009, there have been five Snapshot of Progress reports published. The majority of data in these reports is supplied by regional authorities (effluent compliance figures) and Fonterra (through their annual On-farm Environment and Animal Welfare Assessment surveys).

The main reporting commitment associated with the Accord is an annual Snapshot of Progress (eg, Ministry of Agriculture and Forestry, 2009). The Snapshot of Progress is produced by Accord partners and reports on progress towards each Accord objective and target. However, the Snapshot does not provide information about what environmental outcomes – including improved water quality – are being achieved in dairying catchment waterways.

Monitoring water quality in dairy catchments: this report

There are many routine sampling programmes in New Zealand that aim to monitor water-quality changes in intensively used catchments. However, there has been no nationally concerted effort to draw data together from a wide range of predominantly dairy catchments to try to establish a broadly representative New Zealand-wide picture of water quality in these environments. That is the aim of this report, which has been guided by a monitoring and reporting strategy published by the Ministry for the Environment in 2006 (*A Monitoring and Reporting Strategy for Measuring the Environmental Outcomes of the Accord*).

As the title suggests, the Strategy's intent was to provide a monitoring approach to measure the water quality outcomes of the Accord. However, the Strategy document also stated that there are a number of significant challenges[4] to discriminating between the water-quality outcomes of on-farm management practice changes resulting from the Accord and all the other activities occurring in a particular catchment. These challenges have since been emphasised by Harris Consulting (2008) in the mid-term stocktake of the Accord, who stated:

- ... the Accord itself is not likely to have an impact on water quality outcomes that is discernible against all the other changes that are going on in the operating, regulatory and voluntary environment ...
- ... it would seem appropriate, given the (methodological) difficulties of monitoring the Accord on its own, to integrate the Accord monitoring with other monitoring programmes being undertaken nationally; that is ... it may be more useful to have an overall monitoring programme ... to assist in determining the impact of the whole suite of initiatives rather than just focusing on the Accord.

Given the challenges just described, the Ministry for the Environment considers that the Strategy better represents a 'whole-of-catchment' monitoring strategy rather than an Accord-focused strategy, and it will be further implemented (and interpreted) in the future as such.

The Strategy recommended making use of data from existing monitoring programmes in selected dairy catchments and implementing a small number of new monitoring programmes (see Box 2 below) with a view to producing standardised reporting on water quality in monitored dairying catchments at regular intervals. Such reporting would take the form of a baseline report in the first instance (ie, this report), followed by subsequent follow-up reports every five years.

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[4] See further explanation of these challenges in the 'Data limitations and constraints' section.

Box 2: Implementing the monitoring and reporting strategy

The monitoring and reporting strategy for measuring the environmental outcomes of the Accord (Ministry for the Environment, 2006) recommended using monitoring information from two primary sources to assess the environmental outcomes of the Accord. These are given below and are the basis for the information provided in this report.

Existing best practice (Tier 1) catchments

Concern about increasing degradation of soil and water quality and the long-term sustainability of dairy farming led to the New Zealand dairy industry initiating the Best Practice Dairy Catchments Project in 2001, in which four dairying catchments were chosen for long-term monitoring. These catchments were chosen as being generally representative of some of the challenges of water-quality management in each of the regions.

The goal of the project was to establish an environmental baseline in each catchment against which the effects of the adoption of best management practices can be measured over time.

The catchments are located in two traditional dairy farm areas of the North Island (Waikato and Taranaki), and two areas of the South Island that have only relatively recently undergone conversion to dairy farming (South Canterbury and Southland). Monitoring of a fifth catchment at Inchbonnie on the West Coast of the South Island began in June 2004 (in a waterway known as Pigeon Creek).

Additional (Tier 2) catchments

In addition to the best practice catchments, a further nine predominantly dairying catchments were selected for long-term water-quality monitoring, with a specific focus on assessing how Accord actions can affect water quality. These catchments were chosen to represent New Zealand dairy catchments in which best management practice is generally not as far advanced as in the Tier 1 catchments. Regional councils undertake the monitoring and reporting in these Tier 2 catchments.

All of the Tier 1 and five of the Tier 2 monitoring programmes discussed above have been in place since at least 2002. Four of the Tier 2 catchment programmes were established specifically to generate additional monitoring data in line with the monitoring and reporting strategy, which is why the majority of that data was collected during 2006/07.

Methods

This national baseline report presents a summary of the data received from councils and other agencies. Some of the data reported in this report is previously unpublished, while other data has already been published in council technical reports and in scientific papers. All data sources are listed in the references section of this report, and readers are referred to these sources for specific details about the monitoring and reporting methods in each monitored catchment.

The monitored catchments

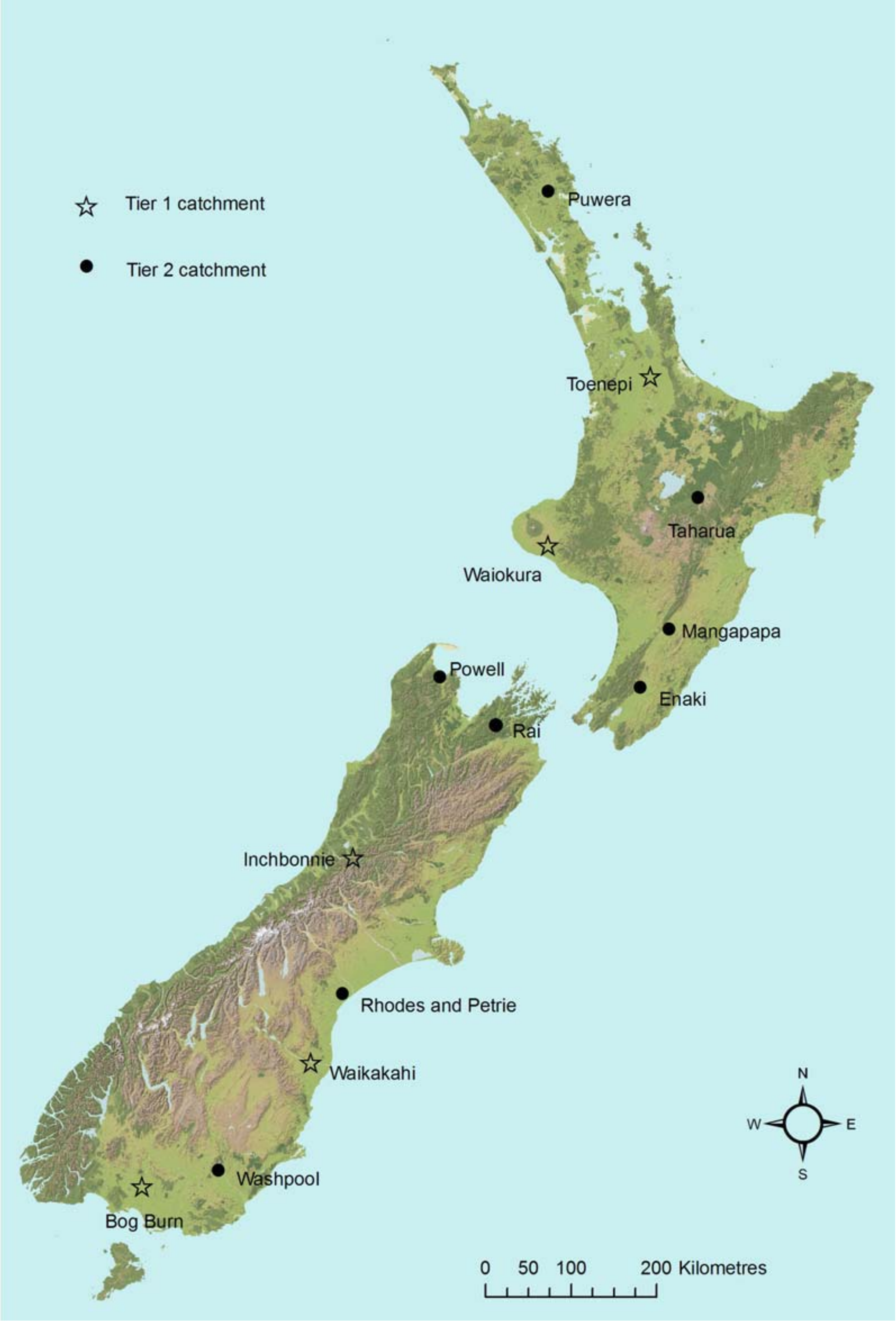
There are five Tier 1 catchments and nine Tier 2 catchments situated in 12 of the 16 regions in New Zealand (see table 1 and figure 1).

Table 1: Monitored catchments and monitoring agencies

Catchment name		Region and greater catchment that monitored catchment contributes to	Monitoring agencies and/or associated regional and district councils
Tier 1 catchments	Toenepi	Waikato; Piako River tributary	NIWA, AgResearch, Environment Waikato
	Waiokura	South Taranaki; discharges to the sea	Taranaki Regional Council, NIWA, AgResearch
	Waikakahi	South Canterbury; lowland tributary of the Waitaki River	Environment Canterbury, NIWA, AgResearch
	Bog Burn	Southland; lowland tributary of the Oreti River	Environment Southland, NIWA, AgResearch
	Inchbonnie (Pigeon Creek)	West Coast; Lake Brunner catchment	NIWA, AgResearch, West Coast Regional Council
Tier 2 catchments	Puwera	Northland; west of Whangarei Harbour	Northland Regional Council
	Taharua	Hawke's Bay; tributary of the Mohaka River	Hawke's Bay Regional Council
	Mangapapa	Manawatu–Wanganui; upper Manawatu River catchment	Horizons (Manawatu–Wanganui Regional Council)
	Enaki	Greater Wellington; tributary of the Mangateretere River (Ruamahanga River catchment)	Greater Wellington Regional Council
	Powell Creek	Tasman; tributary of the Motupipi River	Tasman District Council
	Rhodes–Petrie*	South Canterbury; discharge to Orari river mouth (Rhodes) and Orari River upstream of mouth by 3 km (Petrie)	Environment Canterbury
	Washpool	Southwest Otago; tributary of the Pomahaka River	Otago Regional Council
	Rai River	Marlborough; tributary of the Pelorus River	Marlborough District Council

* The Rhodes Stream and Petrie Creek are small, neighbouring waterways that are part of the same general catchment area. However, they are unconnected, so the water-quality results for each of these streams are generally presented separately later in the report.

Figure 1: Location of Tier 1 and Tier 2 monitoring catchments in New Zealand



Data collection

Land-use and farm information

Information about Tier 1 and 2 catchment features, including land use, was provided by regional councils, mainly from their resource consents and environmental monitoring databases, as well as from other data sets such as the Land Cover Database 2 and AgriBase.

Information about the progress made towards Accord targets in each Tier 1 and 2 catchment was provided by Fonterra Co-operative Group Ltd from its annual on-farm survey results. Survey results for individual farms were aggregated to obtain the catchment figures presented in this report. In a limited number of cases regional councils were able to supplement the Fonterra information with their own farm survey findings (eg, Environment Canterbury), and this supplementary information has been included where appropriate.

Water-quality data

Water-quality baselines have been defined in this report by the *median* (and range of) values for a number of water-quality measurements, including biological measurements. The measurements considered most appropriate for indicating the effects of land use – in this case, dairying – on water quality are listed in Table 2. Non-dairy farming activities in monitored catchments can also substantially influence the results for the parameters listed in table 2, and this is discussed further in the next section ‘Data limitations and constraints’.

Table 2: Water-quality parameters used in this report

Parameters	What do they measure and/or tell us?	Farming influences
Nutrients Nitrate–nitrite nitrogen Soluble inorganic nitrogen Total nitrogen Dissolved reactive phosphorus Total phosphorus	Measure the intensity of land use and the effectiveness of nutrient and effluent management. Indicate the level of potential risk of eutrophication. Dissolved nitrogen and phosphorus are most important in-stream, and total nitrogen and phosphorus are most important in downstream receiving waters.	Diffuse run-off of fertiliser/effluent (nitrate–nitrite nitrogen leaching and surface run-off of phosphorus); stock access to watercourses; effluent entering streams through tile drains, irrigators or direct pond discharges.
Periphyton (benthic algae) and macrophytes (aquatic plants)	Indicate extent of nuisance algae, cyanobacteria and/or weed growth. Usually result from eutrophic conditions (high nitrogen and phosphorus concentrations), increased light and water temperature, and stable flows. Affect recreational (eg, swimming, fishing) and aesthetic values.	Diffuse run-off and leaching of fertiliser/ effluent; stock access to watercourses; effluent entering streams through tile drains, irrigators or direct pond discharges; removal of riparian vegetation, reducing shade.
Bacteria (*Escherichia* coli)	Measure of faecal matter (effluent) in the water. Affect recreational (eg, swimming, fishing) values and stock drinking water quality.	Diffuse run-off of effluent; stock access to watercourses; effluent entering streams through tile drains, irrigators or direct pond discharges.

Parameters	What do they measure and/or tell us?	Farming influences
Stressors and toxicants		
Ammoniacal nitrogen	Toxic to fish and other aquatic animals.	Particularly influenced by point-source (direct) discharges of dairy effluent to streams.
Dissolved oxygen	Measure of the aquatic life-supporting capacity of the water.	Reduced by microbial respiration during the breakdown of organic matter and therefore indicative of organic waste discharges. Reduced under nutrient-enriched conditions by respiration of macrophtyes and periphtyon algae, particularly at night.
Water temperature	Temperature changes can promote nuisance weed growth and have undesirable effects on aquatic species.	Increased by removal of shading trees To a lesser degree can be increased by reduced flow under weed-choked conditions.
Suspended solids and turbidity	Measure of fine solids in the water (sediment from erosion, soil loss and organic matter from direct discharges). Affect habitat quality (eg, fish passage), recreational (eg, fishing, swimming) and aesthetic values (visual quality).	Stock access to watercourses; unstable and erodable land.
Conductivity (measures total dissolved soluble ions)	Coarse but useful indicator of nutrient concentrations and of different water source contributions (mixing).	Diffuse run-off of fertiliser/effluent; stock access to watercourses; effluent entering streams through tile drains, irrigators or direct pond discharges.
Biological		
Stream macroinvertebrates	Important indicators of general stream health and condition and aquatic biodiversity. Their advantage over spot measurements of chemical and physical properties is that communities of macroinvertebrates reflect long-term conditions.	Can indicate direct stock access to streams, poor management of discharges and/or excessive algal growth.
Stream flow	Natural hydrological flow regime of a catchment, which is required to interpret natural perturbations and influences on any information collected. Non-point source contamination often peaks during high flow events as contaminants are washed in from the landscape.	Can be affected by abstractions and catchment/channel disturbance.

In most cases the water-quality samples used to provide data for this report were collected by regional councils from the monitored catchments and processed in accredited laboratories. National Institute of Water and Atmospheric Research (NIWA) field teams also collect data from the Tier 1 catchments.

The design of the monitoring programmes and frequency of sampling varied between catchments and regions. Monthly sampling in some Tier 1 catchments began in the mid-1990s and continues today, although there have been periods of more frequent data collection (eg, weekly and fortnightly). The water quality median data presented for Tier 1 catchments in this report is drawn from the monthly sampling programme for the period 2001–2006.

Of the nine Tier 2 catchments, five were sampled on a monthly basis for a single year ending in mid-2007 for the purpose of deriving a water-quality baseline. However, some of these catchments had data for some aspects of water quality that had been collected before 2006/07. The remaining four Tier 2 catchments had a longer time series of data available because the sample sites are part of wider council state-of-environment monitoring programmes. Where these longer time series of data are available, they have been included in the derivation of Tier 2 catchment statistics.

More detail on the number of samples taken at each site is given in the water-quality data tables in appendix 2 (tables A2-A to A2-N).

All of the catchments continue to be monitored at the time of writing of this report and the current programmes are summarised in appendix 4 (table A4-A). However, the intensity and range of sampling differs between catchments, as does the extent to which monitoring agencies are able to commit resources. This is the subject of some discussion in the ‘Summary’ section of this report.

Data analysis and presentation

The analysis of water-quality data presented in this report was undertaken both by councils and by research agencies (eg, AgResearch, NIWA and the Cawthron Institute). In particular, the research agencies were closely involved with the analysis of water-quality data from the Tier 1 best practice dairy catchments. The Ministry for the Environment was provided with, or accessed through published reports, summary data for each catchment (ie, not raw sample data). As a result, the analysis of data in this report is restricted to the presentation and interpretation of descriptive statistics (ie, medians and ranges – minimum and maximum sample results).

Some linear regression of water-quality results against predictor variables (eg, land use, rainfall) has been attempted in order to define apparent patterns more quantitatively, but in most cases the correlations are poor (see appendix 3, table A3-A). This is likely to be a consequence of data limitations (ie, the number of catchments) and the inability of relatively simple statistical tests to account for the effect of multiple catchment factors on water quality.

Percentiles such as the 5th, 25th, 75th and 95th have not been presented because in some cases catchment statistics were derived from only 12 data points, which is insufficient to examine the distribution about the median in any meaningful way. One of the recommendations of this report (see ‘Recommended next steps‘ section) is that more in-depth, standardised statistical analysis be presented in future reports as the data sets for each catchment increase in size.

Use of guidelines

Water-quality data has been compared with national water-quality guidelines where appropriate. There are no national (binding) standards for ambient water quality in New Zealand, and the guidelines that do exist (eg, ANZECC 2000) are generally intended to be used for management and policy purposes rather than as reporting benchmarks. These guidelines do still provide a useful context for water-quality results, but readers are urged to take note of the specific comments about guidelines in each of the relevant results sections.

Data limitations and constraints

Farm survey data

The data provided by Fonterra is described in more detail in the most recent Accord Snapshot of Progress report (Ministry of Agriculture and Forestry, 2009). With regard to the limitations of the data, it is important to recognise that the on-farm surveys are completed by farmers, who may interpret the Accord wording and how it relates to their land in different ways. This leads to differing views on the reliability of data and different perceptions about progress towards Accord targets (eg, Deans and Hackwell, 2008; Jensen and Harcombe, 2008).

For the authors of this report it remains difficult to judge how well the survey data on progress towards Accord actions in each of the monitored catchments reflects the actual extent of actions (and the effectiveness of those actions). Furthermore, the Fonterra data only applies to waterways that meet Accord criteria. There is no standardised data available that describes the extent of fencing and livestock crossing removal for smaller headwater streams.

Data scale, resolution and time lag issues

Relating relatively coarse-scale land-use data to water-quality results and drawing conclusions about the effects of particular management actions on water quality (eg, the fencing of waterways) is very difficult. This was emphasised in the monitoring and reporting strategy for measuring the environmental outcomes of the Accord (Ministry for the Environment, 2006), and has been reinforced during the collection of data in the preparation of this report.

There are many land-use factors that can affect water quality and/or contribute to fluctuations in water quality over time, for which little or no consistent information can be obtained from the existing monitoring regimes. These factors are often very localised, as opposed to being distributed throughout the catchment, and include (Ministry for the Environment, 2006):

- naturally occurring events such as floods, which can have major effects on suspended sediment, turbidity and in-stream biota
- changes in farm personnel, such as the sharemilker, with subsequent changes in environmental performance
- changes in land use or land-use intensity, such as changing from sheep to deer farming, bringing more beef cattle on to a particular property or increasing dairy herd size
- the amount of fertiliser used by all farmers (not just dairy farmers), the timing of its use and how it is applied – aerial topdressing of hill country may, for instance, have significant impacts on phosphate concentrations and algal biomass in streams, and if there is heavy rainfall within several days of fertiliser application, much of that fertiliser may run off to waterways
- stock access to streams – not just by dairy cattle on smaller non-Accord streams but also by beef cattle, sheep and deer
- fences that are too close to streams, or that are broken or poorly maintained and allow stock access to streams
- non-dairy discharges to water

- wintering dairy stock off-site – this has potential major benefits for water quality during these months
- run-off from land irrigation of dairy effluent entering water courses from mole-and-tile drains
- natural inputs, such as geothermal, soil and geological inputs of phosphorus or arsenic.

A further confounding factor is the time lag between an action being taken (or a past farming activity) and the consequential effects of this action on water quality. The exact nature of this time lag will vary depending on location, size of catchment and activity, and is often difficult to quantify. However, it is generally accepted that applying nutrients to land, for example, does not have an immediate effect on water quality (unless the nutrients directly wash into the waterway), and that the lag time before changes are seen in the stream can span many years. This can have significant implications for monitoring programmes – including the programme presently under discussion – which aim to quantify actual water quality improvements that result from land management changes.

Statistical constraints

Following are brief descriptions of some of the methodological and statistical constraints on assessing the state of water quality and the significance of any changes over time or differences between catchments. These mainly relate to the influence of flow on water quality and the limitations of sampling regimes, and are important to consider when interpreting results in this report, and subsequent related reports.

- To include comparable results from as many of the selected catchments as possible, this report presents statistics (eg, medians) calculated for the whole period of monitoring in each catchment. Although this approach broadly characterises water quality, it ‘averages out’ seasonal changes that may be of importance for measuring the effect of relevant land-use activities. For example, during summer low flows, the effect of removing cattle from streams may be more apparent in the *E .coli* results for that period than in winter because of the overriding influence of flow during winter on *E. coli* concentrations washed in from the landscape during high rainfall events. It may be possible in the next report to explore changes in seasonal data patterns by requesting data from monitoring agencies in a different format and undertaking flow-related analyses. (Data in this report is generally not flow-adjusted).
- As well as fluctuating across seasons, some water-quality measurements (particularly dissolved oxygen and water temperature) can fluctuate considerably during the course of a normal day. For example, dissolved oxygen concentrations and water temperature normally fall to a minimum in the early hours of the morning (pre-dawn) and reach a maximum in the early afternoon. It is these extremes that are most likely to (a) have adverse consequences for aquatic ecosystems and (b) exhibit the greatest changes in response to changing farm practice. However, the statistics presented in this report relate to repeated single measurements made by monitoring staff during daylight hours only, a limitation that should be considered when judging the long-term value of these indicators. In some catchments, continuous (ie, automatic data-logger) data is available to augment the monthly statistics.

- Some of the water-quality variables exhibit large ranges in monthly measurements, and some catchments have as few as 12 data points from which to derive the medians presented in this report. Although these variations introduce some uncertainty when making initial assessments and comparisons of catchments (ie, in this report), they should be mitigated over time as data sets expand and appropriate statistical tests are used to analyse changes.
- It is difficult to know whether the water quality statistics represent typical or atypical climatic periods in each of the catchments. However, the assessment of long-term rainfall patterns (appendix 1, tables A1-A to A1-M) provides some confidence that baseline monitoring did not occur in particularly unusual rainfall years in most catchments. As a further note, catchments with longer time series are considerably more likely to have representative statistics than those with just one year of monitoring data.

Catchment Characteristics

This section contains information about the characteristics of the Tier 1 and Tier 2 catchments discussed in this report (see table 1 and figure 1 for a description of the catchments). It also outlines progress towards the Dairying and Clean Streams Accord targets in each catchment.

Table 3 provides a summary of the geographical, geological and hydrological features of each Tier 1 and 2 catchment as well as an indication of land-use characteristics. Table 4 provides a summary of farm information and Accord actions for each Tier 1 and 2 catchment. This information was predominantly supplied by Fonterra, with supplementary information supplied by regional councils. Further information about each catchment, including location maps, is provided in appendix 1 (figures A1-A to A1-M).

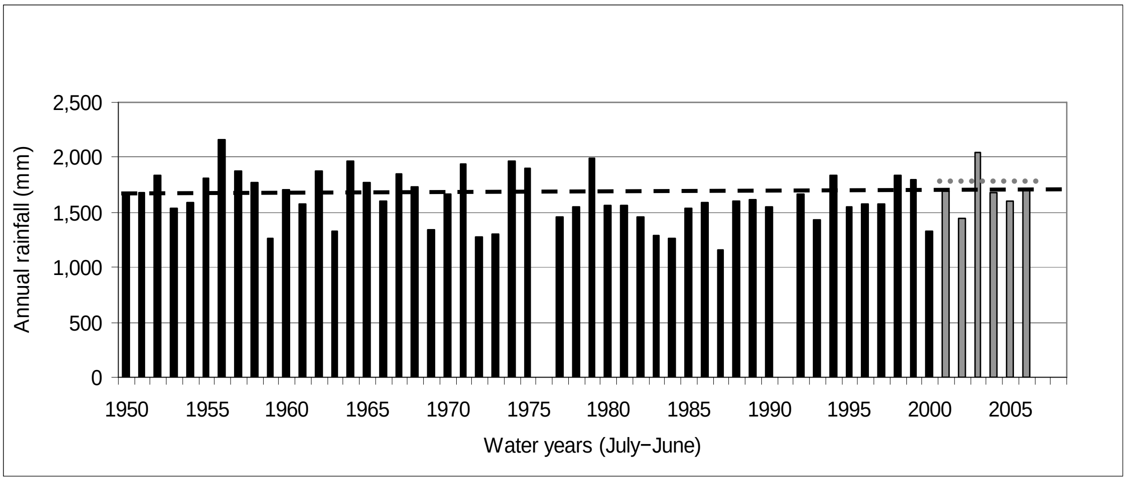
Catchment geography, geology and hydrology

The Tier 1 and 2 dairy catchments generally lie in flat to rolling farmland and range in size from 6 km^2 (Inchbonnie) to 211 km^2 (Rai) (see table 3). They also span a range of latitudes and climatic conditions, as indicated by the River Environment Classification descriptions in appendix 1.

Average annual rainfall in catchments in the drier eastern areas of New Zealand (600–700 mm/yr across the Waikakahi, Rhodes–Petrie and Washpool catchments in Canterbury and Otago) is less than half that of catchments in the wetter central and northern regions and almost 5–10 times lower than the rainfall received in the Inchbonnie catchment on the West Coast of the South Island (4825 mm/yr).

Annual total rainfall for the year(s) of the monitoring programme in each catchment has been compared with long-term rainfall records (generally 1950 to the present) from the nearest rainfall recorder site (NIWA CliFlow Database). The data and plots are provided in appendix 1 (tables A1-A to A1-M) and show that for most monitored catchments the rainfall received during the period of water quality monitoring was reasonably close to the long-term average (ie, monitoring was not conducted during unusually wet or dry periods); for example, see Figure 2. The exceptions are the Waikakahi (table A1-C) and Rhodes–Petrie (table A1-L) catchments in Canterbury, where rainfall during the monitoring periods was lower than the long-term average by approximately 30 per cent. The extent to which this might have had an effect on stream flow and water quality in these catchments is unknown.

Figure 2: **Comparison of annual rainfall totals during the water-quality monitoring period (grey bars) with the long-term record (black bars), Waiokura catchment**



Source: CliFlow Database administered by NIWA.

Notes: The dashed lines are averages for the two periods. The rainfall record is taken from the closest available NIWA rain gauge (8.5 km from the Waiokura catchment).

Stream flow in the catchments is highly variable, which is typical for small waterways in deforested areas. Three of the nine catchment streams for which flow-range data is available had no flow for a time during the monitoring periods, while some catchments had peak flows (following rainfall) well in excess of 20 times their mean flow. Annual flows[5] varied across catchments from 25 L/s (mean; Powell) to 4842 L/s (median; Rai).

Soils and geology are also variable, both within and between catchments. Catchments with predominantly alluvial sediments, such as the sands and gravels in the Rhodes–Petrie catchment on the Canterbury plains and the pumice in the Taharua catchment in Hawke's Bay, are relatively free-draining. By contrast, the weathered soils of the Puwera catchment in Northland and the mudstone and siltstone substrates of the Washpool catchment in Otago are relatively poor-draining.

Land-use and farm information

Table 3 shows that, with the exception of Taharua (Hawke's Bay) and Mangapapa (Manawatu), dairy farming is the predominant land use in all Tier 1 and 2 catchments. The extent of dairy land ranges from 37 per cent of the Bog Burn catchment (Southland) to 100 per cent of the Inchbonnie catchment (West Coast). Dairying accounts for at least twice the land area of the next largest land use in seven of the 12 catchments (including four of the five Tier 1 catchments). Sheep and beef farmland makes up the majority of land not used for dairying in each of the Tier 1 and 2 catchments.

Although the number of dairy farms per catchment varies from three in the Powell (Tasman) and Taharua (Hawke's Bay) catchments to 21 in the Toenepi catchment (Waikato), the dairy cow stocking rate is fairly consistent, ranging from 2.5 to 3.5 cows per hectare across nine of the catchments. The stocking rate is lower in the Inchbonnie and Enaki catchments (2.0 and

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[5] Median flow was provided for some catchments and mean flow for others (see table 3).

1.6 cows per hectare, respectively) and could not be estimated for the Mangapapa and Rai catchments from the data available.

Dairy farming has a long history in most of the catchments (seven) for which information is available, has been introduced since the early 1990s in two catchments (Waikakahi and Bog Burn), and has undergone rapid and recent expansion in two catchments (Taharua and Washpool).

Progress towards Accord targets

Fonterra on-farm survey records from 2007 (summarised in table 4) indicate that the following progress has been made in the monitored dairy catchments.

- The proportion of streams fenced (that meet Accord criteria) ranged from 66 per cent in the Enaki catchment to 100 per cent in the Powell, Rhodes–Petrie, Waikakahi and Bog Burn catchments. Fonterra survey data was not available for four of the catchments. Northland Regional Council have estimated that less than 10 per cent of the Puwera Stream has stock exclusion, although the extent to which this stream is considered to meet Accord criteria is uncertain.
- All, or almost all, of the Accord stream crossings were bridged or culverted in seven of the catchments (Waikakahi, Bog Burn, Inchbonnie, Mangapapa, Powell, Rhodes–Petrie and Washpool). Six crossings (almost half) were not bridged or culverted in the Toenepi catchment, seven in the Enaki catchment, and 37 in the Rai catchment. Survey data was not available for the remaining four catchments.
- Nutrient management plans are in place on all farms in eight of the catchments and on 85 to 90 per cent of farms in two further catchments. No information is available on the extent to which these plans are being actively used to manage nutrient application.

With respect to the first two bullet points, we recognise that the presence of a fence, bridge or culvert does not always mean that stock are excluded from waterways. For example, while on-farm survey figures for the Rhodes–Petrie catchment indicate 100 per cent of Accord streams have stock exclusion and that there are no outstanding crossings to be bridged or culverted, an Environment Canterbury (2007) report showed places in these catchments where fencing and culverting was likely to be ineffective. In these places, stock were likely to be able to gain access to the waterways. Also, although the statistics above (and in table 4) on fencing and crossing removal indicate progress on the main catchment waterways, it is not possible to use them to draw conclusions about progress in the catchment as a whole, particularly on smaller headwater streams.

Information on non-compliance with stock effluent disposal rules was provided by councils and is given in table 4. Few recorded incidents occurred over the period of intensive water-quality monitoring.

Table 3: Catchment features and land-use characteristics

		TIER 1 CATCHMENTS					TIER 2 CATCHMENTS							
		Toenepi **Waikato**	**Waiokura** **Taranaki**	**Waikakahi** **Canterbury**	**Bog Burn** **Southland**	**Inchbonnie** **West Coast**	**Puwera** **Northland**	**Taharua** **Hawke's Bay**	**Mangapapa** **Manawatu**	**Enaki** **Wairarapa**	**Powell** **Tasman**	**Rhodes and Petrie** **Canterbury**	**Washpool** **Otago**	**Rai** **Marlborough**
Catchment features	Area (km^2)	15.8	20.9	41	24.8	6	9	132	26.6	24.7	5.6	7.8	37	211
	Geology	Ignimbrites, basalts and tuff over basement siltstones and conglomerates	Thick deposits of unsorted volcanic debris that forms the Taranaki Ring Plain	Mainly a set of intermediate and lower greywacke gravel terraces	Greywacke in upper catchment, descending into alluvium (sand and gravel) outwash fans spreading across the Oreti Plains	Alluvium	Majority of soils are strongly leached and weathered, ranging from imperfectly to poorly drained	Uncemented ignimbrite, ignimbrite; airfall tephra over greywacke	Greywacke in upper catchment; alluvium and loess progressively more dominant towards the bottom of the catchment	Greywacke in upper catchment; lower catchment predominantly alluvial gravels, loess, sandstone and siltstone	Gravel and siltstone	Mostly free-draining shallow silt and sandy loam	Sedimentary; primarily sandstone base, with some mudstone in lower catchment	Sandstone and siltstone derived semi-schist to the east; bedded sandstone and siltstone to the west; well-sorted gravels along river flood plains
	Slope	Flat to rolling	Flat	Flat	Flat	Flat	Flat to steep	Flat to moderately steep	Hill country with flats at lower end of catchment	Estimated (by council) to be 30% rolling hill and 70% flat	90% rolling to flat, 10% steep	Very flat to gradually sloping	Rolling	Hill country
	Rainfall[1] (mm/yr)	1,121	1,634	604	992	4,825	1,634	1,190	1,282	890	1,764	717	666	1,880
	Flow[2] (L/s)	210 (0–5,530)	448 (69–6,070)	537 (28–3,180)	324 (8–12,600)	396 (28–18,600)	0–282 Highly variable	1,785–5,002 Mean = 2,808 Median = 2,774	Mean annual low flow (MALF) = 40.2	0–3,051 Median = 411	Mean = 25	423–12,000	No data Likely to be variable	Median = 4,842
	REC description[3]	Warm dry, lowland, volcanic, pastoral Stream order = 3	Warm wet, lowland, volcanic, pastoral	Cool dry, lowland, alluvium, pastoral Stream order = 5	Cool dry, lowland, alluvium, pastoral Stream order = 5	Cool extremely wet, hill, volcanic, pastoral Stream order = 3	Warm wet, lowland, hard sedimentary, pastoral Stream order = 3	Cool wet, hill, volcanic, pastoral Stream order = 5	Cool wet, lowland, miscellaneous, pastoral Stream order = 4	Cool wet, lowland, hard sedimentary, pastoral Stream order = 3	Warm wet, lowland, soft sedimentary, pastoral Stream order = 3	Cool dry, lowland, alluvium, pastoral Stream order = 2	Cool dry, lowland, soft sedimentary, pastoral Stream order = 3	

		TIER 1 CATCHMENTS					TIER 2 CATCHMENTS							
		Toenepi **Waikato**	**Waiokura** **Taranaki**	**Waikakahi** **Canterbury**	**Bog Burn** **Southland**	**Inchbonnie** **West Coast**	**Puwera** **Northland**	**Taharua** **Hawke's Bay**	**Mangapapa** **Manawatu**	**Enaki** **Wairarapa**	**Powell** **Tasman**	**Rhodes and Petrie** **Canterbury**	**Washpool** **Otago**	**Rai** **Marlborough**
Land use (%)	Dairy	83	99	62	37	100	70	28	27	54.5	56.6	~90	63	23[4] (mix of dairy and beef)
	Sheep and beef	17	1	38	33		25	~5	39.2	41.8	28.7	~5	33	
	Native							37%	25.8		< 2			57
	Crop										10.3	~5		
	Other				30		5	30%		3.7			Minor deer and forestry	20
	Historical information or changes	Predominantly dairy for at least 50 years	Predominantly dairy for at least 50 years	Most of the dairy farms converted from sheep and beef since the early to mid-1990s	Dairy farms all converted from sheep and beef since 1991		Lifestyle blocks are a recent addition to the catchment	Dairying has approximately tripled in area since 1995; there are 3 new large farms (37.25 km^2) that occupy 28% of the catchment		Dairying has been the predominant catchment land use for at least 50 years, although it is intensifying (stocking rates increasing etc)	Reasonably static land use	Has been predominantly dairying for some time	Dairy conversion is recent and rapid. In 1999, ~5% of catchment was dairy. By the end of 2008, 85–100% was expected to be dairy	Long history of dairy farming in the catchment. In past few years a trend of less farms but more cows per farm

Source: Unless otherwise stated, from Wilcock, Monaghan et al, 2007; Monaghan et al, 2004; and Muirhead et al, 2002 for Tier 1 catchment information, and regional councils for Tier 2 catchment information.

Notes:

1 Rainfall is the long-term (1950 to the present in most cases) average annual total for the rainfall recorder closest to each catchment as well as the average total for the period coinciding with the monitoring of water-quality data. The source is the CliFlow Database administered by NIWA. These totals have been presented in favour of totals provided by regional councils to ensure a consistent method is applied across regions and comparisons between short- and long-term averages for each catchment are done using the same rainfall recorder.

2 Flows are means and ranges (unless otherwise stated) for periods coinciding with water-quality monitoring in each catchment.

3 REC = River Environment Classification analysis undertaken by the Ministry for the Environment using the most downstream point of the main catchment stream.

4 Marlborough District Council considers that the large majority of this 23% is made up of dairying and it is the single largest land-use type (by area) in the catchment.

Table 4: Catchment dairy farm information

		TIER 1 CATCHMENTS					TIER 2 CATCHMENTS							
		Toenepi **Waikato**	**Waiokura[1]** **Taranaki**	**Waikakahi** **Canterbury**	**Bog Burn** **Southland**	**Inchbonnie[2]** **West Coast**	**Puwera** **Northland**	**Taharua** **Hawke's Bay**	**Mangapapa** **Manawatu**	**Enaki** **Wellington**	**Powell** **Tasman**	**Rhodes and Petrie Canterbury**	**Washpool** **Otago**	**Rai** **Marlborough**
Dairy farm information	Number of dairy farms	21	17	11	7	5	6	3	ND	11	3	10	9	19
	Number of cows	4,431	4,352	7,315	5,236	2,125	1,800	9,500	ND	2,147	525	4,651	6,600	4,686
	Stock density (cows/ha)	3.0	3.4	2.8	2.9	2.0	2.9	2.5	ND	1.6	3.5	2.9	2.8	ND
Accord actions	Percentage of Accord streams with stock exclusion	85	ND	100	100	70	< 10[3]	ND	98	66	100	100	94	ND
	Number of Accord stream crossings	15	ND	19	28	ND	ND	ND	41	35[5]	4	5	31	112[4]
	Number of unbridged or unculverted Accord stream crossings	6	ND	0	0	0	ND	ND	0	7	0	0	1	37
	Nutrient budgets in place	All	All	All	All	All	ND	All	All	9 out of 11	All	10 out of 11	All	ND
Significant recorded non-compliance		Not supplied	1999–2004 average of 1.25 incidents of discharge to water per year (97.5% compliance annually). Since 2004, 1 incident (99.5% compliance annually)	Between 2001 and 2006 there were 18 incidences of significant non-compliance out of 46 visits (39% of catchment farm visits)	4 non-compliance issues in 2008, including stock access to water, over application of dairy effluent and discharge of dairy effluent to water through tile drain	None identified	None identified	1 non-compliant property	2 incidents in 2006: 1 of effluent draining to a drain and another of effluent ponding on land	All farms fully compliant during 2004–07 (except 1 technical non-compliance). In 2007/08 3 farms were non-compliant	Not supplied	Between 2001 and 2006 there were 2 incidences of significant non-compliance out of 31 visits (6% of catchment farm visits)	No infringement notices issued in the 12-month monitoring period	3% in 2006/07

Source: Unless otherwise stated, Accord actions information is from the Fonterra on-farm survey (provided by Fonterra to regional councils during 2007 and 2008); all other information is supplied by regional councils.

Notes:

1 A complete data set is not available for this catchment. A dairy farm survey due to be undertaken in March 2009 will address areas of incomplete data.

2 The Accord is not in place on the West Coast of the South Island so no Accord-related data exists for the Inchbonnie catchment.

3 Fonterra data is not available for this catchment. The number provided has been estimated by Northland Regional Council.

4 This is the total number of crossings in the Rai catchment. The large majority will be on Accord waterways but some are on smaller streams.

5 This number was provided by Greater Wellington Regional Council from compliance data so may not fit with Accord criteria for a stream crossing.

The number of dairy farms and stocking rates in Tier 1 catchments is from Muirhead et al, 2002. Stocking rates for Tier 2 catchments were estimated by the Ministry for the Environment using cow numbers (provided by councils) and dairy land area.
ND = No data. A complete data set is not available for this catchment.

Water-quality Baseline

The following section presents a summary of baseline water quality in the Tier 1 and Tier 2 dairy catchments. Data for each of the water quality parameters listed in table 2 is presented in graphical format. However, a summary of the statistics underpinning the graphs, and details on sampling regimes and data set size, are provided in tables A2-B to A2-N in appendix 2.

The same tables also provide the time periods of monitoring for each catchment, and water quality parameter, from which medians have been derived. Time periods varied between catchments and parameters but were generally 2001/02–2006 for the Tier 1 catchments and two Tier 2 catchments (Enaki and Washpool), and 2006–2007 for the remaining Tier 2 catchments (with the exception of the Taharua: 2000–2008).

The section finishes with a brief account of water-quality changes (trends) that have been observed in the monitored catchments (where information is available to do this).

Presentation of data

Results for different water-quality and stream health variables are not presented in any particular order of importance. For freshwater managers, the relative importance of nutrients versus physical and chemical stressors versus measures of ecosystem health will vary according to local management priorities.

Unless otherwise stated the statistics presented in each figure and referred to in the text are for the most downstream monitoring site in the catchment.

The order of catchments along the horizontal axes of the graphs is consistent throughout this section and is based on the amount of catchment area under dairy farming: dairy area as a percentage of total catchment area decreases from left to right in each graph.

It is important to note that although catchment results are presented together, drawing conclusions about the overall condition of catchments relative to one another should be done with caution for two reasons: firstly, because of the abovementioned variability in time periods of monitoring between catchments, and secondly, because the actual consequences of disturbances to water and habitat quality are catchment specific. The primary value of water-quality indicators is to track change at one site (or catchment) over time, rather than to make comparisons with other sites, although the latter can be informative.

Many of the graphs in this section have logarithmic scales on the vertical axes to enable large spreads of data from different sites to be presented together.

The Australia and New Zealand Environment and Conservation Council guidelines for fresh water quality (ANZECC, 2000) have been used in several cases to benchmark findings. It is important to note that the ANZECC guideline values are default ‘trigger values’ intended primarily to assess the risk of adverse effects to aquatic ecosystems, rather than thresholds to report against. They should therefore be interpreted in this report as indicative, rather than absolute, thresholds. More information about specific guidelines is included in text for each water-quality variable.

Faecal contaminants

Faecal contamination of waterways poses a public health risk. Illness may be contracted as a direct result of ingesting bacterial, viral and protozoal pathogens that occur in faecal material. Faecal material reaches streams in run-off from the land through effluent pond discharges (eg, Smith et al, 1993) and from cows defecating directly into the water (eg, Davies-Colley et al, 2004).

Risk of illness is primarily associated with recreational activities where water may be ingested (including harvesting fish and other aquatic food for consumption). The indicator commonly used to assess this risk is *E. coli*, a faecal coliform bacterium that originates in the gut of warm-blooded animals and indicates the presence of other potentially harmful microbes. There are several reference values and guidelines used for interpreting *E. coli* data (Table 5).

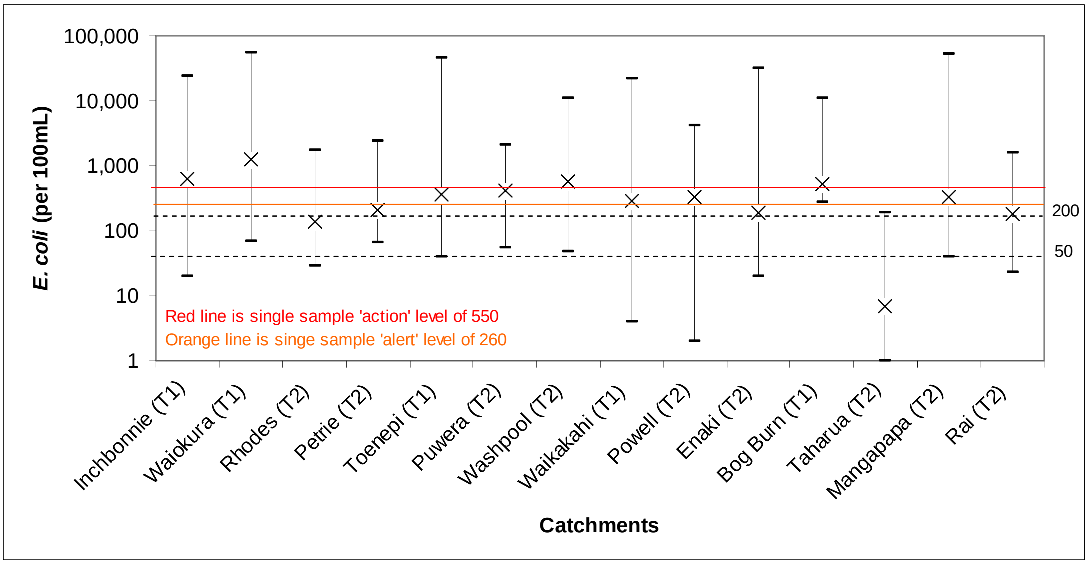
Table 5: Reference values and guidelines used for interpreting *E. coli* data in Figure 3

Values and guidelines used	*E. coli* per 100 mL	Description and source
Reference values		Based on assessments of regional council state-of-environment monitoring data (1996–2002) for different land-use categories. Data held by the Ministry for the Environment.
Natural catchments	50	Based on median value of 42 *E. coli* per 100 mL. Data from 75 sites and 1,572 samples.
Pastoral catchments (both high- and low-intensity pastoral use)	200	Based on a median value of 200 *E. coli* per 100 mL. Data from 259 sites and 6,330 samples.
Contact recreation		*Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas* (Ministry for the Environment and Ministry of Health, 2003).
Single sample 'Alert'	260	Single sample thresholds indicating elevated health risk (Alert) and unsafe concentrations of pathogens (Action).
Single sample 'Action'	550	
Stock drinking	100*	ANZECC, 2000. However, ANZECC also recommends that "investigations of likely causes (of contamination) are warranted when 20% of results exceed four times the trigger value".

* Faecal coliforms per 100mL (not *E. coli*).

Figure 3 shows the median and range of *E. coli* measurements in the monitored dairy catchments in relation to several reference values that are summarised in table 5. The dashed lines are based on median values for catchments in New Zealand with predominantly natural and pastoral land uses and provide an indication of the relative extent to which the monitored dairy catchments are polluted with faecal matter. The solid lines are 'single sample' contact recreation thresholds and provide a further indication of the extent to which water quality in the catchments could be considered hazardous to humans.

Figure 3: ***E. coli* medians and ranges for the most downstream site for each catchment during the monitoring period**



Notes:

Dashed lines are reference medians for pastoral (upper) and natural (lower) catchments.

Data, details on monitoring periods, guidelines, reference values and sample numbers are provided in appendix 2, table A2-B.

The vertical axis has a logarithmic scale.

T1 = Tier 1 catchment and T2 = Tier 2 catchment.

The majority (10) of the monitored catchments had median *E. coli* concentrations that exceeded the overall median for pastoral catchments in New Zealand (200 *E. coli* per 100 mL). This indicates that these monitored catchments are more heavily affected by faecal contamination than the ‘average’ pastoral farming catchment. Three catchments (the Rhodes, Rai and Enaki) had median *E. coli* concentrations just below 200 per 100 mL, indicating faecal pollution exists but could be considered moderate in the context of all pastoral catchments. One catchment, the Taharua, had a median *E. coli* concentration of well below 50 per 100 mL, which compares with values found for unmodified (natural) catchments.

All catchments except the Taharua had peak (sampled) bacteria counts of well over 1000 per 100 mL (and seven catchments had peaks of well over 10,000 per 100 mL) suggesting microbiological pollution is a substantial, if occasional, problem in all cases. However, such peaks are not uncommon in other (non-dairy) farmed and urban catchments and generally correspond with high rainfall run-off (eg, Greater Wellington Regional Council, 2006).

Dry-weather peaks in *E. coli* are arguably of more concern in a dairy environment because they may relate to poor farm practice such as overflowing effluent ponds or stock defecating directly into the stream. It would be useful in future reports to include a stream flow-related analysis of *E. coli* concentrations to determine whether there is any change in the magnitude and frequency of dry-weather peaks.

Human health risk – contact recreation

Some of the catchments are recreational areas in their own right, such as the Rai River, where swimming and kayaking are common, while many of the other catchment streams drain into larger water bodies where contact recreation or food harvesting takes place (see appendix 5, table A5-A for a description of recreational values in each catchment). Examples include swimming and whitebait fishing areas on the Motupipi River, into which Powell Creek drains; and swimming, trout fishing and eeling on the Pomahaka River, into which the Washpool Creek drains.[6]

Although only the Rai River is routinely monitored for recreational water-quality purposes, it is informative to consider the bacterial water quality in all of the dairy catchments in relation to recreational water-quality guidelines (table 5).

Three catchments – Waiokura, Inchbonnie and Washpool – had median *E. coli* concentrations in excess of the Action level of 550 per 100 mL. This means that more than half of the samples taken in each of these catchments had concentrations of *E. coli* that exceeded 550 per 100 mL. This is *indicative* of an unacceptable health risk, although it should be noted that activities such as swimming are not known (by council staff) to occur in the streams in these catchments (see appendix 5, table A5-A). A further six catchments had median *E. coli* concentrations that exceeded the Alert threshold level of 260 per 100 mL. This means that more than half of the samples taken in each of these catchments had concentrations of *E. coli* that would, if the sites were recognised and monitored for contact recreation, trigger follow-up sampling and investigations.

The remaining five catchments had median *E. coli* concentrations below 260 per 100 mL, meaning that on more than half of the occasions these sites were sampled, water quality was acceptable for contact recreation.

Stock drinking-water quality

The microbiological quality of stream water is also important in farmed catchments for stock health reasons, because water is sometimes drawn untreated from this source for a stock drinking supply. However, there appears to be very little, if any, reliable data on acceptable numerical limits for microbes (Sinton and Weaver, 2008; Ministry of Agriculture and Forestry, 2004).

In the absence of an adequate pool of scientific data, the ANZECC (2000) guideline ‘trigger value’ for stock drinking water quality is often referred to in New Zealand and has been used in this report as a reference point. ANZECC recommends a trigger value of 100 faecal coliforms per 100 mL, but also recommends taking action to remediate a stock drinking supply once 20 per cent of samples taken over an extended period exceed four times this value (ie, 400 per 100 mL). Although 20th percentile data was not available for this report, five of the monitored farm catchments had median *E. coli*[7] concentrations exceeding 400 per 100 mL (ie, at least 50 per cent of samples exceeded 400 per 100 mL).

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[6] It should be noted that some regional plans designate all water bodies as having recreational value. For example, the Manawatu Catchment Water Quality Regional Plan sets contact recreation standards that apply to all surface waters at flows under half median flow.

[7] *E. coli* are a subset of the faecal coliform bacteria family. Therefore, a count of 400 *E. coli* per 100 mL will equate to a higher count of faecal coliforms (eg, a conversion of 200 faecal coliforms per 100 mL to 126 *E. coli* in marine waters is given in Ministry for the Environment and Ministry of Health, 2003).

Nutrients (nitrogen and phosphorus)

Nitrogen and phosphorus are essential nutrients for the growth of aquatic plants and algae that form an important part of any healthy stream ecosystem. However, excessive in-stream concentrations can lead to proliferations of algae (eg, rock slime) and macrophtyes (aquatic plants), which in turn may compromise a range of in-stream values such as amenity, native fish conservation and recreation (Biggs, 2000).

Measuring nitrogen and phosphorus concentrations therefore provides an important indication of the potential for proliferations to occur in the monitored catchments (all other factors such as light, stream bed and temperature conditions being equal). These measurements also provide an indication of the contribution of nutrients from the monitored catchments to downstream receiving waters such as larger rivers, lakes and estuaries.

The main routes for nitrogen loss from pasture to streams are (1) leaching through soils from livestock urine patches and applied fertiliser, (2) direct input of livestock excreta (dung and urine) to streams and excreta run-off from paddocks, and (3) soil erosion (eg, McKergow et al, 2007). Phosphorus is generally lost to pastoral waterways from paddock run-off of eroded soil and fertiliser as well as effluent pond discharges (either directly or through a land application) (eg, McDowell et al, 2008).

Box 3: Nutrient guidelines

The determination of guidelines relating to nutrient concentrations in rivers and streams is a scientifically complex issue. The concentrations at which nitrogen or phosphorus actually begin to have an adverse effect on ecosystem health or amenity values is highly site- and catchment-specific and depend on many factors. For example, a stream with relatively fast, variable flow that discharges to an open coastline may be able to support high nutrient concentrations that do not have an observable impact (eg, nuisance growths). However, if that stream discharges to a lake or an estuary where nutrients are likely to accumulate and boost plant growth, then in-stream concentrations become much more important to control. Likewise, a stream with primarily sandy substrate may be more resistant to nuisance blooms than a rock- or cobble-bottomed stream (given similar concentrations of nutrients).

In New Zealand, two national guidelines are commonly used to assess nutrient concentrations, and they have been used in this report.

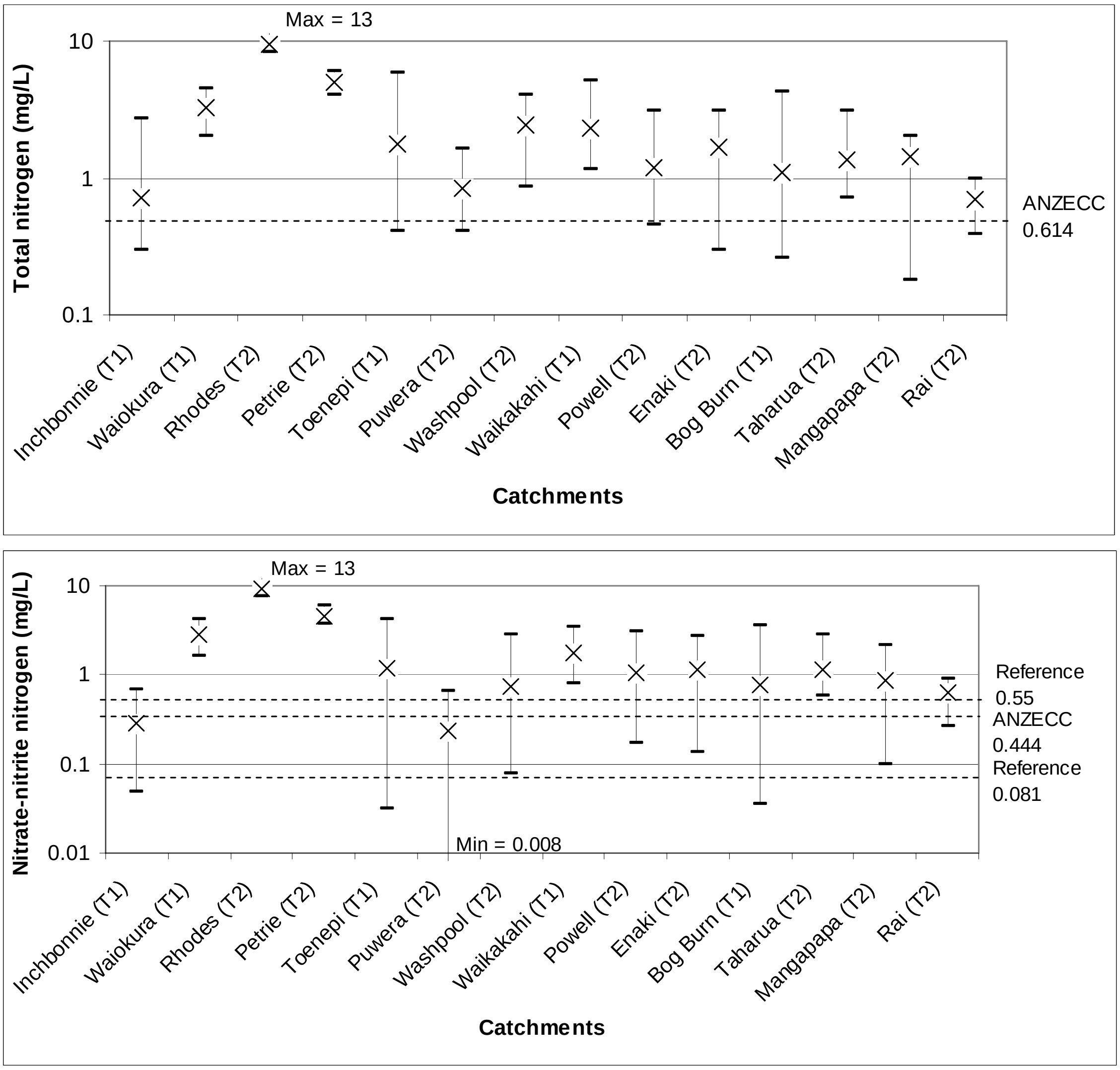
1. Periphyton guidelines (Biggs, 2000). These guidelines provide suggested thresholds for the dissolved nitrogen and phosphorus concentrations required to control periphyton growth. A range of thresholds are provided that are related to flow conditions (high flow events tend to scour out periphyton growth). For this report the upper guideline values suggested by Biggs and relating to “20 mean days of accrual” have been adopted: 0.295 mg/L soluble inorganic nitrogen and 0.026 mg/L dissolved reactive phosphorus.

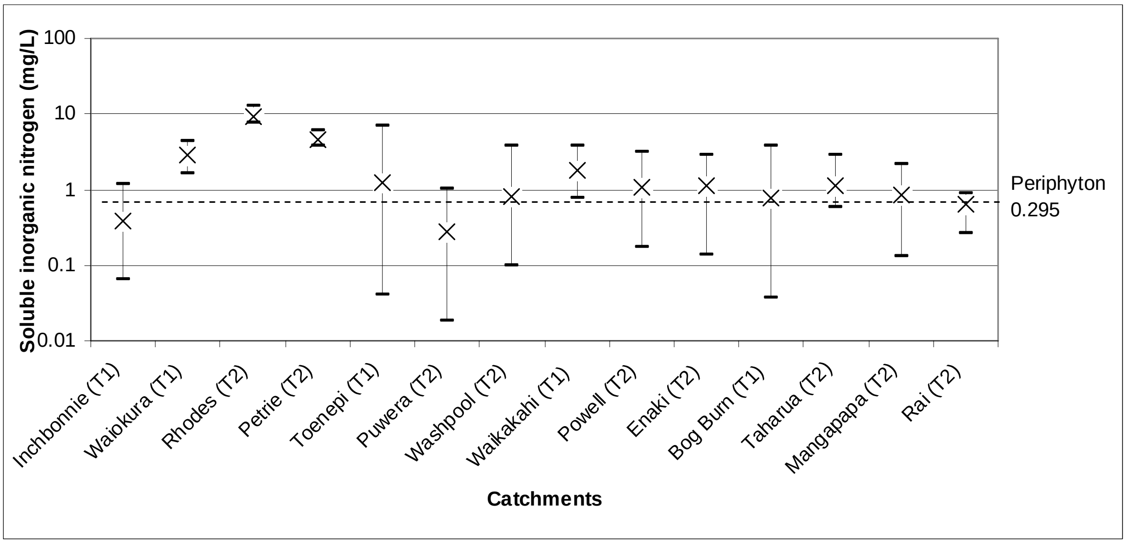
2. ANZECC guidelines (ANZECC, 2000). These guidelines provide default trigger values for total and dissolved nitrogen and phosphorus for assessing the risk of adverse effects in slightly disturbed ecosystems. These trigger values are based on the 80th percentile of a distribution of reference data and have the following values for lowland rivers: 0.614 mg/L for total nitrogen; 0.444 mg/L for oxides of nitrogen (nitrate–nitrite nitrogen); 0.033 mg/L for total phosphorus; and 0.01 mg/L for dissolved reactive phosphorus.

Arguably, both the periphyton and ANZECC guidelines could be considered environmentally conservative for highly modified dairy catchments. However, in the absence of more appropriate reference data for these modified systems, both guidelines still provide useful contexts for the data in this report.

The medians and ranges of nitrogen and phosphorus measurements in the monitored dairy catchments are presented in figure 4. The commentary below is focused on dissolved nitrogen (nitrate–nitrite nitrogen and soluble inorganic nitrogen) and phosphorus (dissolved reactive phosphorus) as these forms of each nutrient are most readily available for plant uptake in running stream waters. However, total concentrations are also important, particularly as they contribute to the overall nutrient loading in downstream water bodies.

Figure 4: **Medians (crosses) and measured ranges (min, max) for total nitrogen (top), nitrate–nitrite nitrogen (middle), and soluble inorganic nitrogen (bottom) for the most downstream site during monitoring period**





Notes:

A log scale is used on the y axis.

Data, guideline values (dashed lines), sample number and monitoring period for individual catchments are provided in tables A2-C to A2-E in appendix 2.

Where bars go off the edge of the y axis scale the minimum or maximum is noted next to the bar.

T1 = Tier 1 catchment and T2 = Tier 2 catchment.

With few exceptions, total nitrogen and nitrate–nitrite nitrogen concentrations exceeded the ANZECC guidelines for protection of ecosystem health (see figure 4). Soluble inorganic nitrogen (nitrate–nitrite nitrogen + ammoniacal nitrogen) exceeded the periphyton guidelines in all catchments except for Puwera (see figure 4, bottom).[8] (See box 3 for an explanation of guideline values.)

Nitrate–nitrite nitrogen concentrations in the Rhodes and Petrie catchments are particularly high (between two to four times the concentrations found in catchments with the next highest values). This probably reflects the relative importance of groundwater as a source of stream recharge in these Canterbury Plains catchments: groundwater samples taken upgradient of the Rhodes and Petries catchments are also high in nitrate–nitrite nitrogen and conductivity (Environment Canterbury, 2007).

Total phosphorus and dissolved reactive phosphorous concentrations were generally lower relative to the guidelines than nitrogen, as is typical in New Zealand freshwaters (see figure 5). However, most catchments (nine) exceeded the ANZECC guideline for total phosphorus and half (seven) exceeded the periphyton guideline for dissolved reactive phosphorus.[8]

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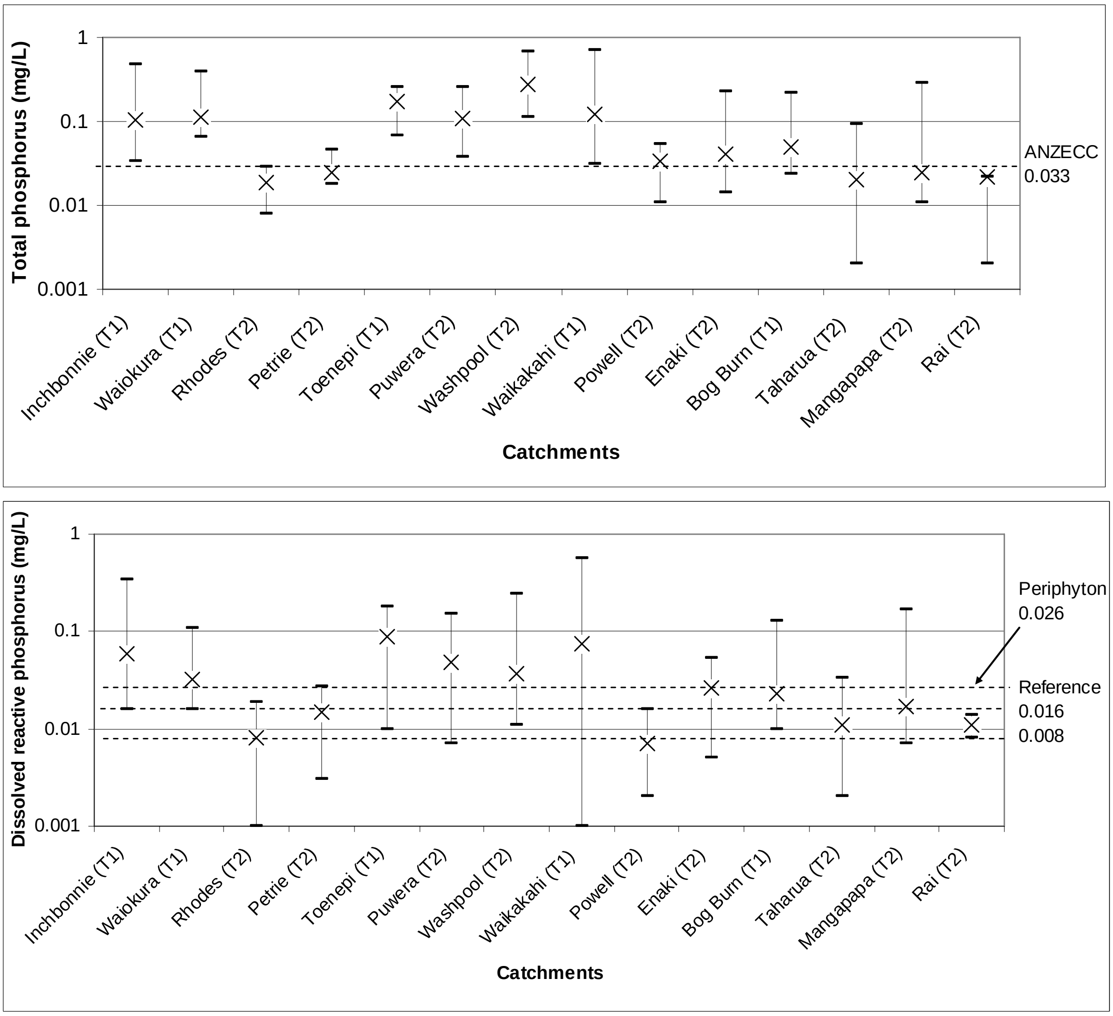
[8] Note that the periphyton guidelines are based on **mean** concentrations, which are being compared with **median** data in this report.

Figure 5: Medians (crosses) and measured ranges (min, max) for total phosphorus (top), and dissolved reactive phosphorus (bottom) for the most downstream site during the monitoring period



Notes:

A log scale is used on the y axis.

Data, guideline values (dashed lines), sample number and monitoring period for individual catchments are provided in tables A2-F and A2-G in appendix 2.

T1 = Tier 1 catchment and T2 = Tier 2 catchment.

As is clear from figure 5, total and dissolved phosphorus concentrations are noticeably lower in most of the Tier 2 catchments compared with the Tier 1 catchments. Phosphorus commonly enters waterways bound to soil particles, and so the relatively high concentrations of this nutrient in the Tier 1 catchments may be an indication of the importance of soil loss and erosion as management issues in these catchments. RJ Wilcock (pers. comm., 2009) advises that the Tier 1 catchments generally have high Olsen phosphorus soil concentrations[9] with high run-off potential to waterways.

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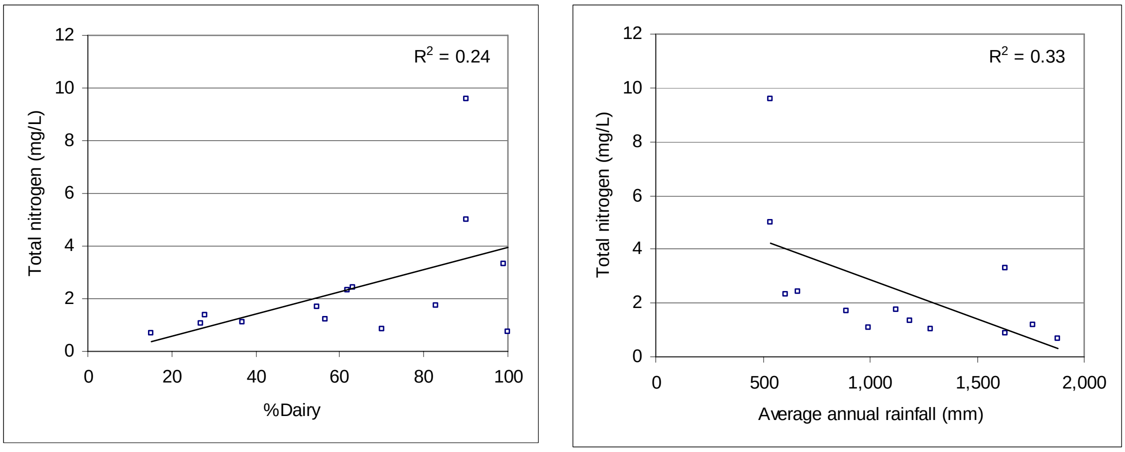
[9] Olsen phosphorus: the plant-available (bicarbonate extractable) form of phosphorus in soil.

The results of linear regression between nitrogen and phosphorus and three catchment variables –percentage catchment area under dairy (%Dairy), average annual rainfall and mean stream flow – do not reveal any particularly strong relationships (see table A3-A in appendix 3). However, it is worth noting the apparent influence both increasing %Dairy and decreasing rainfall have on increasing nitrogen concentrations (see figure 6).

Figure 6: **Regression of %Dairy (left) and average annual rainfall (right) with median total nitrogen for all monitored catchments (n = 14)**



Comparison with reference conditions and other pastoral catchments

Figures 4 and 5 show that concentrations of both nitrate–nitrite nitrogen and dissolved reactive phosphorus are well above the medians reported for reference (ie, relatively undisturbed) catchments in New Zealand by Scarsbrook (2008) (with the exception of the Powell and Rhodes catchments for dissolved reactive phosphorus). Furthermore, in all but the Inchbonnie and Puwera catchments, nitrate–nitrite nitrogen concentrations exceed the median for lowland pastoral catchments[10] of 0.55 mg/L reported by Scarsbrook (see table A2-D in appendix 2). Dissolved reactive phosphorus concentrations for the dairy catchments are more comparable with the median of 0.016 mg/L for lowland pastoral catchments reported by Scarsbrook (see table A2-G in appendix 2); nine catchments exceeded and five were below.

Nitrogen:phosphorus ratios

Exceedances of guidelines for either nitrogen or phosphorus do not necessarily lead to algal proliferation. Given sufficient light, and suitable water temperatures and substrate conditions, the extent to which nutrient concentrations will lead to nuisance plant growth is controlled largely by the relative abundance of dissolved nitrogen to phosphorus (ie, the SIN:DRP ratio).

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[10] As defined by the land-cover layer in the River Environment Classification. Catchments are defined as ‘pastoral’ once pasture exceeds 25% of the catchment area (but may be a mix of dry stock cattle, dairy, sheep and other pastoral land uses).

Wilcock, Biggs et al (2007) suggest that SIN:DRP ratios of 50:1 and 3:1 probably indicate phosphorus-limitation and nitrogen-limitation of algae growth, respectively, unless concentrations of both SIN and DRP are well above those expected to saturate growth (in which case neither nutrient is limiting).

Table 6 shows the SIN:DRP ratios for each monitored dairy catchment (where data was available), derived from medians for each of the variables.

Table 6: SIN:DRP ratios for each monitored dairy catchment (based on data for the most downstream site)

Catchment	Median concentrations (mg/L)		SIN:DRP ratio
	SIN	DRP	
Inchbonnie	0.388	0.059	7
Waiokura	2.846	0.032	89
Rhodes	9.374	0.008	**1,172**
Petrie	4.627	0.015	**308**
Toenepi	1.212	0.089	14
Puwera	0.276	0.048	6
Washpool	0.824	0.037	22
Waikakahi	1.782	0.075	24
Powell	1.098	0.007	**157**
Enaki	1.135	0.026	44
Bog Burn	0.775	0.023	34
Taharua	1.135	0.011	**103**
Mangapapa	0.86	0.017	51
Rai	0.63	0.011	57
Guideline (Biggs, 2000) for 20-day accrual period	0.295	0.026	

Note: Bolded ratios indicate strongly p-limiting conditions.

It is not possible from the data presented in table 6 to make conclusive statements about the extent to which nutrients are limiting growth in each of the catchments. However, four catchments, including three from the South Island, have SIN:DRP ratios exceeding 100 as well as relatively low median DRP concentrations. These catchments are likely to be strongly p-limited (on average). Two catchments, Inchbonnie and Puwera, have considerably lower SIN:DRP ratios than the other catchments, and nitrogen is likely to be the limiting nutrient (on average) in these catchments.

The interpretation above is based on a simplistic analysis and is intended only to provide an indication of average nutrient conditions in relation to nuisance growth potential. SIN:DRP ratios can fluctuate considerably within catchments and across seasons. For example, although the Toenepi Stream is, on average, tending towards p-limitation, with a SIN:DRP ratio of 25, during the summer low-flow period the stream is known to be N-limited (Wilcock, Biggs et al, 2007). Phosphorus inputs were clearly variable in all of the catchments (see the ranges in table 4), providing further indication that there are likely to be times when this nutrient is not limiting.

Nuisance weed and algal growth

The type of plant or algal growth that occurs in a stream is largely dependent on bed conditions. In hard-bottomed (rock- or gravel-bedded) streams, periphyton in the form of algal slime on the rocks (diatom algae) and filamentous strands of greenish algae attached to rocks, is the most common form of nuisance growth. In soft, sandy-bottomed streams, some filamentous periphyton may establish, but submerged and emerging macrophytic 'weeds' are generally more prevalent. Given sufficient nutrients, excessive algal and weed growths are most common in late summer or early autumn, when stream flows are lowest and water temperatures are highest. However, nuisance growth can occur in winter (eg, Horizons Regional Council, 2007).

Although comparing nuisance growth between sites and over time is difficult, because measures are generally subjective (eg, observer estimates of bed coverage), some published information is available for some of the monitored catchments to help characterise this aspect of water quality.

Wilcock et al (2006) summarised the weed and periphyton growth in the five Tier 1 catchments qualitatively as follows.

- Pigeon Creek in the Inchbonnie catchment is a stony, hard-bottomed stream and has summer blooms of periphyton and filamentous green algae.
- The Toenepi Stream is soft-bottomed and at times has a high biomass of emergent macrophytes, notably swamp willow weed, as well as submerged macrophytes and filamentous green algae.
- The Waiokura Stream is a soft-bottomed stream that is reasonably well shaded and periphyton blooms are not considered a problem (by the author).
- The Bog Burn has a gravelly substrate but with some fine sediments. Macrophyte cover is limited, but periphyton mats and filamentous green algae do occur in summer.

With respect to the Tier 2 catchments, the following records have been made.

- The Rhodes and Petrie Streams both have submerged and emerging macrophyte growth, often to the extent that the channels are choked during summer months and require weed spraying and mechanical clearing (Environment Canterbury, 2007). Periphyton and macrophyte growth has been classed by Environment Canterbury during their habitat assessments as "marginal" to "poor" (on a qualitative scale) over all years of the monitoring programme (2000–2007).
- Horizons Regional Council (2007) report that in the Mangapapa catchment, periphyton biomass and coverage were measured in 2007 at up to 12 sites. Mean periphyton biomass ranged from 8.7 mg/m^2 at the uppermost reference site to 152.5 mg/m^2 in one of the tributaries of the Mangapapa Stream, lower in the catchment. Five of the nine sites at which biomass measurements were made exceeded the national guideline value for the protection of benthic biodiversity of 50 mg/m^2 chlorophyll *a* (Biggs, 2000). With respect to bed coverage, half of the 12 sites exceeded 60 per cent for diatom algae – the national guideline threshold for aesthetic quality (Biggs, 2000) – and five of these exceeded 80 per cent coverage. Only one site exceeded the national aesthetic guideline of 30 per cent (Biggs, 2000) for filamentous green algae.

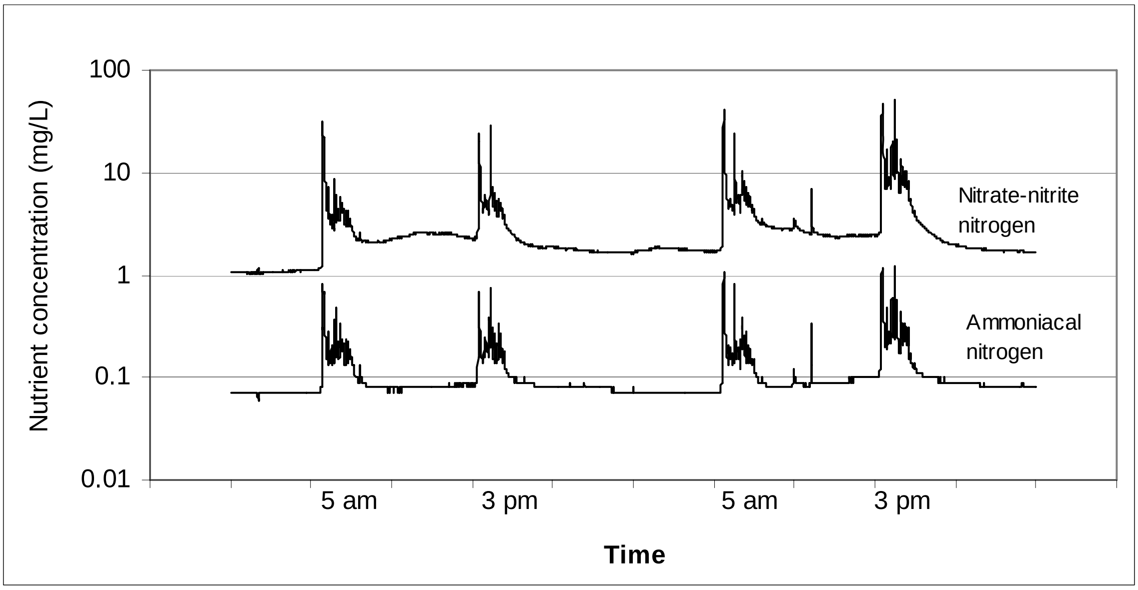
- Summer periphyton (Rapid Cover Assessment) scores from 2006 to 2009 in the lower Powell catchment are typically below 5, indicating excessive periphyton growth (scores close to zero indicate periphyton is abundant, close to 10 indicate periphyton absence). Across the rest of the Powell catchment in the summer of 2007 only one other site produced a score less than 7, indicating low quantities of algae (T James, Tasman District Council, pers. comm., 2009).
- Sampling in the Enaki catchment between 2002 and 2007 shows that excessive periphyton growth has occurred on occasion. Biomass (chlorophyll *a*) ranged from 4.3 to 45.3 mg/m^2 for most years (below the 50 mg/m^2 guideline for protecting benthic biodiversity) but reached 801 mg/m^2 in 2003, indicating bloom conditions. The aesthetic guideline for filamentous cover (30 per cent) was exceeded on three out of 52 monthly sampling occasions (Greater Wellington Regional Council, 2008).
- Periphyton biomass was measured on six occasions at each of three monitoring sites on the Taharua River between 2000 and 2008. All three sites had average measurements of less than 20 mg/m^2, while the most downstream site had a maximum measurement that exceeded 50 mg/m^2 but was below the 120 mg/m^2 guideline being applied by Hawke's Bay Regional Council (Hawke's Bay Regional Council, in press).

To summarise the above results: of the nine catchments (combining results for Rhodes–Petrie) for which measurements or observations have been made, all but two have exhibited excessive weed or algal growth on occasion. However, the subjective elements of this assessment need to be restated and point towards a need to improve the way quantitative periphyton and macrophyte data is collected and assembled for the purpose of national-scale reporting (see 'Summary and recommendations').

Case Study 1: Removal of dairy herd stream crossings on the Rai River, Marlborough

The adverse effects of dairy herds crossing the Rai River and its tributaries have been identified as a priority for action by the Marlborough District Council (2003). In addition to elevated bacterial loadings at crossing points, nutrient pulses coinciding with herd crossing times (ie, for milking) are obvious from in-stream monitoring data collected by the council (see figure 7).

Figure 7: **Nitrogen pulses during herd crossing on a tributary of Rai River over two days in September 2001**



Source: Marlborough District Council.

Note: A logarithmic scale has been used.

A stream crossing survey by the Council in 2003, identified 112 crossings in the catchment. Forty-eight of these crossings were considered a high priority for elimination (ie, replacement with a bridge or culvert). Since then, each farmer in the catchment has entered into an agreement with the Council to eliminate the highest-priority crossings on their land. By 2007, a total of 28 high-priority crossings, and a further 28 less significant crossings, in the Rai catchment had been eliminated (Marlborough District Council, 2007).

Although quantitative data on the individual effect of each crossing removal is not available, some qualitative observations can be made. For example, visual assessments indicate marked improvements in water and habitat quality immediately downstream of crossing points after a bridge or culvert has been put in place (see figure 8). Marlborough District Council report that where crossings have been eliminated, the stream substrate has in all cases changed from a clogged, fibrous bed to open cobbles with clear water and abundant macroinvertebrates (Marlborough District Council, 2008). Furthermore, it is logical to expect that the spikes in nutrient (and other pollutant) concentrations associated with herd crossings have been significantly reduced.

Figure 8: **Example of stream bed condition before (left) and after (right) herd crossing removal on a tributary stream in the Rai catchment**

Source: Marlborough District Council, 2008.

Although local-scale improvements are obvious, the collective effect on catchment water quality of all crossing eliminations so far has not been quantitatively assessed. It is the intent of the ongoing catchment-wide water-quality monitoring programme to do this over time (Marlborough District Council, 2008).

Stressors and toxicants

Figures 9 to 12 show medians and ranges for several water-quality measurements that indicate toxic or otherwise stressful conditions for aquatic organisms. Electrical conductivity is included in this section because it can indicate the presence of pollutants, although it is not a stressor *per se*. Some water-quality measurements described below (dissolved oxygen and water temperature) often fluctuate considerably during the course of a normal day. The implications of such daily variations for interpreting the measurement statistics are discussed in the ‘Data constraints and limitations’ section.

Ammoniacal nitrogen

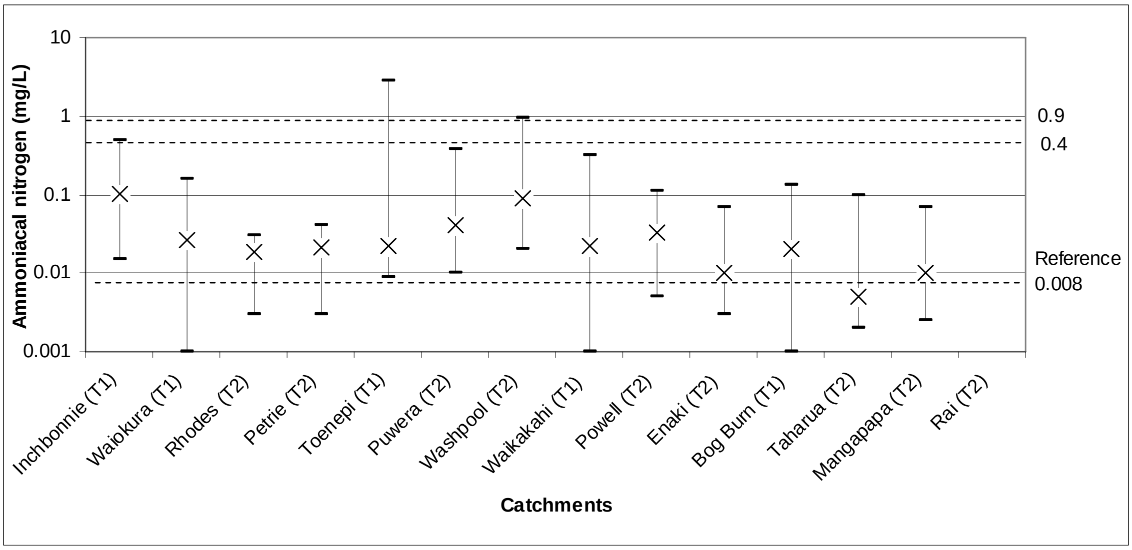
Ammoniacal nitrogen can, at sufficiently high concentrations, be toxic to fish and other aquatic life (in addition to contributing to eutrophication). In farmed catchments, elevated concentrations of this compound generally arise from stock effluent reaching the streams via direct discharge, paddock run-off or direct stock access to stream banks and beds. This is most likely to be exacerbated when stream flows are low (eg, in late summer), when cattle are often near waterways and when dilution rates are low. Run-off and leaching of urea fertiliser can also contribute.

The concentration at which ammoniacal nitrogen becomes toxic is dependent on stream water temperature and pH (ANZECC, 2000). ANZECC recommends adopting a trigger value of 0.9 mg/L ammonia nitrogen for pH 8 and 20°C to adequately protect 95 per cent of species. The average of measured catchment maximums was just over 8 for pH (provided in table A2-I but not graphically presented) and just over 20°C for water temperature; this indicates that a 0.9 mg/L trigger value for ammoniacal nitrogen is a reasonable guideline to report against for these catchments (ANZECC, 2000). Maximum measured water temperature was just over 25°C (Enaki) and maximum measured pH was 9 (Bog Burn), indicating conditions in some of the catchments where ammonia may become toxic at lower concentrations of around 0.4 mg/L.

Figure 9 shows that four catchments – Inchbonnie, Toenepi, Puwera and Washpool – had peak ammoniacal nitrogen concentrations that came very close to, or exceeded, 0.4 mg/L. Two of these catchments had peak concentrations that exceeded 0.9 mg/L. All catchments except Taharua had median concentrations of ammoniacal nitrogen that were elevated above concentrations found in predominantly natural catchments (see figure 9).

While there has been a relatively high rate of progress in the Washpool catchment towards Accord targets aimed at excluding stock from waterways (ie, 94 per cent of Accord waterways fenced and only one stream crossing still existing, see table 4), this catchment has the highest median concentration of ammoniacal nitrogen. Sampling from multiple sites throughout this catchment (reported by Otago Regional Council, 2007) reveals that a high proportion of ammonia in the main stem of the Washpool Stream originates from tributary mole-and-tile drains (artificial channels used to drain paddocks, which are particularly common in Otago). Although mole-and-tile drains have been specifically identified for management action through an Accord-related memorandum of understanding between Otago Regional Council and Fonterra, there is some progress yet to be made to meet targets.[11]

Figure 9: Medians (crosses) and ranges for ammoniacal nitrogen for the most downstream sites during the monitoring period



Notes:

A log scale has been used on the y axis.

The upper dashed lines are based on the ANZECC toxicant trigger values of 0.4 mg/L for 95% ecosystem protection (assuming a water temperature of 25°C and pH 9), and 0.9 mg/L for 95% ecosystem protection (assuming a water temperature of 20°C and pH 8). The lower dashed line is the median for predominantly natural catchments.

Data and further information on guidelines are provided in table A2-H in appendix 2.

Ammoniacal nitrogen concentrations at the Rai catchment site were reported as median of <0.01 mg/L and a maximum of 0.01 mg/L.

T1 = Tier 1 catchment and T2 = Tier 2 catchment.

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[11] The target agreed by Fonterra and Otago Regional Council is that “100% of dairy farms on tile and mole drained land to have the approved environmental management system section from the *Best on Farm Practice Manual* completed by September 2006”. Fonterra monitoring of 70 dairy farms in the Clydevale area, in which the Washpool catchment is included, indicated that, as of May 2008, approximately 35% of dairy farms had met the target completely while approximately 5% had made no progress (E Brown, Otago Regional Council, pers. comm., 2009).

Dissolved oxygen

The concentration of oxygen that is dissolved in water and available for respiration by aquatic animals is a crucial indicator of the life-supporting capacity of a stream. Dissolved oxygen concentrations are commonly increased during the daytime by the photosynthesis of periphyton and aquatic plants and reduced at night by periphyton and microbial respiration and the decay of organic matter. As a result, streams with undesirable organic waste discharges or proliferations of algal and weed growth often exhibit large fluctuations in dissolved oxygen, including dangerous depletions at night.

The depletion concentrations at which aquatic species show signs of impairment are variable. However, a study by Deans and Richardson (1999) indicates a drop below 5 mg/L (equating roughly to 50–60 per cent saturation) may begin to affect some less tolerant fish species in New Zealand. Another study by Landman et al (2005) indicates prolonged (ie, 48-hour) concentrations of less than about 3 mg/L start to have lethal effects on inanga (whitebait). The Resource Management Act 1991 suggests a minimum threshold of 80 per cent saturation[12] to protect aquatic life, while ANZECC (2000) suggests saturation levels between 98 and 105 per cent are optimal for lowland reference sites (ie, only slightly disturbed ecosystems).

Dissolved oxygen statistics (mostly from monthly spot measurements) are shown in two plots in figure 10. This is because both methods of measurement (per cent saturation and concentration) were employed by the monitoring agencies who provided the data and there is no ready conversion from one method to the other (without accounting for temperature). The five Tier 1, as well as Taharua, Enaki, Rai and Powell, catchment results are given as per cent saturation, and medians were all above 80 per cent, indicating that daytime oxygen concentrations were generally adequate to support aquatic life. However, six of these nine catchments had daytime minimums that indicated oxygen concentrations fell below the guideline on occasion, and the Toenepi daytime median of 80.7 percent saturation indicates more frequent oxygen sags below the guideline.

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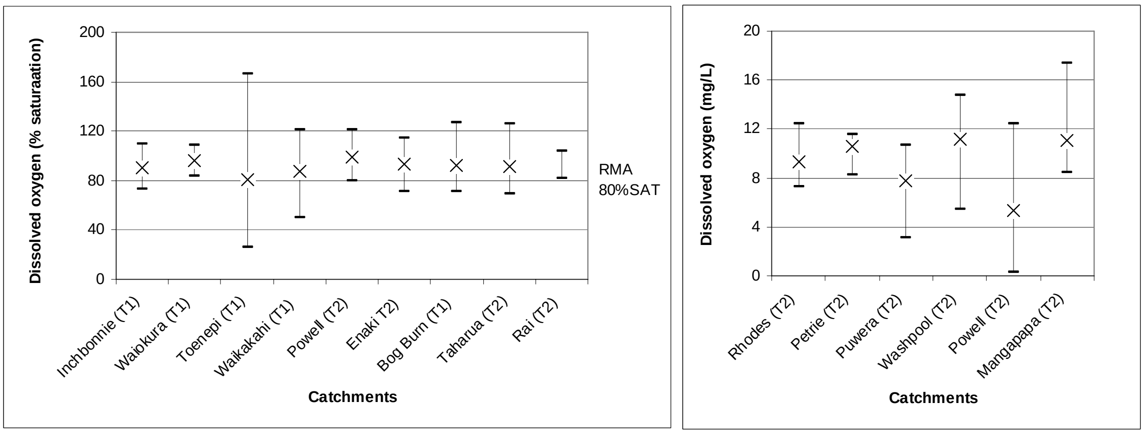
[12] The RMA guideline value is widely used in New Zealand to broadly benchmark dissolved oxygen concentration. However, it is recognised that councils and other agencies also develop and use other dissolved oxygen thresholds depending on their specific management aims. For example, Wilcock et al (2006) have proposed a threshold value of 40 per cent saturation for use in the Toenepi catchment in Waikato.

Figure 10: Medians (crosses) and ranges for dissolved oxygen for the most downstream site (unless specified otherwise) during the monitoring period



Notes:

Powell data in the left figure (%SAT) is from monthly daytime spot measurements over one year, and in the right figure (mg/L) is from two-week summer deployment of an oxygen meter. (Note the units differ from data for Powell in the left graph.)

The y axes are different in the two graphs.

The guideline is the RMA guideline for ecosystem protection (80 per cent).

T1 = Tier 1 catchment and T2 = Tier 2 catchment.

Furthermore, several catchments had maximums well over 120 per cent, or 12 mg/L, indicating occasional super-saturation with oxygen during the daytime (eg, Mangapapa, Toenepi, Washpool). This is indicative of high rates of photosynthesis during the day (probably related to eutrophication) but also suggests, correspondingly, that there may have been high rates of respiration depleting oxygen at night (in the absence of photosynthesis). While two of the catchments mentioned above did indeed exhibit relatively low dissolved oxygen minimums, giving an inkling of the overall fluctuation, daytime measurements are unable to pick up the true bottom of the oxygen profile (which often occurs around dawn).

A much better representation of dissolved oxygen concentrations is gained from continuous 24-hour measurements (ie, measurements that include night-time measurements). Such measurements have been made in four of the Tier 1 catchments and indicate that actual oxygen minimums were about 10 percentage points lower (indicating greater oxygen depletion) in these catchments than the routine monthly monitoring results suggest (with minimums ranging from about 25 to 60 per cent saturation in the Toenepi, Waikakahi and Bog Burn catchments).[13] Only the Waiokura catchment remained relatively well aerated throughout 24-hour periods and across seasons. Night-time dissolved oxygen concentrations as low as 6 per cent saturation have been measured at Tahuroa Road monitoring site in the Toenepi Stream (Wilcock et al, 2006).

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[13] Estimated from a comparison of ranges from daily (ie, 24-hour continuous) dissolved oxygen and routine monthly daytime measurements reported in Wilcock, Monaghan et al, 2007.

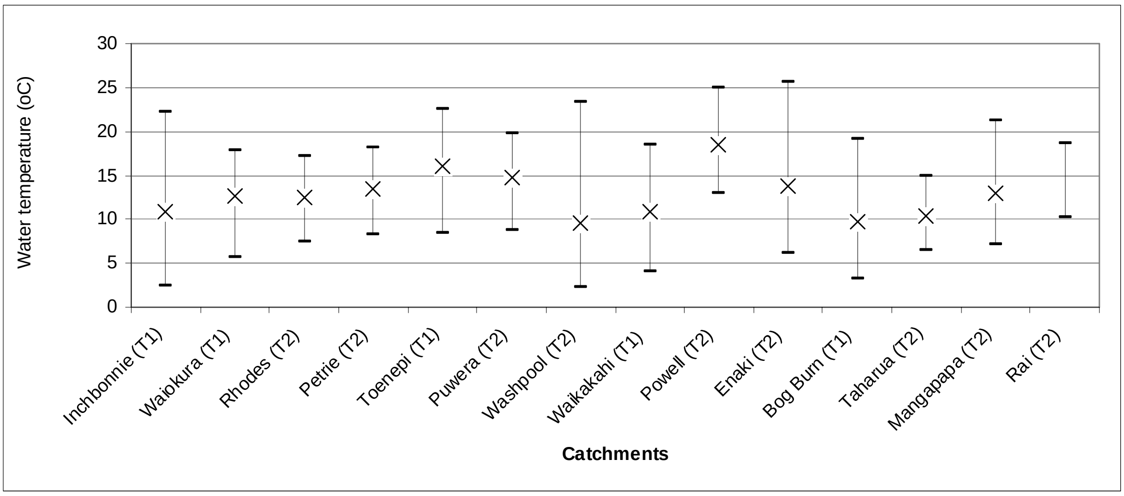
Continuous measurements have also been made in the Powell catchment. These are shown, in addition to the monthly results for the Powell catchment, in figure 10 (right graph). These results are from the short-term (two-week) summer deployment of an oxygen logger. The short-term summer median (5.35 mg/L) is much lower than the medians from monthly measurements for the other Tier 2 catchments (9.3–11.2 mg/L), while the range is much greater. This highlights the need to consider seasonal continuous data (especially in summer low-flow conditions), in addition to monthly daytime measurements, when making assessments of water-quality change.

Water temperature

Stream water temperatures that vary too much from the natural range, or climb too high, can be detrimental to aquatic life. For example, temperatures exceeding 22°C begin to have lethal effects on some mayfly insects (Quinn et al, 1994), while temperatures over about 30°C may be lethal to some fish, such as inanga/whitebait (eg, Richardson et al, 1994). Generally, pastoral streams are susceptible to warm spikes in temperature as a result of riparian vegetation (shade) removal and channel disturbance reducing natural flows.

Figure 11 shows that most individual catchments had a seasonal range (as defined by single daytime readings) of at least 10°C. Two catchments, the Powell and Enaki, had measured peak temperatures reaching, or in excess of, 25°C – a threshold that is considered to be the upper tolerance limit for trout (Schedule 3 of RMA, 1991). In the case of the Powell catchment, this measurement is an actual peak as it comes from a continuous temperature sensor record (as opposed to the highest single daytime measurement).

Figure 11: Medians and ranges for the most downstream site during the monitoring period for water temperature



Notes:

Powell data from two-week summer deployment of an oxygen meter.

Data, details on monitoring periods and sample numbers are provided in table A2-K in appendix 2.

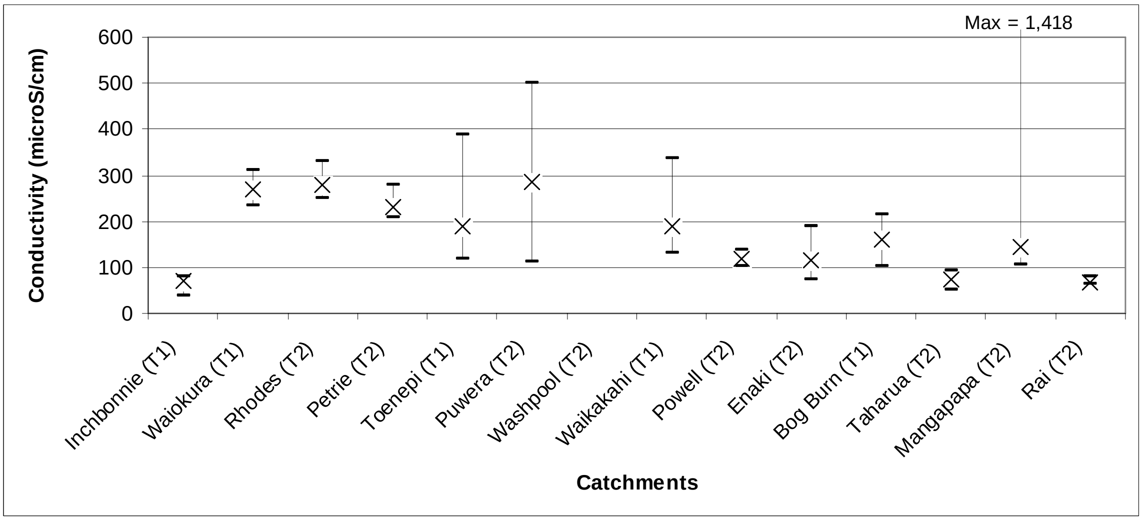
T1 = Tier 1 catchment and T2 = Tier 2 catchment.

Electrical conductivity

Electrical conductivity is a measure of the total dissolved salts or ions in the water. Elevated concentrations may indicate the presence of point-source discharges (eg, effluent) or diffuse nutrient inputs, but can also be a naturally occurring result of catchment geology.

Median electrical conductivity generally lies in the range of 100–300 microS/cm across catchments (see figure 12). The Mangapapa catchment shows the greatest range in monthly measurements (as it does for many of the other measurements) discussed in this report, including some of the nutrient forms. The pattern across catchments is broadly correlated with nitrate–nitrite nitrogen (eg, the Rhodes–Petrie and Waiokura catchments register high values for both measurements).[14] The most notable exception is the Puwera catchment, where conductivity is high but nitrate–nitrite nitrogen is very low.

Figure 12: **Medians (crosses) and ranges for electrical conductivity for the most downstream site during the monitoring period**



Notes:

A log scale is used on the y axis.

Data and details on monitoring period and sample number are provided in table A2-L in appendix 2.

Where bars go off the edge of the y axis scale the minimum or maximum is noted next to the bar.

T1 = Tier 1 catchment and T2 = Tier 2 catchment.

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[14] Linear regression of the catchment medians for conductivity with nitrate–nitrite nitrogen (n = 12) had an r^2 of 0.59. The Puwera catchment was excluded from this regression as an outlier.

Sediments and visual quality

Suspended solids and turbidity are important indicators of aquatic habitat and visual quality and affect human values such as fishing, swimming and amenity. If concentrations of suspended solids are too high for prolonged periods, mobile species (eg, fish) may not have sufficient light to navigate and feed effectively, and juvenile recruitment or passage of fish into catchments may be limited (Richardson and Jowett, 2001). As fine sediments settle out of the water column, benthic habitats may be smothered.

High suspended solids concentrations are commonly associated with higher flows and are also naturally elevated in catchments with soft (erosion-prone) geology or sandy-bottomed streams. However, high suspended solids and turbidity (which generally result in low visual clarity (ANZECC, 2000) may also indicate stream bank and paddock erosion associated with poor land management.

Suspended solids and turbidity are generally correlated for each catchment,[15] with Waiokura and Washpool having particularly high medians for both measurements (see figure 13). Four of the catchments have median turbidity levels that are at, or in excess of, ANZECC guidelines for ecosystem protection (5.6 NTU). Cawthron Institute research on trout fisheries indicates that turbidity in excess of the ANZECC guideline may result in a reduction in visual foraging area of drift-feeding trout of about 60 per cent (from clean water conditions), even for small fish (< 10 cm) (John Hayes, Cawthron Institute, pers. comm., 2009). A similar relationship is likely for drift-feeding native fish such as inanga and smelt, with a proportional decrease in energy (food) intake and adverse consequences for fish growth, condition and possibly survival (John Hayes, Cawthron Institute, pers, comm., 2009).

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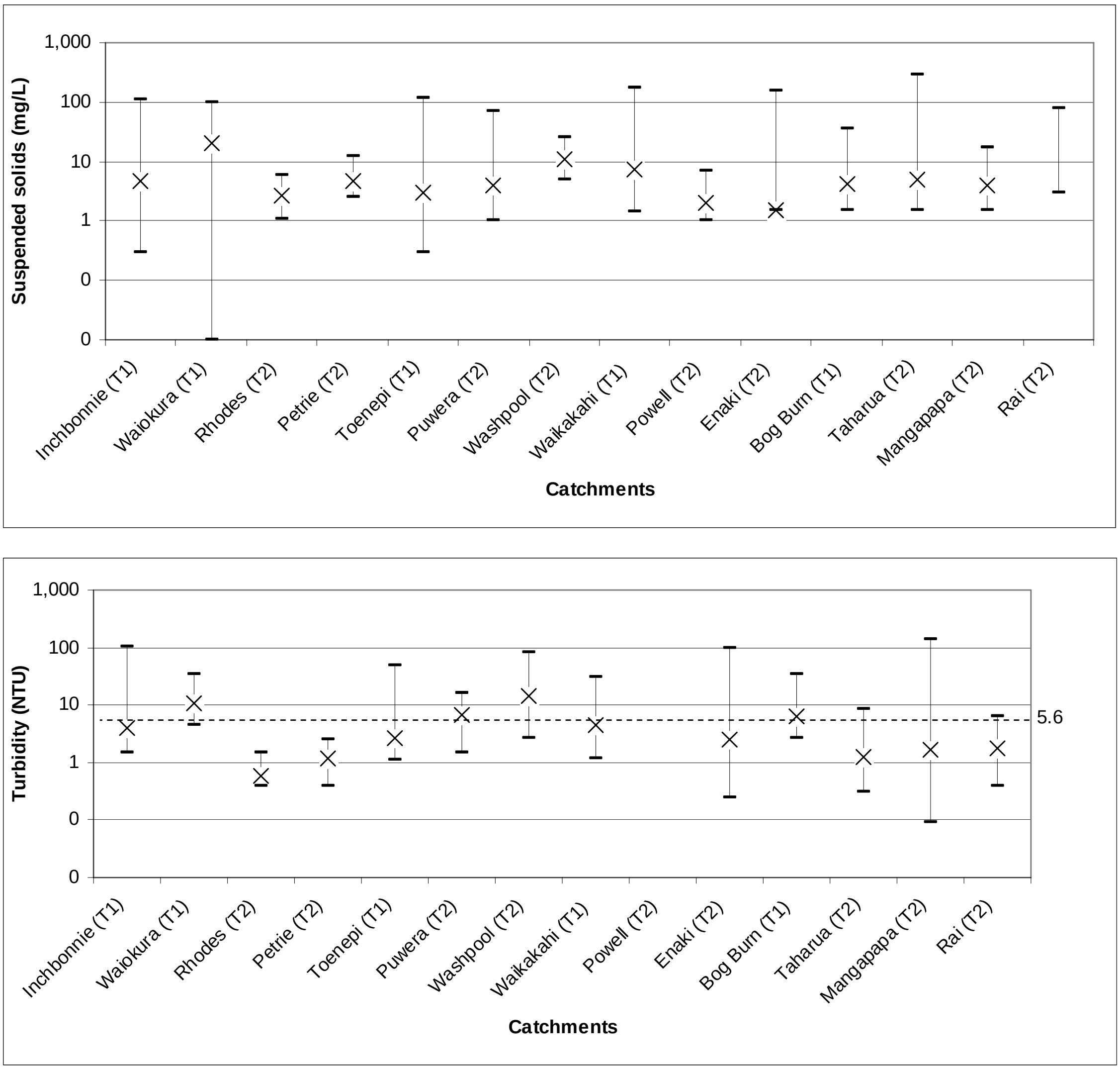
[15] Linear regression of the catchment medians for suspended solids with turbidity ($n = 12$) had an r^2 of 0.56.

Figure 13: Medians (crosses) and ranges for the most downstream site during the monitoring period for suspended solids and turbidity



Notes:

A log scale is used on the y axes.

The dashed line in the lower graph is the guideline threshold for turbidity (5.6 NTU, from ANZECC trigger values for ecosystem protection in lowland waterways).

Data, details on monitoring period and sample number are provided in tables A2-M and A2-N in appendix 2.

T1 = Tier 1 catchment and T2 = Tier 2 catchment.

Although concentrations of suspended solids indicate potential habitat impacts, measurements of deposited fine sediment (as percentage sediment cover on the stream bed) would add important additional information. Deposited fine sediment has been identified as a key stressor for agricultural stream ecosystems in New Zealand in recent years (eg, Niyogi et al, 2007) because it tends to accumulate during periods of normal and low stream flows. As a result, it affects stream organisms for longer periods of time than do suspended solids. This measurement could be considered for inclusion in ongoing catchment monitoring programmes.

Visual clarity data was not sought for this report,[16] but a summary for the period 2001 to 2006 has been published for the five Tier 1 catchments by Wilcock, Monaghan et al (2007). Median visual clarity was closely correlated with suspended solids ($r^2 = 0.75$) and turbidity ($r^2 = 0.69$) and ranged between 0.38 metres (Waiokura) and 1.4 metres (Toenepi). For reference, the ANZECC (2000) guideline (trigger value) for ecosystem protection in lowland waterways is 0.6 m.

Benthic macroinvertebrates

In addition to the measurements of water quality already described, benthic macroinvertebrates (ie, the insects, worms and snails that live on stream beds) are also good indicators of stream water quality, habitat quality and overall ecosystem health. Samples of macroinvertebrate population numbers and species types can be used to calculate biotic indices, such as the Macroinvertebrate Community Index (MCI),[17] which reflect the range of water quality and habitat conditions experienced in a stream over time. In a degraded stream, for example, the macroinvertebrate community will be dominated by pollution-tolerant species such as snails, worms and midge larvae. In a more pristine stream, larvae of insects such as mayflies and caddisflies will predominate.

Table 7 provides a summary of the average MCI and Quantitative MCI (QMCI) scores from the monitored catchments for which data is available (10 out of 14 – considering Rhodes–Petrie catchments together). Where multiple sampling sites existed within catchments, scores have been averaged. However, upper catchment sites (ie, those that could be considered unaffected) have been excluded.

One way of interpreting macroinvertebrate scores is to apply the water quality categories defined by Wright-Stow and Winterbourn (2003) and presented in table 8. Since there are some differences between catchments in terms of the type of metric available, it is not appropriate to apply these categories in a rigid manner, but they can be used to broadly characterise the catchments: five catchments had average QMCI scores above 5.0 (or a high MCI in the case of Taharua), indicating relatively clean water or mild degradation, while the other five had average QMCI scores below 5.0, indicating moderate to severe pollution.

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[16] Although, visual clarity is measured in all but two of the monitored catchments (see table A4-A) and could be considered for inclusion in future reporting.

[17] See *A User Guide for the MCI* (Stark and Maxted, 2007) for a description of the use of the MCI and its variants in New Zealand.

Table 7: Average MCI and QMCI scores

Catchment	Method of score calculation and data source	Substrate	**Average MCI score** (range between site averages in brackets, or standard deviation)	**Average QMCI score** (range between site averages in brackets, or standard deviation)
Taharua (T2)	3 sites sampled 4–6 times each between 1999 and 2005. Average for each site used to calculate overall average (Hawke's Bay Regional Council, 2006)	Predominantly mobile pumice sands	**122** (110–147)	
Waiokura (T1)	3 sites sampled on 3 occasions between 2001 and 2003 (2 summer and 1 winter). Average for each site used to calculate overall average (Scarsbrook et al, 2005)	Dominated by fine silt and sand upstream, becoming coarser downstream	**111** (SD = 10.7)	**6.2**[a] (SD = 0.3)
Enaki (T2)	1 site, 3 replicate samples taken annually between 2002 and 2007. Mean scores given in columns to the right (Greater Wellington Regional Council, 2008)		**104** (SD = 11.4)	**5.6**[a] (SD = 1.25)
Bog Burn (T1)	3 sites sampled on 3 occasions between 2001 and 2003 (2 summer and 1 winter). Average for each site used to calculate overall average (Scarsbrook et al, 2005)	Variable. Becoming progressively finer downstream. Moderate concentrations of deposited fine sediment have been observed on occasion	**100** (SD = 6.5)	**5.3**[a] (SD = 0.58)
Waikakahi (T1)	3 sites sampled on 3 occasions between 2001 and 2003 (2 summer and 1 winter). Average for each site used to calculate overall average (Scarsbrook et al, 2005)	Gravel and cobble bed. Fine sediment deposits are typically a minor component	**99** (SD = 8.2)	**5.3**[a] (SD = 1.13)
Mangapapa (T2)	Average of 6 sites on the Mangapapa and tributaries sampled on 1 occasion each during low flow in 2007[b] (Horizons Regional Council, 2007)	Predominantly gravels and small cobbles with 3 sites dominated by sands and silts	**89** (73–105)[c]	**4.2** (2.9-5.9)[c]
Powell (T2)	Average of 5 sites on the Powell and tributaries sampled on 2 occasions each during 2006/2007[b] (Tasman District Council, 2007)	Variable. Some sites dominated by silts and muds, others gravel and cobble	**81** (56–95)	**4.0** (2.75–4.49)
Puwera (T2)	2 sites on the main stem sampled 4 times each between 2006 and 2007. Average for each site used to derive overall average (Northland Regional Council, 2007)		**82** (74–89)	**3.6** (2.76–4.05)
Rhodes (T2)	2 sites sampled 12 times between 1999 and 2006. Average of each site used to derive overall average (Environment Canterbury, 2007)	Variable along length from heavily sedimented to gravelly		**3.5** (1.76–4.74)
Petrie (T2)	1 site sampled 13 times between 1999 and 2006. Average score taken (Environment Canterbury, 2007)	Variable along length from heavily sedimented to gravelly		**3.3** (1.97–4.59)
Rai (T2)	No data available for this report			
Toenepi (T1)				
Inchbonnie (T1)				
Washpool (T2)				

Notes:

a SQMCI (not QMCI).

b The most upstream site (considered reference site) has been excluded.

c Ranges in brackets are for site averages (actual sample data was not available).

Numbers in brackets indicate ranges in metric scores: the minimum and maximum actual sample scores across all monitoring sites in each catchment, except for the Tier 1 and Enaki catchments where the average standard deviation is given and the Mangapapa catchment where the range of average site scores is given.

T1 = Tier 1 catchment and T2 = Tier 2 catchment.

SD = Standard deviation.

Table 8: MCI and QMCI degradation categories suggested by Wright-Stow and Winterbourn (2003)

MCI range	QMCI range	Degradation category
125–200	6.2–10.0	Clean (water)
105–115	5.2–5.7	Mild
85–95	4.2–4.7	Moderate
< 75	0–3.7	Severe

Although the MCI may be influenced by water quality, it may also be influenced to greater or lesser degrees by other catchment factors such as land and channel disturbance, stream substrate and flow conditions. For example, Environment Canterbury (2007) has attributed the low MCI scores in the Rhodes and Petrie catchments more to channel alteration and significant habitat degradation than to poor water quality *per se*. Conversely, the relatively high MCI scores in the Waiokura catchment are probably more a reflection of favourable substrate (gravel and rock) and flow conditions (eg, see analysis below) than good quality water.

Results of regression analyses indicate a relatively strong relationship between stream flow and average MCI ($r^2 = 0.89$) and QMCI ($r^2 = 0.79$) scores, although this analysis is based on only a small number of data points (see table A3-A in appendix 3). There is also an apparent, but weaker, linear relationship between each metric and percentage catchment area under dairy ($r^2 = 0.27$ for MCI and 0.35 for the QMCI); note that the Waiokura catchment is excluded from this analysis as an outlier.

With respect to limitations, it should be noted that the MCI scores summarised in table 7 are averages from the results of all available monitoring sites in each catchment. The ranges of site results (given in brackets in table 7) indicate significant variability within catchments.

It should also be noted that MCI scores have been derived using the approach designed for hard-bottomed streams. There is now a soft-bottomed variant of the MCI (Stark and Maxted, 2007). The suitability of this variant for use in any of the monitored catchments should be determined.

Upstream vs downstream measurements

One of the methods for assessing the effects of best practice management in the monitored catchments over time is to compare water quality from upstream of the main dairy farming area with downstream water quality. Assuming water quality is higher upstream, if management interventions on the dairy farmland are effective, the gradient (ie, degree of difference) between upstream and downstream water quality would be expected to reduce over time.

Tables A2-A to A2-N in appendix 2 present median and range data for upstream sites (where available) in each monitored catchment. In some cases, such as in the Mangapapa catchment, these sites represent true reference conditions (ie, are upstream of all significant modified land use), while in other cases, such as in the Powell catchment, they are as far upstream as is practicable for the monitoring agency to visit but may still have significant modified land use above them.

Table 9 shows the percentage change between median values for nitrate–nitrite nitrogen, dissolved reactive phosphorus, *E. coli* and suspended solids at upstream sites and downstream sites for each catchment (where suitable comparative data existed).

Table 9: Comparison of upstream and downstream measurements

Catchment	**Percentage change in measurement between upstream and downstream monitoring sites**			
	Nitrate–nitrite nitrogen	**Dissolved reactive phosphorus**	***E. coli***	**Suspended solids**
Inchbonnie (T1)	↑ (+42)	↑ (+51)	↑ (+24)	↑ **(+130)**
Waiokura (T1)	↑ (+22)	↓ (–55)	↑ **(+168)**	↓ (–2)
Rhodes (T2)	↑ (+28)	↓ (–38)	↓ (–67)	↑ (+86)
Petrie (T2)	↓ (–13)	↑ (+88)	↑ (+92)	↑ **(+400)**
Toenepi (T1)	ND	ND	ND	ND
Puwera (T2)	↓ (–38)	↓ (–53)	↑ (+7)	↑ (+33)
Washpool (T2)	↑ **(+1144)**	ND	↓ (–24)	↑ **(+159)**
Waikakahi (T1)	↑ (+9)	↓ (–23)	↓ (–76)	↓ (–71)
Powell (T2)	↓ (–21)	↑ **(+133)**	↓ (–59)	0
Enaki (T2)	ND	ND	ND	ND
Bog Burn (T1)	↑ **(+529)**	↑ (+5)	↑ **(+2550)**	↓ (–43)
Taharua (T2)	↓ (–55)	↓ (–39)	↓ (–18)	↑ **(+233)**
Mangapapa (T2)	↑ **(+580)**	↑ **(+240)**	↑ **(+1367)**	↑ **(+100)**
Rai (T2)	↑ **(+1160)**	↑ (+10)	↓ (–60)	ND
Total positive (↑) gradients	**8**	**6**	**6**	**7**
Total negative (↓) gradients	**4**	**5**	**6**	**3**

Notes:

Positive numbers and upward arrows indicate a downstream increase (deterioration) in measurement value; negative numbers and downward arrows indicate a decrease (improvement). Numbers in bold indicate the magnitude of the increase or decrease was greater than 100 per cent of the upstream value.

Derived from data in tables A2-B to A2-N in appendix 2.

ND = No data, which in most cases means there is no data for both an upstream and downstream site for this catchment.

T1 = Tier 1 catchment and T2 = Tier 2 catchment.

The expected gradients in measurements – indicating water quality deterioration from upstream to downstream– are found in most of the catchments for nitrate–nitrite nitrogen, dissolved reactive phosphorus and suspended solids/turbidity. However, there are exceptions to this. In addition, gradients of *E. coli* increase in the downstream direction in half of the catchments, but decrease in the downstream direction in the other half. Of note, all of the largest changes, for all four variables (ie, those that are greater than 100 per cent of the upstream median value – see bolded numbers in Table 9), represent deteriorations in the downstream direction.

It is difficult to speculate about the reasons for variable patterns in the downstream gradient of water quality. The nature of land-use activities, stream inputs, and riparian disturbance and protection differ within, and between, catchments, highlighting the complex nature of the relationships between land use and water quality. For example, access to waterways may be easier for stock in upstream reaches where the channel is smaller than in downstream reaches where it may be more incised and/or protected by fences. This effect may more than offset the normal downstream accumulation of pollutants that results from other, less direct, sources along the stream length.

Land use above the upstream monitoring sites in the catchments under discussion can also account for ‘reverse’ gradients. For example, in the Powell catchment, both nitrate–nitrite nitrogen and *E. coli* concentrations are higher at the upstream monitoring site. Tasman District Council (2008) notes that there is a considerable amount of sheep and beef farming and unfenced waterway in the headwaters of the Powell catchment that may account for this loading.

The analysis presented in table 9 is descriptive only and should be validated in future reports with more in-depth assessment of the raw data for each site. For example, understanding the frequency with which gradients strengthen, weaken or reverse would reveal much more information about land-use influences and water-quality change through the dairy areas. It should also be noted that in those catchments where intensive dairying is continuous throughout the catchment (eg, the Rhodes and Petrie), the comparison of upstream and downstream sites is less useful for interpreting the effect of land-use interventions.

Observed temporal changes

Information on trends and changes in water quality over various time periods is available for some of the catchments. This information is summarised here because it provides a useful context for the baseline data and any future assessments of long-term trends in the monitored catchments.

However, it is important to note that the results of statistical analyses are only available for four catchments (Enaki, Taharua, Toenepi and Waiokura), and these should be considered preliminary findings because they are based on relatively short time series (five to seven years). All other results, unless otherwise stated, are based on comparative observations rather than formal statistical tests. It should also be noted that trends are not necessarily related to existing or recent land-use activities and may reflect historical farming activities.

In the Taharua River, statistically significant increasing concentrations of nitrogen (in both dissolved and total forms) have been measured at all three monitoring sites over the period 2001–2005, but the trends are strongest (up to 0.366 mg/L per year) at the closest downstream monitoring site to the farming activity in the catchment (Twin Culverts). Monitoring does not show any other significant trends in water quality (Hawke’s Bay Regional Council, 2006).

In the Enaki catchment, statistically significant decreasing trends in water temperature (0.8^{o}C per year) and total phosphorus (0.004 mg/L per year) were found for the period 2002 to 2006. Although the phosphorus result is not thought to be particularly ecologically significant, the decrease in water temperature may indicate that fencing and planting carried out by Greater Wellington Regional Council in recent years is starting to have some beneficial effect (Perrie, 2008).

A comparison of sampling results between 2003 and 2006 for the Washpool catchment indicates that water quality is deteriorating (Otago Regional Council, 2007). Annual mean values of *E. coli*, nitrate–nitrite nitrogen, turbidity, ammoniacal nitrogen and total phosphorus were all higher in 2006 than in 2003. Only dissolved oxygen showed some improvement over this period (Otago Regional Council, 2007).

In the Rhodes–Petrie catchment, there is not yet enough water-quality chemistry data to perform robust statistical analysis. However, some observations have been made by comparing measurements made by Environment Canterbury (2007). The main long-term trends appear to be an increase in total nitrogen since the late 1990s and a decrease in habitat quality since 2000. Reduction in habitat quality is said to be related to siltation, removal of riparian vegetation and channel alteration (Environment Canterbury, 2007).

There also appear to have been some water-quality improvements in the Rhodes–Petrie catchment. There have been slight reductions in phosphorus and turbidity since 1999/2000, and a noticeable elimination of large spikes in these measurements. This may indicate improved bank stability and stock control in some places (Environment Canterbury, 2007).

Descriptive assessments of water-quality changes in several Tier 1 catchments were summarised three years ago by Wilcock et al (2006); briefly, the Bog Burn and Inchbonnie streams showed little change over the five years of monitoring from 2001 to 2006. The Waikakahi catchment, which also has a longer monitoring history, showed some improvement in suspended solids as a result of better riparian management, but changed little in other respects.

The Toenepi Stream, which has been monitored since the mid-1990s, has undergone more formal trend assessment. Wilcock et al (2006) report that, for the period 1995 to 2004, average water quality changed little but that there were some notable improvements, including statistically significant decreases in total nitrogen, ammoniacal nitrogen and suspended solids, and an improvement in visual clarity.

Recent analyses of data from the Waiokura catchment have revealed that some changes in water quality have occurred during the period 2001–2007 (Wilcock et al, in press). These include statistically decreasing concentrations of total and dissolved phosphorus, suspended solids and *E. coli* that have been attributed to improvements in point-source discharges, permanent stock exclusion and riparian planting. Concentrations of total and nitrate–nitrite nitrogen increased significantly over the period, reportedly because of intensification of land use and increased nitrogen cycling (Wilcock et al, in press).

No trend information is yet available for the Mangapapa, Puwera, Powell or Rai catchments.

Summary and Recommendations

This section provides a summary of baseline land use and water quality in the 14 monitored catchments, drawing on information in the previous two sections. It then offers some considerations and recommendations about the ongoing use of regional data sets, and the requirements for analysis to enable future national-scale trend assessments.

Summary of catchment characteristics and water quality

The monitored catchments discussed in this report differ from each other in a number of respects that have implications for measuring national water-quality outcomes related to dairy land management (including initiatives such as the Dairying and Clean Streams Accord).

Catchment features and land use

The catchments range in size from about 6 to 211 km^2. The smallest catchments (the Rhodes, Petrie and Powell) have the most detailed land-use information available as a consequence of the relative ease with which these catchments can be surveyed. For example, in these catchments there is accurate council survey information, which augments the Fonterra figures on the extent and condition of stream fencing and crossings.

Although most of the Accord targets are reported to have been met (or to be close to being met) in the majority of the monitored catchments, there are two catchments (Enaki and Puwera) where significant progress has yet to be made in fencing and culverting.

For most catchments there is no information on the extent to which nutrients are being actively managed (as opposed to nutrient budgets being in place). It is probably reasonable to expect, on the basis of statements in the 2006/2007 Snapshot of Progress report (Ministry for the Environment, 2008), that many of the monitored catchment nutrient budgets are not being fully implemented.

The drainage regime, geology and upstream land use of each catchment differs. Of particular note are:

- the Puwera catchment, where the variability in flow means that much of the main-stem stream is not perceived as an Accord waterway, and therefore has not been subject to Accord actions
- the Washpool catchment, where the prevalence of mole-and-tile drains appears to be having a dominant influence on water quality
- the Rhodes and Petrie catchments, where free-draining substrates and nitrate–nitrite nitrogen-enriched groundwater recharge of the streams means that water quality in these catchments is driven to some extent by land-use practices external to their area of surface water capture.

Water quality

Concentrations of nitrogen (total, nitrate–nitrite nitrogen and soluble inorganic nitrogen) are close to, or in excess of, guideline thresholds in almost all of the monitored catchments. However, the range of medians across catchments is considerable. For example, nitrate–nitrite nitrogen concentrations in the Rhodes catchment in Canterbury are about 40 times those in the Puwera catchment in Northland. This variation possibly reflects differences in the relative importance of nitrogen as a focal point for management response, although this will depend on observed effects.

Concentrations of phosphorus are close to, or in excess of, guideline thresholds in all of the Tier 1 catchments but are notably lower in most of the Tier 2 catchments (more than half of the Tier 2 catchments have concentrations of total and dissolved phosphorus that are not in excess of guideline thresholds). Although most catchments are tending towards phosphorus-limiting conditions, four catchments (the Rhodes and Petrie, Powell and Taharua) are strongly phosphorus-limited, while two (Inchbonnie and Puwera) are tending towards nitrogen limitation.

Although the majority (10) of the monitored catchments had uniformly high median *E. coli* concentrations, the Taharua catchment in Hawke’s Bay had much lower concentrations – similar to those found in catchments with predominantly natural land use (ie, relatively undisturbed).

Macroinvertebrate scores varied widely. Five catchments had average metric scores indicating relatively clean water or mild degradation, while another five had average scores indicating moderate to severe pollution (no data was available for four catchments). Of note, one of those catchments in the highest quality class for macroinvertebrate community health, the Waiokura, could be considered one of the poorest in terms of physical and chemical water quality.

Considerations for ongoing monitoring

As set out at the beginning of this report, there are a number of challenges to successfully assessing the water-quality outcomes of best practice management in dairying catchments. Some of these challenges have been highlighted in the description of baseline water-quality results and require further consideration in the context of any ongoing monitoring programme.

Land-use information

Improvements in the coverage and resolution of land-use information are required to identify the relationships between changing farm actions and water-quality trends in the monitored catchments. In addition to the land-use activities quantified and described in this report, there are many localised activities (eg, the change in rate of take from a river water abstraction point) that may also have relatively large impacts on water quality. However, there are considerable practical and financial constraints to capturing and quantifying these types of activities in a consistent way as part of the monitoring programmes under discussion.

Potential opportunities to draw on other studies to provide additional context for the land-use information presented in this report, and any subsequent related reports, should be considered. One example is a three-year research project, started in 2007 and led by AgResearch, titled The State and Change of Industry Practice and N and P Losses from Pastoral Farms. One of the objectives of this project is to benchmark, and show change in, land-use practices (N. Botha, AgResearch, pers. comm., July 2008). One thousand farmers have been independently surveyed as part of this study and there are plans to follow up with the same farmers in 2009.

Water-quality information

The existing sampling regimes (see table A4-A in appendix 4) allow some aspects of water quality to be quantified at the catchment scale, and it is likely that net changes in measurements over time will generally be detected at this scale in the data being collected. However, it is unclear, particularly with respect to the Tier 2 catchments, whether the existing monitoring is sufficient to detect more subtle long-term changes in water quality (ie, those that are seasonally driven or of a magnitude that requires intensive sampling to detect), and/or those that can be attributed to particular dairy management actions (including those taken under the Accord).

For example, it has generally not been possible in this report to characterise water quality during particular periods of the year when dairying impacts are likely to be accentuated (eg, channel disturbance during low flows in summer and higher nutrient delivery to waterways in winter). This is either because an intensive seasonal monitoring programme has not been undertaken, or because more data analysis is required at both the regional and national scale.

One exception is the Powell Stream, where continuous data logging of temperature and dissolved oxygen was carried out during the summer months of 2006/07; dissolved oxygen results for this period are considerably lower (worse) than the annual average results presented for the other monitored catchments. Focusing future monitoring on the time of the year when effects are most pronounced, such as has been done in the Powell catchment (and more recently in the Taharua catchment), is more likely to capture the most significant water-quality improvements resulting from changes in land-use practice.

To resolve uncertainties about whether present monitoring programmes meet national reporting needs, this report recommends that each catchment monitoring programme be reviewed, while recognising that contributing data for national reporting is only one of many outputs for these monitoring programmes. Some preliminary considerations are offered below.

Merits of the existing monitored catchments for national reporting

The five Tier 1 Best Management Practice catchments

These catchments are valuable components of a national long-term monitoring programme. Monitoring regimes are well established, with a detailed and consistent approach to water-quality measurements being taken. Routine stream monitoring is augmented by two-yearly surveys of farm management practices as well as discrete research projects,[18] both of which add to the overall understanding of land-use effects on water quality. There is a wealth of water-quality data for these catchments, much of which has not been reviewed here because it is the subject of other study outputs, which should be examined for future reports.

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[18] For example, the results of a two-year study on nitrate–nitrite nitrogen levels in the shallow groundwater of the Toenepi catchment have recently been published by Stenger et al (2008).

Tier 2 catchments

- **Puwera catchment in Northland.** It appears that few actions have been taken in this catchment to minimise the losses of pollutants to the stream. Northland Regional Council estimates that stock is excluded from less than 10 per cent of waterways in the catchment. The stream flow can cease altogether in summer months, which means the stream does not meet the Accord definition of "permanently flowing". This leads to some uncertainty about the extent to which landowners will adopt Accord and other best practice management actions over time. However, high flow variability is a feature of many Northland catchments. The Puwera catchment therefore (arguably) provides a typical and realistic picture of the relationship between water quality and dairying land use in the region. If Puwera is retained as a long-term monitoring catchment, more detailed information on land-use change will be required.
- **Taharua catchment in Hawke's Bay.** Like the Tier 1 catchments, the Taharua catchment has a history of routine water quality monitoring dating back to 2000, which provides a good basis for assessing any change in the future. Studies currently underway will establish the extent of interactions between surface and ground waters (G Sevicke-Jones, Hawke's Bay Regional Council, pers. comm., July 2008), and this may help clarify the impacts of dairying activities in the catchment. However, relatively recent (late 1990s) and continued expansion of dairying in the catchment means that any water-quality improvements resulting from the adoption of best practice management may be offset to some extent by the increase in overall dairy activity – a complicating factor that needs to be considered as part of any ongoing monitoring and reporting programme.
- **Mangapapa in Manawatu**. The Mangapapa catchment is the only one of the Tier 1 and 2 catchments in which dairying occupies significantly less land area (27 per cent) than sheep and beef farming (39 per cent). Also, much of the dairying catchment area does not meet the Accord requirements for stream size and depth (K McArthur, Horizons Regional Council, pers. comm., 2009). Both of these factors mean that, for this catchment in particular, action related to the Accord and other initiatives on the dairy land may make relatively little appreciable difference to water quality over time. However, Horizons Regional Council are committed to long-term water quality monitoring at the lower end of the catchment, so it may be worthwhile exploring whether additional focus on one of the sub-catchments that is dominated by dairy land use is possible.
- **Enaki in Wairarapa.** There is a history of routine water-quality monitoring in this catchment dating back to 2002, which provides a good basis for assessing any change in the future. Detailed analyses have been reported recently by Greater Wellington Regional Council (2008). Much of the monitoring work has focused on the water-quality changes resulting from riparian rehabilitation work on a small stretch of the Enaki Stream. The understanding of stream responses to very localised actions gained so far may be particularly useful for future interpretation of water-quality results relating to wider catchment land-use changes. Both Fonterra survey figures in this report and regional council comments (Greater Wellington Regional Council, 2008) suggest substantial progress has yet to be made in the Enaki catchment towards good practice. Assuming such progress will be made, the water-quality responses in the catchment will be of particular interest.
- **Powell, Rhodes and Petrie catchments in Tasman and Canterbury.** These South Island catchments have quite different characteristics within the overall group of monitored catchments. Their relatively small size has enabled the monitoring councils to compile quite detailed information on land use and farm practice. Updates to this information through repeated surveys and 'ground-truthing' of management actions (such as the length of effective fencing in place) may enable associations between these actions and any

changes in water quality to be made with greater confidence than may be the case for other catchments.

However, there are complicating factors in all three catchments: the Rhodes and Petrie catchments potentially receive nitrate–nitrite nitrogen-rich inflows of groundwater from outside the stream catchment, while relatively high nitrate–nitrite nitrogen and *E. coli* loadings in the upper Powell catchment are thought to originate from sheep and beef farmland.

- **Washpool catchment in Otago.** Water quality appears to be influenced to a large extent by the mole-and-tile drainage system in the catchment. There is an Accord-related agreement between Otago Regional Council and Fonterra to specifically address mole-and-tile drains in the Washpool catchment and some progress has been reported. The drainage system in Washpool is typical of that in many intensive dairy farming areas in Otago and New Zealand more generally, and deserves continued investigation. Like Puwera, Washpool offers good insight into a catchment where minimising the impacts of land use may be particularly challenging.
- **Rai catchment in Marlborough**. The focus of attention in the Rai catchment has been on eliminating stream crossings, and good progress has been made. Marlborough District Council has recently reconfigured the monitoring programme so that temporal trends in water quality can be measured with more certainty (Marlborough District Council, 2008). Given the commitment to ongoing monitoring and detailed information available on the status and number of stream crossings, it is appropriate to retain this catchment in any future national monitoring programme.

Recommended next steps

As noted earlier, the aim of this report is to establish a broadly representative nationwide picture of baseline water quality in dairy environments. This baseline may help, when used as a reference point over the long term, to assess how the adoption of best practice management on dairying land is affecting water quality (along with other local and regional studies). Ultimately, however, the utility of the report depends on the extent to which the monitoring challenges that have been identified or restated in this report can be addressed. It is therefore recommended that the next steps should include – but not be limited to – the following.

Review of Tier 1 and 2 monitoring programmes

It is recommended that each of the Tier 1 and Tier 2 monitoring programmes be reviewed by relevant agencies to assess their ‘fit’ with the objectives of the national programme. Such a review should be coordinated by the Ministry for the Environment to help promote a consistent process, and should begin by clearly re-confirming, and agreeing between parties, the national monitoring and reporting objectives.

Subsequent to this, other review considerations should include the following.

- *New/additional land-use data requirements* – determine what improvements in land-use information might be possible. Examples of useful additional information include:
  - council consent records of stream allocation (eg, as a percentage of mean annual low flow) and the number of discharges to land and water

  - detailed independent surveys of channel length, the extent and effectiveness of channel and bank protection (including riparian buffers), and nutrient and effluent management (including fertiliser application).

- *New/additional water-quality data requirements and reporting formats* – this report has identified a number of areas where it would be informative to modify the type and format of data reported.
  - Presentation of 5th, 25th, 75th and 95th percentiles in addition to data ranges would better capture the distribution for each water-quality variable. This is particularly important for the *E. coli* data to make comparisons with appropriate contact recreation guidelines. In some cases it is also more appropriate to use mean values than medians (eg, when comparing nitrogen and phosphorus with periphyton guidelines), and a consistent approach should be taken here.
  - Information on periphyton and macrophytes is currently patchy across the monitored catchments. Nuisance growth is a useful – if somewhat subjective – indicator and should be a routine measurement in all catchments. In addition, consideration could be given to introducing visual clarity and fine sediment deposit measurements in those catchments where it is not currently routinely measured.
  - In-depth analysis of the upstream to downstream gradient in water quality would be useful. This might include statistical comparisons of the site data, along with assessments of the frequency and strength of positive and negative gradients across sampling events and seasons.
- *Data requirements for formal trend analyses* – it is unlikely that the comparison of annual (or multi-year) medians will be sufficiently statistically robust to analyses for trends until long data sets have been assembled. For shorter time periods (eg, five years), conventional wisdom suggests, as a minimum, monthly data should be gathered (eg Scarsbrook and McBride, 2007). While this is already happening in most catchments, quarterly data is being gathered in some.
- *Data requirements to detect extremes, seasonal and/or flow-related differences in water quality* – in addition to the year-round monthly data being collected in the target catchments, continuous monitoring could usefully be focused on periods when land use is likely to have the most detrimental effect (and where land-use changes may produce the largest gains); for example, determining changes over consecutive summers (during low flow conditions) in the minimum oxygen and maximum water temperature profiles. Flow-related analyses of several water quality variables could also be very informative (eg, determining how the faecal load in the monitored catchments is changing over time during base flow conditions, compared with the overall flow profile).

Agreement between parties on funding and resourcing arrangements

The cost of catchment water quality monitoring programmes is not insignificant. For example, the cost of monitoring and analyses of data for one year (2006/07) in four of the Tier 2 catchments was $100,000, while around $160-180,000 per year has been spent on the water quality component of the monitoring and reporting programmes in the five Tier 1 catchments. Similar ongoing levels of investment will be required to maintain the existing programmes.

However, the costs of any additional monitoring and analyses deemed necessary for national reporting will need to be considered and agreed between relevant parties. This should include consideration of the interaction between the monitoring objectives of local / central government, science and research providers and industry for each of the catchments.

Future reporting

Notwithstanding the outcome of the review of the existing monitoring programme, the monitoring and reporting strategy for the Clean Streams Accord (Ministry for the Environment, 2006) recommends a five-yearly reporting schedule starting from 2012. Under this strategy, reporting is to comprise regional reports on individual catchments (produced by regional councils) and a national summary report (produced by the Ministry for the Environment), both of which would be referenced against the baseline monitoring that has been the subject of this report.

Although the overall life span of the monitoring and reporting programme is also likely to be the subject of further discussion, the 2006 strategy recommended a minimum life span of 10 years (from 2006/07), and preferably 15 years, to account for time lags between land-use changes and water-quality effects. Assuming these recommendations stand, the Ministry for the Environment expects to produce further reports on water-quality outcomes in the monitored catchments using 2012 and 2017 data.

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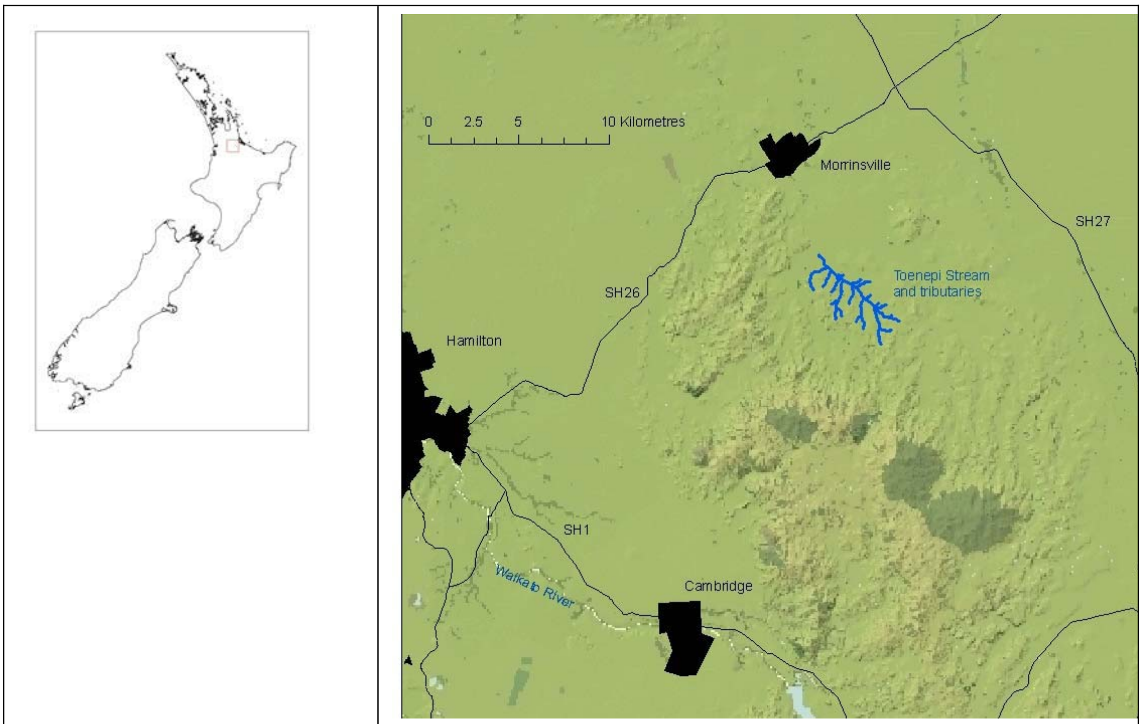
Appendix 1: Monitoring Catchment Details

Figure A1-A: Toenepi Stream catchment (Tier 1), Waikato



Location (most downstream sample point)	E 2735152 N 6385431
River environment classification	**W**arm **D**ry, **L**ow elevation, **V**olcanic, **P**astoral Stream order = 3
Rainfall From NIWA CliFlow database (station ID = Morrinsville 1573 and Toenepi 23908)	**1,121 mm** Average annual total (1965–2007: white bars in graph) **1,099 mm** Average 2001–2006 (water quality monitoring period: grey bars in graph)

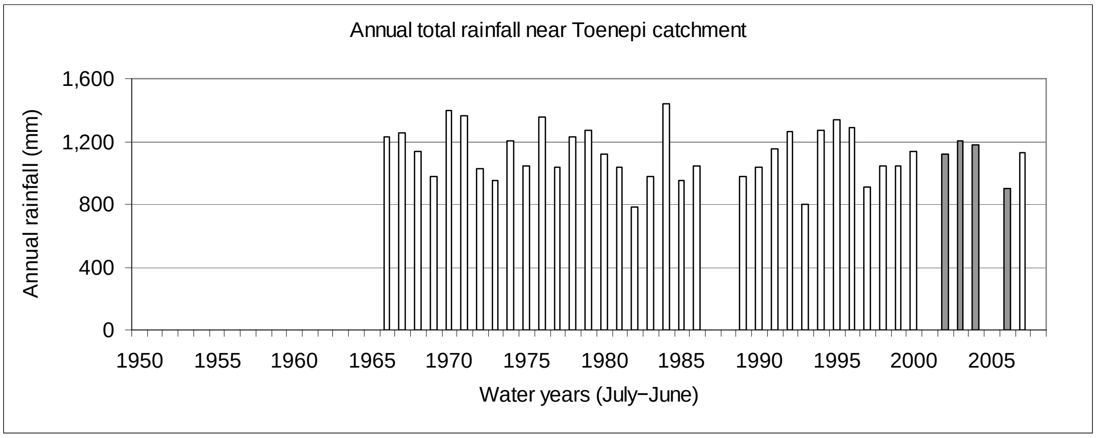
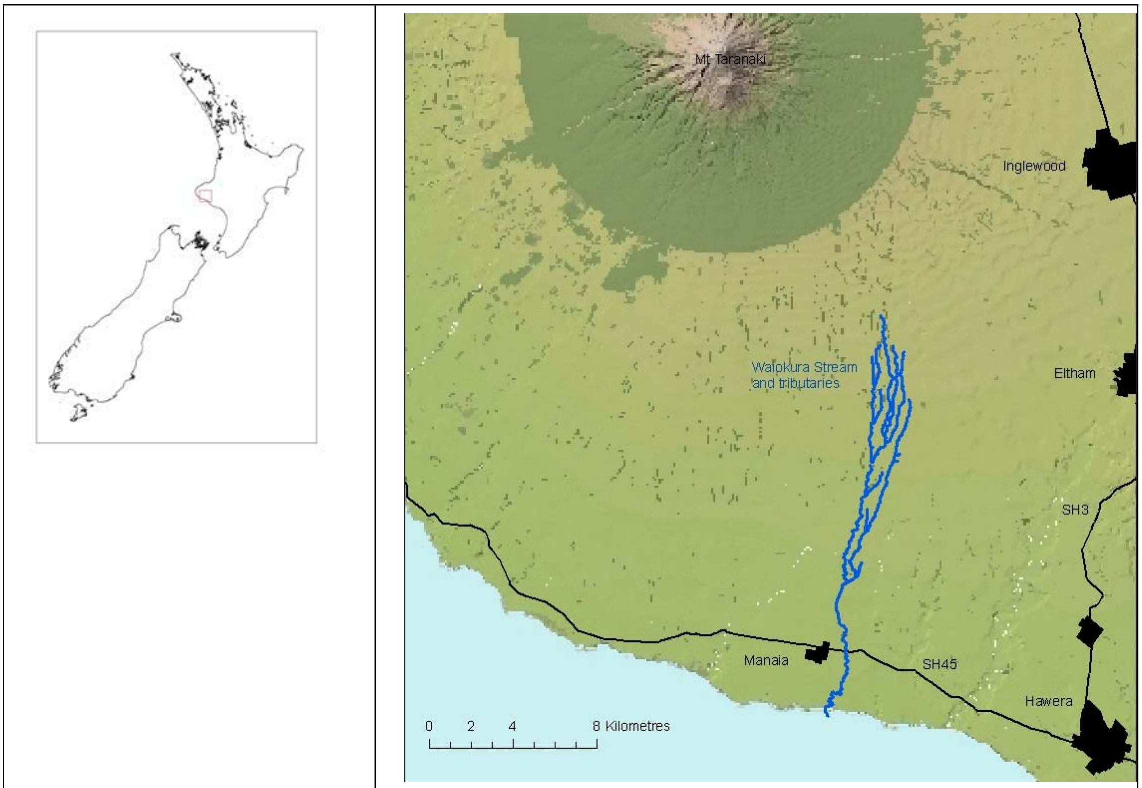


Figure A1-B: Waiokura catchment (Tier 1), South Taranaki



Location (most downstream sample point)	E 2607820 N 6183640
River environment classification	**W**arm **Wet**, **L**ow elevation, **V**olcanic, **P**astoral
Rainfall From NIWA CliFlow database (station ID = Riverlea 3535)	**1,634 mm** Average annual total (1950–2007: white bars in graph) **1,695 mm** Average 2001–2006 (water quality monitoring period: grey bars in graph)

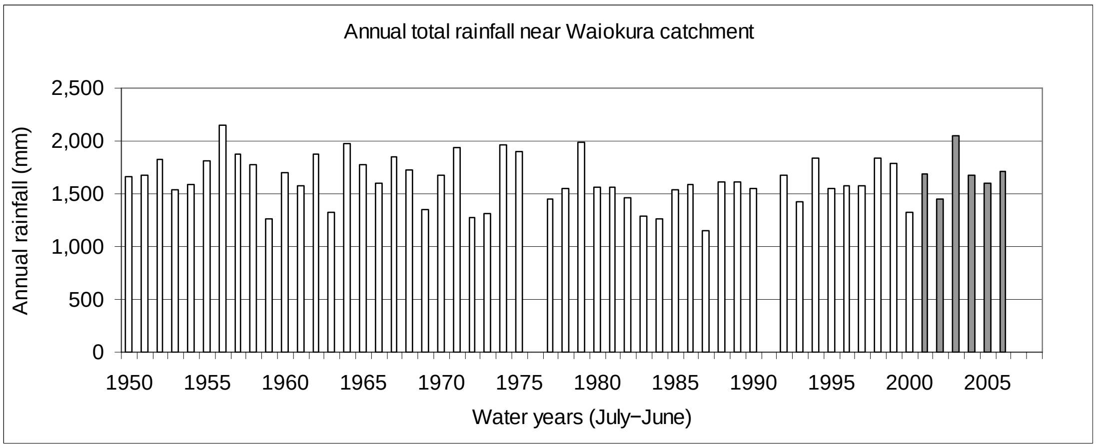
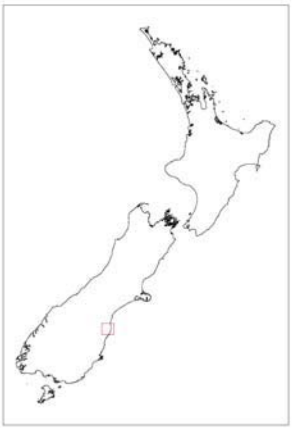
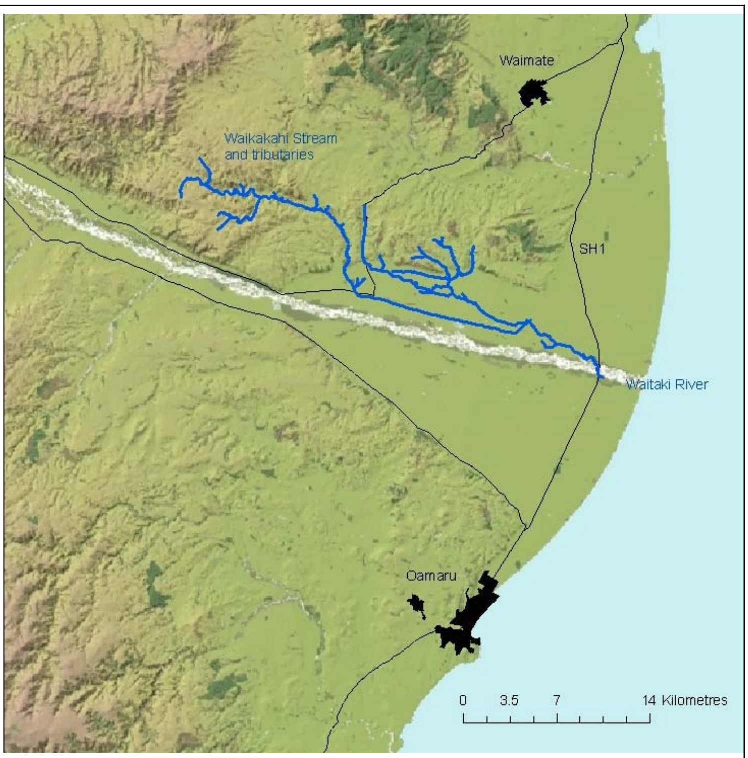


Figure A1-C: Waikakahi catchment (Tier 1), South Canterbury





Location (most downstream sample point)	E 2359600 N 5586150
River environment classification	**C**ool **D**ry, **L**ow elevation, **A**lluvium, **P**astoral Stream order = 5
Rainfall From NIWA CliFlow database (station ID = Waimate 5102)	**604 mm** Average annual total (1951–2007: white bars in graph) **435 mm** Average 2001–2006 (water-quality monitoring period: grey bars in graph)

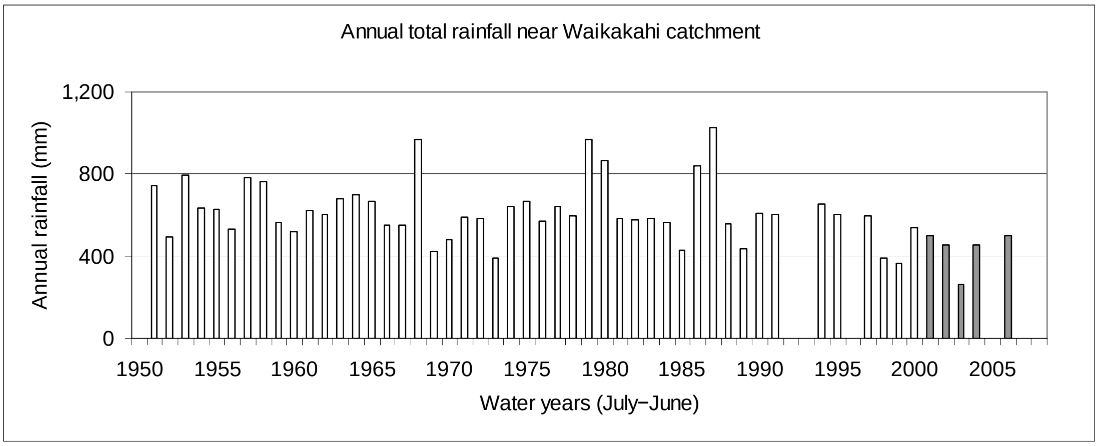
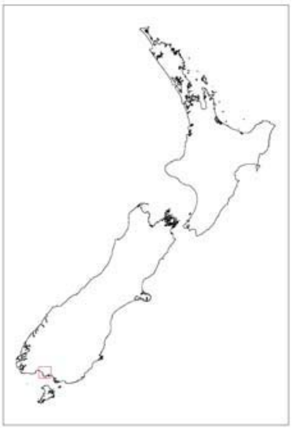
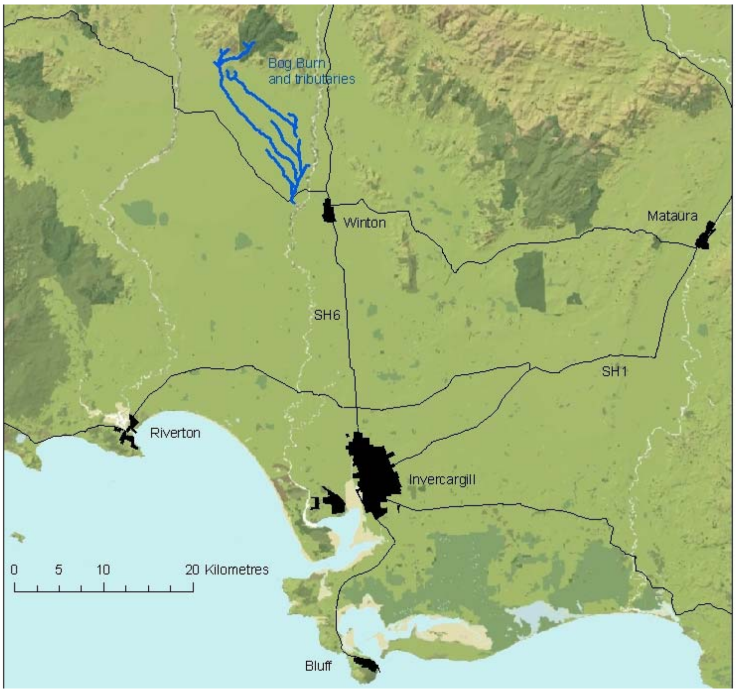


Figure A1-D: Bog Burn catchment (Tier 1), Southland





Location (most downstream sample point)	E 2144580 N 5442570
River environment classification	**C**ool **D**ry, **L**ow elevation, **A**lluvium, **P**astoral Stream order = 5
Rainfall From NIWA CliFlow database (station ID = Nightcaps 5513)	**992 mm** Average annual total (1971–2007: whites bars in graph) **1,077 mm** Average 2001–2006 (water-quality monitoring period: grey bars in graph)

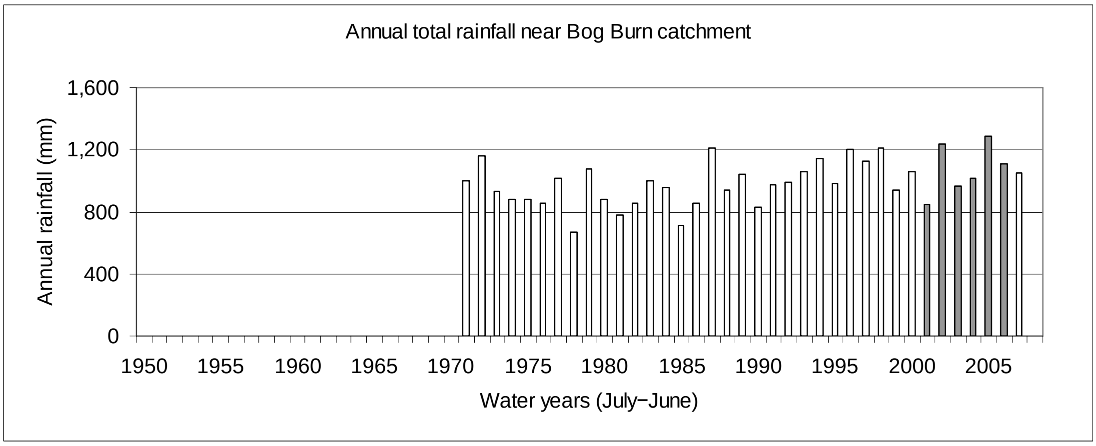
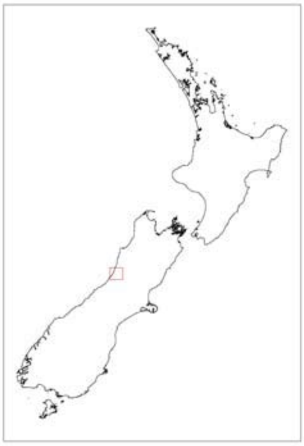
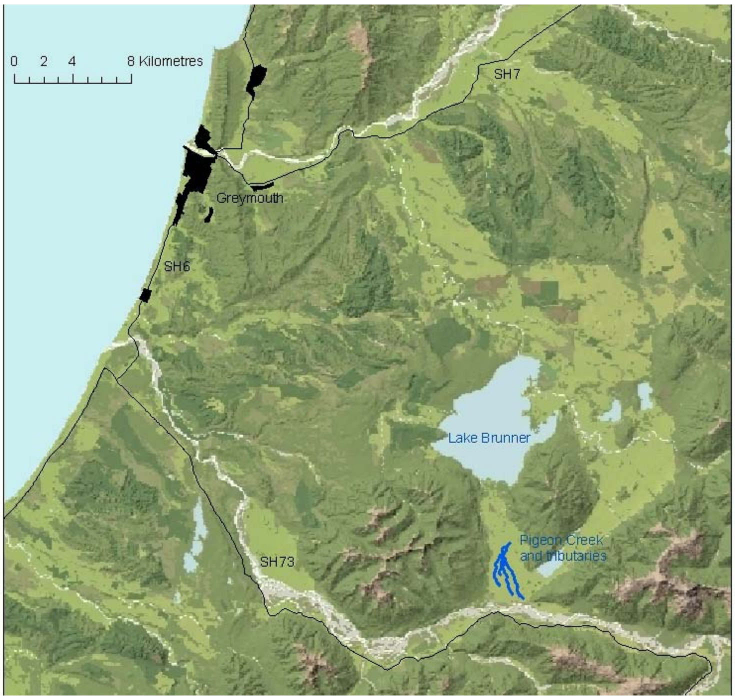


Figure A1-E: Inchbonnie Stream catchment (Tier 1), Westland

<table>
<tr><td></td><td>
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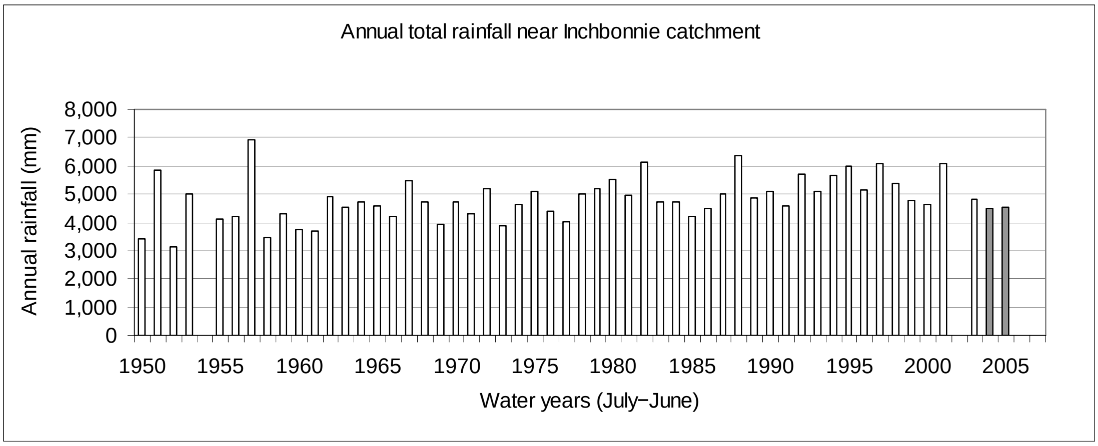
<tr><td>Location
(most downstream sample point)</td><td>E 2383642
N 5835264</td></tr>
<tr><td>River environment classification</td><td>Cool eXtremely wet, Hill, Volcanic, Pastoral
Stream order = 3</td></tr>
<tr><td>Rainfall
From NIWA CliFlow database (station ID = Inchbonnie 3975)</td><td>4,825 mm Average annual total (1950–2007: white bars in graph)
4,526 mm Average 2004–2006 (water-quality monitoring period: grey bars in graph)</td></tr>
<tr><td colspan="2">
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Figure A1-F: Puwera Stream catchment (Tier 2), Northland

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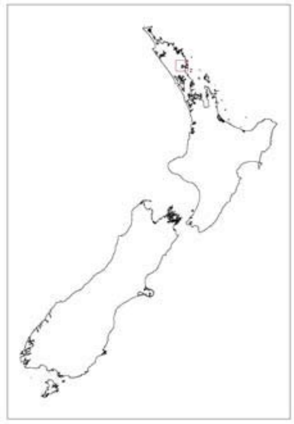
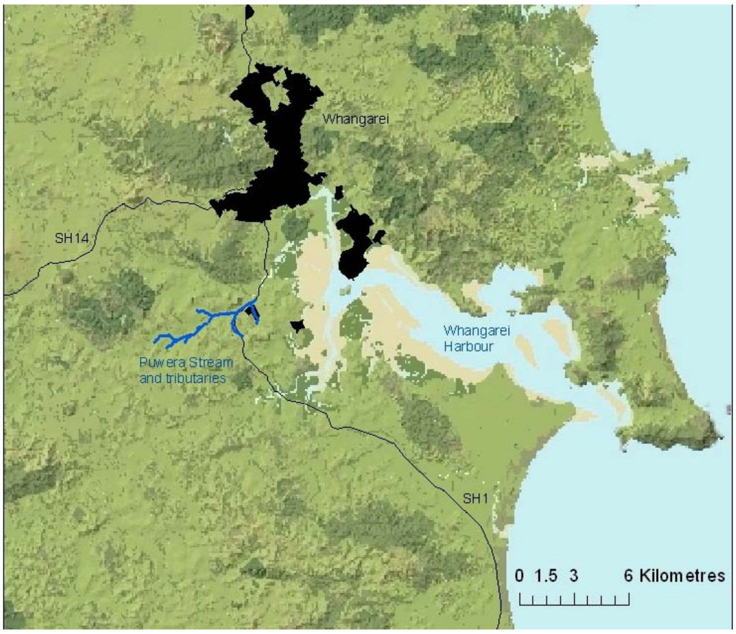
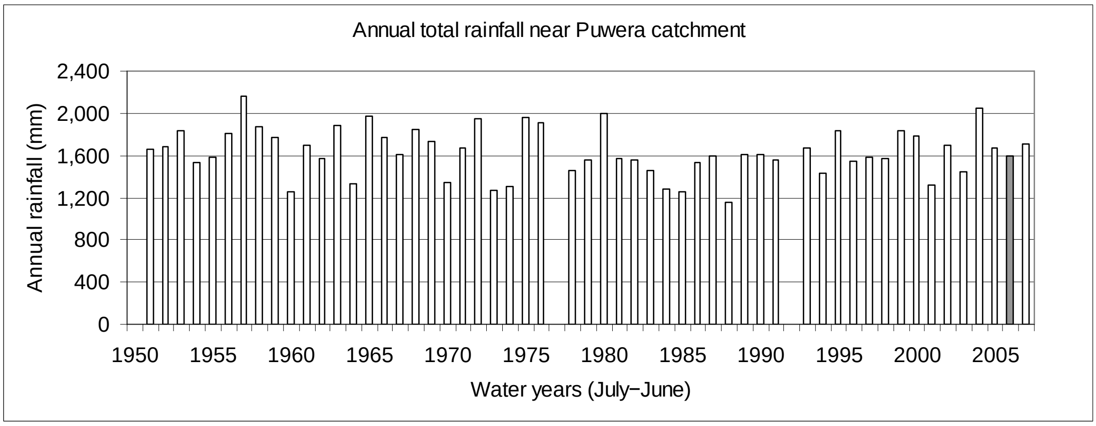
<tr><td></td><td>
</td></tr>
<tr><td>Location
(most downstream sample point)</td><td>E 2626468
N 6599896</td></tr>
<tr><td>River environment classification</td><td>Warm Wet, Low elevation, Hard Sedimentary, Pastoral
Stream order = 3</td></tr>
<tr><td>Rainfall
From NIWA CliFlow database
(station ID = Riverlea 3535)</td><td>1,634 mm Average annual total (1950–2007: white bars in graph)
1,596 mm Total 2006–2007 (water-quality monitoring period: grey bar in graph)</td></tr>
<tr><td colspan="2">
</td></tr>
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Figure A1-G: Taharua River catchment (Tier 2), Hawke's Bay

Location (most downstream sample point)	E 2795595 N 6230876
River environment classification	**C**ool **W**et, **H**ill, **V**olcanic, **P**astoral Stream order = 5
Rainfall From NIWA CliFlow database (station ID = Ripia 2937)	**1,190 mm** Average annual total (1965–2007: white bars in graph) **1,359 mm** Average 2000–2007 (water-quality monitoring period: grey bars in graph)

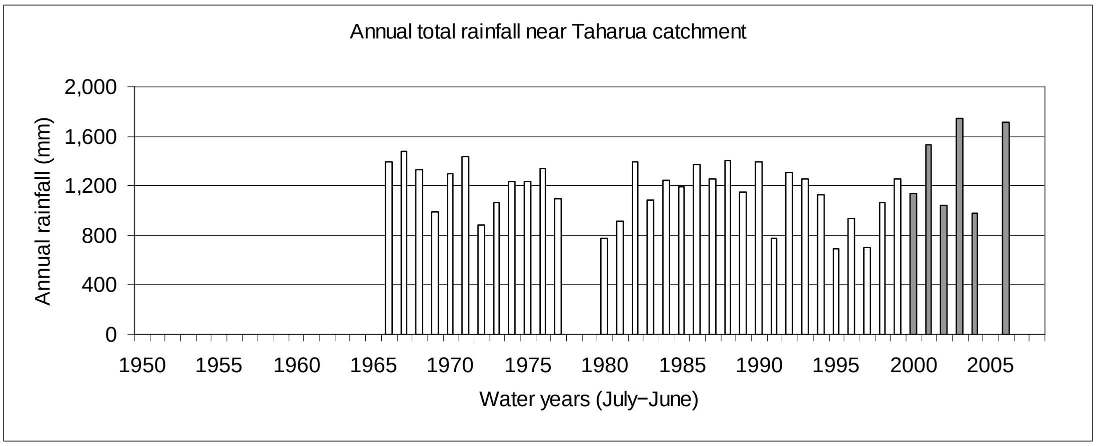
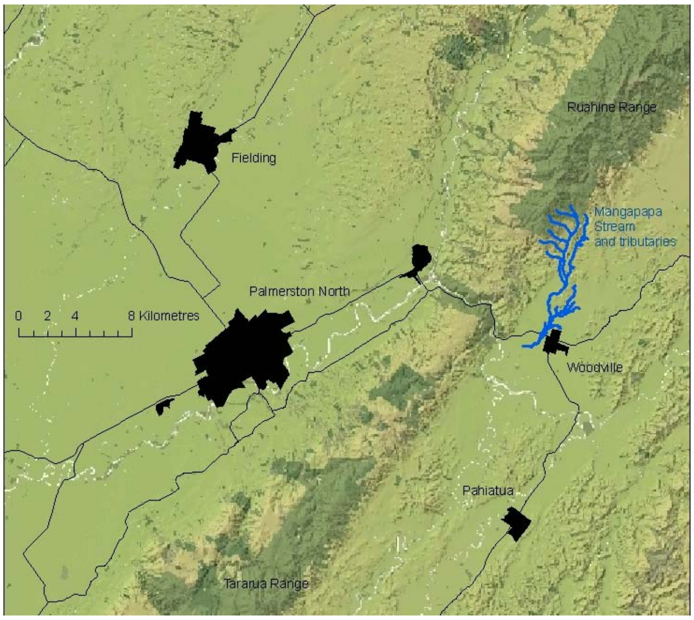


Figure A1-H: Mangapapa catchment (Tier 2), Manawatu

	
Location (most downstream sample point)	E 2751955 N 6092185
River environment classification	**C**ool **Wet**, **L**ow elevation, **M**iscellaneous, **P**astoral Stream order = 4
Rainfall From NIWA CliFlow database (station ID = Waipuna/Woodville 2373)	**1,282 mm** Average annual total (1950–2007: white bars in graph) **1,309 mm** Total 2006–2007 (water-quality monitoring period: grey bar in graph)

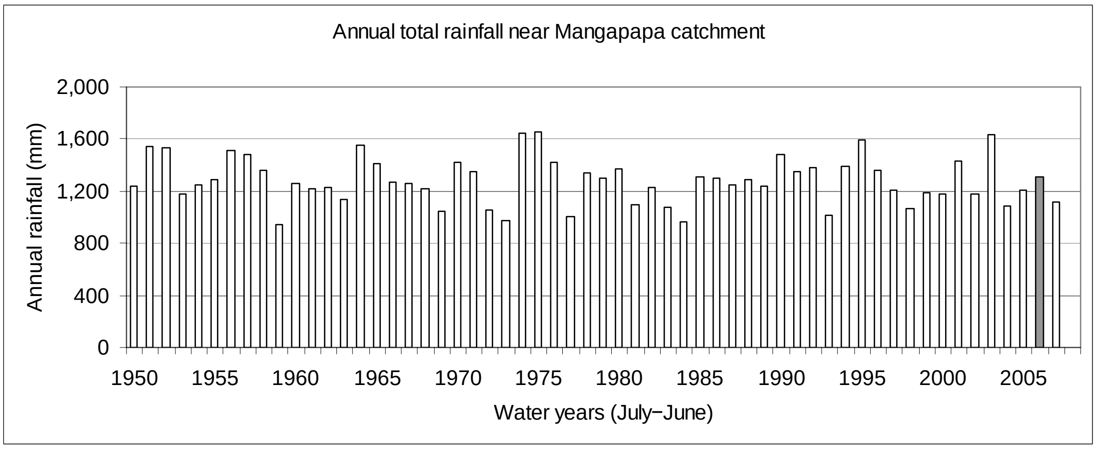
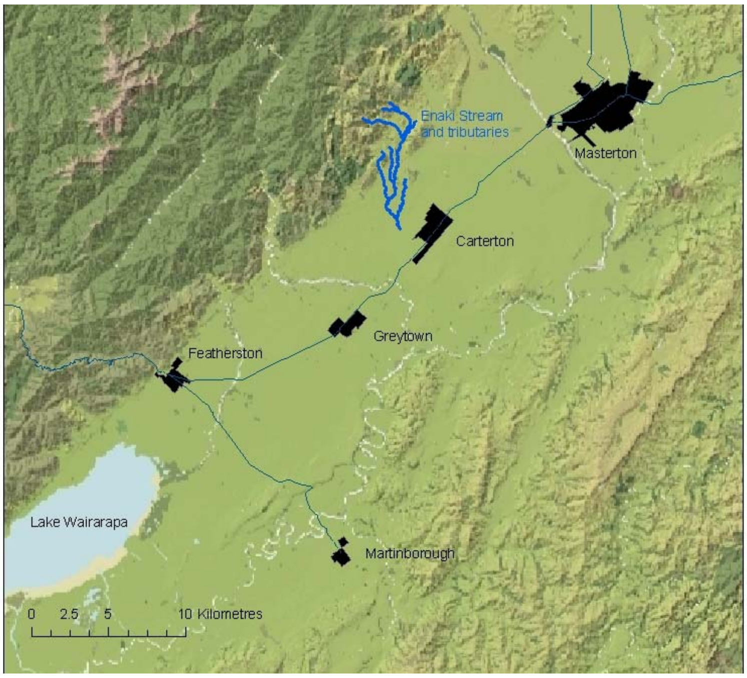


Figure A1-I: Enaki catchment (Tier 2), Greater Wellington

	
Location (most downstream sample point)	E 2719913 N 6017255
River environment classification	**C**ool **Wet**, **L**ow elevation, **H**ard **S**edimentary, **P**astoral Stream order = 3
Rainfall From NIWA CliFlow database (station ID = The Downs 2631)	**890 mm** Average annual total (1950–2007: white bars in graph) **948 mm** Average 2002–2006 (water-quality monitoring period: grey bars in graph)

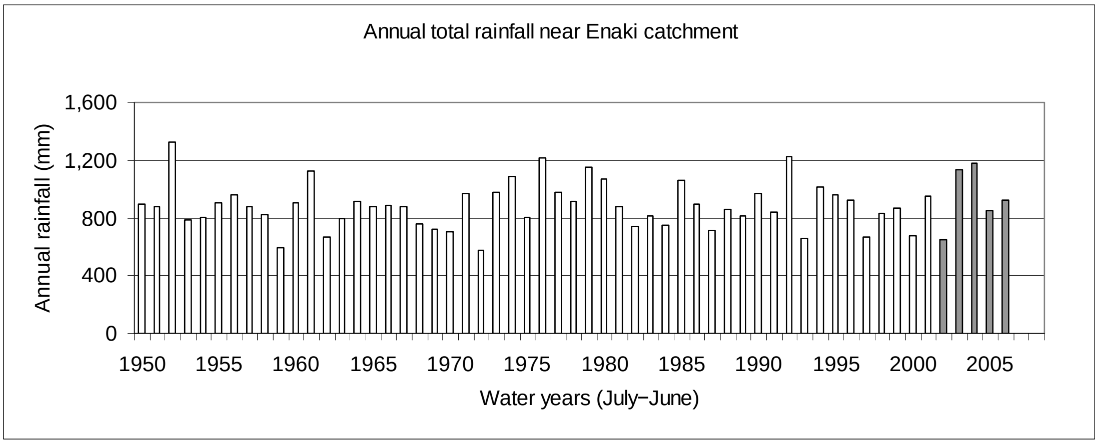
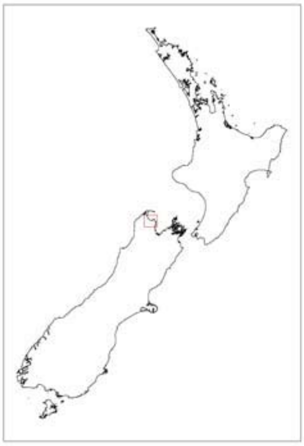
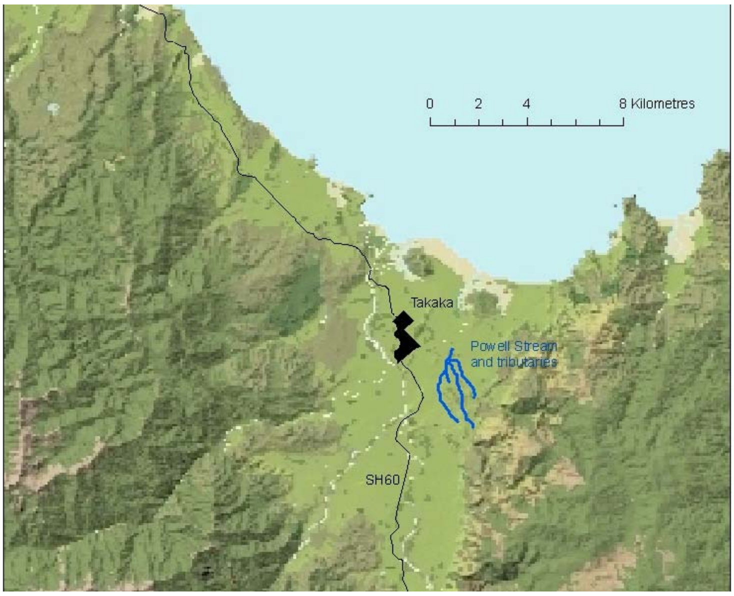


Figure A1-J: Powell Creek catchment (Tier 2), Tasman

	
Location (most downstream sample point)	E 2495805 N 6038900
River environment classification	**W**arm **W**et, **L**ow elevation, **S**oft **S**edimentary, **P**astoral Stream order = 3
Rainfall From NIWA CliFlow database (station ID = Takaka [Kotinga Road 3788 and Pohara 3790 combined])	**1,764 mm** Average annual total (1970–2007: white bars in graph) **1,540 mm** Total 2006–2007 (water-quality monitoring period: grey bars in graph)

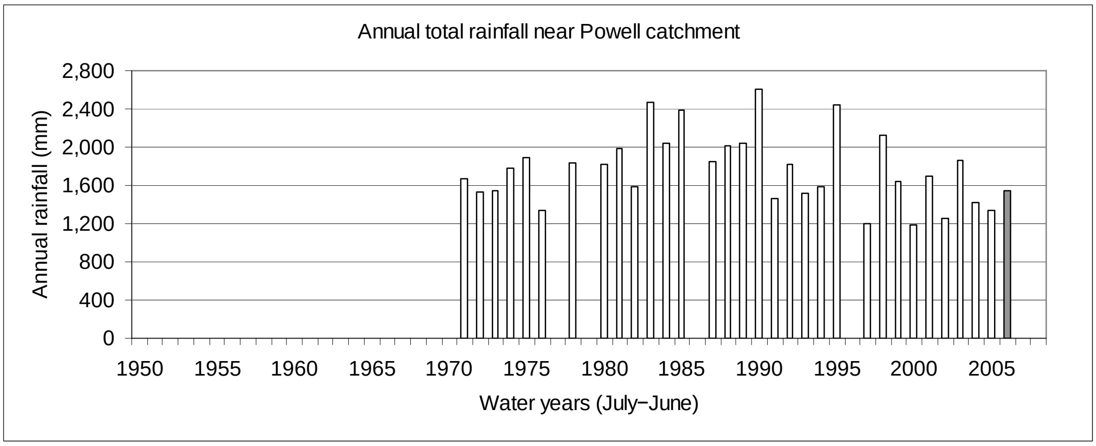
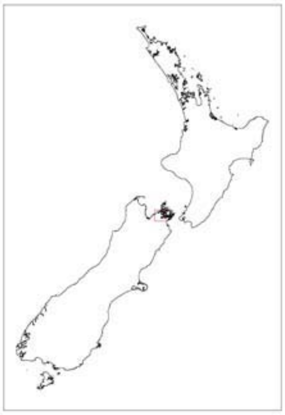
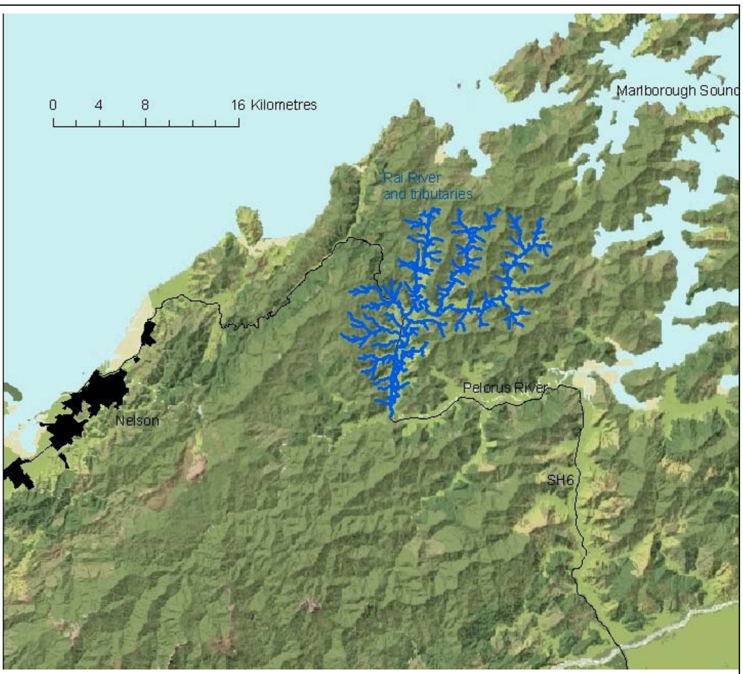


Figure A1-K: Rai catchment (Tier 2), Marlborough

	
Location (most downstream sample point)	E 2557969 N 5990971
River environment classification	**C**ool e**X**tremely Wet, **L**ow elevation, **H**ard **S**edimentary, **I**ndigenous **F**orest Stream order = 5
Rainfall From NIWA CliFlow database (station ID = Twin Falls 4283)	**1,880 mm** Average annual total (1991–2007: white bars in graph) **1,567 mm** Total for 2006–2007 (water quality monitoring period: grey bar in graph)

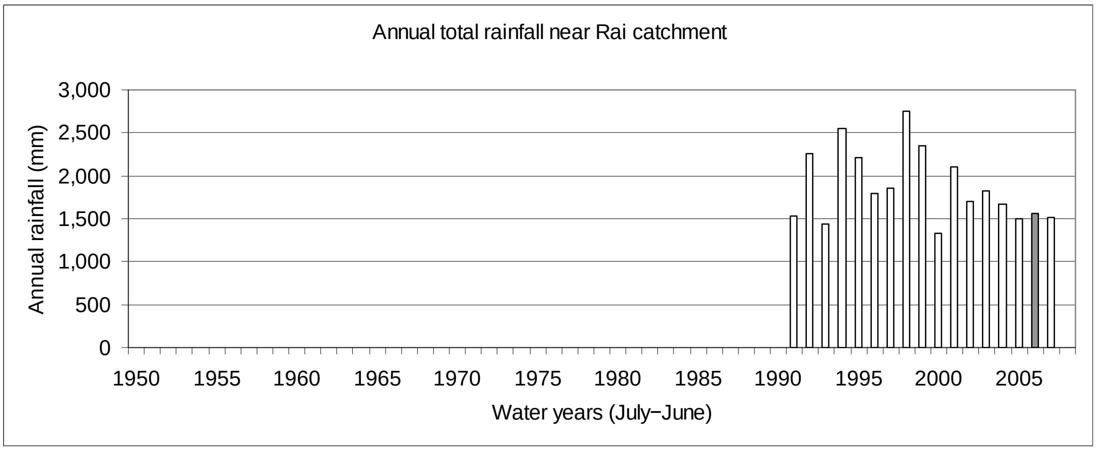
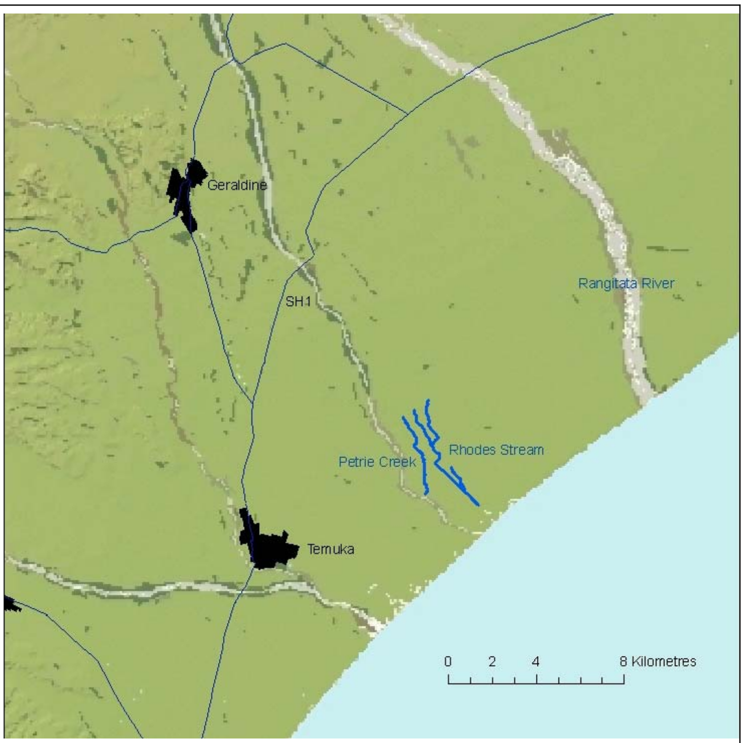


Figure A1-L: Rhodes and Petrie catchment (Tier 2), Canterbury



Location (most downstream sample point)	E 2382954 N 5662643
River environment classification	**C**ool **D**ry, **L**ow elevation, **A**lluvium, **P**astoral Stream order = 2
Rainfall From NIWA CliFlow database (station ID = Orari Estate 5061)	**717 mm** Average annual total (1950–2007: white bars in graph) **534 mm** Total 2006–2007 (water-quality monitoring period: grey bar in graph)

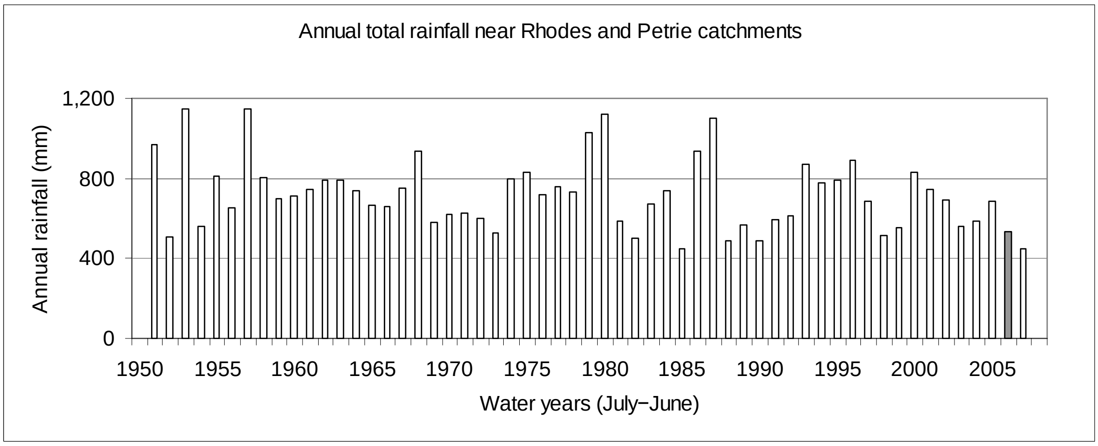
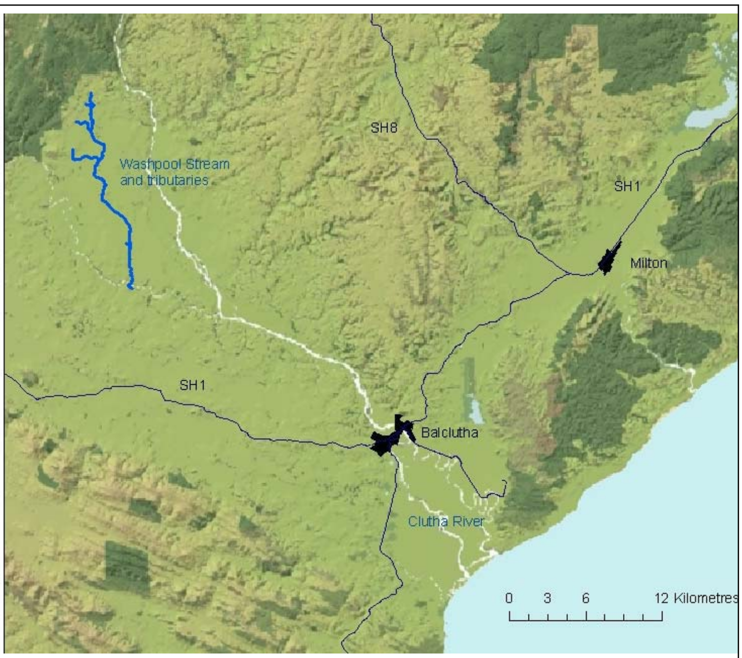
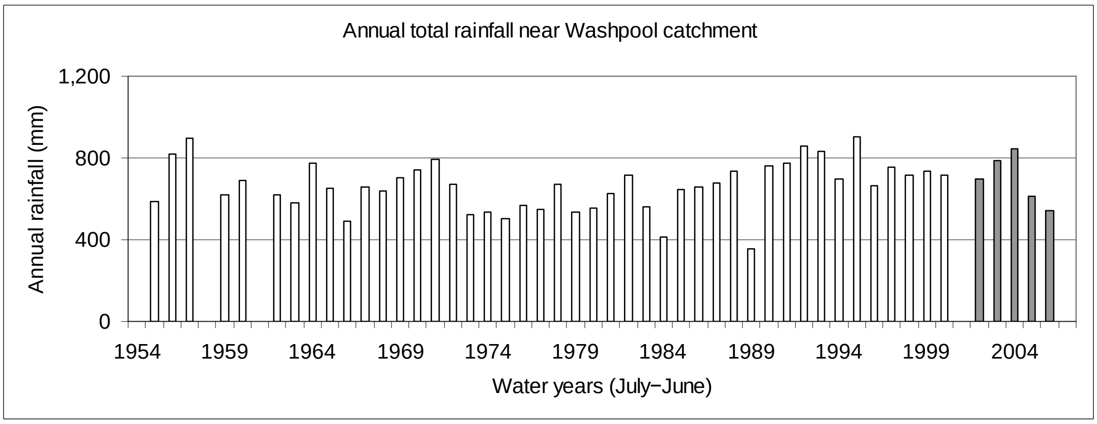


Figure A1-M: Washpool catchment (Tier 2), Otago



Location (most downstream sample point)	E 2237524 N 5448092
River environment classification	**C**ool **D**ry, **L**owland, **S**oft **S**edimentary, **P**astoral Stream order = 3
Rainfall From NIWA CliFlow database (station ID = Baverstock 5849)	**666 mm** Average annual total (1954–2007: white bars in graph) **697 mm** Average 2002–2006 (water-quality monitoring period: grey bars in graph)



Appendix 2: Water-quality Summary Data

Tables in this appendix contain summary water-quality data for each of the monitored catchments discussed in the main report. This data is the basis for the graphics presented in the ‘Water-quality Baseline‘ section. The first table lists the monitoring sites from which the data is collected as well as the data sources (the latter are listed in full in the References section).

Table A2-A: Summary of catchment site details and data sources

Catchment name		Monitoring site ID (ie, name given by monitoring agency)		Data source
		Upstream	Downstream	
Tier 1 catchments	Toenepi	Kiwitahi Road	Tahuroa Road	Wilcock, Monaghan et al, 2007
	Waiokura	Eltham Road	Manaia Golf course	Wilcock, Monaghan et al, 2007
	Waikakahi	Cock and Hen Road	Te Maiharoa Road	Wilcock, Monaghan et al, 2007
	Bog Burn	Forest	Hundred Line Road	Wilcock, Monaghan et al, 2007
	Inchbonnie	Inchbonnie at Bridge	Gault’s farm	Wilcock, Monaghan et al, 2007
Tier 2 catchments	Puwera	108705	108706	Northland Regional Council, unpublished
	Taharua	Taharua at Wairango	Taharua at Poronui	Hawke’s Bay Regional Council, 2006
	Mangapapa	Mangapapa at Coppermine Road (MAN1)	Mangapapa at Troupe Road (MAN7)	Horizons Regional Council, 2007
	Enaki	None	Unnamed	Greater Wellington Regional Council, 2008
	Powell Creek	Powell Creek at Glenview Road	Powell Creek at upstream McConnon Creek	Tasman District Council, 2008
	Rhodes and Petrie	Rhodes Stream at Rolleston Road Petrie Stream at Canal Road	Rhodes Stream at Parke Road Petrie Stream at Orari confluence	Environment Canterbury, 2007
	Washpool	Upper Washpool (Site 14)	Upper Washpool (Site 1)	Otago Regional Council, unpublished
	Rai River	Ronga River (Site RON3) – an upstream tributary of the Rai River	Rai River (Site RAR1)	Marlborough District Council, 2008

Table A2-B: *E. coli*

		Tier 1 catchments					**Tier 2 catchments**								
		Toenepi Waikato	**Waiokura Taranaki**	**Waikakahi Canterbury**	**Bog Burn Southland**	**Inchbonnie West Coast**	**Puwera Northland**	**Taharua Hawke's Bay**	**Mangapapa Manawatu**	**Enaki Wairarapa**	**Powell Tasman**	**Rai Marlborough**	**Canterbury**		**Washpool Otago**
													Rhodes	**Petrie**	
Sample period		2001–2006	2001–2006	2001–2006	2001–2006	2004–2006	2006–2007	2000–2008	2006–2007	2002–2006	2006–2007	2006–2007	2006–2007	2006–2007	2002–2006
Sample number		58	~74	95	77	43	26	~41	12	57	12	12	12	12	35 u/s 7 d/s
Downstream site	Minimum	40	70	4	270	20	54	0	40	20	2	23	29	66	48
	Maximum	46,000	54,800	21,800	11,000	24,300	2,098	190	51,700	31,333	4,100	1,600	17,000	2,400	11,000
	Median	367	1,250	290	530	640	422	7	330	190	336	186*	140	205	580
Upstream site	Minimum		40	13	1	24	10	0			64	15	7	32	290
	Maximum		8,664	20,000	420	24,200	1,986	590			1,800	3,100	2,400	920	2,800
	Median		466	1,220	20	516	393	9	23**		820	462*	425	107	760
Guideline values		260 *E. coli* per 100 mL = Alert threshold 550 *E. coli* per 100 mL = Action threshold *Microbiological Guidelines for Recreational Water Quality* (Ministry for the Environment and Ministry of Health, 2003)													
Reference site values		50 *E. coli* per 100 mL (based on median of 42 for predominantly natural catchment sites across New Zealand; 1996–2002 data set) 200 *E. coli* per 100 mL (based on median of 200 for predominantly natural catchment sites across New Zealand; 1996–2002 data set)													

Source: Wilcock, Monaghan et al, 2007 for Tier 1 catchment results and regional council monitoring reports for Tier 2 catchment results.

Notes:

All units are counts per 100 mL of water sampled.

* Average (not median).

** Average from only two samples (5 MPN per 100 mL and 40 MPN per 100 mL).

Table A2-C: Total nitrogen

		Tier 1 catchments					Tier 2 catchments								
		Toenepi Waikato	**Waiokura Taranaki**	**Waikakahi Canterbury**	**Bog Burn Southland**	**Inchbonnie West Coast**	**Puwera Northland**	**Taharua Hawke's Bay**	**Mangapapa Manawatu**	**Enaki Wairarapa**	**Powell Tasman**	**Rai Marlborough**	**Canterbury**		**Washpool Otago**
													Rhodes	**Petrie**	
Sample period		2001–2006	2001–2006	2001–2006	2001–2006	2004–2006	2006–2007	2005–2008	2006–2007	2002–2006	2006–2007	2006–2007	2006–2007	2006–2007	2002–2003
Sample number		58	~74	95	77	43	26	~68	12	57	12	12	12	12	14
Downstream site	Minimum	0.41	2.05	1.16	0.26	0.30	0.41	0.72	0.18	0.3	0.45	0.39	8.2	4	0.87
	Maximum	5.80	4.50	5.20	4.30	2.70	1.65	3.07	2.01	3.1	3.1	1	13	6	4.03
	Median	1.76	3.29	2.30	1.10	0.71	0.85	1.35	1.42	1.70	1.2	0.69*	9.6	5	2.44
Upstream site	Minimum		1.94	0.88	0.160	1.93	0.49	1.59			1.1	0.06	6.2	4.5	
	Maximum		4.60	4.60	0.820	5.91	34.0	3.28			3.2	0.24	11	6.8	
	Median		2.67	2.09	0.388	0.572	1.18	2.67			1.5	0.14*	7.3	5.6	
Guideline		0.614 mg/L (ANZECC trigger value for ecosystem protection in lowland rivers)													

Source: Wilcock, Monaghan et al, 2007 for Tier 1 catchment results and regional council monitoring reports for Tier 2 catchment results.

Notes:

All units are mg/L unless otherwise stated.

* Averages (not medians).

Table A2-D: Nitrate–nitrite nitrogen

		Tier 1 catchments					**Tier 2 catchments**								
		Toenepi Waikato	**Waiokura Taranaki**	**Waikakahi Canterbury**	**Bog Burn Southland**	**Inchbonnie West Coast**	**Puwera Northland**	**Taharua Hawke's Bay**	**Mangapapa Manawatu**	**Enaki Wairarapa**	**Powell Tasman**	**Rai Marlborough**	**Canterbury**		**Washpool Otago**
													Rhodes	**Petrie**	
Sample period		2001–2006	2001–2006	2001–2006	2001–2006	2004–2006	2006–2007	2000–2008	2006–2007	2002–2006	2006–2007	2006–2007	2006–2007	2006–2007	2002–2006
Sample number		58	~74	95	77	43	26	~68	12	56	12	12	12	12	26 u/s 7 d/s
Downstream site	Minimum	0.032	1.62	0.79	0.036	0.049	0.008	0.576	0.1	0.136	0.17	0.26	7.6	3.7	0.077
	Maximum	4.1	4.26	3.5	3.6	0.60	0.651	2.87	2.13	2.75	1.065	0.89	13.0	6.0	2.82
	Median	1.19	2.82	1.76	0.755	0.284	0.236	1.13	0.85	1.125	3.1	0.63*	9.35	4.6	0.734
Upstream site	Minimum		1.56	0.11	0.025	0.019	0.039	0.87			0.7	0.01	5.7	4.3	0.005
	Maximum		3.20	3.20	0.490	0.451	1.40	3.16			2.8	0.14	9.7	6.1	0.394
	Median		2.31	1.62	0.120	0.198	0.383	2.53	0.13**		1.35	0.05*	7.3	5.3	0.059
Guideline value		0.444 mg/L (ANZECC trigger value for ecosystem protection in lowland rivers)													
Reference site values		0.081 mg/L (median for predominantly **natural** catchment sites across New Zealand; 1996–2002 data set) 0.55 mg/L (median for **lowland predominantly pastoral** catchment sites across New Zealand; 1996–2002 data set) (reported in Scarsbrook, 2008)													

Source: Wilcock, Monaghan et al, 2007 for Tier 1 catchment results and regional council monitoring reports for Tier 2 catchment results.

Notes:

All units are mg/L unless otherwise stated.

* Averages (not medians).

** Average from only two samples (0.1 mg/L and 0.15 mg/L).

Table A2-E: Soluble inorganic nitrogen (SIN)

		Tier 1 catchments					**Tier 2 catchments**								
		Toenepi Waikato	**Waiokura Taranaki**	**Waikakahi Canterbury**	**Bog Burn Southland**	**Inchbonnie West Coast**	**Puwera Northland**	**Taharua Hawke's Bay**	**Mangapapa Manawatu**	**Enaki Wairarapa**	**Powell Tasman**	**Rai Marlborough**	**Canterbury**		**Washpool Otago**
													Rhodes	**Petrie**	
Sample period		2001–2006	2001–2006	2001–2006	2001–2006	2004–2006	2006–2007	2000–2008	2006–2007	2002–2006	2006–2007	2006–2007	2006–2007	2006–2007	2002–2006
Sample number		58	~74	95	77	43	26	~68	12	56	12	12	12	12	~25 u/s 7 d/s
Downstream site	Minimum	0.041	1.621	0.791	0.037	0.064	0.018	0.582	0.13	0.139	0.175	0.260	7.624	3.738	0.097
	Maximum	6.990	4.419	3.815	3.730	1.169	1.031	2.88	2.16	2.820	3.21	0.890	13.010	6.019	3.780
	Median	2.212	2.846	1.782	0.775	0.388	0.276	1.135	0.860	1.135	1.098	0.630	9.374	4.627	0.824*
Upstream site	Minimum	SIN not derived for upstream sites													
	Maximum														
	Median														
Guideline value		< 0.295 mg/L (NZ Periphyton Guideline (Biggs, 2000)) for 20-day accrual period													

Source: Wilcock, Monaghan et al, 2007 for Tier 1 catchment results and regional council monitoring reports for Tier 2 catchment results. Data has been derived (as NOx-N + NH4) for some catchments and is actual reported SIN values for others.

Notes:

All units are mg/L unless otherwise stated.

* Averages/means (not medians).

** Average from only two samples (0.11 mg/L and 0.16 mg/L).

Table A2-F: Total phosphorus

		Tier 1 catchments					Tier 2 catchments								
		Toenepi Waikato	**Waiokura Taranaki**	**Waikakahi Canterbury**	**Bog Burn Southland**	**Inchbonnie West Coast**	**Puwera Northland**	**Taharua Hawke's Bay**	**Mangapapa Manawatu**	**Enaki Wairarapa**	**Powell Tasman**	**Rai Marlborough**	**Canterbury**		**Washpool Otago**
													Rhodes	**Petrie**	
Sample period		2001–2006	2001–2006	2001–2006	2001–2006	2004–2006	2006–2007	2000–2008	2006–2007	2002–2006	2006–2007	2006–2007	2006–2007	2006–2007	2002–2006
Sample number		58	~74	95	77	43	26	~68	12	58	12	12	12	12	24 u/s 5 d/s
Downstream site	Minimum	0.068	0.064	0.031	0.024	0.033	0.038	0.002	0.011	0.014	0.011	0.002	0.008	0.018	0.114
	Maximum	0.251	0.392	0.699	0.22	0.251	0.251	0.092	0.289	0.23	0.053	0.022	0.029	0.045	0.690
	Median	0.174	0.111	0.120	0.05	0.102	0.108	0.02	0.025	0.041	0.034	0.022*	0.019	0.025	0.281
Upstream site	Minimum		0.870	0.029	0.021	0.018	0.076	0.006			0.01	0.006	0.009	0.004	0.046
	Maximum		0.081	0.870	0.089	0.442	10.1	0.125			0.033	0.021	13.0	0.028	0.082
	Median		0.129	0.160	0.037	0.057	0.22	0.022	0.0095**		0.017	0.014*	0.029	0.013	0.061
Guideline value		0.033 mg/L (ANZECC trigger value for ecosystem protection in lowland rivers)													

Source: Wilcock, Monaghan et al, 2007 for Tier 1 catchment results and regional council monitoring reports for Tier 2 catchment results.

Notes:

All units are mg/L unless otherwise stated.

* Averages (not medians).

** Average from only two samples (0.01 mg/L and 0.009 mg/L).

Table A2-G: Dissolved reactive phosphorus

		Tier 1 catchments					Tier 2 catchments								
		Toenepi Waikato	**Waiokura Taranaki**	**Waikakahi Canterbury**	**Bog Burn Southland**	**Inchbonnie West Coast**	**Puwera Northland**	**Taharua Hawke's Bay**	**Mangapapa Manawatu**	**Enaki Wairarapa**	**Powell Tasman**	**Rai Marlborough**	**Canterbury**		**Washpool Otago**
													Rhodes	**Petrie**	
Sample period		2001–2006	2001–2006	2001–2006	2001–2006	2004–2006	2006–2007	2000–2008	2006–2007	2002–2006	2006–2007	2006–2007	2006–2007	2006–2007	2002–2006
Sample number		58	~74	95	77	43	26	~68	12	57	12	12	12	12	11
Downstream site	Minimum	0.010	0.016	0.001	0.010	0.016	0.007	0.002	0.007	0.005	0.002	0.008	0.001	0.003	0.011
	Maximum	0.177	0.107	0.560	0.130	0.336	0.149	0.033	0.027	0.054	0.016	0.015	0.019	0.027	0.245
	Median	0.089	0.032	0.075	0.023	0.059	0.048	0.011	0.017	0.026	0.007	0.011*	0.008	0.015	0.037
Upstream site	Minimum		0.033	0.002	0.003	0.011	0.025	0.002			0.002	0.009	0.001	0.002	
	Maximum		0.318	0.670	0.054	0.261	5.12	0.093			0.006	0.014	0.029	0.019	
	Median		0.071	0.098	0.022	0.039	0.102	0.018	0.005**		0.003	0.01*	0.013	0.008	
Guideline value		0.01 mg/L (ANZECC trigger value for ecosystem protection in lowland rivers) < 0.026 mg/L (NZ Periphyton Guidelines (Biggs, 2000)) for 20-day accrual period													
Reference site value		0.008 mg/L (median for predominantly **natural** catchment sites across New Zealand; 1996–2002 data set) 0.016 mg/L (median for **lowland predominantly pastoral** catchment sites across New Zealand; 1996–2002 data set) (reported in Scarsbrook, 2008)													

Source: Wilcock, Monaghan et al, 2007 for Tier 1 catchment results and regional council monitoring reports for Tier 2 catchment results.

Notes:

All units are mg/L unless otherwise stated.

* Averages (not medians).

** Average from only two samples (0.008 mg/L and 0.0025 mg/L).

Table A2-H: Ammoniacal nitrogen

		Tier 1 catchments					Tier 2 catchments								
		Toenepi Waikato	**Waiokura Taranaki**	**Waikakahi Canterbury**	**Bog Burn Southland**	**Inchbonnie West Coast**	**Puwera Northland**	**Taharua Hawke's Bay**	**Mangapapa Manawatu**	**Enaki Wairarapa**	**Powell Tasman**	**Rai Marlborough**	**Canterbury**		**Washpool Otago**
													Rhodes	**Petrie**	
Sample period		2001–2006	2001–2006	2001–2006	2001–2006	2004–2006	2006–2007	2000–2008	2006–2007	2002–2006	2006–2007	2006–2007	2006–2007	2006–2007	2002–2006
Sample number		58	~74	95	77	43	26	~66	12	58	12	12	12	12	23 u/s 7 d/s
Downstream site	Minimum	0.009	0.001	0.001	0.001	0.015	0.010	0.002	0.0025	0.003	0.005	< 0.01	0.003	0.003	0.02
	Maximum	2.800	0.159	0.315	0.13	0.498	0.380	0.01	0.07	0.07	0.11	0.01	0.03	0.041	0.96
	Median	0.022	0.026	0.022	0.02	0.104	0.040	0.005	0.01	0.01	0.033	< 0.01 *	0.019	0.021	0.09*
Upstream site	Minimum		0.011	0.005	0.001	0.001		0.005			0.011	< 0.01	0.006	0.003	0.01
	Maximum		0.756	1.20	0.018	0.841		0.043			0.11	< 0.01	0.058	0.023	0.02
	Median		0.066	0.082	0.012	0.136		0.01	0.005		0.022	< 0.01 *	0.022	0.015	0.02*
Guideline value		0.4–0.9 mg/L (based on range of water temperature and pH data and the ANZECC toxicant trigger values for 95 per cent ecosystem protection)													
Reference site value		0.008 mg/L (median for **predominantly natural catchment** sites across New Zealand) (reported in Scarsbrook, 2008)													

Source: Wilcock, Monaghan et al, 2007 for Tier 1 catchment results and regional council monitoring reports for Tier 2 catchment results.

Notes:

All units are mg/L unless otherwise stated.

* Averages or means (not medians).

Table A2-I: pH

		Tier 1 catchments					Tier 2 catchments								
		Toenepi Waikato	**Waiokura Taranaki**	**Waikakahi Canterbury**	**Bog Burn Southland**	**Inchbonnie West Coast**	**Puwera Northland**	**Taharua Hawke's Bay**	**Mangapapa Manawatu**	**Enaki Wellington**	**Powell Tasman**	**Rai Marlborough**	**Canterbury**		**Washpool Otago**
													Rhodes	**Petrie**	
Sample period		2001–2006	2001–2006	2001–2006	2001–2006		2006–2007	2000–2008	2006–2007	2002–2006	2006–2007	2006–2007	2006–2007	2006–2007	
Sample number		58	~74	95	77		26	~66	12	58	12	12	12	12	
Downstream site	Minimum		7.3	7.1	6.6		6.6	6.6	6.9	5.1	7.0		6.4	6.8	
	Maximum		7.9	8.9	9.0		7.4	7.6	7.9	8.6	7.8		7.2	8.0	
	Median		7.7	7.9	7.3		7.0	7.2	7.4	7.0	7.4		7.1	7.5	

Source: Wilcock, Monaghan et al, 2007 for Tier 1 catchment results and regional council monitoring reports for Tier 2 catchment results.

Table A2-J: Dissolved oxygen

Upper numbers (standard font) are % saturation measurements and lower numbers (in italics) are concentrations (mg/L)

		Tier 1 catchments					**Tier 2 catchments**								
		Toenepi Waikato	**Waiokura Taranaki**	**Waikakahi Canterbury**	**Bog Burn Southland**	**Inchbonnie West Coast**	**Puwera Northland**	**Taharua Hawke's Bay**	**Mangapapa Manawatu**	**Enaki Wairarapa**	**Powell Tasman**	**Rai Marlborough**	**Canterbury**		**Washpool Otago**
													Rhodes	**Petrie**	
Sample period		2001–2006	2001–2006	2001–2006	2001–2006	2004–2006	2006–2007	2000–2008	2006–2007	2002–2006	2006–2007	2006–2007	2006–2007	2006–2007	2002–2006
Sample number		58	~74	95	77	43	26	~68	12	54	12 *1,632**	12	12	12	22 u/s 7 d/s
Downstream site	Minimum	25.5	83.9	49.7	70.7	73.5	*3.1*	69.1	*8.40*	71.4 *5.8*	80 *0.25*	81.4 *8.21*	*7.24*	*8.24*	*5.4*
	Maximum	166	109	121	127	110	*10.7*	126.3	*17.38*	114 *12.39*	121 *12.44*	104 *12.06*	*12.41*	*11.59*	*14.8*
	Median	80.7	96.5	87.4	92.5	90.6	*7.8*	91.5	*11.05*	93 *9.6*	99 *5.35*		*9.3*	*10.62*	*11.2*
Upstream site	Minimum		85.3	58.2	74.8	78.8		57.6			83 *2*	81.2 *8.7*	*5.43*	*5.66*	*8.0*
	Maximum		104.9	113.5	104.8	100.3		111.5			120 *19.25*	100.1 *11.46*	*12.06*	*9.98*	*11.8*
	Median		95.3	88.5	87.7	95.0		74.65			97 *8.67*		*9.51*	*8.14*	*9.8*
Guideline value		> 80% saturation (RMA 1991, Schedule 3 – Water being managed for aquatic purposes)													

Source: Wilcock, Monaghan et al, 2007 for Tier 1 catchment results and regional council monitoring reports for Tier 2 catchment results.

Notes:

Units are % saturation for all values in standard font and mg/L for all values in italics.

* 15-minute interval data from 26 January 2006 to 12 February 2006.

Table A2-K: Water temperature

		Tier 1 catchments					**Tier 2 catchments**								
		Toenepi Waikato	**Waiokura Taranaki**	**Waikakahi Canterbury**	**Bog Burn Southland**	**Inchbonnie West Coast**	**Puwera Northland**	**Taharua Hawke's Bay**	**Mangapapa Manawatu**	**Enaki Wairarapa**	**Powell Tasman**	**Rai Marlborough**	**Canterbury**		**Washpool Otago**
													Rhodes	**Petrie**	
Sample period		2001–2006	2001–2006	2001–2006	2001–2006	2004–2006	2006–2007	2000–2008	2006–2007	2002–2006	2006–2007	2006–2007	2006–2007	2006–2007	2002–2006
Sample number		58	~74	95	77	43	26	~69	12	56	4,368*	12			25 u/s 6 d/s
Downstream site	Minimum	8.5	5.6	4.1	3.3	2.4	8.8	6.5	7.1	6.18	12.94	10.2	7.4	8.3	2.2
	Maximum	22.5	17.8	18.5	19.2	22.2	19.8	15	21.2	25.7	24.94	18.7	17.2	18.1	23.3
	Median	16.0	12.6	10.9	9.8	10.9	14.8	10.4	13.01	13.8	18.46		12.5	13.4	9.5
Upstream site	Minimum		6.8	4.7	3.3	2.1	8.9	9.5			11.05	8.0	7.9	8.3	7.4
	Maximum		14.2	19.1	12.4	20.8	15.0	14			26.35	16.9	18.7	14.6	21.0
	Median		11.2	11.2	8.0	9.8	20.6	11			18.2		12.35	12	11.52

Source: Wilcock, Monaghan et al, 2007 for Tier 1 catchment results and regional council monitoring reports for Tier 2 catchment results.

Notes:

All units are degrees Celsius.

* 30-minute data from 10 December 2006 to 10 March 2007.

Table A2-L: Electrical conductivity

		Tier 1 catchments					**Tier 2 catchments**								
		Toenepi Waikato	**Waiokura Taranaki**	**Waikakahi Canterbury**	**Bog Burn Southland**	**Inchbonnie West Coast**	**Puwera Northland**	**Taharua Hawke's Bay**	**Mangapapa Manawatu**	**Enaki Wairarapa**	**Powell Tasman**	**Rai Marlborough**	**Canterbury**		**Washpool Otago**
													Rhodes	**Petrie**	
Sample period		2001–2006	2001–2006	2001–2006	2001–2006	2004–2006	2006–2007	2000–2008	2006–2007	2002–2006	2006–2007	2006–2007	2006–2007	2006–2007	
Sample number		58	~74	95	77	43	26	~69	12	55	12	12			
Downstream site	Minimum	119	233	132	103	37	111	51	105	73	104	64	250	210	
	Maximum	387	311	338	215	81	500	94.4	1,418	188	137	81	330	280	
	Median	188	271	190	161	71	284	73.1	143.5	115	119	66*	280	230	
Upstream site	Minimum		171	147	70	34.9		76.6			95	56	200	200	
	Maximum		226	330	98	82.0		109.6			131	106	270	260	
	Median		206	244	87	69.6		94.5	57.5		109	77*	225	215	

Source: Wilcock, Monaghan et al, 2007 for Tier 1 catchment results and regional council monitoring reports for Tier catchment results.

Notes:

All units are microS/cm.

* Averages (not medians).

Table A2-M: Suspended sediments

		Tier 1 catchments					Tier 2 catchments								
		Toenepi Waikato	**Waiokura Taranaki**	**Waikakahi Canterbury**	**Bog Burn Southland**	**Inchbonnie West Coast**	**Puwera Northland**	**Taharua Hawke's Bay**	**Mangapapa Manawatu**	**Enaki Wairarapa**	**Powell Tasman**	**Rai Marlborough**	**Canterbury**		**Washpool Otago**
													Rhodes	**Petrie**	
Sample period		2001–2006	2001–2006	2001–2006	2001–2006	2004–2006	2006–2007	2000–2008	2006–2007	2002–2006	2006–2007	2006–2007	2006–2007	2006–2007	2003
Sample number		58	~74	95	77	43	~26	~68	12	58	12	12	12	12	17
Downstream site	Minimum	0.3	6.0	1.4	1.5	0.3	1	1.5	1.5	1.5	1.0	< 3	1.1	2.5	5.0
	Maximum	120	98.0	175.0	36.0	110	71	293	17	155	6.8	80	5.8	12.0	26.0
	Median	3.0	20.5	7.2	4.2	4.6	4	5	4	1.5	2.0		2.6	4.75	11.0
Upstream site	Minimum		15.0	2.2	4.4	0.3	1	0.5			1.0	< 3	1.0	0.25	
	Maximum		160	160	36	95	105	72			6.0	6	4.9	3.7	
	Median		21.0	24.8	7.4	2.0	3	1.5	1.5*		2.0		1.4	0.95	

Source: Wilcock, Monaghan et al, 2007 for Tier 1 catchment results and regional council monitoring reports for Tier 2 catchment results.

Notes:

All units are mg/L.

* Average from only two samples (both 1.5 mg/L).

Table A2-N: Turbidity

		Tier 1 catchments					**Tier 2 catchments**								
		Toenepi Waikato	**Waiokura Taranaki**	**Waikakahi Canterbury**	**Bog Burn Southland**	**Inchbonnie West Coast**	**Puwera Northland**	**Taharua Hawke's Bay**	**Mangapapa Manawatu**	**Enaki Wairarapa**	**Powell Tasman**	**Rai Marlborough**	**Canterbury**		**Washpool Otago**
													Rhodes	**Petrie**	
Sample period		2001–2006	2001–2006	2001–2006	2001–2006	2004–2006	2006–2007	2000–2008	2006–2007	2002–2006		2006–2007	2006–2007	2006–2007	2002–2006
Sample number		58	~74	95	77	43	~26	~62	12	58		12			22 u/s 7 d/s
Downstream site	Minimum	1.1	4.5	1.2	2.6	1.5	1.5	0.31	0.09	0.25		0.4	0.4	0.4	2.6
	Maximum	48	35	30	34	101	16.1	8.53	137	95		6.24	1.5	2.5	82.1
	Median	2.6	11	4.6	6.2	4	6.9	1.26	1.61	2.55		1.81	0.6	1.15	14.5
Upstream site	Minimum		5.1	0.6	7.6	0.6	0.7	0.13				0.53	0.3	0.2	2.2
	Maximum		70	60	34	75.2	79	3.67				4.76	1.8	0.8	6.9
	Median		8.4	11.1	11.0	2.6	4.5	0.44	0.5*			1.67	0.5	0.4	5.6

Source: Wilcock, Monaghan et al, 2007 for Tier 1 catchment results and regional council monitoring reports for Tier 2 catchment results.

Notes:

All units are nephelometric turbidity units (NTU).

* Average (not median).

Appendix 3: Regression Analyses

Table A3-A: Regression analyses

Water-quality variable	Correlation (r^2) with water-quality (predictor) variable			
	% Dairy	Average annual rainfall	Mean or median annual stream flow	Other
Total nitrogen	0.24 (n = 14)	0.17 (n = 14)	< 0.01 (n = 8)	
Nitrate–nitrite nitrogen	0.19 (n = 14)	0.14 (n = 14)	< 0.01 (n = 8)	Conductivity = 0.33 (n = 14) Conductivity = **0.58** (n = 13, Puwera excluded)
Soluble inorganic nitrogen	0.22 (n = 14)	0.14 (n = 14)	< 0.01 (n = 8)	
Total phosphorus	0.11 (n = 14)	< 0.01 (n = 14)	0.18 (n = 8)	
Dissolved reactive phosphorus	0.16 (n = 14)	0.04 (n = 14)	0.11 (n = 8)	
Ammonia nitrogen	0.18 (n = 10)	0.41 (n = 10)	0.11 (n = 7)	
Conductivity	0.33 (n = 13)	0.19 (n = 13)	0.16 (n = 7)	
Suspended solids	0.12 (n = 14)	< 0.01 (n = 14)	< 0.01 (n = 8)	Turbidity = **0.54** (n = 12)
Turbidity	0.05 (n = 13)	< 0.01 (n = 13)	0.17 (n = 7)	
E. coli	0.22 (n = 14)	0.11 (n = 14)	0.18 (n = 8)	
MCI	< 0.01 (n = 8) 0.27 (n = 7*)	0.13 (n = 8)	**0.89**** (n = 6)	
QMCI	< 0.01 (n = 9) 0.35 (n = 8*)	0.02 (n = 9)	**0.79**** (n = 5)	

* Waiokura excluded.

** Logarithmic trend line fit.

Appendix 4: Current Monitoring Programmes

Table A4-A: Current (2009) monitoring programme

Catchment	Water-quality variable				Frequency of monitoring	Flow	Comment
	Nutrients: **total nitrogen** **total phosphorus** **nitrate–nitrite nitrogen** **soluble inorganic nitrogen (SIN)** **dissolved reactive phosphorus**	**Toxicants/stressors:** **ammoniacal nitrogen** **dissolved oxygen, pH** **water temperature** **suspended sediments** **turbidity** **visual clarity** **conductivity**	**Biological:** **periphyton** **macrophytes** **macroinvertebrates** **fish**	**Microbiological:** ***E. coli*** **enterococci**			
Inchbonnie (T1)	All + total organic carbon	All		*E. coli*	Monthly spot samples for all variables, as well as occasional seasonal deployments of continuous loggers for water temperature, pH and dissolved oxygen.	Continuous recorders at catchment outlet	
Waiokura (T1)	All + total organic carbon	All	Macroinvertebrates*	*E. coli*	Monthly spot samples for all variables, as well as occasional seasonal deployments of continuous loggers for water temperature, pH and dissolved oxygen. Macroinvertebrates sampled twice a year at 2 sites in spring and summer.	Continuous recorders at catchment outlet	
Rhodes (T2)	All + dissolved organic carbon	All	Macroinvertebrates and periphyton	*E. coli*	Quarterly water quality monitoring at two sites. Macroinvertebrates annually.	Spot gauging to maintain flow record	
Petrie (T2)	All + dissolved organic carbon	All	Macroinvertebrates and periphyton	*E. coli*	Quarterly water quality monitoring at two sites. Macroinvertebrates annually.	Spot gauging to maintain flow record	
Toenepi (T1)	All + total organic carbon	All		*E. coli*	Monthly spot samples for all variables, as well as occasional seasonal deployments of continuous loggers for water temperature, pH and dissolved oxygen	Continuous recorders at catchment outlet	
Puwera (T2)	All except SIN	All except clarity. Also do BOD5	Periphyton (Chlorophyll a) and macroinvertebrates	*E. coli* and faecal coliforms	Monthly spot samples for all variables and macroinvertebrates every two years	Monthly spot gaugings at downstream site	Upstream and downstream sites monitored

Catchment	**Water-quality variable**				**Frequency of monitoring**	**Flow**	**Comment**
	Nutrients: **total nitrogen** **total phosphorus** **nitrate–nitrite nitrogen** **soluble inorganic nitrogen (SIN)** **dissolved reactive phosphorus**	**Toxicants/stressors:** **ammoniacal nitrogen** **dissolved oxygen, pH** **water temperature** **suspended sediments** **turbidity** **visual clarity** **conductivity**	**Biological:** **periphyton** **macrophytes** **macroinvertebrates** **fish**	**Microbiological:** ***E. coli*** **enterococci**			
Washpool (T2)	All except SIN	Ammoniacal nitrogen and suspended sediments	Fish	*E. coli*	Fortnightly spot sampling for all except fish (annual sampling).	Continuous recorder at downstream site	
Waikakahi (T1)	All + total organic carbon	All	Macroinvertebrates and periphyton	*E. coli*	Monthly spot samples for all variables, as well as occasional seasonal deployments of continuous loggers for water temperature, pH and dissolved oxygen.	Continuous recorders at catchment outlet	
Powell (T2)	All	All	Macroinvertebrates and periphyton	*E. coli*	Quarterly spot samples for all water quality variables, as well as occasional seasonal deployments of continuous loggers for water temperature and dissolved oxygen (eg, every 3–5 years). Twice-yearly periphyton and annual macroinvertebrates.	Continuous	
Enaki (T2)	All plus total kjeldahl nitrogen and total organic carbon	All except visual clarity	All	*E. coli*	Monthly spot samples for all water-quality variables, as well as occasional seasonal deployments of continuous loggers for water temperature. Monthly periphyton cover and annual biomass. Macroinvertebrates annually and fish monitoring every 3 years.	Flow is gauged monthly at time of sampling	Site being monitored now (and in the future) is 500 m downstream from that for which baseline data in this report is presented.
Bog Burn (T1)	All	All	Initiating in 2008	*E. coli* and faecal coliforms	Monthly spot samples for all variables, as well as occasional seasonal deployments of continuous loggers for water temperature, pH and dissolved oxygen.	Continuous recorders at catchment outlet	
Taharua (T2)	All + bicarbonate, carbonate, hardness	All + pH Volatile suspended solids Alkalinity	Routine periphyton (tax and biomass) and macroinvertebrates and periodic fish and habitat quality survey	*E. coli*	Monthly spot samples for all water-quality variables, annual periphyton and habitat quality, and bi-annual macroinvertebrates. 5-yearly fish survey. Continuous logger for water temperature; dissolved oxygen has been deployed since September 2008.	Continuous recorders at catchment outlet	Three sites routinely monitored plus recent addition of one just upstream of Mohaka confluence (Red Hut).

Catchment	Water-quality variable				Frequency of monitoring	Flow	Comment
	Nutrients: **total nitrogen** **total phosphorus** **nitrate–nitrite nitrogen** **soluble inorganic nitrogen (SIN)** **dissolved reactive phosphorus**	**Toxicants/stressors:** **ammoniacal nitrogen** **dissolved oxygen, pH** **water temperature** **suspended sediments** **turbidity** **visual clarity** **conductivity**	**Biological:** **periphyton** **macrophytes** **macroinvertebrates** **fish**	**Microbiological:** ***E. coli*** **enterococci**			
Mangapapa (T2)	All plus dissolved organic phosphorus. Total oxidised nitrogen instead of nitrate–nitrite nitrogen	All	Periphyton, macroinvertebrates, fish routinely. Habitat quality on occasion	*E. coli*	Monthly spot samples / measurements for water quality and periphtyon. Fish surveyed 5-yearly.	Continuous at downstream site (Troup Road)	
Rai (T2)	All except SIN	All except visual clarity	Macroinvertebrates only.	*E. coli* and faecal coliforms	Monthly spot measurements for water quality with fortnightly monitoring during the summer. Annual macroinvertebrate sampling.	Continuous	

Notes:

All sampling at Tier 1 sites undertaken by NIWA unless marked with an asterisk, in which case it is the regional council.

T1 = Tier 1 catchment and T2 = Tier 2 catchment.

Appendix 5: Recreational Values

Table A5-A: Recreational values of the catchment streams and downstream receiving waters

Catchment	Is there swimming or other contact recreation and/or food harvested (eg, fish, shellfish) from the stream or downstream receiving environment?
Inchbonnie (T1)	No specific knowledge of recreation on Pigeon Creek in the Inchbonnie catchment, but Lake Brunner (directly downstream) is a popular recreational lake (swimming, kayaking, fishing)
Waiokura (T1)	No swimming observed – too small/shallow. At most farms families may fish for eels.
Rhodes (T2)	Extensive recreational values in receiving water (Orari River); creek utilised as cultural (mahinga kai) harvest (eels, cress, etc) and trout fishery. No contact recreation sites.
Petrie (T2)	Extensive recreational values in receiving water (Orari River); creek utilised as cultural (mahinga kai) harvest (eels, cress, etc) and trout fishery. No contact recreation sites.
Toenepi (T1)	No specific knowledge, but the Piako catchment (into which the Toenepi drains) has been classified 'contact recreation' in the Waikato Regional Plan following submissions from the community.
Puwera (T2)	No specific knowledge of recreation on the Puwera Stream but considered unlikely. Discharges into Otaika Stream, which is tidal. Recreational activities probably include kayaking and contact recreation. There is no shellfish gathering in the Otaika Stream.
Washpool (T2)	Swimming and fishing in receiving river (Pomahaka River), trout and eels
Waikakahi (T1)	Trout and salmon spawning and fishery. Also cultural harvest. No contact recreation sites.
Powell (T2)	One potential swimming hole on Powell Creek but poor access. Motupipi River – fishing (whitebaiting and mulleting); not highly valued for swimming because water cold but is likely to affect coastal beach water quality downstream at Rototai.
Enaki (T2)	Some contact recreation occurs downstream in the Mangatarere Stream, although this is not a significant waterway for recreation compared with the Waiohine River further downstream.
Bog Burn (T1)	Contact recreation (fishing, swimming, jet skiing, boating, etc) in the Oreti River (downstream). Fishing in the Oreti River and shellfish in the New River Estuary (downstream).
Taharua (T2)	No specific knowledge of recreation on the Taharua, but the receiving river (the Mohaka) is protected by a Water Conservation Order which includes specific mention of outstanding water sports values. Trout fishing and rafting are common.
Mangapapa (T2)	No contact recreation known within catchment, but this occurs within downstream receiving environment. (Note; all natural water bodies in the Manawatu–Wanganui region are designated for 'contact recreation' in the operative and proposed regional plan.) People may eel in the catchment, but there is no information about this or other fishing.
Rai (T2)	Both contact recreation (eg, swimming, kayaking) and fishing take place in the Rai and downstream in the Pelorus River.

Notes:

The descriptions in this table are based on the perceptions of regional council staff or interpretations from reports, not a formal survey. They may not represent whole-of-council or other community views, and there may be other/different recreational values that have not been captured.

T1 = Tier 1 catchment and T2 = Tier 2 catchment.