Impacts of dairy farming on water quality and biological communities of streams in Tararua District, New Zealand

A thesis presented in partial fulfilment of the requirements for the degree of Master of Science in Ecology at Massey University, Palmerston North, New Zealand.

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ABSTRACT

Water quality in dairy farming areas has increasingly been the focus of attention in New Zealand as more land is converted to dairying and the intensity of operations increases. Regional councils and the dairy industry have encouraged removal of existing treated dairy shed effluent discharges from waterways and the minimisation of diffuse sources of contaminants such as nutrients and bacteria.

There has been limited scientific data collected on the impacts of dairy shed effluent discharges on streams, nor on the overall water quality and biotic integrity in small sub-catchments with intensive dairy farming. This study aimed to address these issues, as well as investigating the scale influence (temporal and spatial) on the results.

Streams in two sub-catchments of the Manawatu River, Tararua District, New Zealand, were subject to regular monitoring over the summer low-flow period of 2001. Intensive dairy farming is the predominant land use in the catchments. Twenty-two sites were measured on seven occasions for bacteria, nutrients, turbidity, periphyton, temperature, conductivity, dissolved oxygen (DO) and pH. Macroinvertebrate samples were taken at 18 of the sites on one occasion. Twelve of the sites were paired above and below five dairyshed effluent discharges and one urban sewage treatment discharge.

The water quality in the small streams did not meet chemical or microbiological guidelines at most sites on most sampling occasions. While point-source discharges influenced some sites, other sites with no obvious contaminant discharges also did not meet guidelines. However, biological monitoring showed periphyton levels were always within guidelines and macroinvertebrate communities indicated only 'moderate' enrichment.

The discharges of treated dairyshed effluent into streams and drains had a significant impact on *Escherichia coli (E.coli)*, dissolved reactive phosphorus (DRP), nitrate, ammonia, turbidity and conductivity measures. However, periphyton levels generally decreased below discharges. Macroinvertebrate communities showed some change

below discharges to dominance by indicators of poor water quality, but this was not statistically significant. The variation between individual discharges indicates that there is a need to assess the impacts on a case-by-case basis.

Temporal trends below a dairy shed effluent discharge showed 24-hour cycles in temperature and DO but not in conductivity. In addition, there was a weak 12-hour cycle in temperature but this was unlikely to be due to pulses of effluent from twice-daily milking. Conductivity within the stream was affected by random events (for example pond desludging) influencing effluent discharges, indicating that individual variation in system management can have localised impacts on water quality. However, the proximity of cows at the time of sampling had no detectable effect on water quality measures. Rainfall affected *E.coli* levels in both streams, however the influence of rain on periphyton levels appeared to be subject to individual stream characteristics.

There was considerable spatial variation in water quality throughout the catchments. While some of this variation could be attributed to point-source discharges, much remains unexplained but is likely due to variation in overland runoff from grazed pastures and groundwater inputs. Data from State of the Environment (SoE) monitoring in the Manawatu catchment was also compared with results from this study to determine if the SoE monitoring is accurately reflecting water quality at these smaller scales. Larger waterways of the Manawatu catchment had similar levels of dissolved oxygen as the smaller streams, however there was a wide variation in nutrient levels in the different waterways.

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General Introduction

Dairy farming is a key industry in New Zealand's economy. The dairy industry makes up 20% of the total exports, and 7% of New Zealand's Gross Domestic Product (GDP). There are 3.5 million dairy cows in the country, producing one billion kilograms of milkfat per year. Fonterra is the main company producing, marketing and distributing the milk products in New Zealand, 95% of which are exported (www.fonterra.com, 2003).

There is ongoing pressure to increase productivity from the land, an example being the New Zealand Dairy Board objective of a four percent increase in productivity per year (Leslie 2000). Operations are trending towards larger herd sizes – often several small farms amalgamating into one large farm or increasing the number of cows per hectare. The industry has seen a change from low intensity, single worker, pasture-based systems to more intensive, large herd, often supplementary fed, systems (Ministry for the Environment 1999). This intensification may increase the environmental impact from operations if not managed well.

The dairy industry relies on its "clean green" image to sell much of the dairy produce, but this reputation has been increasingly scrutinised and debated with the expansion of dairy farming into areas historically dominated by other, less intensive, agricultural activities (Ministry for the Environment 1999). Degradation of New Zealand's waterways is one environmental issue that has arisen from land use changes. Previous research has shown dairy farming areas have poor water quality in terms of high bacterial levels and nutrients, and low levels of dissolved oxygen (for example Smith et al. 1993, Wilcock et al. 1999) and compromised instream biodiversity (Quinn and Hickey 1990, Quinn 2000). There has been intense media interest regarding the impacts on streams from stock crossings, dairyshed effluent discharges and general runoff from dairy farms (for example Johnson 2001, Morgan 2002, Pyle 2002).

In New Zealand, Regional Councils are the local government agencies responsible for water quality under the Resource Management Act, 1991 (RMA). Regional plans, created by each regional council in accordance with the RMA, regulate activities such as disposal of dairy shed effluent. There are a number of water quality guidelines and standards for waterways in New Zealand. These include those in the third schedule of the RMA; the Australian and New Zealand Environment and Conservation Council (ANZECC) guidelines (ANZECC 2000); and Ministry for the Environment (MfE) guidelines for bacteria (Ministry for the Environment 2002) and periphyton (Biggs 2000). In addition, the Macroinvertebrate Community Index (MCI) was developed to provide a biological method of water quality assessment, particularly for organic enrichment (Stark 1985).

In 2001 the former New Zealand Dairy Board published the "Dairy industry environmental and animal welfare policies". This was followed by the release of "Market Focused" (Dairying and the Environment Committee 2001), a voluntary best practice manual for dairy farmers focusing on environmental issues and animal welfare. In December 2002, Fonterra recommended the development of an industry based "Clean Streams Accord" to protect the 'clean green' dairying image, the content of which is to be further discussed with shareholders (Fonterra Co-operative Group 2002b). The draft accord anticipates cows being fenced out of streams, rivers, lakes and their banks, and nutrient budgets developed for each farm. However the accord is not binding on dairy farmers (Fonterra Co-operative Group 2002a).

Farmers have been encouraged to recognise the benefits of fencing and planting riparian zones and this has already been done on some farms (Taranaki Regional Council 2001). Economic benefits of riparian protection include preventing injuries to stock from falling down banks, preventing stream erosion into paddocks, use as an area for planting timber to harvest, or simply for aesthetic purposes to increase property value. However this is an evolving process as research convinces farmers the cost of riparian protection is outweighed by the benefits to farm management and the environment. The environmental benefits from riparian margins include reducing overland runoff into streams and nutrient removal (Syverson 2002), providing shade (Rutherford et al. 1997), habitat for adult aquatic insects (Collier and Scarsbrook 2000) and leaf litter inputs as food source and habitat for aquatic invertebrates (Davies-Colley 1997).

Regional Council policies encouraging waste to be irrigated onto pasture rather than discharged into waterways is having a substantial impact on effluent disposal decisions. In addition, there is increasing recognition of the fertiliser value of dairy shed effluent (Longhurst et.al. 2000).

Non-regulatory measures used by a number of councils include environmental grants for replanting riparian areas, field days organised by environmental education officers, water monitoring courses for rural communities, brochures demonstrating best practice and awards to recognise environmentally sustainable operations (Ministry for the Environment 1999).

This study was encouraged by horizons.mw (Manawatu-Wanganui Regional Council) in order to gather more information on the water quality of streams smaller than those they routinely monitor. The former New Zealand Dairy Research Institute (now Fonterra Research Centre) was also interested in gathering more data on water quality in dairy farming areas. This was to complement their project in the Toenipi catchment, Waikato, New Zealand, which has now expanded to three other catchments (J.W. Barnett, Fonterra Research Centre, pers.comm. 2003). The Toenipi study initially involved regular monitoring at three sites on the stream for two years. The data from these first two years showed nutrient levels, ammonia and summer maximum temperatures were generally above guidelines and dissolved oxygen showed wide fluctuations (Wilcock et.al. 1998).

There is little scientific knowledge on impacts of direct dairy shed effluent discharges into water, which this study aimed to address. In addition, the variation in temporal and spatial trends in small streams has had little study. This study investigated some of these influences on the water quality data collected.

The study area is two subcatchments of the Manawatu River, Tararua District, New Zealand. The stream's headwaters are in the southeast Ruahine Ranges, between the townships of Dannevirke and Woodville (see Fig.2.1 in Chapter 2). These streams were chosen because the area is intensively farmed and each stream has a number of dairy shed effluent discharges. The streams studied flow into the Manawatu River, which has a number of recreational uses. Fishing, kayaking and swimming are common throughout the larger waterways in the catchment.

REFERENCES

ANZECC. (2000). "The Australian and New Zealand Guidelines for Fresh and Marine Water Quality." Australian and New Zealand Environment and Conservation Council, Canberra, Australia.

Biggs, B. J. F. (2000). "New Zealand periphyton guideline: detecting, monitoring and managing enrichment of streams." Ministry for the Environment, Wellington.

Collier, K. J., and Scarsbrook, M. R. (2000). "Use of riparian and hyporheic habitats." In: *New Zealand stream invertebrates: ecology and implications for management*, Collier, K. J. and Winterbourn, M. J., (eds.), New Zealand Limnological Society, Christchurch, pp.179-206.

Dairying and the Environment Committeee, and Otago Regional Council. (2001). "Market Focused: An environmental management system for New Zealand Dairy Farmers." Ministry for the Environment, Wellington, New Zealand.

Davies-Colley, R. J. (1997). "Stream channels are narrower in pasture than in forest." *New Zealand Journal of Marine and Freshwater Research*, **31**, 599-608.

Fonterra Co-operative Group. (2002a). "Media statement: Background notes on Fonterra's environmental initiatives." Fonterra Co-operative Group, Wellington.

Fonterra Co-operative Group. (2002b). "Media statement: Fonterra's environmental initiatives." Fonterra Co-operative Group, Wellington.

Johnson, B. (2001). ""Dirty dairying" condemned by Fish and Game New Zealand." Media release, Fish and Game New Zealand, Wellington.

Leslie, M. (2000). "What is 4% productivity gain." *Livestock Improvement Farm Advisor*, Issue **4**, p4.

Longhurst, R.D., Roberts, A.H.C., O'Connor, M.B.(2000). "Farm dairy effluent: a review of published data on chemical and physical characteristics in New Zealand." *New Zealand Journal of Agricultural Research*, **43**, 7-14.

Ministry for the Environment. (1999). "Resource Management Act: practice and performance, a case study of farm dairy effluent management." Ministry for the Environment, Wellington.

Ministry for the Environment. (2002). "Recreational water quality guidelines: guidelines for the management of waters used for marine and fresh water recreation and recreational shellfish-gathering." Ministry for the Environment, Wellington.

Morgan, J. (2002). "Dirty Dairying." *The Dominion*, May 25, 2002, Wellington, p3.

Pyle, E. (2002). "Quicker action needed to clean up dairy streams." Press release, Royal Forest and Bird Protection Society of New Zealand (Inc.), Wellington.

Quinn, J. M. (2000). "Effects of pastoral development." In: *New Zealand stream invertebrates: ecology and implications for management*, Collier, K. J. and Winterbourn, M. J., (eds.), New Zealand Limnological Society, Christchurch, pp. 208-229.

Quinn, J. M., and Hickey, C. W. (1990). "Characterisation and classification of benthic invertebrate communities in 88 New Zealand rivers in relation to environmental factors." *New Zealand Journal of Marine and Freshwater Research*, **24**, 387-409.

Rutherford, J. C., Blackett, S., Blackett, C., Saito, L., and Davies-Colley, R. J. (1997). "Predicting the effects of shade on water temperature in small streams." *New Zealand Journal of Marine and Freshwater Research*, **31**(5), 707-721.

Smith, C. M., Wilcock, R. J., Vant, W. N., Smith, D. G., and Cooper, A. B. (1993). "Towards sustainable agriculture: freshwater quality in New Zealand and the influence of agriculture." *Report No. 93/10*, MAF Policy, Hamilton.

Stark, J. D. (1985). "A Macroinvertebrate Community Index of water quality for stony streams." *Report No. 87*, National Water and Soil Conservation Authority, Ministry of Works and Development, Wellington.

Syverson, N. (2002). "Effect of a cold-climate buffer zone on minimising diffuse pollution from agriculture." *Water Science and Technology*, **45**, 69-76.

Taranaki Regional Council. (2001). "Investing in our banks: the benefits of riparian management." Taranaki Regional Council, Stratford.

Wilcock, R. J., Nagels, J. W., Rodda, H. J. E., O'Connor, M. B., Thorrold, B. S., and Barnett, J. W. (1999). "Water quality of a lowland stream in a New Zealand dairy farming catchment." *New Zealand Journal of Marine and Freshwater Research*, **33**(4), 683-696.

Wilcock, R. J., Rodda, H. J. E., Scarsbrook, M. R., Cooper, A. B., Stroud, M. J., Nagels, J. W., Thorrold, B. S., O'Connor, M. B., and Singleton, P. L. (1998). "The influence of dairying on the Freshwater Environment (The Toenipi Study): Volume I. Summary of Major Findings." *Report No. DRI60202*, NIWA, Hamilton, New Zealand.

2

Impacts of dairy farming on streams at the subcatchment scale, Manawatu River catchment, New Zealand

ABSTRACT

Streams in two sub-catchments of the Manawatu River, Tararua District, New Zealand, were studied to determine impacts of dairy farming on the water quality and biological communities, and if they met ANZECC, national and regional guidelines. Intensive dairy farming is the predominant land use in the area studied. Sites were measured on seven occasions for bacteria, nutrients, turbidity, periphyton, temperature, dissolved oxygen, pH and on one occasion for macroinvertebrates. The tests show that the streams did not meet chemical or microbiological water quality guidelines at most sites on most sampling occasions. Levels of periphyton however were always within guidelines and a macroinvertebrate community index (MCI) indicated only 'moderate' enrichment. This indicates that biotic indices were ineffectual at detecting water quality problems in these catchments.

INTRODUCTION

It has been well documented that agricultural activities can have adverse effects on water quality and biodiversity in streams (e.g. Quinn and Hickey 1990). Catchments where dairy farming is the predominant landuse are often known to have poor water quality (e.g. Wilcock et.al. 1998a, Wilcock et.al. 1999). This can be attributed to both point source discharges such as those from dairyshed effluent treatment ponds and non-point source discharges such as runoff from grazed pasture and inappropriate fertiliser application. Given the increasing tendency towards high intensity dairy farming in New Zealand over the past decade (Flowerday 1999), there is increasing concern for the impact on rivers, streams and wetlands (Sinner 1992).

There are a number of water quality guidelines and standards that relate to freshwater systems in New Zealand. These include the Australian and New Zealand

Environment and Conservation Council (ANZECC) guidelines for physical, chemical and biological variables (ANZECC 2000). A ministerial council of both Australian and New Zealand environment and conservation ministers formulated these to be useful in both countries. The intention of these guidelines is that they are 'triggers' for further investigation and as such can be adapted for site-specific conditions and management objectives. This is a departure from previous New Zealand guidelines, which used a single number standard approach that made managing on a reach or catchment basis difficult.

In New Zealand, the third schedule of the Resource Management Act 1991 (RMA) gives some water quality standards for classes of water being managed for different purposes. These general standards have been transferred to a number of regional plans as the environmental 'baseline' or default standard. However, in practice, resource consent conditions tend to be based on ANZECC and Ministry for the Environment (MfE) guidelines, which give more specific limits.

This study was carried out in the Tararua District in New Zealand, with streams sourced from the southeast Ruahine Ranges. The local government agency responsible under the RMA for water resources in this study region is horizons.mw (Manawatu-Wanganui Regional Council). This council has specific standards for streams in the Manawatu River catchment, as set out in the Manawatu River Catchment Water Quality Regional Plan (MCWQRP), which was prepared under the RMA 1991 (Manawatu-Wanganui Regional Council 1998).

The Ministry for the Environment has published Recreational Water Quality Guidelines (Ministry for the Environment 2002), which set freshwater *E.coli* levels for high use recreational sites, providing both running median and one off sample maximum guidelines. These guidelines outline actions required if the levels are exceeded. For example if a single sample from a freshwater site is over 410cfu/100mL, signs are to be erected at the site, monitoring increased to daily, public informed via the media and a sanitary survey undertaken. While the streams sampled in this study are not known for swimming or food gathering uses, they do contribute to the background contaminant flows into the Manawatu River, which is a popular recreational river for swimming, fishing and kayaking (Manawatu-Wanganui Regional Council 1998).

Periphyton guidelines developed for MfE are given in Biggs (2000b). Like the 2000 ANZECC guidelines they can be used to set specific limits on a particular reach of a stream or river as the base level.

While physico-chemical measures of water quality can indicate the immediate health of the stream, they are often unduly influenced by temporal patterns in water quality (e.g. diurnal variation), by flow conditions at the time of sampling, or unusual events. In contrast, biotic indices are perceived as an indicator of the long-term ability of the stream to sustain living organisms (Rosenburg 1986, Cummins 1992). Loss of sensitive species, or change in community composition may be due to changes in water quality, but also physical habitat changes (ANZECC 2000). The Macroinvertebrate Community Index (MCI) (Stark 1985) is intended to reflect nutrient enrichment in streams and is widely used in New Zealand. Visual assessment of periphyton cover and type are also commonly used as an indicator of water quality, due to the correlation between nutrient concentrations and algal growths in the absence of other limiting factors (Biggs 2000b).

Short term or one-off sampling has shown poor water quality at sites with intensive dairy farming activity (Smith 1993, Wilcock and Barnett 1999, Foy 2001). A study on Toenipi Stream in Waikato looked at sites on the top, middle and bottom of the catchment to investigate trends in water quality within a catchment with over 70% of the landuse in intensive dairying (Wilcock et al. 1999). This study has been underway since 1995 and has been able to monitor temporal trends in water quality and attribute them to changes in dairy farming intensity and practice. This programme of long term monitoring set up by the former New Zealand Dairy Research Institute (now Fonterra Research Centre) was expanded in 2000 to include streams in the Taranaki, Southland and Canterbury regions (J.W. Barnett, Fonterra Research Centre, pers.comm. 2003).

It is relatively easy to determine the location and cause of point-source impacts. However, non-point source contamination can come from fertiliser, animal manure, urine and effluent irrigation. They may reach nearby streams via overland flow, or travel via shallow groundwater systems. Studies have found that riparian margins lower the amount of contamination entering the waterways from non point-source discharges. Syverson (2002) found that the average phosphorus removal was 76-89% and nitrate removal of 62-81% with 5 and 10-metre respectively riparian buffer areas.

A previous study looking at levels of contaminants where dairy farming was the predominant landuse found that bacterial and nutrient concentrations were high, temperature maximums were high in summer and dissolved oxygen had wide diurnal variation (Wilcock et al. 1998a). Wilcock et al also found that MCI scores were lowest in summer and in general the macroinvertebrates found were indicative of highly modified and polluted streams (Wilcock et al. 1998b).

This study aimed to look at the impact of dairy farming on the water quality and biological communities at multiple sites within two streams in the Manawatu Catchment and to assess them against the relevant guidelines. The link between the chemical and ecological indicators of water quality was investigated, to determine if water sampling and biotic indices gave a consistent picture of the health of the streams.

METHODS

Study area

The study was carried out on the Otamaraho and MangaAtua Streams. The streams are within the Southeast Ruahine ranges and discharge to the Manawatu River (Fig.2.1). The dominant landuse of the catchments is dairying. Exact map references have been excluded to ensure individual farms remained anonymous.

Sampling points were chosen above and below six discharges to water (point-source discharges). Five discharges were dairyshed effluent treated via two-pond systems consisting of an anaerobic and a facultative (aerobic and anaerobic) pond and one from the municipal sewage treatment plant at Woodville. Of these six effluent pond discharges, two were directly into the Otamaraho Stream, two directly into the MangaAtua Stream and one into a drain within each stream catchment (shown as "D" sites in the results). The other sites were located throughout the two streams at convenient access points. With the exception of four sites in drains (paired sites above and below two direct discharges) and site O7, all samples were taken on the main stem of the two streams. Site O7 was on a spring-fed tributary of the Otamaraho Stream.

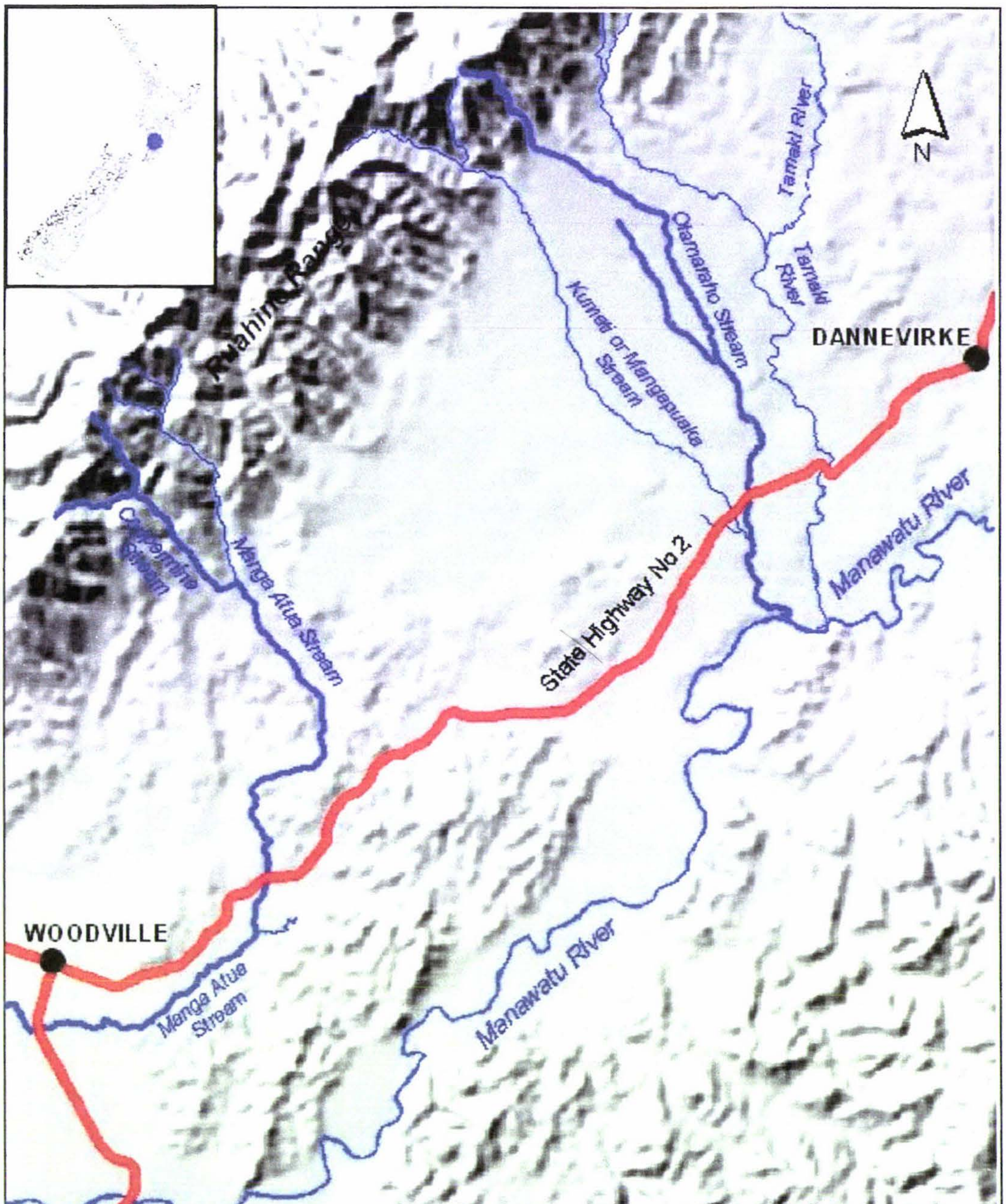

Figure 2.1: Map showing study streams (thick lines) in relation to the Manawatu River, major roads and towns.

Stock have very limited access to the MangaAtua Stream, as the riparian zone has been mostly fenced and planted under the South-East Ruahines scheme (Manawatu Catchment Board 1980). Conversely the Otamaraho Stream has almost no riparian vegetation or fencing, allowing cattle unrestricted access to the water for approximately 90% of the stream length.

Table 2.1: Physical features of the two sub-catchments (data from horizons.mw GIS information 2002; T23 and T24 topographical maps).

	MANGAATUA STREAM	OTAMARAHO STREAM
Area	9,699 hectares	1,810 hectares
Annual rainfall (mm/yr)	1191	1400
Altitude range	160 - 500 m asl [1]	90 – 340 m asl [1]
Percentage Pastoral landuse	88% [2]	89% [2]
Average fall (channel gradient)	1 in 83 m [1]	1 in 52 m [1]
NZ Soil Groups	Recent soil, yellow-brown loam.	Recent soil, yellow-brown earth, yellow-brown loam.
Surface Geology	Loess, Gravels, Greywacke	Loess, Gravels, Greywacke

[1] Measurements taken from the edge of the Ruahine Forest Park to the confluence with the Manawatu River, asl = above sea level.

[2] Measurements from the entire catchment including the Ruahine Forest Park.

Data collection

Water samples were collected in sterilised plastic bottles at each of 22 sites on seven occasions at four-day intervals from 7 February 2001 to 3 March 2001 inclusive. Sample times were random, visiting sites at different times of the day on each date. Samples were stored in a chilli-bin on ice immediately after collection, then transported to the laboratory and analysed within 24 hours.

Water samples were analysed by an IANZ accredited laboratory (Kerson Laboratory Services (HB) Ltd, Hastings, New Zealand) with standard procedures as described in American Public Health Association (1998). These were:

- turbidity (NTU) by nephelometry APHA 2130B;
- dissolved reactive phosphorus (DRP, gm^{-3}) by molybdenum blue colorimetry following ascorbic acid reduction APHA 4500 PE PB;
- ammoniacal nitrogen (the sum of ionised and un-ionised forms, NH^4-N, $g\ m^{-3}$) by indophenol blue colorimetry APHA 4500 -NH^3 B,F;
- nitrate nitrogen (NO_3-N, $g\ m^{-3}$) by automated Cd reduction and colour development with sulphanilamide and N- (naphthyl)-ethylenediamine dihydrochloride APHA 4500 NO^3-Nitrogen;
- *E.coli* by membrane filtration methods

Field measurements of temperature, conductivity, dissolved oxygen and pH were made using portable meters. Temperature and dissolved oxygen was measured with YSI model 59; conductivity with an Orion model 122; and pH with an Orion SA250.

While in the field, observations were made of the proximity of cows to each sampling point. The maximum distance noted was 4 paddocks upstream from a site (up to 400 metres) and the closest was that cows were in the site paddock. It was also noted if recent dung was evident in the site paddock even if the cows had been moved out, as this could potentially wash into the stream.

Water samples were also taken on the 17 March 2001 to determine the level of variability within a site at one specific time, in order to get some measure of the expected sampling and analytical error. Three sites were chosen – one with consistently good water quality (M1), one with consistently poor quality (O7) and another that had a high level of variability (as noted from previous sampling) (O3). Seven water samples were collected in sterilised plastic bottles at each of the three sites. These were taken within a three-minute timeframe at the same spot, labeled randomly and sent to the laboratory for processing.

Rainfall data used was that available from sites on the Otamaraho Stream (Ruaroa substation map ref T23: 682 085, horizons.mw) and the MangaAtua Stream (map ref T24: 540971, Tararua Roading Limited).

Biological sampling

Periphyton samples were taken with a 28-millimetre diameter scouring sampler described in Davies and Gee (1993). Three sub-samples from separate stones were taken at each stream site on each sampling occasion and kept on ice in individual snap-lock bags prior to storage at -20^{o} C. Chlorophyll-a was extracted with 10 millilitres of 90% acetone and analysed by spectrophotometry using the methods of Moss (1967). Results from the three subsamples were combined using the geometric mean.

Three 0.1 m^2 Surber samples (300 µm mesh net) were taken at each site by scrubbing all stones within the frame and stirring the remaining substrate to collect invertebrates. These were taken in separate shallow riffles of similar depth and flow. Samples were preserved in 70% ethanol within 5 hours of collection. Invertebrates were handpicked from a white tray. Sorting was undertaken for a maximum of two hours, followed by subsampling a tenth of the remainder under a dissecting microscope at 65x magnification.

It was impractical to collect periphyton or invertebrates from the drains due to their small size, little flow and fine substrate, so biological data is from stream sites only.

Biotic indices of water quality, macroinvertebrate community index (MCI), quantitative MCI (QMCI) (Stark 1985) and diversity indices were calculated following Boothroyd and Stark (2000), using the sum of the three samples from each site.

Data analysis

Results were compared to guidelines using box-plots. MfE guidelines for bacteria include median and single sample limits for *E.coli*. The median values are calculated from all the samples taken at a site over the sampling programme. Note that there was less than the twenty samples recommended by MfE for the median calculation.

For statistical analysis, where the data did not fit the normal distribution they were log transformed (*E. coli*, DRP, nitrate, ammonia, turbidity and conductivity). To avoid the problem of undefined log (0) values, half the minimum detectable value was added to these variables prior to log transformation.

Correlations between water quality variables were explored with a principal components analysis (PCA) in SYSTAT 8.0. The first principal component was interpreted as a general water quality index and used in subsequent ANOVA to determine whether the proximity of cows affected water quality. The type of site (drain or stream) was included as a factor in this analysis to account for an obvious source of variation.

RESULTS

Within-sample variability

The results from samples taken within a short time frame at each of three sites are shown in the following graphs as V1, V2 and V3. Figure 2.2 shows high procedural variability in *E.coli* levels even from samples taken within a short time frame (shown as V1, V2, V3).

The other water quality measures had low levels of procedural variability as can be seen in Figures 2.3 to 2.6 with V1, V2 and V3 consistently showing low variability.

Guideline breaches

The majority of water quality variables did not meet the relevant guidelines at most of the sites on a number of occasions. While most sites below the direct effluent discharges exceeded guidelines, other sites also had excessive levels at times.

E. coli

The median values for the Otamaraho Stream sites exceeded the MfE median guideline in 10 out of 11 sites. Every site in that stream had at least one sample that exceeded the action zone in a single sample.

In the MangaAtua Stream three out of nine sites met the median guideline. The action level was exceeded less frequently than in the Otamaraho catchment, although four of the seven sites did exceed this in at least one sample.

Drains showed an impact from dairy shed effluent discharges. However even the sites above discharge points (D1, D3) exceeded guidelines.

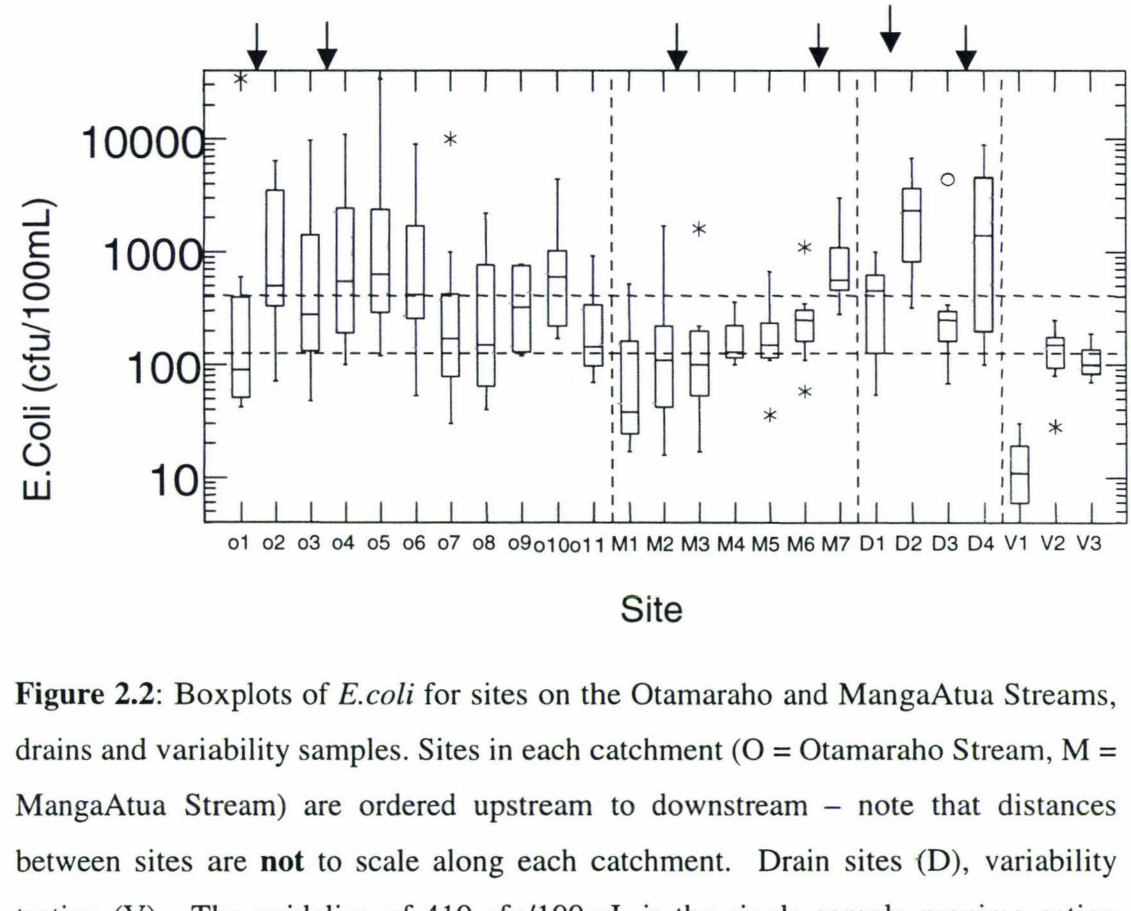

Figure 2.2: Boxplots of *E.coli* for sites on the Otamaraho and MangaAtua Streams, drains and variability samples. Sites in each catchment (O = Otamaraho Stream, M = MangaAtua Stream) are ordered upstream to downstream – note that distances between sites are **not** to scale along each catchment. Drain sites (D), variability testing (V). The guideline of 410 cfu/100mL is the single sample maxima action mode and 126 cfu/100mL is the running median acceptable mode (MfE and MoH 2002). Note the log scale on the y-axis. The arrows indicate locations of point-source discharges.

Dissolved Reactive Phosphorus

Most sites exceeded the MCWQRP guidelines as shown in Figure 2.3. The uppermost site and a spring tributary (O1 and O7) in the Otamaraho Stream were the only two that were not consistently over the guideline. The MangaAtua Stream had increasing DRP levels down the catchment and exceeded the guideline value from the State Highway 2 site downstream. The drains were clearly impacted by discharges, although variability in below sites of drains was high.

Differences between the catchments were noticeable, with the Otamaraho Stream having a DRP median value 0.053mg/l and the MangaAtua Stream 0.017mg/l (excluding drains). The maxima also varied, with 1.08 mg/l and 0.32 mg/l respectively.

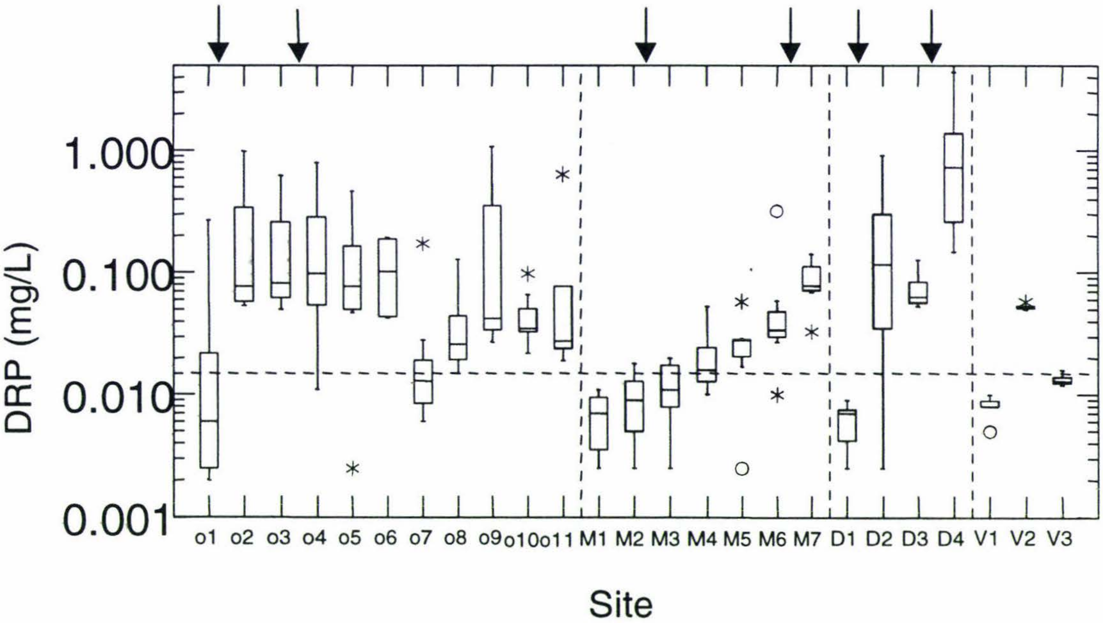

Figure 2.3: Boxplot of DRP for sites on the Otamaraho and MangaAtua Streams, drains and the variability samples. The guideline of 0.015 mg/l is from the MCWQRP (Manawatu-Wanganui Regional Council 1998). See also Fig.2.2. caption.

Nitrate

There is a clear difference in baseline levels between the two catchments (Figure 2.4). Median values for each site on the Otamaraho Stream exceed the guidelines and the median of the all stream sites (excluding drains) is 1.8mg/l. The MangaAtua Stream nitrate levels remain below the guideline at all sites and the overall median is 0.100mg/l. The impact of discharges is less obvious for nitrate than *E.coli* and DRP.

The drain in the Otamaraho catchment was over the guideline but samples from a drain in the MangaAtua catchment were generally within the guideline level.

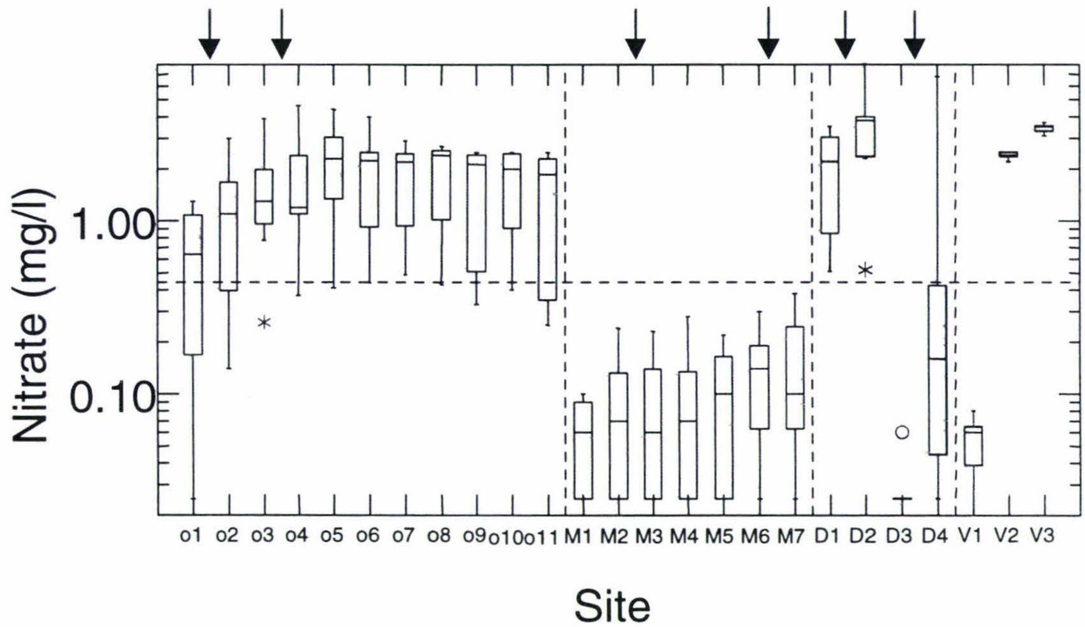

Figure 2.4: Boxplots of nitrate for sites on the Otamaraho and MangaAtua Streams, drains and variability samples. The guideline is the trigger value of 0.444 mg/l from the ANZECC 2000 guidelines. See also Fig.2.2. caption.

Ammonia

The level of ammonia was impacted strongly by dairy shed effluent discharges, as shown by differences in sites either side of the arrows. The level of ammonia in the Otamaraho Stream was highest below the first dairyshed discharge point where it exceeded guidelines some of the time, but decreased once beyond the discharges and met the guidelines. The MangaAtua Stream has much lower levels of ammonia, generally below detection limits.

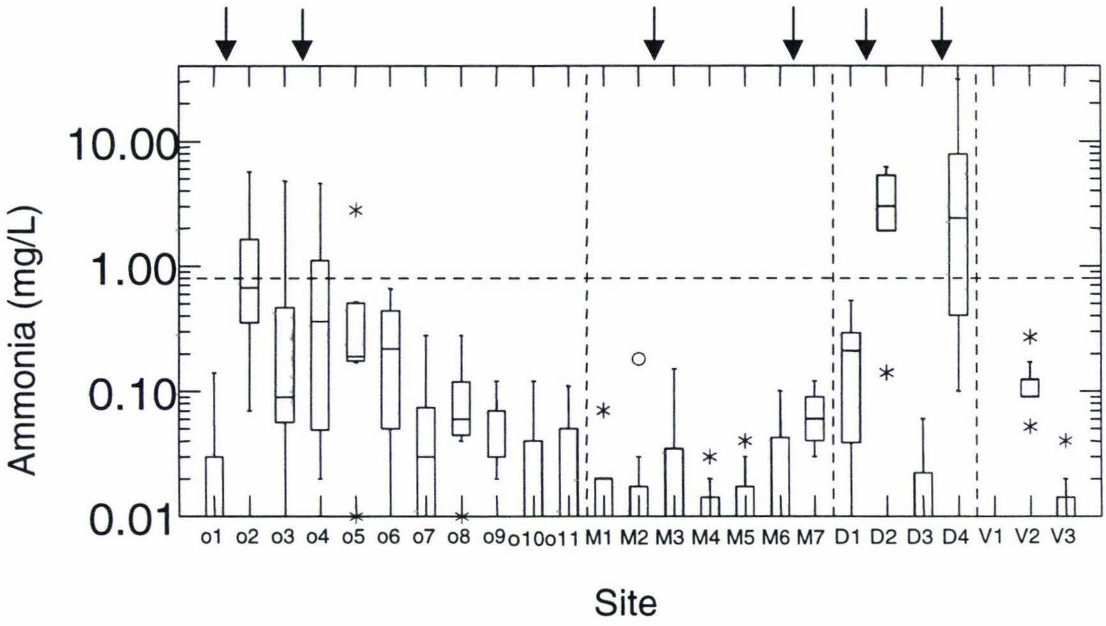

Figure 2.5: Boxplots of ammonia for sites on the Otamaraho and MangaAtua Streams, drains and the variability samples. The guideline of 0.8 mg/L is from the MCWQRP for water over 15°C. See also Fig.2.2. caption.

Turbidity

Turbidity also showed an impact from the direct discharges of dairy shed effluent to water, in particular between sites o1 and o2 and in the drains. Although the Otamaraho Stream had medians below the guideline, the 75th percentile exceeded it in five out of eleven sites. In the MangaAtua Stream maximum levels exceeded the guideline but the median remained below it in all but the bottom most site.

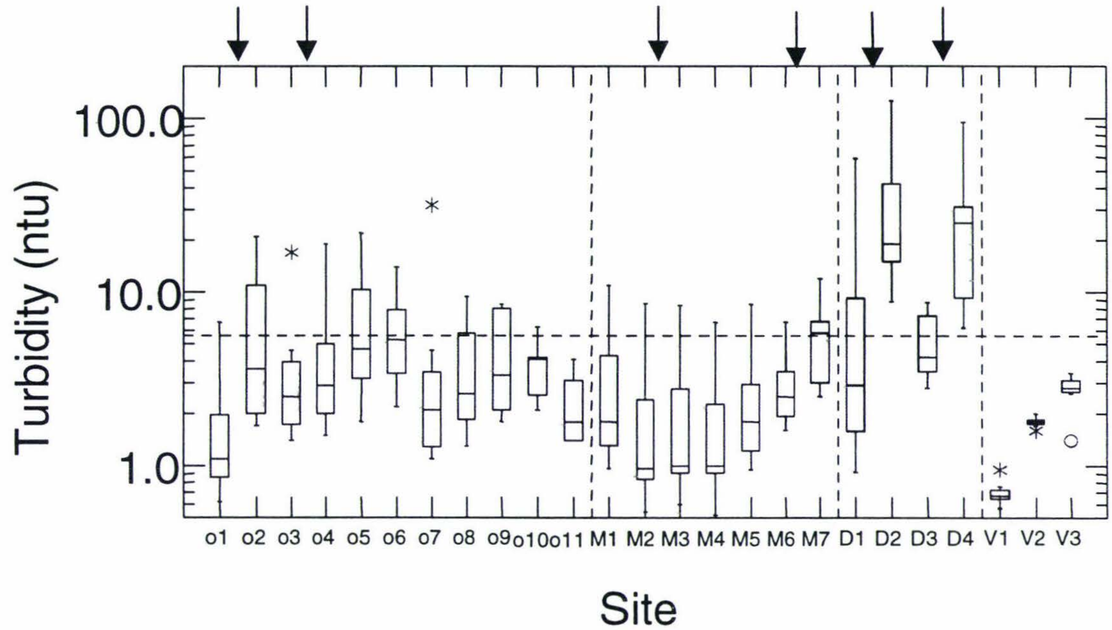

Figure 2.6: Boxplots of turbidity for sites on the Otamaraho and MangaAtua Streams, drains and the variability samples. The guideline of 5.6 ntu is from the 2000 ANZECC guidelines and is the default trigger value for lowland rivers for protection of aquatic ecosystems. See also Fig.2.2. caption.

Temperature

Temperature at all sites was consistently below the guideline in the MCWQRP of 25 °C. Drains had the highest median temperature.

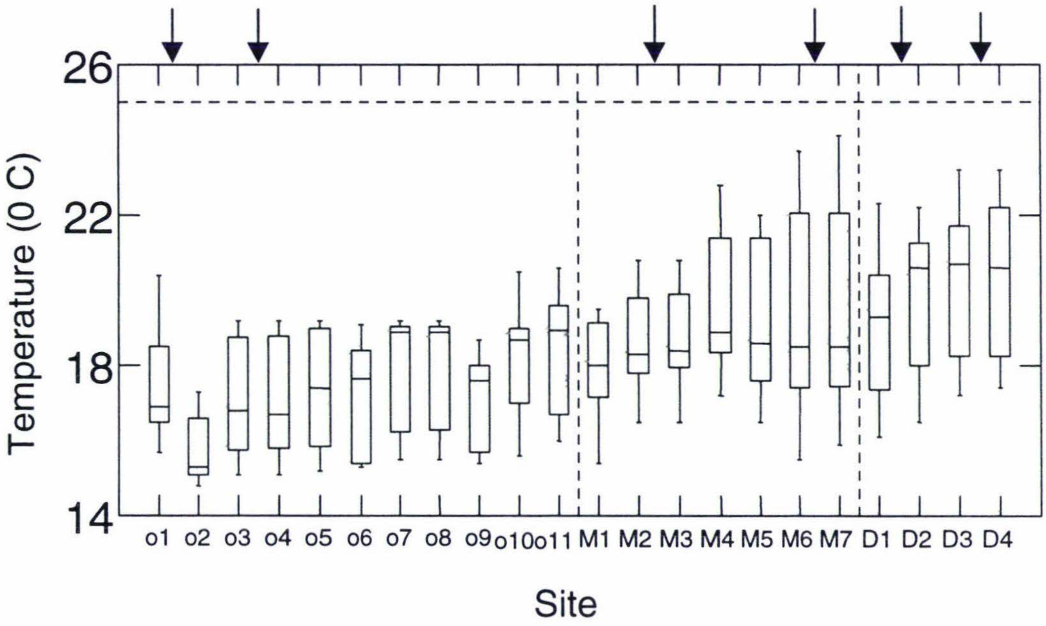

Figure 2.7: Boxplot of temperature for sites on the Otamaraho and MangaAtua Streams and drains. The guideline of 25° celsius is from the MCWQRP. The arrows indicate point-source discharges.

Conductivity

Conductivity levels in the Otamaraho Stream have high variation below the first two discharges, which decreases further downstream. The MangaAtua Stream shows little variation within each site. There is no guideline value stated, because conductivity is dependent on geology and the landuse of the catchment.

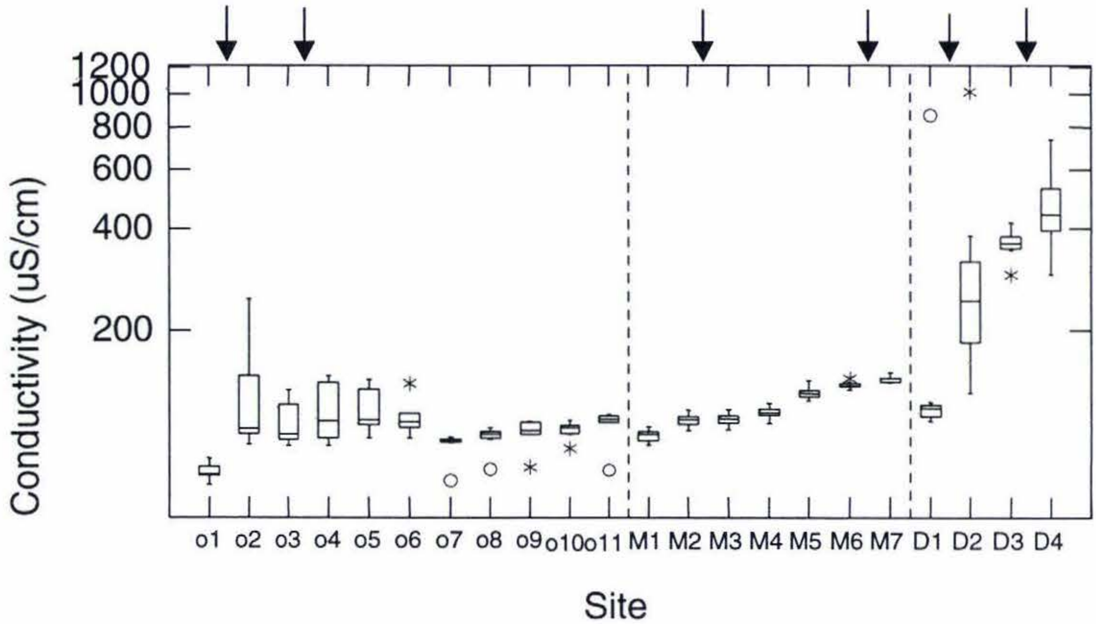

Figure 2.8: Boxplot of conductivity for sites on the Otamaraho and MangaAtua Streams and drains. The arrows indicate point-source discharges.

Percentage Saturation of Dissolved Oxygen

The median saturation levels of dissolved oxygen in streams were consistently over recommended guideline of 80% saturation. Some single samples in the Otamaraho Stream however were below this minimum level. Drains tended to be low in dissolved oxygen concentration levels. The dairy shed effluent discharges did not appear to have much influence on daytime DO levels.

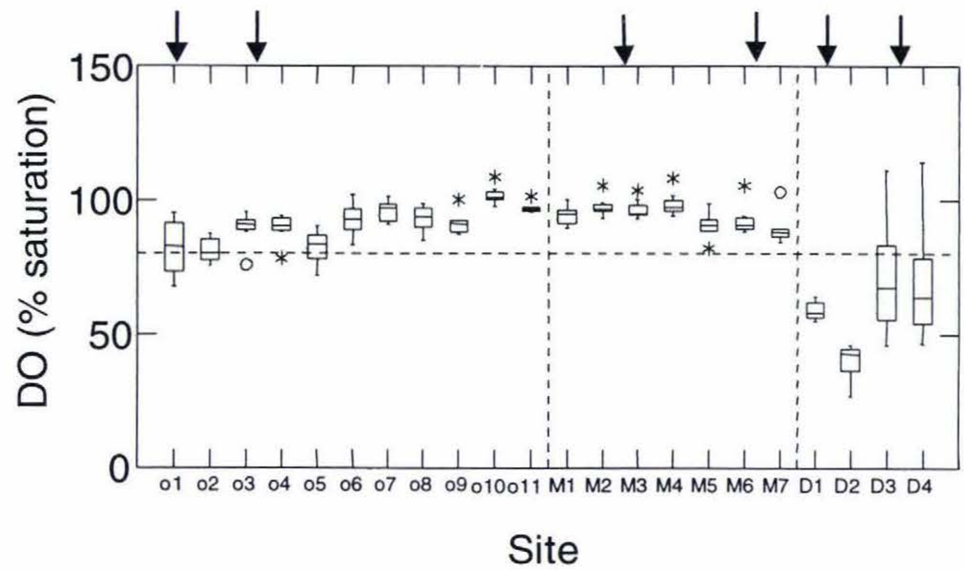

Figure 2.9: Boxplot of percentage saturation dissolved oxygen for sites on the Otamaraho and MangaAtua Streams and drains. The guideline of greater than 80% saturation comes from the third schedule of the RMA and also Rule 3 MCWQRP. The arrows indicate point-source discharges.

pH

The pH of Otamaraho Stream was highly variable, with ranges between 6.1 and 8.5. Most remained within the guidelines of 6.5 to 8. MangaAtua Stream had higher pH, with site medians close to 8. Drains had varied pH, again with obvious differences between catchments.

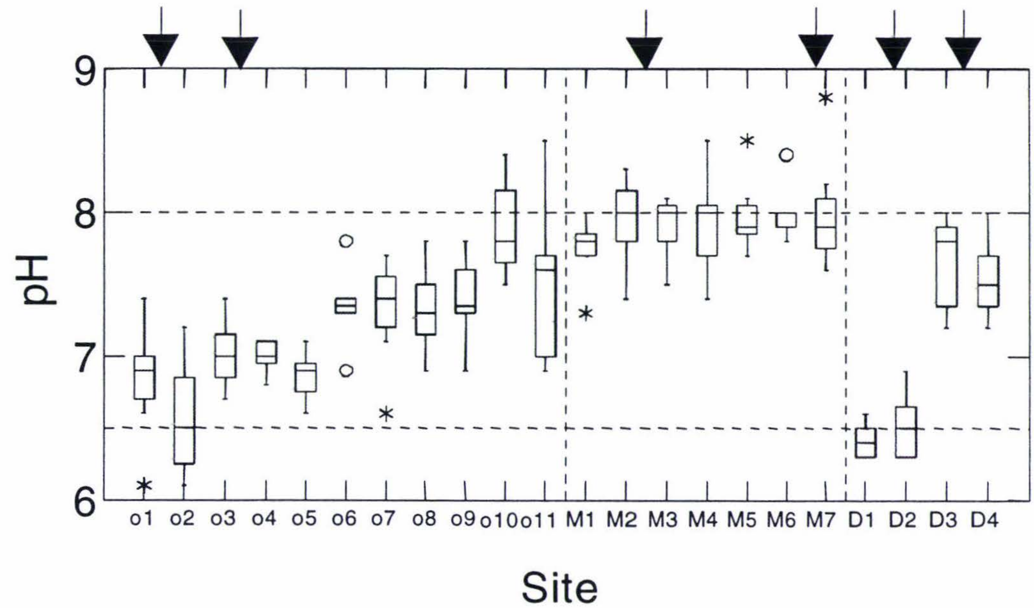

Figure 2.10: Boxplot of pH for sites on the Otamaraho and MangaAtua Streams, and drains. The lower guideline of 6.5 comes from the ANZECC (1992) guidelines. The upper limit of 8 relates to the ammonia standard in the MCWQRP. The arrows indicate point-source discharges.

Periphyton

Periphyton levels, measured as chlorophyll-a, were low overall, remaining consistently below both guidelines. No site had a median above either guideline. However, the 3rd site in the Otamaraho Stream is close to the 100mg limit, with the 75th percentile exceeding it. Other sites in the Otamaraho Stream had upper values over the guidelines. Overall the Otamaraho Stream had higher levels of periphyton than the MangaAtua Stream.

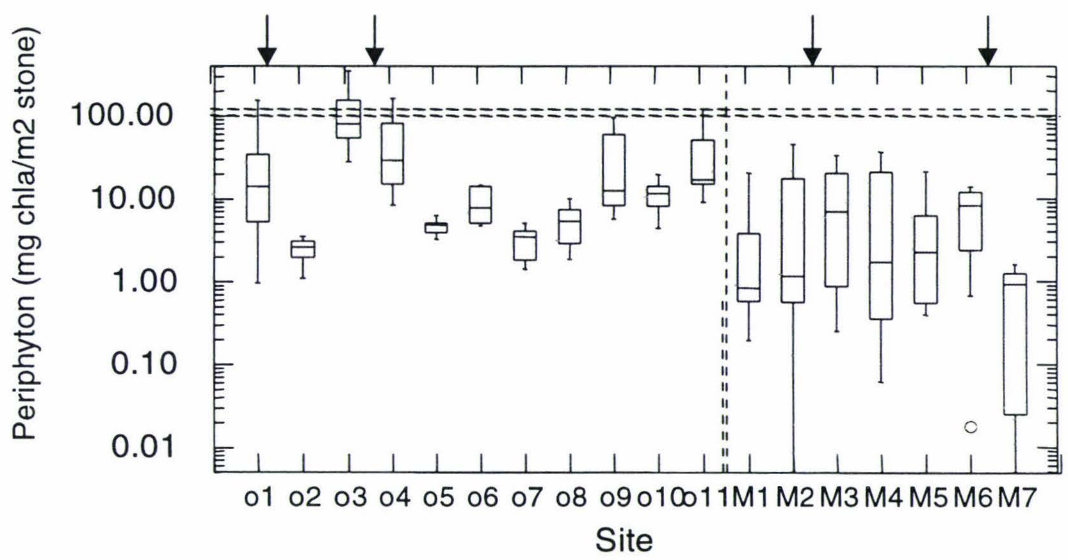

Figure 2.11: Boxplot of periphyton for sites on the Otamaraho and MangaAtua Streams. The lower guideline of 100mg chla/m^2 is from the MCWQRP. The upper guideline of 120mg chla/m^2 is from 2000 MfE guidelines (Biggs 2000b). See also Fig.2.2. caption.

Macroinvertebrates

With the exception of one site low on the Otamaraho Stream, all MCI scores were over 80 and the majority over 100. The MangaAtua Stream in general has higher MCI levels than the Otamaraho Stream with some samples exceeding 120, which is an indicator of 'clean water' sites.

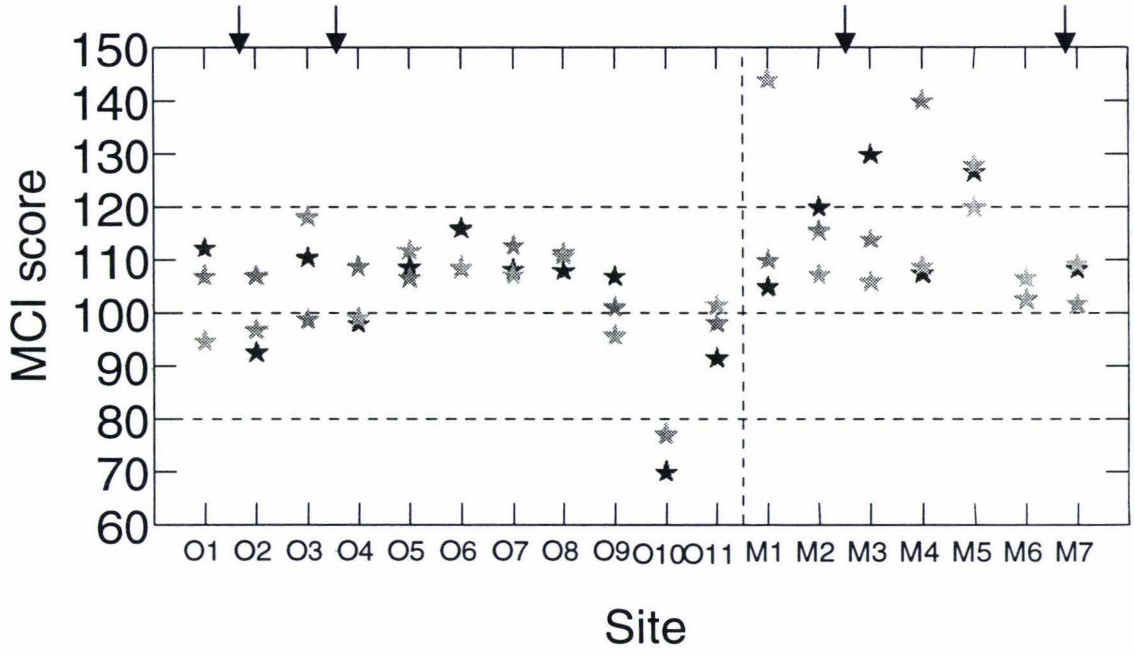

Figure 2.12: Scatterplot showing the MCI scores from each of three surber samples at sites on the Otamaraho and MangaAtua Streams. The scores of <80 indicate 'probable severe pollution', 80-99 'probable moderate pollution', 100-119 doubtful quality or possible mild pollution' and >120 'clean water' - from Boothroyd and Stark (2000). The arrows indicate point-source discharges.

The QMCI graph shows a similar result to the MCI, with the MangaAtua Stream having slightly higher scores than the Otamaraho Stream. Again one site on the Otamaraho Stream is an exception to the overall 'moderate' rating.

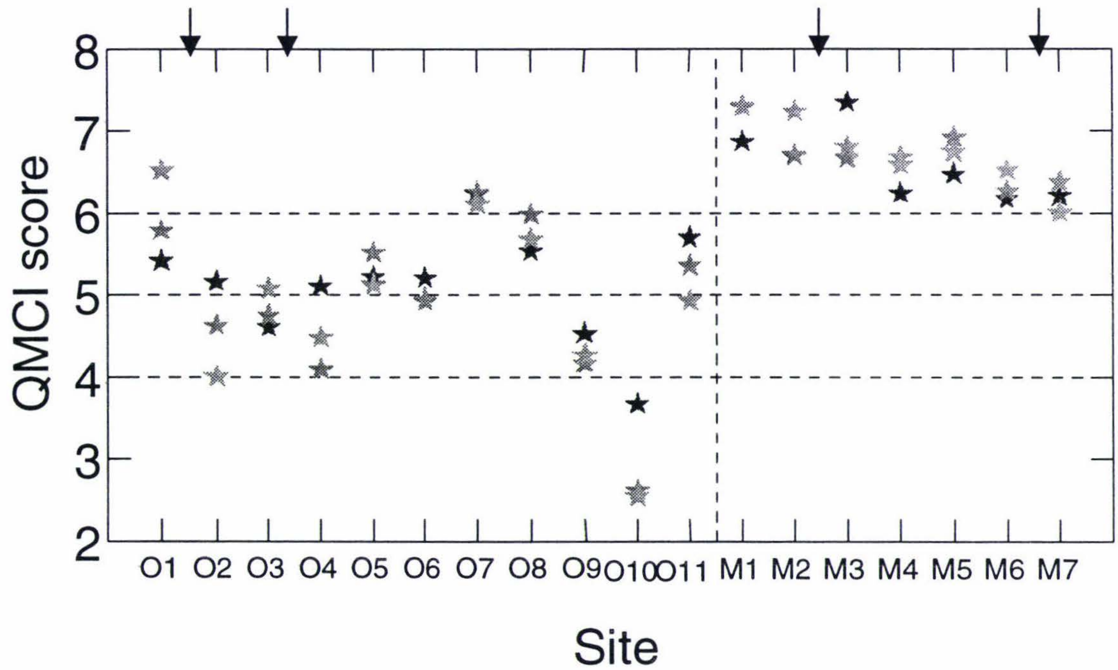

Figure 2.13: Scatterplot showing the QMCI scores from each of three surber samples at sites on the Otamaraho and MangaAtua Streams. The score of <4 indicates 'probable severe pollution', 4.00-4.99 'probable moderate pollution', 5.00-5.99 doubtful quality or possible mild pollution' and >6 'clean water' - from Boothroyd and Stark (2000). The arrows indicate point-source discharges.

Principal Components Analysis (PCA)

The first axis of the PCA explained 39% of the variance and the second axis 18%.

Axis one has strong positive loadings for the most variables associated with poor water quality (*E. coli*, DRP, ammonia, turbidity and conductivity). Variables indicating good water quality (dissolved oxygen and percentage saturation of DO) are negatively loaded on axis one.

Axis two has high positive loadings for periphyton and nitrate and high negative loadings for temperature and conductivity. These first two variables do not appear to be correlated with water chemistry measures (i.e. axis one) but are set independently on axis two.

Axis one is a useful general score for water quality, although nitrate, temperature and periphyton are independent of this axis.

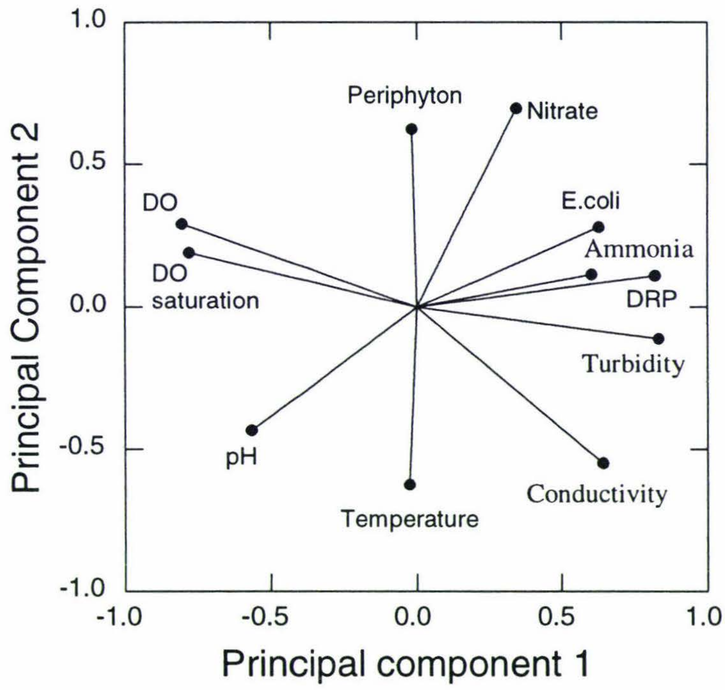

Figure 2.14: Principal Components Analysis of all water quality variables. Note that *E. coli*, DRP, nitrate, ammonia, turbidity, conductivity and periphyton values were log transformed prior to analysis.

The influence of cow proximity on water quality

The ANOVA (Table 2.3) shows that the drains had significantly lower water quality than the stream samples (as measured by first principle component of eleven water quality variables). The proximity of cows at the time of sampling did not significantly affect water quality.

Table 2.3: ANOVA of cow proximity to sampling location. The dependent variable is PC 1 of 11 water quality variables (see Fig 2.14).

Source	Sum of squares	Df	Mean-square	F-ratio	P
Drain	18.9	1	18.90	34.0	0.0000
Cows near	2.6	3	0.88	1.5	0.1973
Drain*cows near	2.1	3	0.68	1.2	0.2998
Error	79.5	143	0.56		

The category with the poorest water quality was the intermediate 'cows in paddocks upstream' (Fig 2.15), the rest were of a similar level.

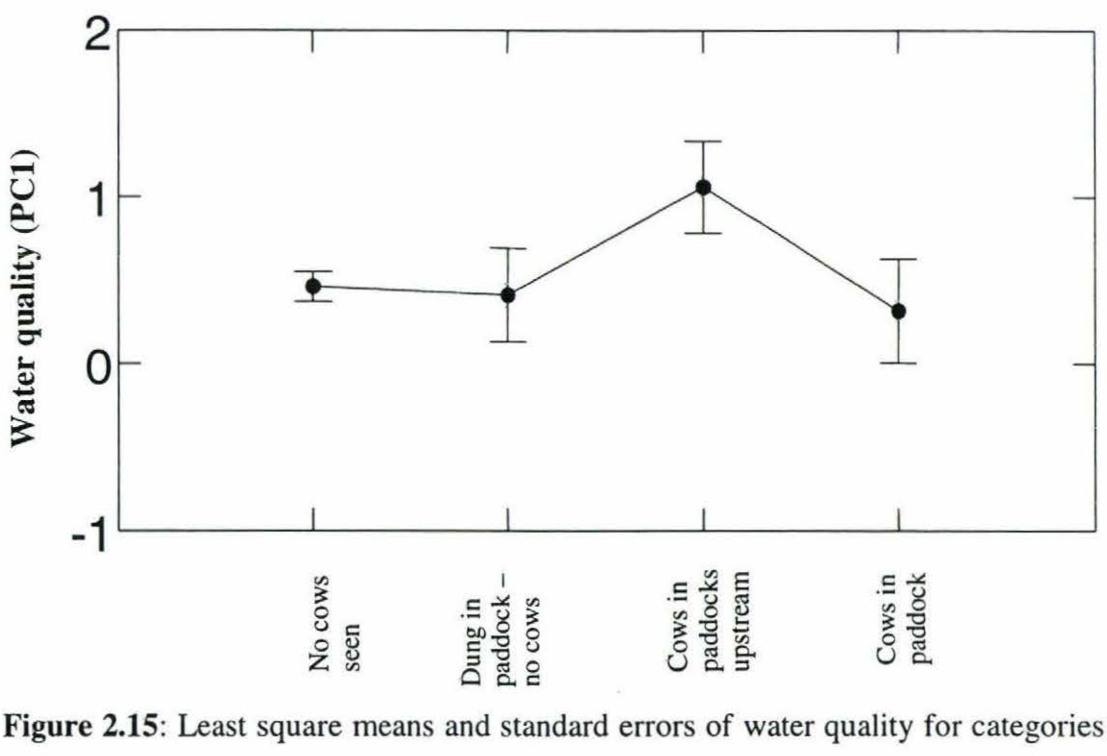

Figure 2.15: Least square means and standard errors of water quality for categories of cow location at sampling. Higher scores on PC1 indicate poor water quality.

DISCUSSION

Water quality

Within-sample variability

The variation within samples taken in a short time frame is small for most variables. This indicates that the variation seen at different sampling dates is true variation, not measurement or laboratory error. The only water quality parameter of concern is *E.coli*, which has high variability. The log scale used magnified this, however the results indicate that procedural variability in *E.coli* could account for most of the variation at some sites.

Laboratory data

The *E.coli* levels in both streams were well above the accepted guidelines from Ministry for the Environment (2002). Sources of bacteria are most likely from overland runoff from pastures, cattle access to streams in the Otamaraho, point-source discharges from effluent ponds, as well as other sources such as birds and septic tank leaks. The high levels of bacteria are not unusual for this area, Smith et al. (1993) noted that the water quality in the Manawatu River decreases downstream, with faecal coliform contamination exceeding guidelines. The Toenipi study also found that bacteria levels frequently exceeded upper limit recreation guidelines of 107 enterococci/100mL from DOH (1992) and even exceeded the stock water supply limit on occasions (Wilcock et al. 1998a). The same study noted that bacteria levels tend to increase in winter when there is more rainfall and discharges from oxidation ponds increase. However, Phillips (2001) found that bacteria levels were highest after summer/autumn flood events.

Nutrient levels were high and frequently exceeded guidelines, especially in the Otamaraho Stream and the drains. The study by Smith et al. (1993) showed that rivers in intensive dairying areas are generally in poor condition, with high levels of bacteria and nutrients. They also showed that in particular, nitrogen levels were high in tributaries of the Manawatu River.

The maximum DRP levels in the Toenipi Stream (Waikato, NZ) were 0.555 mg/l. This is lower than the 1.080 mg/l maximum recorded in this study (Otamaraho Stream). However the maximum recorded in the MangaAtua Stream was less at 0.320 mg/l. It is likely that this can be attributed to the Otamaraho catchment having much greater levels of nutrients due to the large dairy shed effluent discharges at the top end of the catchment, as well as the lack of any riparian buffer zone and stock having access to the stream.

The baseline levels of nitrate in the MangaAtua Stream were much lower than the Otamaraho Stream. This may be due to the fenced and planted riparian buffer throughout most of the main stem of this catchment. Protected riparian zones are noted to moderate the impacts from livestock grazing on water quality (Osborne 1993, Williamson et al. 1996).

The level of nitrate in groundwater in the MangaAtua catchment appears to be low, with one result near the stream of 0.02mg/l (data from horizons.mw's groundwater database, as at June 2002). The results from bores near the Otamaraho Stream vary between 2.1 and 9.7mg/l. As the Otamaraho Stream is largely groundwater fed (J.Watson, horizons.mw, pers.comm. 2002), this could account for the higher baseline levels of nitrate found in this catchment.

The likely cause of high nutrient levels overall are high stocking rates, excessive fertiliser use, inadequate riparian buffers, preferential drainage paths and cattle access to streams. For example Vant et al. (2000) found that the nitrogen yield was highly correlated with stocking rate in farms in the Waikato region. Surveys discussed in Gourley et al. (2002) have shown that Australian dairy farmers need a better knowledge of fertilisers and nutrient requirements to minimise losses of nutrients. This field is also being developed in New Zealand, with nutrient budgeting models such as Overseer* being developed for farmers (Roberts and Ledgard 1999).

Ammonia levels were generally within the guidelines set in the MCWQRP. While dairyshed effluent discharges resulted in a number of spikes in ammonia levels, these appear to be localised and returned to pre-impact levels within the distance between sites. In comparison to the Toenipi study, where the mean ammoniacal nitrogen level ranged between 0.165 and 0.272 mg/l (Wilcock et al. 1999), the Otamaraho Stream had a mean ammonia level of 1.523mg/l below the first large discharge. This rose again after the second discharge in that reach before reducing to pre-discharge levels further down the catchment. The lower end of the ammonia range was a mean of 0.007 mg/l at the State Highway 2 site on the MangaAtua Stream.

Ammonia levels can be critical to stream health, as ammonia has an immediate toxicity to fish and invertebrates, as well as exerting a significant oxygen demand (Hickey et al. 1989, Hickey and Vickers 1994). The high level of ammonia below discharges is expected to alter invertebrate community composition and impede migration of some species of fish (Richardson 1997).

Turbidity levels were relatively low considering the potential level of disturbance in the Otamaraho Stream from cattle, discharges and runoff from pasture. Impacts on turbidity levels from discharges were detected, but they appeared to be localised. However these localised breaches could cause a variety of instream effects. Examples are reducing photosynthesis, coating stone surfaces and clogging spaces between them, modifying movements and migrations of instream biota and reducing food availability (Smith et al. 1993, Selvarajah 1996).

Field collected data

The temperature in the streams, even in the summer low flow period which is expected to be the peak, remained below the 25 °C threshold for fish survival given in the MCWQRP guidelines. Although the MangaAtua Stream was fenced and planted the temperature was, in general, higher than in the Otamaraho Stream. The difference could have been from the cooler groundwater influence and the smaller surface area (narrow and deep) of the Otamaraho Stream. The MangaAtua Stream was much wider, with shading covering a relatively small percentage of the water. It is also predominately rainwater fed, with minimal groundwater interactions (J. Watson, horizons.mw, pers.comm. 2002).

Some invertebrates have lower thermal tolerances than the guideline level. There tends to be wide range of tolerances observed in stream invertebrates (Quinn et al. 1994). Quinn et al demonstrated that over a 96-hour period at 22.6 °C, 50% of *Deleatidium* individuals were killed. However over shorter time periods (e.g. 24 hours), the invertebrates tended to survive higher temperatures. Thus, at times, the higher temperatures in the lower MangaAtua Stream may have had some effect on macroinvertebrate densities and composition.

The high level of variability in conductivity measurements near point-source discharges is likely due to fluctuations in flow, both through the pond and in the stream, as well as fluctuations of conductivity levels in the pond outflow. This is consistent with Hickey et al. (1989) who found considerable variation in effluent composition within ponds with time. There is no biotic effect directly associated with conductivity, it is more of an indicator associated with geology, land use, and the presence of waste discharges.

The 80% standard for dissolved oxygen given in the RMA was met at most stream sites in this study. Below the two discharges on the upper Otamaraho Stream the median DO level was only just meeting the guideline, with the lower quartile below the 80% standard. The poorer DO below these discharges may be due to the organic loading from the effluent (Hickey et al. 1989). The generally high oxygen levels are in contrast to the Toenipi study which found daytime DO levels were often low, down to 20-40% saturation (Wilcock et al. 1998b).

These samples were taken during the daytime and therefore are more likely to be maximum levels due to photosynthesis by algae during high temperatures and with light present (ANZECC 1992). The ANZECC guidelines also note that the diurnal variation should be known. DO tends to decrease at night (e.g. Smith et al. 1993), however it is generally periphyton which leads to dissolved oxygen depletion (Hickey et al. 1989). As periphyton levels were relatively low in these streams, night-time oxygen depletion is not likely. This is confirmed by continuous sampling, see Chapter 4.

pH generally met guidelines in both catchments but not in drains. There was however a clear difference between the catchments, likely due to the local geological properties and possibly the groundwater interaction in the Otamaraho Stream lowering the pH.

Correlations between water quality measures

Given that there are generally limited budgets for water quality monitoring, testing a wide variety of variables is often not feasible. Some studies have noted that certain variables may be highly correlated with levels of contamination for other variables and can be used as an "indicator" of water quality. Testing of these indicators can be a useful way of assessing the likely concentration of other contaminants. For example Hickey et al. (1989) in a study of dairy shed effluent found conductivity a good variable to use as an indicator of nutrient levels, correlating with suspended solids, total phosphorus and BOD. Quinn and Stroud (2002) also found that conductivity is positively correlated with DRP but that it is negatively correlated with nitrate.

As DRP and turbidity have the highest loadings on PC1, which relates to general water quality, they would be the best 'general' indicators of water quality in these streams. Conductivity also had a high loading on PC1 and given its ease of measurement, has use as an indicator of general water quality. However, in these two catchments nitrate levels are varying independently of other water quality variables, including conductivity.

Biological monitoring

Periphyton

Periphyton levels were consistently below guideline levels at all sites, despite no obvious nutrient limitations. DRP has been shown in studies to be a critical component of eutrophication and excessive algal growths in the absence of other limiting factors (e.g. Carpenter 1998, Biggs 2000a). Phosphorus is more often the limiting factor for periphyton production rather than nitrate. This is due to levels of nitrates being high from biological fixing and atmospheric inputs in New Zealand (Withers, 1998). However, in this study there were no excessive periphtyon growths and chlorophyll levels were positively correlated with nitrate, rather than DRP. Other factors may have influenced the level of periphyton production or retention, as discussed below.

Disturbance is a factor that can limit periphyton growth (Biggs, 1995) and may explain low levels of periphyton especially in the MangaAtua Stream which is predominately rainfed and subject to flood disturbance (J.Watson, horizons.mw, pers.comm. 2002). However, even stable springfed sites in the Otamaraho Stream have low periphyton levels. The Otamaraho Stream is more likely influenced by steepness, with an average fall of one metre for every 52 metres of stream length. This creates a higher water velocity (Biggs et al. 1998), which can limit the ability of periphyton to establish (e.g. Francoeur et al. 1998, Biggs 2000b).

Other factors limiting periphyton biomass in these streams may be shading, invertebrate grazing and sub-stratum type being limited (Welch et al. 1992).

Davies-Colley and Quinn (1998) found that periphyton biomass correlated broadly with lighting. However, in this study, despite the MangaAtua Stream being fenced off and planted, it has relatively little shading and the Otamaraho Stream has even less. Therefore light is unlikely to be a limiting factor for periphyton.

Invertebrate grazing is another factor that is frequently noted to limit periphyton growth. Welch et al. (1992) note that grazers of approximately 3000 per square metre can control periphyton regardless of nutrient concentration. The sites in this study had algal grazers such as snails, case caddisflies and mayflies present at between 1,070 to 18,000 per square metre (average 8,200 m^2) which would contribute to the control of periphyton growth.

In conclusion, one or a mixture of the above reasons are likely to be the factors preventing excessive periphyton build up in these streams. However, the detailed analysis of periphyton community composition and dynamics was not part of this study. An interesting outcome of this study is that if periphyton chlorophyll levels were used as an indicator of stream health, the conclusion would be that the stream has high water quality. This is contrary to much of the water chemistry data which showed poor water quality that did not meet guidelines and standards.

Invertebrates

Invertebrate composition in degraded streams and the role of nutrient impacts on community structure has been the subject of much research e.g. Quinn and Hickey (1990). A number of studies, including Scarsbrook and Halliday (1999) and Quinn et al. (1997) have found that ordinations of invertebrate communities were strongly correlated with water quality variables. Miltner and Rankin (1998) also found that nutrients, particularly phosphorus, are negatively correlated with the biotic integrity of rivers in Ohio. Their results indicated that macroinvertebrate community structure is more sensitive than fish to changes in water chemistry.

However, in the present study there was little relationship between water chemistry and the MCI. Some sites with high nutrient and bacteria loadings (e.g. site M5 in the MangaAtua Stream) had MCI scores consistent with 'clean water' as defined in Boothroyd and Stark (2000).

These results may be due to the timing of the sampling. The study coincided with the period of highest impact on the stream – during summer low flows in the middle of milking season where inputs from dairysheds were highest. The invertebrate community may not have responded to this higher level of water chemistry parameters and may be able to survive if nutrient levels are reduced during the rest of the year. As noted in Stark (1985), seasonal variation may lead to spot measurements of physico-chemical variables having poor correlations with MCI.

Another factor influencing invertebrate communities may be physical stream stability and substrate type, the latter of which was the most important variable in a study by Richards et al. (1993).

Site O10 in the Otamaraho Stream was an extreme site with low MCI and QMCI scores. The water chemistry at this site was similar to the other sites with higher MCI scores, which confirms that the MCI was poor at detecting nutrient loadings in these streams. The relationship may be clearer if there were sites with more extreme water quality – i.e. very high or low rather than moderate. Another possible reason for the poor relationship may be the higher aeration in these relatively steep streams, which may aid invertebrate survival in compromised water quality.

Cow proximity to sampling location

Water chemistry measures were not significantly affected by the proximity of cows to the sampling site. This was unexpected as cattle grazing is a well-known source of disturbance in streams and has been demonstrated to increase nutrient levels in the stream through manure deposition (Strand, 1999). del Rosario et al. (2002) quotes figures from Moore (1988) that each cow deposits 2.3kg of manure per day directly into streams when they have unlimited access. However this study did not detect a difference from cows being close to the sampling location, perhaps because water quality influenced more by other factors such as overland runoff (Wilcock 1986), or by direct discharges of effluent.

This has significant implications on setting up a monitoring scheme for this area, as it implies that monitoring can be undertaken without having to allow for the location of the cows at the time. While in the MangaAtua Stream this could be due to the riparian buffer, the Otamaraho Stream (where cows have full access to the stream) also has no significant change.

Conclusion

The streams studied showed high bacterial and nutrient levels, exceeding *E.coli* and DRP guidelines, and nitrate at some sites, as well as showing high conductivity readings. However they do meet ammonia, turbidity, temperature, dissolved oxygen, pH and periphyton guidelines on most occasions at most sites. While some of these elevated levels can be explained by point-source discharges to water, there are other diffuse sources also.

Macroinvertebrate indices rate most sites as 'clean water' and there are no major algal problems in the study streams. The lack of consistency between biological and chemical measures indicate that biotic indices may not be detecting the problem and also that a good knowledge of catchment characteristics is essential when interpreting results. Alternatively it may be that invertebrate communities are more resilient to water quality impacts than anticipated, especially as these streams were fast flowing and relatively cool.

REFERENCES

American Public Health Association, American Water Works Association and Water Environment Federation. (1998). "Standard methods for the examination of water and wastewater." American Public Health Association, Washington D.C., United States of America.

ANZECC, Australian and New Zealand Environment and Conservation Council. (1992). "Australian water quality guidelines for fresh and marine waters." Australian and New Zealand Environment & Conservation Council, Canberra, Australia.

ANZECC, Australian and New Zealand Environment and Conservation Council. (2000). "National water quality management strategy: The Australian and New Zealand guidelines for fresh and marine water quality." Australian and New Zealand Environment & Conservation Council, Canberra, Australia.

Biggs, B., (1995). "Disturbance effects on periphyton." *Freshwater Biology* **33**, 419-438.

Biggs, B., Kilroy, C., and Mulcock, C. (1998). "New Zealand stream health monitoring and assessment kit: stream monitoring manual." *NIWA Technical report 40*, NIWA, Christchurch.

Biggs, B. J. F. (2000a). "Eutropichation of streams and rivers: dissolved nutrient-chlorophyll relationships for benthic algae." *Journal of the North American Benthological Society*, **10**(1), 17-31.

Biggs, B. J. F. (2000b). "New Zealand periphyton guideline: detecting, monitoring and managing enrichment of streams." Ministry for the Environment, Wellington.

Boothroyd, I., and Stark, J. (2000). "Use of invertebrates in monitoring." In: *New Zealand stream invertebrates: ecology and implications for management*, Collier, K. J. and Winterbourn, M. J., (eds.), New Zealand Limnological Society, Christchurch, pp.344-373.

Carpenter, S.R., Caraco, N.F., Correll, D.L., Howarth, R.W., Sharpley, A.N., Smith, V.H.. (1998). "Nonpoint pollution of surface waters with phosphorus and nitrogen." *Ecological Applications*, **8**, 559-568.

Cummins, K. W. (1992). "Invertebrates." In: *The Rivers Handbook: Volume I*, Calow, P. and Petts, G. E. (eds.), Blackwell Scientific Publications, Oxford, U.K., pp. 234-249.

Davies, A. L., and Gee, J. H. R. (1993). "A simple periphyton sampler for algal biomass estimates in streams." *Freshwater Biology*, **30**, 47.

Davies-Colley, R. J., and Quinn, J. M. (1998). "Stream lighting in five regions of North Island, New Zealand: control by channel size and riparian vegetation." *NZ Journal of Marine and Freshwater Research*, **32**(4), 591-605.

del Rosario, R. B., Betts, E. A., and Resh, V. H. (2002). "Cow manure in headwater streams: tracing aquatic insect responses to organic enrichment." *Journal of the North American Benthological Society*, **21**(2), 278-289.

Department of Health (1992). "Provisional microbiological water quality guidelines for recreational and shellfish-gathering waters in New Zealand." Public Health Service Department of Health, Wellington.

Flowerday, M. (1999). "New Zealand dairy industry on-farm quality system." *Livestock Improvement Farm advisor*, Issue **4**(4) p6.

Foy, R.H., Lennox, S.D., Smith, R.V. (2001). "Assessing the effectiveness of regulatory controls on farm pollution using chemical and biological indices of water quality and pollution statistics." *Water Research*, **35**, 3004-3012.

Francoeur, S. N., Biggs, B. J. F., and Lowe, R. L. (1998). "Microform bed clusters as refugia for periphyton in a flood-prone headwater stream." *New Zealand Journal Marine and Freshwater Research*, **32**(3), 363-374.

Gourley, C. J. P., Aarons, S. R., Eckard, R. J., Burkitt, L. L., Irvine, J. N., Awty, I. M., and Ellis, M. J. (2002). "Changing our approach to nutrient management for an expanding dairy industry." In: *Dairy farm soil management*, Currie, L.D. & Loganathan, P. (eds.). Occasional report No.15. Fertilizer and Lime Research Centre, Massey University, Palmerston North, pp.333-344.

Hickey, C. W., Quinn, J. M., and Davies-Colley, R. J. (1989). "Effluent characteristics of dairy shed oxidation ponds and their potential impacts on rivers." *New Zealand Journal of Marine and Freshwater Research*, **23**, 569-584.

Hickey, C. W., and Vickers, M. L. (1994). "Toxicity of ammonia to nine native New Zealand freshwater invertebrate species." *Archives of Environmental Contamination and Toxicology*, **26**, 292-298.

Manawatu Catchment Board. (1980). "Farmers' guide to South-East Ruahine scheme." Manawatu Catchment Board, Palmerston North.

Manawatu-Wanganui Regional Council. (1998). "Manawatu catchment water quality regional plan." *Publication 98/EXT/331*, Manawatu-Wanganui Regional Council, Palmerston North.

Miltner, R. J., and Rankin, E. T. (1998). "Primary nutrients and the biotic integrity of rivers and streams." *Freshwater Biology*, **40**, 145-158.

Ministry for the Environment. (2002). "Recreational water quality guidelines: guidelines for the management of waters used for marine and fresh water recreation and recreational shellfish-gathering." Ministry for the Environment, Wellington.

Moss, B. (1967). " A spectrophotometric method for the estimation of percentage degradation of chlorophylls to pheo-pigments in extracts of algae." *Limnology and Oceanography*, **12**, 335-340.

Osborne, L.L., Kovacic, D.A. (1993). "Riparian vegetated buffer strips in water-quality restoration and stream management." *Freshwater Biology*, **33**, 419-438.

Phillips, J.R. (2001). "Whanganui catchment water quality." *Report No.2001/EXT/467,* horizons.mw, Palmerston North.

Quinn, J. M., Cooper, A. B., Davies-Colley, R. J., Rutherford, J. C., and Williamson, R. B. (1997). "Land use effects on habitat, water quality, periphyton, and benthic invertebrates in Waikato, New Zealand, hill-country streams." *New Zealand journal of marine and freshwater research*, **31**, 579-597.

Quinn, J. M., and Hickey, C. W. (1990). "Characterisation and classification of benthic invertebrate communities in 88 New Zealand rivers in relation to environmental factors." *New Zealand Journal of Marine and Freshwater Research*, **24**, 387-409.

Quinn, J. M., Steele, G. L., Hickey, C. W., and Vickers, M. L. (1994). "Upper thermal tolerances of twelve New Zealand stream invertebrate species." *New Zealand Journal of Marine and Freshwater Research*, **28**, 391-397.

Quinn, J. M., and Stroud, M. J. (2002). "Water quality and sediment and nutrient export from New Zealand - land catchments of contrasting land use." *New Zealand Journal of Marine and Freshwater Research*, **36**, 409-429.

Richards, C., Host, G., and Arthur, J. (1993). "Identification of predominant environmental factors structuring stream macroinvertebrate communities within a large agricultural catchment." *Freshwater Biology*, **29**, 285-294.

Richardson, J. (1997). "Acute ammonia toxicity for eight New Zealand indigenous freshwater species." *New Zealand Journal of Marine and Freshwater Research*, **31**, 185-190.

Roberts, A., and Ledgard, S. (1999). "Overseer TM - a nutrient budgeting model." *Manaaki Whenua*, Te Papa, Wellington.

Rosenburg, D.M., Danks, H.V., Lehmkuhl, D.M. (1986). "Importance of insects in environmental impact assessment." *Environmental Management*, **10**, 773-783.

Scarsbrook, M. R., and Halliday, J. (1999). "Transition from pasture to native forest land-use along stream continua: effects on stream ecosystems and implications for restoration." *New Zealand Journal of Marine and Freshwater Research*, **33**(2), 293-310.

Selvarajah, N. (1996). "Dairy farm effluent treatment pond performance in teh Waikato region: a preliminary review of the regional survey." Tertiary treatment options for dairyshed and piggery wastewaters, Mason, I. G. (ed.), Massey University, Palmerston North, pp. 18-25.

Sinner, J. (1992). "Agriculture and water quality in New Zealand: MAF Policy technical paper 92/17." *Report 92/17*, Ministry of Agriculture and Fisheries Policy, Wellington.

Smith, C. M., Wilcock, R. J., Vant, W. N., Smith, D. G., and Cooper, A. B. (1993). "Towards sustainable agriculture: freshwater quality in New Zealand and the influence of agriculture." *Report 93/10*, MAF Policy, Hamilton.

Stark, J. D. (1985). "A Macroinvertebrate Community Index of water quality for stony streams." *Soil and water miscellaneous publication No. 87*, National Water and Soil Conservation Authority, Ministry of Works and Development, Wellington.

Strand, M., Merritt, R.W. (1999). "Impacts of livestock grazing activities on stream insect communities and the riverine environment." *American Entomologist*, **45**, 13-29.

Syverson, N. (2002). "Effect of a cold-climate buffer zone on minimising diffuse pollution from agriculture." *Water Science and Technology*, **45**, 69-76.

Vant, B., Taylor, A., and Wilson, B. "Land use and river condition in the Waikato region." In: *Water 2000 Water conference and expo: Guarding the global resource*, NZWWA, Auckland, New Zealand.

Welch, E. B., Quinn, J. M., and Hickey, C. W. (1992). "Periphyton biomass related to point-source nutrient enrichment in seven New Zealand streams." *Water Resources*, **26**(5), 669-675.

Wilcock, R. J. (1986). "Agricultural runoff, a source of water pollution in New Zealand?" *New Zealand Agricultural Science*, **20**, 98-103.

Wilcock, B., and Barnett, J. (1999). "What water quality can we expect in dairying catchments?" *NIWA - Aniwaniwa* #**10**(10), 7.

Wilcock, R. J., Nagels, J. W., Rodda, H. J. E., O'Connor, M. B., Thorrold, B. S., and Barnett, J. W. (1999). "Water quality of a lowland stream in an New Zealand dairy farming catchment." *New Zealand Journal of Marine and Freshwater Research*, **33**(4), 683-696.

Wilcock, R. J., Rodda, H. J. E., Scarsbrook, M. R., Cooper, A. B., Stroud, M. J., Nagels, J. W., Thorrold, B. S., O'Connor, M. B., and Singleton, P. L. (1998a). "The influence of dairying on the freshwater environment (the Toenipi study): volume I. summary of major findings." *Report No. DRI60202*, NIWA, Hamilton, New Zealand.

Wilcock, R. J., Rodda, H. J. E., Scarsbrook, M. R., Cooper, A. B., Stroud, M. J., Nagels, J. W., Thorrold, B. S., O'Connor, M. B., and Singleton, P. L.

(1998b). "The influence of dairying on the freshwater environment (the Toenipi study): volume II. technical rReport." *Report No. DRI60202*, NIWA, Hamilton, New Zealand.

Williamson, R. B., Smith, C. M., and Cooper, A. B. (1996). "Watershed riparian management and its benefits to a eutrophic lake." *Journal of Water Resources Planning and Management*, 1996.

Withers, P.J.A., Jarvis, S.C. (1998). "Mitigation options for diffuse phosphorus loss to water." *Soil Use Management*, **14**, 186-192.

3

The impact of oxidation pond discharges on water quality and biological communities in two small streams, Manawatu River catchment, New Zealand

ABSTRACT

The impact from effluent discharges to streams and drains was studied in twelve sites in the Tararua District, New Zealand. Sites above and below discharges to water from five dairy farm oxidation ponds and one urban sewage treatment plant were measured on seven occasions for bacteria, nutrients, turbidity, temperature, dissolved oxygen, pH and periphyton. Macroinvertebrates were also sampled at eight of the sites on one occasion. Where effluent was discharged directly into the stream, the impact on water quality was measurable. This was particularly so for *E.coli*, DRP, nitrate, ammonia, turbidity and conductivity measurements, which increased significantly. Stream biology was also affected with a significant decrease in periphyton growth downstream of discharges. Macroinvertebrate indices however showed no significant difference upstream and downstream of discharge sites, but some shift in community composition was indicated by an ordination by detrended correspondence analysis.

This study on impacts of point-source discharges supports policy direction to remove effluent discharges to waterways to protect water quality. It also demonstrates the variability between discharges and the need to assess them on a case-by-case basis.

INTRODUCTION

Dairy farming, like any industry, creates undesirable by-products that are potentially harmful to the natural environment. Cow faeces and urine are waste products produced and disposed of on the farm. On average each cow produces between 50 and 70 litres of effluent per day (Dairying and the Environment Committee 1996). In New Zealand dairy farms much of this is deposited in paddocks, with an estimated 10-20% deposited in the dairy shed during milking (Sukias et al. 2001). Typically in New Zealand, this waste is washed from the milking shed using water and then must be disposed of. Key components of the waste are nitrates, phosphates, organic solids, pathogens and sulfates (Taranaki Regional Council 1995). In general, ten percent of the farm dairy effluent is excreta with four percent teat washings and the other 86 percent washwater plus other foreign material (Longhurst et al. 2000, Wrigley 1994). This other material may be detergents, spilled milk, mucus, soil, salt, feed and other contaminants (Dairying and the Environment Committee 1996).

Historically the waste was disposed of into soakage ponds, streams or drains directly from the milking shed. This impacted on stream ecosystems, with poor water quality in streams with large numbers of point-source discharges (Hickey and Rutherford 1986, Taranaki Regional Council 1995). In 1967 the National Soil and Water Conservation Act was enacted amid increasing concern about water contamination (Ministry for the Environment 1999). In the 1970's the two-pond system of treatment was encouraged, utilising anaerobic and aerobic decomposition before discharge into the waterways (Sukias et al. 2000). In 1984 there were approximately 7850 point-source discharges of treated dairy shed effluent to rivers and streams in New Zealand (Hickey and Rutherford 1986).

Increasing environmental and cultural awareness has led to a focus on minimising discharges into waterways. The Resource Management Act of 1991 and the resultant obligation for Regional Councils to develop regional plans, which regulate direct discharges to waterways, was a key method for advancing the change. All regional councils in New Zealand require operators of dairy sheds discharging effluent to water to obtain resource consent. The discharge to water is classified as discretionary activity in all regions except Auckland and Taranaki where it is a controlled activity if specified standards are met (Ministry for the Environment 1999).

The statutory authority in this study area, Manawatu-Wanganui Regional Council (trading name horizons.mw), encourages farmers to discharge to land, as set out in policy 11.3 of their Regional Policy Statement (Manawatu-Wanganui Regional Council 1998). Methods to implement these policies in plans, such as short term consents for discharges to water, can be a significant influence on a farmers' decision to move to land irrigation (Ministry for the Environment 1999). Most dairyshed effluent is irrigated over land, either after travelling through the two-pond system, a storage pond, or directly from the milking shed to the irrigator system. The soil type or topography makes it impractical to discharge dairy shed effluent to land on some New Zealand farms. In these instances improvements to pond performance to ensure environmentally sustainable disposal of the effluent are required such as additional maturation ponds, wetland treatment and use of mechanical aerators (Sukias et al. 2000).

In surveys of dairy farmers undertaken at the end of 1999 by Bigham (2000), 30% of Manawatu farmers disposed of waste via the twin pond system into waterways and 50% disposed of it to land either directly or through a pond system. In comparison 60% of Taranaki farmers disposed of dairy shed effluent to water from a twin pond. The same study noted that 91% of farmer respondents attempt to manage their effluent well as they are aware that an image of environmental concern is important for the industry - 83% of farmers modified their practices to be more in line with community concerns about environmental issues. Since the above study, a large number of consents for discharge to waterways in the Manawatu/Wanganui region have expired and farmers have chosen to with discharge to land instead.

The scientific rationale for removing discharges from waterways has not been so well documented. Quinn (2000) noted that the impact of these discharges on invertebrates should be studied. It is expected that discharges with high levels of nutrients, bacteria and sediment, as documented in Hickey et al. (1989) and Sukias (2001), would have adverse effects on the stream ecosystem. Nutrients, known to be high in dairy shed effluent (Hickey et al. 1989), frequently cause excessive algal growths that then affect the habitat of invertebrates and fish as well as impact on the natural character and aesthetics of the waterway (Biggs 2000). These algal growths, together with organic material decay and nitrification of ammonia can lead to reduced oxygen levels within the stream, impacting on instream biota (Sinner 1992, Walling and Webb 1992). Hickey et al. (1989) suggest that when multiple discharges occur, there is a significant toxic risk to fish and invertebrates (Hickey 1994).

Increased levels of sediment can smother instream biota, either reducing abundance or changing community composition towards more resilient species (Ward and Talbot 1988). Pathogens in streams reduce its suitability for recreational usage by presenting a health risk to users. Faecal coliforms pose no direct risk, rather they are an indicator of the likely presence of pathogens like leptospirodium, salmonella, streptococcus and staphylococcus which pose a direct health risk (Giffney 1984).

This study aims to provide more information regarding the impact of oxidation pond discharges to water and the impact of these on recreational suitability and instream biological communities in the Tararua District.

METHODS

Study area

The study was carried out on the Otamaraho and MangaAtua Streams, Tararua District, New Zealand. Sampling points were chosen above and below six discharges to water (point-source discharges). Of these six discharges, two were directly into the Otamaraho Stream, two directly into the MangaAtua Stream and one into a drain within each stream catchment. The discharges were from dairy shed effluent ponds except discharge five, which was from the Woodville municipal sewage treatment plant. These discharges to water were operating under resource consents issued by horizons.mw under the Resource Management Act 1991. All milking sheds were seasonal, with effluent inflow between August and May. See Chapter Two for further details.

Data collection

Water samples were collected above and below each of the six discharges on seven occasions at four-day intervals from 7 February 2001 to 3 March 2001 inclusive. The above sites were within ten metres upstream of the discharge. The below sites were within twenty metres of the discharge. This distance allowed the discharges to mix across the streams but ensured that the discharge was the only variation between the two sites.

The water samples were analysed for *E.coli*, DRP, nitrate, ammonia and turbidity. Field measurements of temperature, conductivity, dissolved oxygen and pH were made using portable meters. Sampling protocol and laboratory analysis is described in Chapter Two.

Biological sampling

Three stone surface periphyton samples were taken at each site on each sampling occasion and chlorophyll-a extracted. Three invertebrate surber samples were taken at each stream site on one occasion (MangaAtua Stream sites on 24 February 2001, Otamaraho Stream on 25 February 2001). It was impractical to collect periphyton or invertebrates from the drains due to their small size, little flow and fine substrate so biological data is from stream sites only. Further details are given in Chapter Two.

Data analysis

In the following graphs and tables, labels '1' and '2' correspond to discharges into the Otamaraho Stream, '4' and '5' to MangaAtua Stream, '3' and '6' are drains that flow into each of the two streams respectively.

For each water quality variable there were seven measurements from above and below each discharge point. The discharges were distributed over two catchments and discharges into drains were considered a third "catchment" type. This was analysed with an analysis of variance (ANOVA) with above/below, catchment type and discharge nested within catchment as factors. *E.coli*, DRP, nitrate, ammonia, turbidity, conductivity and periphyton were log transformed prior to analysis to eliminate positive skew and heteroscedasticity of residuals.

An ordination of invertebrate community by detrended correspondence analysis was used to identify trends in community structure, focusing on the difference between above and below discharge sites. Indicator species analysis and Multiple Response Permutation Procedure (MRPP) using PC-ORD were performed on the invertebrate data. A blocked MRPP with median alignment, which took into account the fact that the sites were paired, was also used.

From the invertebrate data the Macroinvertebrate Community Index (MCI) (Stark 1985), Quantitative MCI (QMCI) (Stark, 1998), percentage of Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa and Shannon diversity index (Boothroyd and Stark 2000) were calculated. Paired t-tests were carried out on these macroinvertebrate indices and number of taxa and the total number present, comparing sites above and below discharges.

RESULTS

Water Quality

The same ANOVA model was fitted to each water quality measure. The ANOVA for DRP is shown in detail in table 3.1 and summaries of results for other variables in Table 3.2. All factors and interactions had a significant effect on DRP ($p<0.05$, bold in Tables 3.1 and 3.2).

DRP levels differ among the three catchments and also among discharge sites. There is a strong effect of effluent discharge (above/below factor) but the magnitude of the impact differs among sites and between catchments, as shown by the significant interactions.

Table 3.1: Nested ANOVA using log transformed **DRP** as the dependent variable. A/B = above/below discharge.

Effect	**SS**	**df**	**MS**	**F**	**P**
Catchment	19.5	2	9.7	8.8	**<0.001**
A/B	31.2	1	31.2	28.3	**<0.001**
Catchment*A/B	12.7	2	6.4	5.8	**0.005**
Discharge(Catchment)	50.7	3	16.9	15.3	**<0.001**
A/B*Discharge (Catchment)	9.7	3	3.3	2.9	**0.039**
Error	79.5	72	1.1		

Table 3.2 shows there was a significant difference between the three catchments for all water quality measurements (refer also Fig. 3.1-3.5). The MangaAtua Stream had lower levels of contaminants as illustrated on the graphs and the drains tended to have the highest.

There was a significant increase in the levels of all five dependent variables below the discharges.

The middle row of table 3.2 shows that while the above/below difference is significant for all variables, the amount of difference changes between catchments for DRP, ammonia and turbidity. The bottom line in table 3.2 shows that the difference between above/below also varies between individual discharges for DRP and ammonia.

Table 3.2: Probability values from nested ANOVA model on log transformed laboratory tested water quality variables. A/B = above/below discharge.

Effect	*E.coli*	**DRP**	NO_3	NH_4	**Turbidity**
Catchment	**0.034**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
A/B	**0.005**	**<0.001**	**0.012**	**0.012**	**<0.001**
A/B*Catchment	0.515	**0.005**	0.060	**<0.001**	**0.037**
Discharge (Catchment)	0.171	**<0.001**	**<0.001**	0.172	0.102
A/B*Discharge (Catchment)	0.672	**0.039**	0.217	**0.025**	0.389

As with the laboratory-measured variables, all of the field-measured variables in Table 3.3 show a significant difference between the three catchments (note that there were only two catchments for periphyton, as drains could not be sampled).

There was a significant increase in the levels of conductivity and a significant decrease in periphyton below the discharges (refer Fig. 3.6 & 3.7). There was no above/below pattern in the graphs of temperature, DO and pH and no significant result in the ANOVA.

Unlike the majority of the laboratory-tested variables, there were no significant interactions between above/below and catchment or discharge.

Table 3.3: Probability values from nested ANOVA model on field measured and periphyton data.

Effect	Conductivity	Temperature	DO% Saturation	pH	Periphyton (Chl-a)
Catchment	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
A/B	**0.002**	0.806	0.076	0.437	**0.031**
A/B*Catchment	0.096	0.521	0.185	0.638	0.633
Discharge (Catchment)	**<0.001**	0.478	**<0.001**	**<0.001**	**0.003**
A/B* Discharge (Catchment)	0.211	0.743	0.216	0.559	0.054

The following graphs (Fig. 3.1-3.6) demonstrate the trends of six key variables at points above and below point-source discharges to water.

Figure 3.1 shows an increase in *E.coli* below the discharge in all of the paired sites.

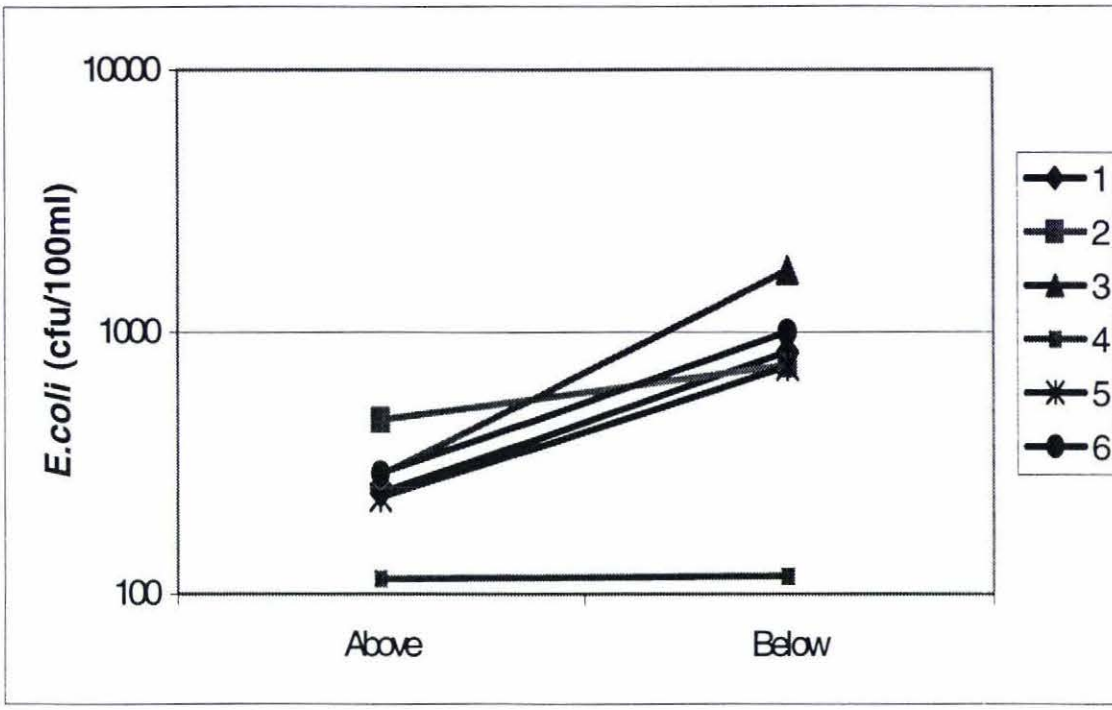

Figure 3.1: *E.coli* levels above and below six effluent discharges (geometric mean of seven samples at each site).

DRP levels (Fig 3.2) also increased below discharges in five out of the six paired sites, with particularly large increases associated with discharges 1, 3 and 6, the latter two of which are drain sites.

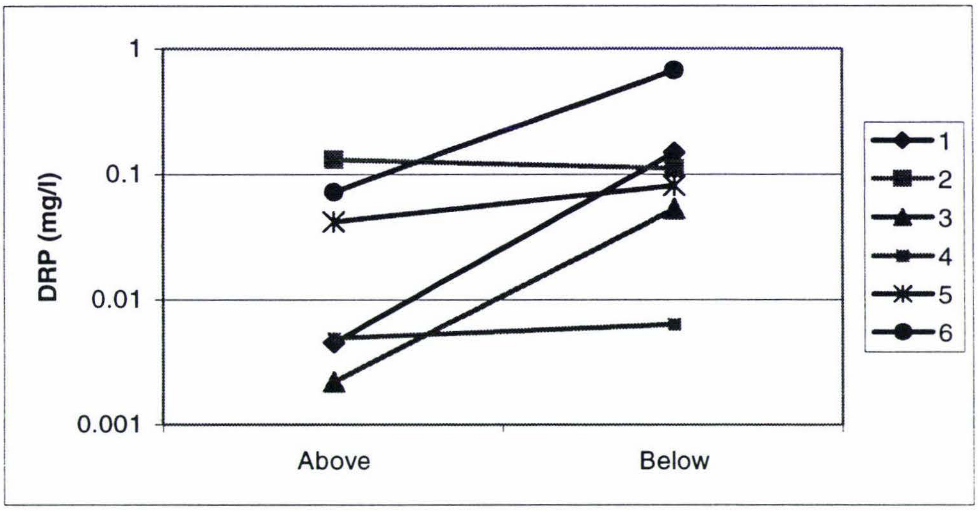

Figure 3.2: DRP levels above and below six effluent discharges (geometric mean of seven samples at each site).

Nitrate levels (Fig. 3.3) increased below five out of the six discharges (the same five as DRP). The increase was relatively small in all but the MangaAtua drain site (6), but was a significant increase overall.

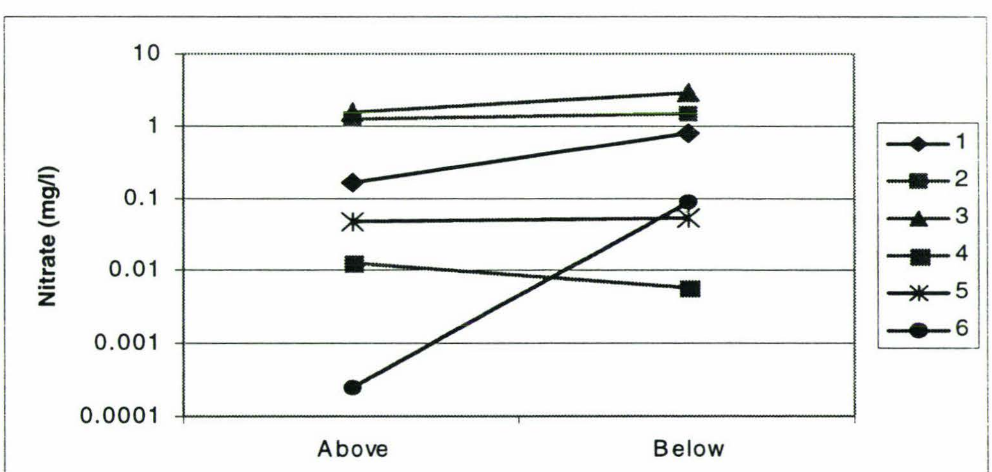

Figure 3.3: Nitrate levels above and below six effluent discharges (geometric mean of seven samples at each site).

Ammonia showed increases below all discharges, with 1000-fold increases in drains (Fig. 3.4).

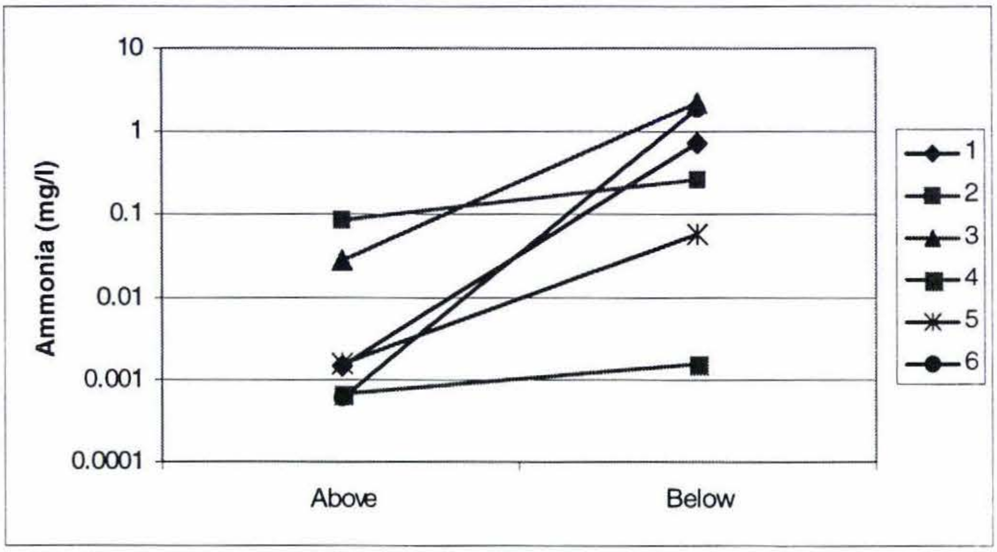

Figure 3.4: Ammonia levels above and below six effluent discharges (geometric mean of seven samples at each site).

Turbidity increased below all discharges (Fig. 3.5). Drains showed the biggest increase.

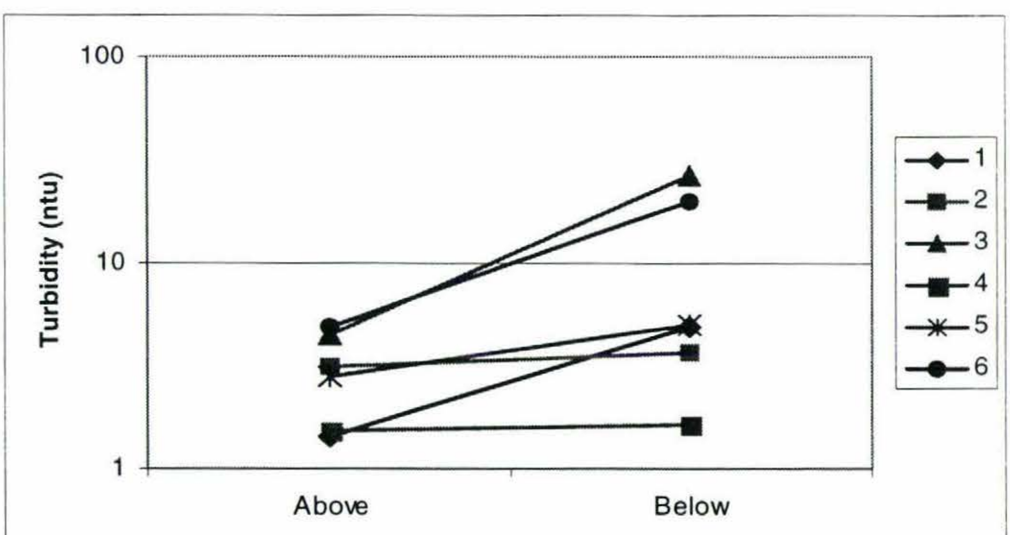

Figure 3.5: Turbidity levels above and below six effluent discharges (geometric mean of seven samples at each site).

Figure 4.6 shows conductivity increased below discharges in each pair of samples.

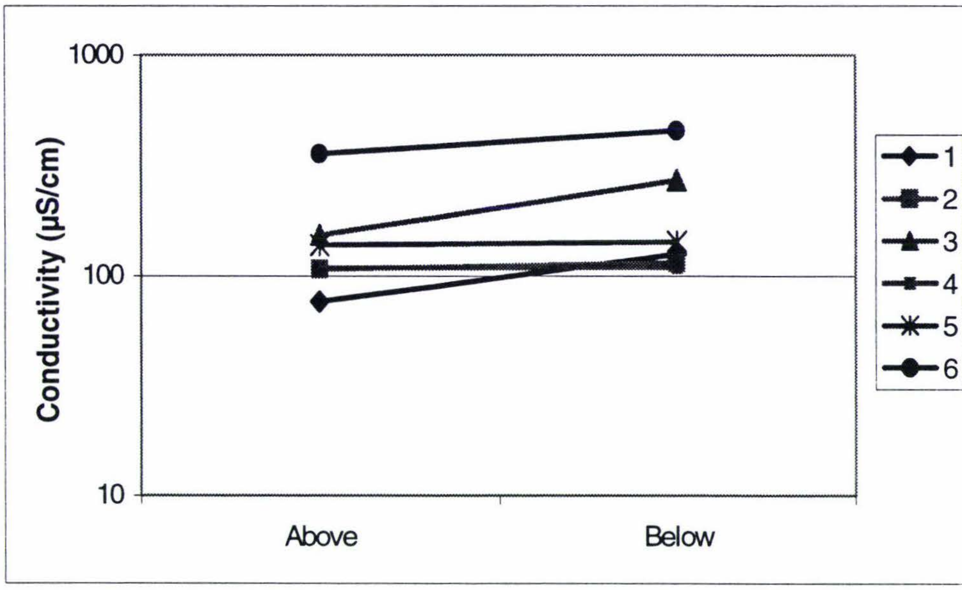

Figure 3.6: Conductivity levels above and below six effluent discharges (geometric mean of seven samples at each site).

Periphyton

Periphyton levels (measured as chlorophyll-a) decreased below discharges in three out of four cases (Figure 3.7). This was a significant overall change.

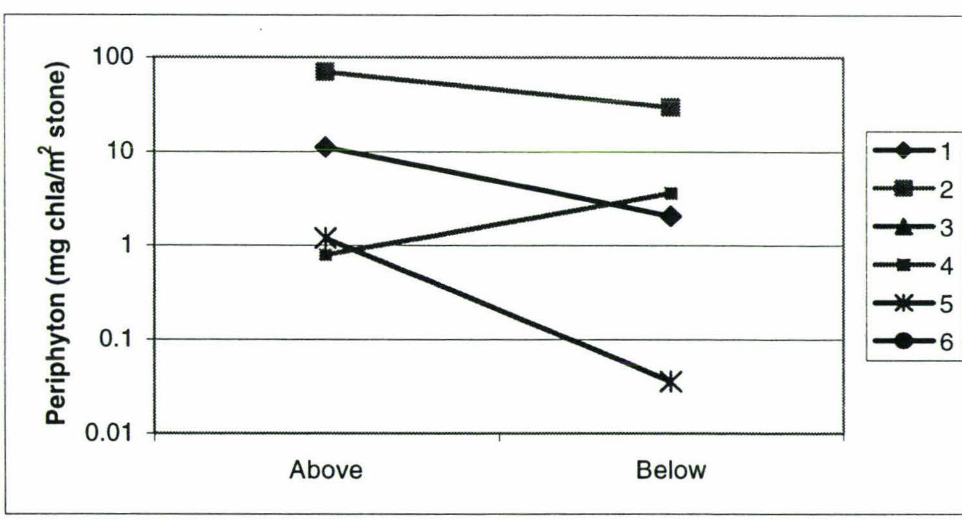

Figure 3.7: Periphyton levels above and below four effluent discharges (geometric mean of seven samples at each site).

Temperature, dissolved oxygen and pH did not show a significant change (neither increase nor decrease) associated with the discharge (refer Table 3.3).

Discharges four and five, in the MangaAtua catchment, show less change than discharges one and two (Otamaraho catchment). The drains (discharges three and six) frequently show large changes below a discharge. This is especially clear in the graphs for ammonia and turbidity. The catchments also vary in the background levels of contaminants. The Otamaraho Stream has higher base levels of *E.coli*, DRP and nitrate, while the drains had notably higher levels of ammonia, turbidity and conductivity.

Invertebrates

An ordination by detrended correspondence analysis did not clearly separate above and below sites (Fig.3.8). However the paired sites show a consistent change in community structure in the direction of axis one. However this difference is not as large as the overall variation amongst sites.

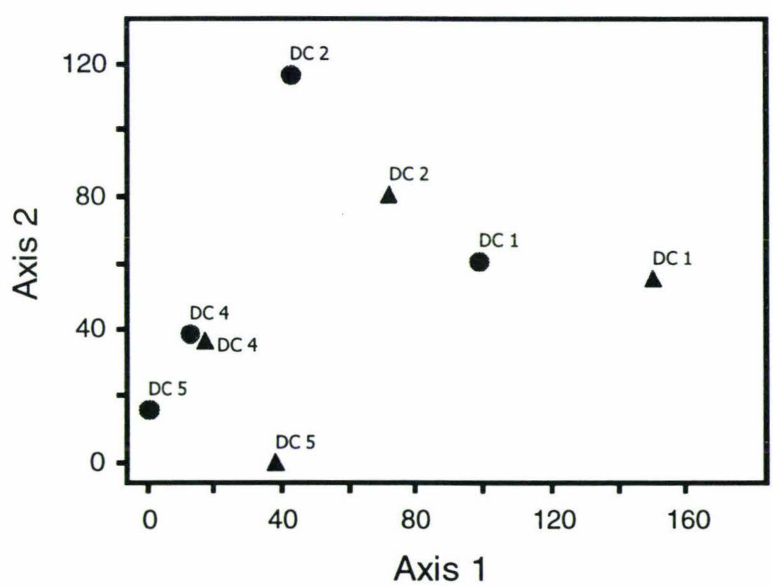

Figure 3.8: Ordination of log transformed macroinvertebrate data by detrended correspondence analysis from sites above and below discharges (circle and triangle respectively). DC = discharge number.

Most invertebrate taxa had positive correlations with axis one (Appendix Two) indicating a general increase in the invertebrate density across the ordination. In addition, most taxa with high positive correlations (>+0.7) are low scoring taxa in the MCI biotic index, indicating a preference or tolerance of organic enrichment (Stark 1985).

Axis two (Fig.3.8) separates the two catchments with discharge one and two (Otamaraho Stream) higher than discharge three and four (MangaAtua Stream). However, there are no obvious patterns in the taxon correlations with axis two (see Appendix Two).

Indicator species analysis found no significant indicator species for the above/below comparison. In other words there were no species found consistently in only above or only below sites.

A Multiple Response Permutation Procedure (MRPP) found that the difference in invertebrate assemblages between above and below sites was not significant, with a p-value of 0.92. However a blocked MRPP was almost significant (p=0.062). This is consistent with the ordination in Fig 3.8. Samples from above or below discharges are in general not more similar within the groups compared to between groups, but there is a consistent difference in community composition within paired sites.

While MCI scores generally decreased below discharges (Table 3.5), this was not significant (paired t-tests p=0.23). The exception to the general decrease was discharge five - the Woodville oxidation pond discharge. A paired t-test of the above/below difference in MCI for just the three dairy pond discharges was highly significant (p=0.009).

The Quantitative MCI (QMCI) showed a decrease from above to below sites for all discharges, however this was not significant in a paired t-test (p=0.19).

The percentage of EPT taxa showed the same pattern as the MCI – three out of four sets of discharges showing a decrease below the discharge. Again, the Woodville oxidation pond discharge was the exception. A paired t-test of the three dairy shed discharges was significant (p=0.03).

Shannon diversity, number of taxa and total number of invertebrates did not show any consistent pattern, with both increases and decreases between paired sites. The paired t-tests showed no significant change.

Table 3.5 Results from invertebrate samples above and below effluent discharges (discharge 1&2 are to Otamaraho Stream; 4&5 are to MangaAtua Stream).

Discharge No.	**1**		**2**		**4**		**5**	
Above/Below	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
MCI	104.83	93.33	112.5	102.14	120	109.09	104	110.59
QMCI	5.89	4.69	4.81	4.52	6.93	6.86	6.31	6.13
%EPT	49.03	43.17	40.68	33.62	55.29	51.51	27.16	28.72
Shannon Diversity	3.19	3.26	2.70	2.88	1.61	1.55	1.51	1.74
Number taxa	29	33	24	28	14	11	20	17
Total No	3049	4709	3380	2986	888	1058	4138	3489

DISCUSSION

The choice of sample sites close to the discharge ensured that the discharge was the only difference between the paired samples, with no tributaries or changes in stream characteristics between sites.

Water Quality

Each of the laboratory-tested variables (*E.coli*, DRP, nitrate, ammonia and turbidity) were significantly different below the discharge compared to above. This shows that the discharge had an impact on water quality in the short distance sampled. Hickey and

Rutherford (1986) cite a number of studies on the impacts of waste discharges on rivers with similar findings. The wastes in their review were from factories, meat works and sewage discharges and in a number of instances filamentous algae proliferated from raised nutrient levels.

Interestingly, of the field-measured variables only conductivity and periphyton were significantly different between the above/below paired comparison. Thus the discharges do not appear to have had an impact on the daytime instream temperature, dissolved oxygen, or pH.

All water quality variables (both lab and field) differed among the three catchments as seen in the ANOVA results and the graphs. This is likely due to the varied hydrological factors such as flow, groundwater influence and rainfall, as well as soil type, vegetative cover, substrate and plant species present.

The above/below factor in the model had a significant interaction with catchment for DRP, ammonia and turbidity. Thus the level of change of the variables in the above/below comparison is more obvious in some catchments than others. This was expected due to differences in the size of receiving streams and thus dilution rates. Drains were of poor water quality even above discharges, with relatively stagnant flow conditions. Ministry for the Environment (1999) state that farm drains can conceivably become part of the treatment process for dairy shed effluent and that councils could allow discharges to them if the risks are managed. However, in this instance the effluent decreased the water quality in the drains significantly for many variables and the assimilation and dilution prior to entering the streams may not have been enough to compensate for the water quality deterioration.

In contrast to the laboratory-tested data, no field data shows an interaction between the above/below factor and catchment. The lack of an interaction with conductivity would seem to rule out different dilution factors as the cause of other interactions. However the three discharges (2, 4 and 5) that generally showed smaller (or even opposite) effects with

E.coli, DRP, nitrate, ammonia and turbidity also had minimal impact on conductivity (see Fig 3.6). So although not statistically significant, the overall pattern for conductivity is the same as other water quality variables.

DRP and ammonia showed variation among discharges in this study. Irrespective of catchment, there were differences in the impact of individual discharges for these two variables. Visually, individual discharges appeared to vary from an infrequent trickle to a steady flow. In particular the Otamaraho stream had one very large consistently flowing discharge and one discharge which was very small and intermittent. Hickey et al. (1989) found that each effluent treatment pond can be different, even within the same region, for some or all variables. In that study the variability between pond effluent (measured at the outfall) was very high for some variables, for example between-pond differences of nitrate were 1270-fold, bacteria 2700-fold and ammonia 27-fold. However the difference was much lower for DRP with less than 10-fold differences in Hickey's study. This is quite low compared to this study where DRP has a greater than 100-fold variability between discharges. Part of the difference could be the variation in stream dilution and assimilation capability, which would not be a factor when measuring the outfall as in the Hickey study.

Variation in ponds may be due to the size of ponds relative to the effluent volumes, residual time in ponds, algae present (Sukias et al. 2001), whether stormwater has been diverted away from the ponds (Gibson 1995), the amount of seepage and evaporation loss (Sukias et al. 1996) and frequency of sludge removal. Sukias et al. (2001) also found a large variability when comparing ponds both within and between regions. Manawatu ponds had higher temperature, pH, conductivity, DRP and ammonia than the other four regions studied and the lowest DO.

Periphyton

Periphyton levels decreased in three out of the four discharge sites. Only discharge four showed an increase in periphyton and this was the site that consistently showed the greatest impact on other water quality measures (*E.coli*, DRP, nitrate, ammonia and turbidity). Increased nutrient levels were expected to result in an increase in periphyton, as found by Welch et al. (1992) downstream of domestic sewage, dairy factory waste and slaughterhouse effluent discharges. Riparian shade, macroinvertebrate grazer densities and unsuitable attachment surfaces can affect periphyton biomass (Welch et al. 1992), but these factors could not account for the reductions seen in the present study as the paired sites did not vary in these characteristics.

The decrease in periphyton below discharges in this study could be due to the sediment in the discharges (a significant increase below discharges) reducing light penetration and/or smothering the algae growth. Wrigley (1990) notes that ammonia is toxic for a wide range of algal species. Thus high ammonia levels in the effluent discharge may have limited photosynthesis and reproduction of algae below the outfall.

Invertebrates

The ordination demonstrated that there are catchment or site specific differences in invertebrate communities but no clear separation of communities above and below discharges. There was an apparent trend towards increased numbers of taxa tolerant of organic enrichment in the sites downstream of discharges, but this was not statistically significant. Statistical tests comparing biotic indices above and below discharges were also not significant.

Hickey and Rutherford (1986) analysed data from two unpublished studies and found that community structure changed close to various point source discharges in New Zealand rivers in 24 out of 31 paired sites. Twenty sites had changes to the community even 50-600 metres downstream of the outfalls. Stony rivers were generally affected both close to the outfall and further downstream.

Winterbourn (1981) note that the settling of organic matter may block interstitial spaces and affect oxygen levels, impacting on community structure. Tremblay and Wratten

(2001) investigated the impact of drenches, wash detergents, disinfectants and similar chemicals on the organisms in the pond. They suggest some that of the drenches may have an impact on invertebrate communities, but further study needs to be done to verify this.

The composition of invertebrates in the two streams studied in this thesis appeared to show a shift to taxa more tolerant of enrichment at the downstream sites with a larger number of low scoring Oligochaeta compared to upstream. There were still EPT taxa (mayflies, stoneflies and caddisflies) present downstream of most discharges, in contrast to findings by Hickey and Rutherford (1986). These EPT species present may have been present due to downstream drift, rather than having established within that site.

Conclusion

The overall results show high levels of bacteria, nutrients, turbidity and conductivity downstream of discharges. This would imply that there is some need to take the discharges out of waterways. The biological monitoring shows reduced periphyton growth below most discharges and no significant change in the invertebrate communities. The dramatic increases in contaminant levels (up to 1000-fold) are not associated with obvious changes in biological communities within the streams. The impact of the effluent is variable and depends on the characteristics of each discharge (especially for ammonia and DRP), the receiving water body and the standards expected in that area - for example drains are not meeting standards prior to the discharge.

REFERENCES

Biggs, B. J. F. (2000). "New Zealand periphyton guideline: detecting, monitoring and managing enrichment of streams." Ministry for the Environment, Wellington.

Bigham, R. (2000). "Use of policy instruments in land management and dairy farm effluent treatment: Survey of Regional Councils and dairy farmers." *BSc (Hons) thesis*, Natural Resource Management, Massey University, Palmerston North.

Boothroyd, I., Stark, J. (2000). "Use of invertebrates in monitoring." In: *New Zealand stream invertebrates: ecology and implications for management*, Collier, K. J. and Winterbourn, M. J., (eds.), New Zealand Limnological Society, Christchurch, pp. 344-373.

Dairying and the Environment Committee. (1996). "Managing dairy farm effluent." Heatley, P. (ed.), New Zealand Dairy Research Institute, Palmerston North, New Zealand.

Gibson, C. (1995). "Farm dairy effluent management." *New Zealand Dairy Exporter*, **72**, 22-24.

Giffney, A. R. (1984). "Land application." *Agricultural Waste Manual*, Vanderholm, D. H. (ed.), NZAEI, Lincoln College, Christchurch, pp. 7.1-7.29.

Hickey, C. W., and Vickers, M. L. (1994). "Toxicity of ammonia to nine native New Zealand freshwater invertebrate species." *Archives of Environmental Contamination and Toxicology*, **26**, 292-298.

Hickey, C. W., Quinn, J. M., and Davies-Colley, R. J. (1989). "Effluent characteristics of dairy shed oxidation ponds and their potential impacts on rivers." *New Zealand Journal of Marine and Freshwater Research*, **23**, 569-584.

Hickey, C. W., and Rutherford, J. C. (1986). "Agricultural point source discharges and their effects on rivers." *New Zealand Agricultural Science*, **20**, 104-110.

Longhurst, R. D., Roberts, A. H. C., and O'Connor, M. B. (2000). "Farm dairy effluent: a review of published data on chemical and physical characteristics in New Zealand." *New Zealand Journal of Agricultural Research*, **43**, 7-14.

Manawatu-Wanganui Regional Council. (1998). "Regional Policy Statement." Manawatu-Wanganui Regional Council, Palmerston North.

Ministry for the Environment. (1999). "Resource Management Act: practice and performance, a case study of farm dairy effluent managment." Ministry for the Environment, Wellington.

Quinn, J. M. (2000). "Effects of pastoral development." In: *New Zealand stream invertebrates: ecology and implications for management*, Collier, K. J. and Winterbourn, M. J., (eds.), New Zealand Limnological Society, Christchurch, pp. 208-229.

Sinner, J. (1992). "Agriculture and water quality in New Zealand." *MAF Policy Technical Paper 92/17*, Ministry of Agriculture and Fisheries Policy, Wellington.

Stark, J. D. (1985). "A Macroinvertebrate Community Index of water quality for stony streams." *Soil and Water Miscellaneous Publication No.87,* National Water and Soil Conservation Authority, Ministry of Works and Development, Wellington.

Stark, J. D. (1998). "SQMCI: a biotic index for freshwater macroinvertebrate coded-abundance data." *New Zealand Journal of Marine and Freshwater Research*, **32**, 55-66.

Sukias, J. P. S., Craggs, R. J., Tanner, C. C., and Davies-Colley, R. J. "Dairy farm pond performance and potential upgrade options." In: *Water 2000: Guarding the resource*, NZWWA, Auckland.

Sukias, J. P. S., Davies-Colley, R. J., and Tanner, C. C. (1996). "Dairy shed waste stabilisation ponds: a review of treatment processes, upgrading options and research needs." *NIWA Science and Technology Series 33*, National Institute of Water and Atmosphere, Hamilton.

Sukias, J. P. S., Tanner, C. C., Davies-Colley, R. J., Nagels, J. W., and Wolters, R. (2001). "Algal abundance, organic matter, and physico-chemical characteristics of dairy farm facultative ponds: implications for treatment performance." *New Zealand Journal of Agricultural Research*, **44**, 279-296.

Taranaki Regional Council. (1995). "Discharges to land and water strategy background report: strategy for the management of dairyshed effluent." Taranaki Regional Council, Stratford, New Zealand.

Tremblay, L. A., and Wratten, S. D. (2001). "A brief overview of the potential effects of ivermectin and chemical components of dairy discharges that may lead to endocrine disruption and other toxic effects in terrestrial and aquatic invertebrates." *Contract Report LC0102/041*, Centre for Environmental Toxicology (CENTOX), Christchurch.

Walling, D. E., and Webb, B. W. (1992). "Water quality I: physical characteristics." In: *The rivers handbook: volume I*, Calow, P. and Petts, G.E. (eds), Blackwell Scientific Publications, Oxford, U.K., pp. 61-68.

Ward, J., and Talbot, J. (1988). "Water quality management." *Information paper No. 8*, Centre for Resource Management, Massey University, Palmerston North.

Welch, E. B., Quinn, J. M., and Hickey, C. W. (1992). "Periphyton biomass related to point-source nutrient enrichment in seven New Zealand streams." *Water Resources*, **26**(5), 669-675.

Winterbourn, M. J. (1981). "The use of aquatic invertebrates in studies of stream water quality." *Water and soil publication* **22**, 5-16.

Wrigley, R. (1994). *Managing dairy-shed wastes*. Dairy Research and Development Corporation, East Melbourne, Australia.

4

Temporal and spatial influences on water quality data from two small streams, Manawatu River catchment, New Zealand

ABSTRACT

Samples collected in two small streams of a predominately dairy farming catchment in the Tararua District, New Zealand were used to analyse temporal and spatial factors influencing interpretation of water quality results. Data collected by horizons.mw (Manawatu-Wanganui Regional Council) as part of their State of the Environment (SoE) monitoring programme was also available for comparison.

Continuous monitoring with a Hydrolab datasonde below a dairy shed effluent outfall from oxidation ponds detected 24-hourly cycles in temperature and dissolved oxygen. A 12-hour cycle detected in temperature did not appear to be related to twice daily wash down of the milking shed. Conductivity was relatively constant over time except where large flushes of effluent were washed from the ponds into the waterway or during rainfall events. High spatial variation in bacteria and nutrients was detected throughout the catchments. While tributaries and point-source discharges appear to have some influence on the variation, there are other factors influencing individual site results.

Subcatchments in this study display higher levels of nutrients and lower dissolved oxygen than SoE data from three larger catchments in the area. Rainfall appears to have different effects in the each of the two catchments. High rainfall had a flushing effect on periphyton in one stream, while the other stream with little or no riparian vegetation had increased levels of bacteria after rain but no clear effect on periphyton.

INTRODUCTION

A large number of New Zealand's catchments have become subjected to more intensive farming methods. Dairy herds in New Zealand have increased by 57%

between the 1977/78 and 1997/98 seasons to 3.22 million cows, with average herd size of 220 cows (121 in 1997/98) (Anon 1998). The average stocking rate in New Zealand, as determined by a survey of 400 farmers undertaken by dexcel in July 2000, was 2.75 cows per hectare (www. Dexcel.co.nz/library_doc.cfm?id=10.cfm). The Tararua District is close to this average with 2.64 cows per hectare, with an average of 239 cows per farm.

The impact from individual dairy farms may vary depending on a range of factors. These include the physical farm characteristics (e.g. soil type, contour); how wastes are managed (e.g. point-source discharges); the presence of a riparian buffer; and the management of the farm e.g. fertiliser application and stream crossings.

It is misleading to focus on the stream or river only within a farm boundary, as stream and river systems are a continuum and activities both above and below a defined section will impact on the overall health of the waterway. Migratory fish highlight this, as they require that no physical or chemical 'barriers' exist through the length of a catchment to ensure passage into tributaries. In the lower sections of catchments there may be cumulative effects from the direct transfer of pollutants and a lower gradient creating less turbulent flows accentuating their effect. However, there may also be dilution from unimpacted tributaries and assimilation of pollutants (e.g. denitrification).

Historically the focus has been on larger rivers due to their recreational usage and higher public interest. Regular monitoring such as that for state of the environment (SoE) reporting, tends to be done at a few sites which are on large rivers. More recently attention has turned to ecosystem management which requires monitoring of whole catchments, including the smaller streams. It is not known whether monitoring a large water system is accurately detecting the state of water quality in smaller subcatchments in this region, but it is expected that there will be spatial variation due to differences in inputs and instream assimilation.

Temporal variation in water quality of streams has had limited study. While some variables such as temperature and dissolved oxygen have known daily cycles (Walling and Webb 1992), the temporal cycles or patterns of other variables at this subcatchment scale is less well known. Such temporal patterns would have consequences for the design of monitoring programs and their interpretation. For example the twice-daily washing of the each dairy shed would provide a pulse of effluent to ponds. If ponds are full to capacity, this may follow through to create distinct pulses of contaminants discharging into the stream at certain times of the day.

Factors such as rainfall can also impact on the concentration of water quality variables at any given sampling time. A number of studies such as horizons.mw (2001) have found that levels of bacterial contamination are elevated during rainfall events due to surface runoff. Other water quality parameters such as conductivity could be expected to decrease during high flows due to dilution (Allan 1995).

This study investigates the temporal and spatial changes in water chemistry of two small streams in the Manawatu catchment and compares them to the water quality in the river they flow into. It also investigates the impact of rainfall on water quality parameters and periphyton.

METHODS

Study area

The study was carried out in streams and farm drains of the Otamaraho and MangaAtua catchments, Tararua District, New Zealand. See Chapter Two for more details.

Data collection

Water samples were collected at each of the 22 sites on seven occasions at four-day intervals from 7 February 2001 to 3 March 2001 inclusive. *E.coli*, DRP, nitrate, ammonia and turbidity were analysed.

Field measurements of temperature, conductivity and dissolved oxygen were made using portable meters during each sampling occasion. Further details are as described in Chapter Two.

In addition conductivity, temperature, pH and dissolved oxygen were measured by a water quality multiprobe datalogger (Hydrolab datasonde) every half-hour from 15 February to 3 March 2002 at site O2 in the Otamaraho Stream. This site was approximately 8 metres downstream of a large, permanently flowing discharge from a dairyshed effluent treatment pond (twin-pond system). The hydrolab was calibrated as per the manufacturers instructions before the sampling period using two point pH calibration (pH 7 and 10); single point calibration using standard solution for conductivity and water saturated air for dissolved oxygen (DO).

Rainfall data was available from sites near the MangaAtua Stream (map ref T24: 540971, Tararua Roading) and the Otamaraho Stream (Ruaroa substation, map ref T23: 682 085, horizons.mw).

Biological sampling

Three periphyton samples were taken at each site (excluding drains) on each sampling occasion, and chlorophyll-a extracted. Refer to Chapter Two for more details.

Data analysis

Periodic variation in temperature, dissolved oxygen and conductivity data was investigated by fourier decomposition following removal of any linear trend (SYSTAT version 8.0). As samples were taken half-hourly, each day was made up of 48 samplings.

To illustrate spatial variation the probability of guidelines being exceeded at each site was estimated from a Normal Probability Plot with linear smoothing for each variable. The E.coli guideline was the 410cfu/100ml single sample maxima from Ministry for the Environment (2002) and the DRP guideline of 0.015mg/l is from the Manawatu Catchment Water Quality Regional Plan (Manawatu-Wanganui Regional Council 1998). Diagrammatic sketches of the two catchments show these probabilities (Fig. 4.7 & 4.8).

The study data (excluding that from drain sites) was compared to data from horizons.mw's "State of the Environment" (SoE) monitoring programme (data from horizons.mw's water quality database, as at October 2002). The rivers and streams are in the same vicinity as the study area. The Tamaki River is situated immediately north of the Otamaraho Stream and the two sites are at the headwaters and at State Highway 2. The Mangatera Stream is further north again and the SoE site is below the Dannevirke municipal oxidation pond discharge. The site on the Manawatu River, into which all these other waterways flow, is between the Otamaraho and MangaAtua Stream inflows. SoE data from the same time period (February to March), but between 1998 and 2002, was used as this is expected to be during similar low flow periods.

RESULTS

Temporal variation

Temperature

Figure 4.1 shows a distinct daily cycle in temperature of +/- 1-2 °C and a general trend of decreasing temperature during the sampling period.

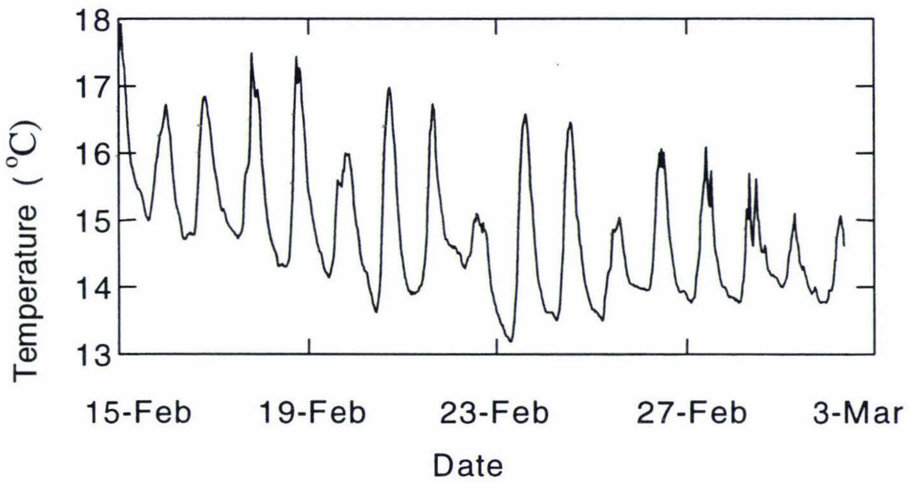

Figure 4.1: Time plot of temperature (untransformed data), for the period 15 February to 3 March 2001.

Fourier analysis (Fig. 4.2) shows a strong peak corresponding to a 24-hour cycle (1/48 half-hourly intervals=0.021) and a much smaller peak corresponding to a 12-hour cycle (frequency=0.042). The 24-hour cycle has an amplitude of +/- 0.96°C and the 12-hour cycle an amplitude of +/- 0.25°C. Because of the phase differences of the two cycles, the 12-hour component adds to the mid-afternoon peak making it more acute than a pure sine wave and truncates the night-time lows (see Fig.4.1). If the 12-hour cycle was due to the twice-daily milking cycle it would mean there was a time delay of approximately six hours from dairy wash-down to impact on the streams.

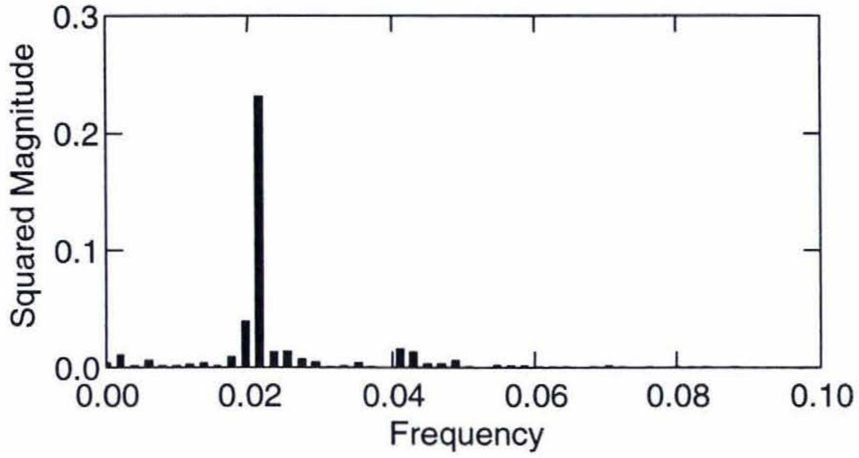

Figure 4.2: Periodogram of temperature following removal of linear trend.

Dissolved oxygen

Figure 4.3 shows a daily cycle similar to that of temperature but with a longer-term cycle superimposed and some erratic variation from day to day. While there were some daily trends in the levels of dissolved oxygen, there was still a large amount of variation between days.

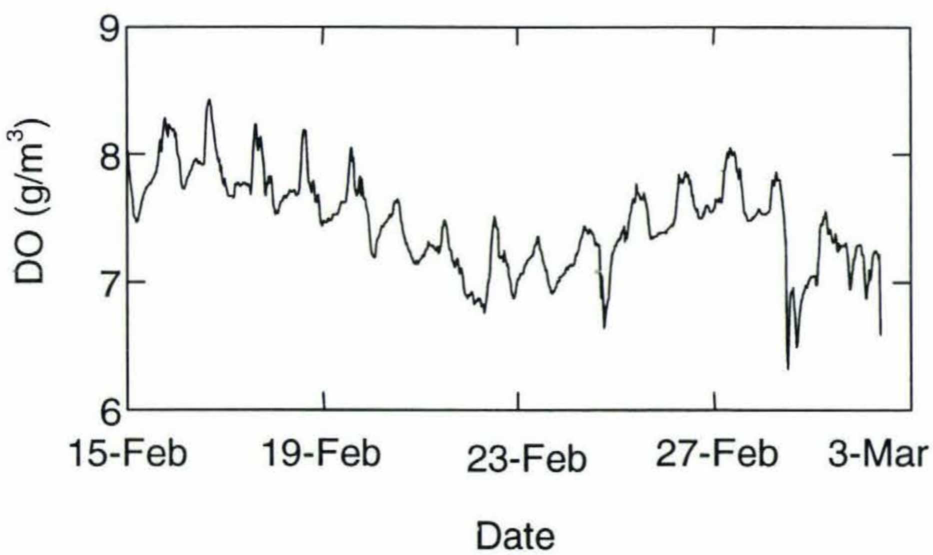

Figure 4.3: Time plot of dissolved oxygen (untransformed data) for the period 15 February to 3 March 2001.

The periodogram (Fig 4.4) shows a cycle of 10.7 days or every 256 hours. The smaller spike, near frequency 0.02, is a 24 hourly cycle but there is no clear indication of a 12-hour cycle.

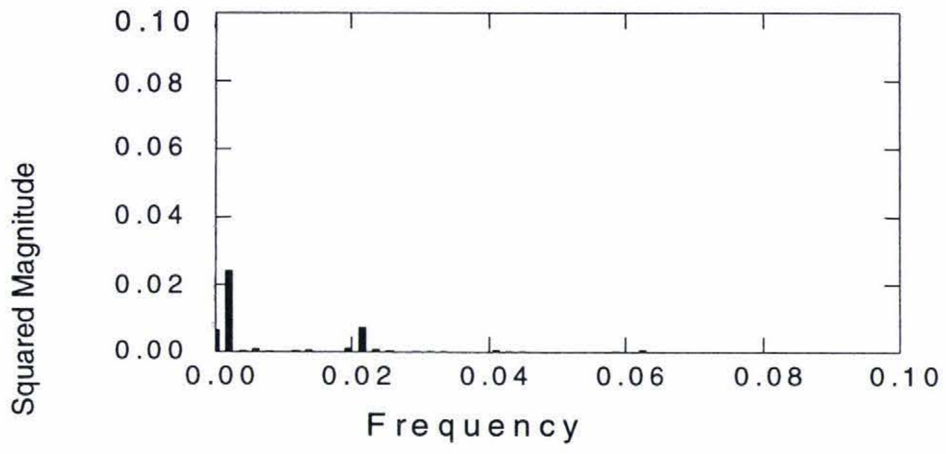

Figure 4.4: Periodogram of dissolved oxygen following removal of linear trend.

Conductivity

Figure 4.5 shows no obvious cyclical pattern with conductivity, however there are two 'peaks' over the time period measured, around the 23rd February and 2nd March 2001.

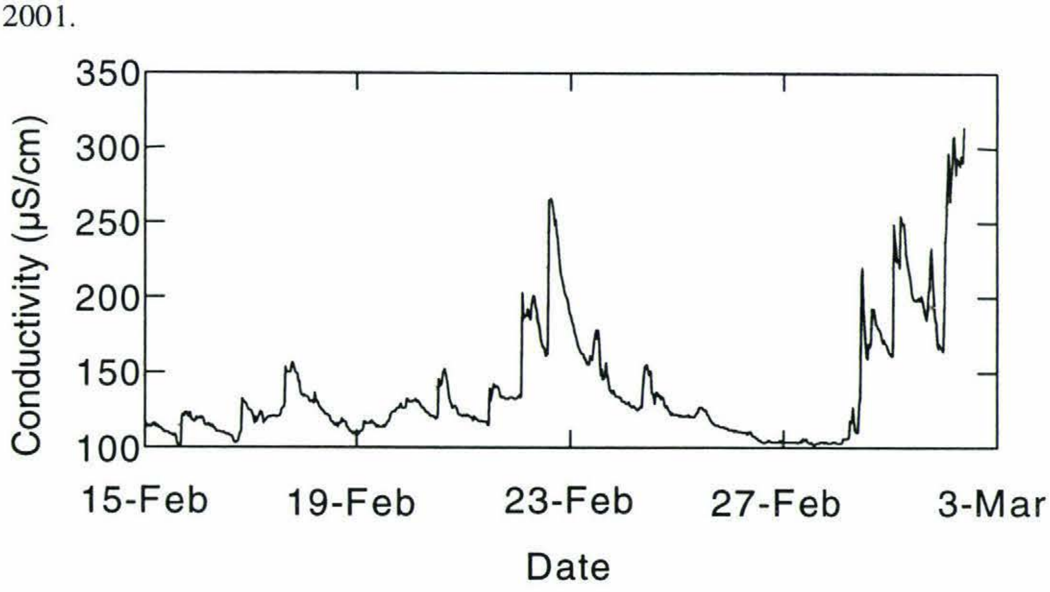

Figure 4.5: Time plot of conductivity (untransformed data) for the period 15 February to 3 March 2001.

The periodogram (Fig.4.6) shows a broad peak at low frequency corresponding to approximately five-day cycles (matching the peaks on 18 and 23 February, and 2 March). There is also a 24 hourly cycle at frequency 0.02, however this has relatively low magnitude corresponding to +/- 6 μS/cm.

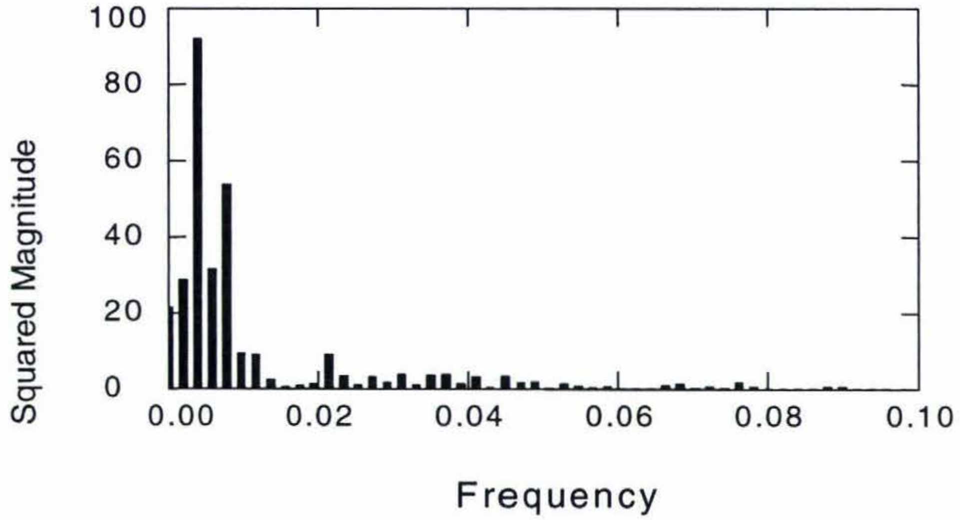

Figure 4.6: Periodogram of conductivity following removal of linear trend.

Spatial variation

E.coli

Figure 4.7 indicates that there is variation in the percentage of *E.coli* samples exceeding the guideline between and within the catchments. The levels are generally higher immediately below point-source discharges (arrows). In particular the drain on the true left of the Otamaraho Stream, and the oxidation pond discharge at the bottom of the MangaAtua Stream increase bacteria to levels where guidelines are always exceeded. However other increases occur with no obvious source (e.g. between two sites in the lower MangaAtua Stream the level increased from 60 to 74%).

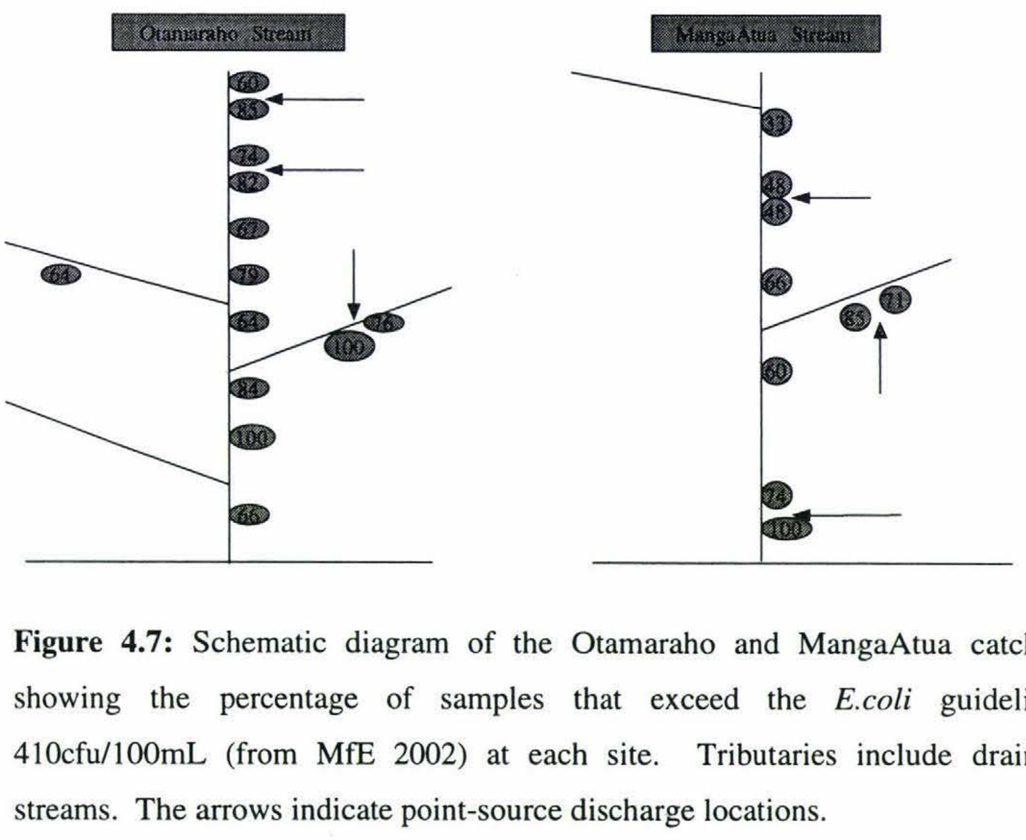

Figure 4.7: Schematic diagram of the Otamaraho and MangaAtua catchments showing the percentage of samples that exceed the *E.coli* guideline of 410cfu/100mL (from MfE 2002) at each site. Tributaries include drains and streams. The arrows indicate point-source discharge locations.

DRP

DRP levels in both streams are influenced by point-source discharges, however there are reaches in which DRP increases where no point discharges are known.

The Otamaraho Stream has fluctuations in DRP levels down the catchment. The MangaAtua Stream has a clear increase down the catchment.

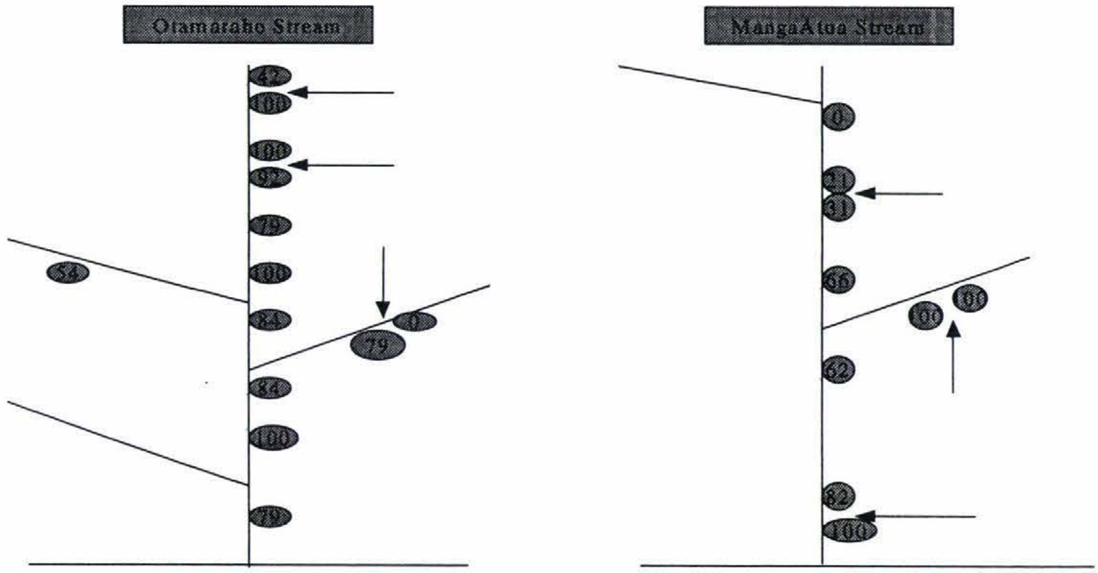

Figure 4.8: Schematic diagram of the Otamaraho and MangaAtua catchments showing the percentage of samples that exceed the DRP guideline of 0.015mg/l (MCWQRP) at each site. Tributaries include drains and streams. The arrows indicate point-source discharge locations.

Catchment variation

DRP and Nitrate

Figure 4.9 shows the difference in average nutrient levels between the two catchments sampled in this study (MangaAtua and Otamaraho Streams) and three waterways sampled regularly as part of the State of the Environment (SoE) monitoring by horizons.mw. The Otamaraho Stream has high levels of nitrate in particular, but also higher DRP than all but the Mangatera Stream. Nitrates in the Manawatu River site are relatively high compared to the Tamaki River.

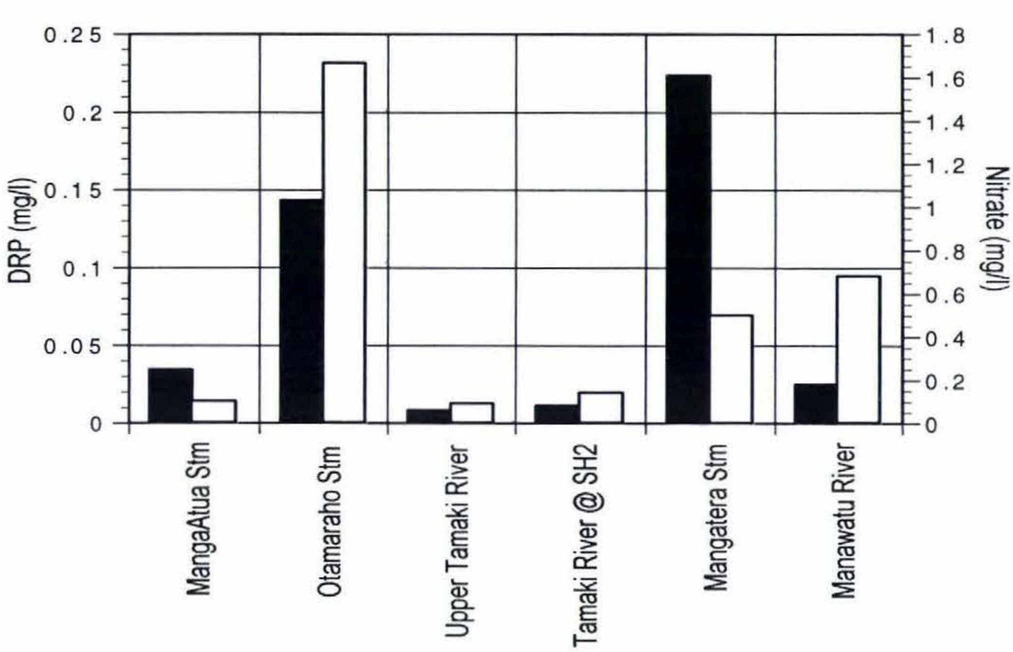

Figure 4.9: Comparison of average DRP (dark solid) and nitrate (grey) concentrations in streams and rivers of the Manawatu Catchment.

Conductivity

Figure 4.10 shows conductivity measurements in the study streams were average compared to SoE monitoring data, with readings of 120 μS/cm in the MangaAtua Stream and 105 μS/cm in the Otamaraho Stream. The average conductivity readings in the Manawatu River are higher than the others measured by horizons.mw in this area at 220 μS/cm.

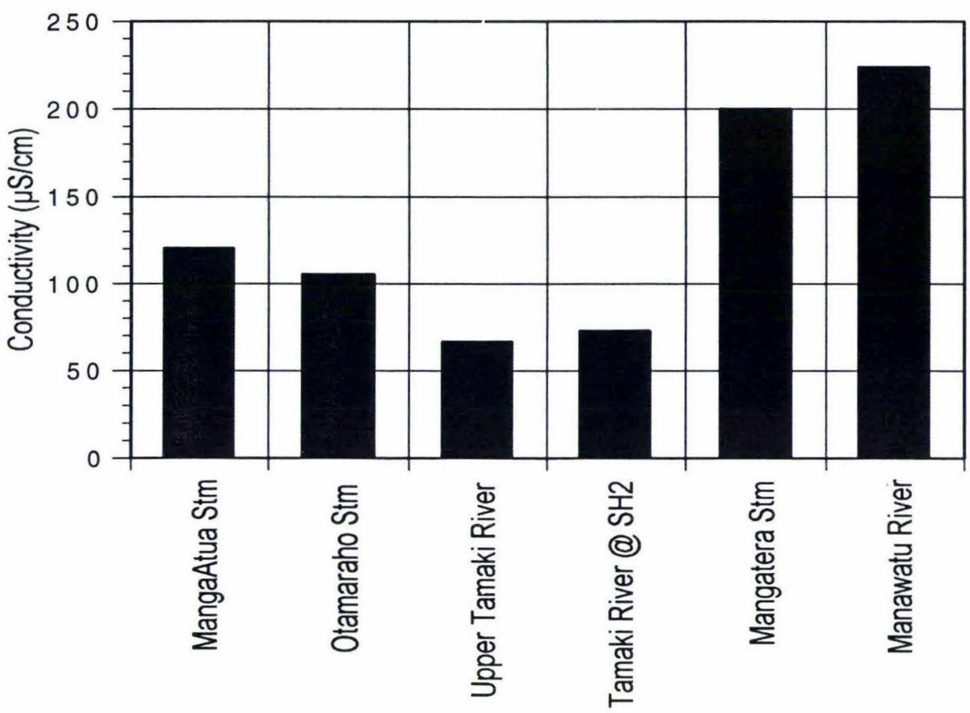

Figure 4.10: Comparison of average conductivity in streams and rivers of the Manawatu Catchment.

Dissolved oxygen

Dissolved oxygen levels in the study streams are slightly lower than in the other waterways measured by horizons.mw. The Manawatu River has slightly poorer DO than the Tamaki River or the Mangatera Stream. However all variation is relatively small, with all DO levels within accepted guidelines.

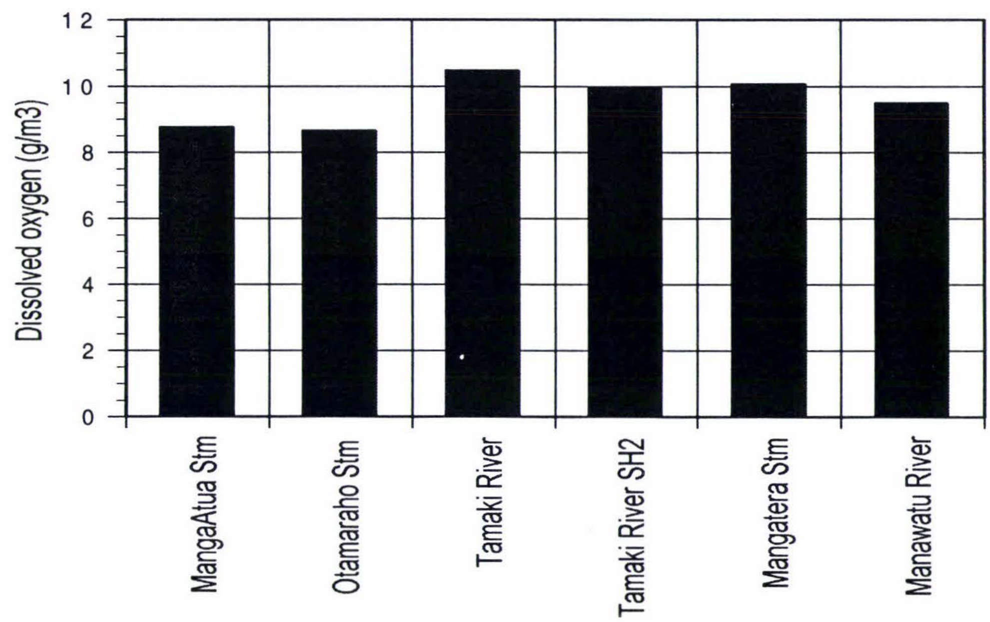

Figure 4.11: Comparison of average dissolved oxygen in streams and rivers of the Manawatu Catchment.

Influence of rainfall

E.coli

The E. coli levels in the Otamaraho Stream showed some relationship with rainfall levels. High rainfall, particularly in early March, corresponds with high bacteria counts.

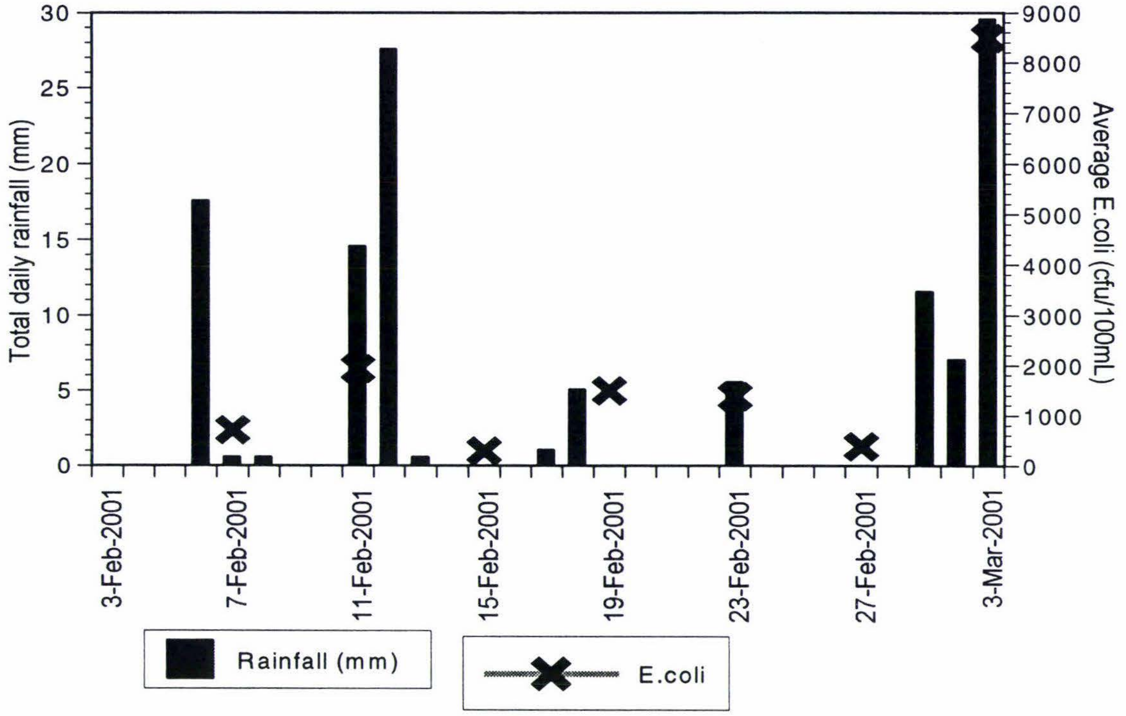

Figure 4.12: Average *E.coli* in the Otamaraho Stream (9 sites per date) shown with daily total rainfall from the catchment.

Rainfall is less correlated with *E.coli* levels in the MangaAtua Stream (Fig.4.13). A high rainfall event on 11 February did not result in as high bacteria levels as in the Otamaraho Stream, nor as high as during a much smaller rainfall event (for this catchment) in early March.

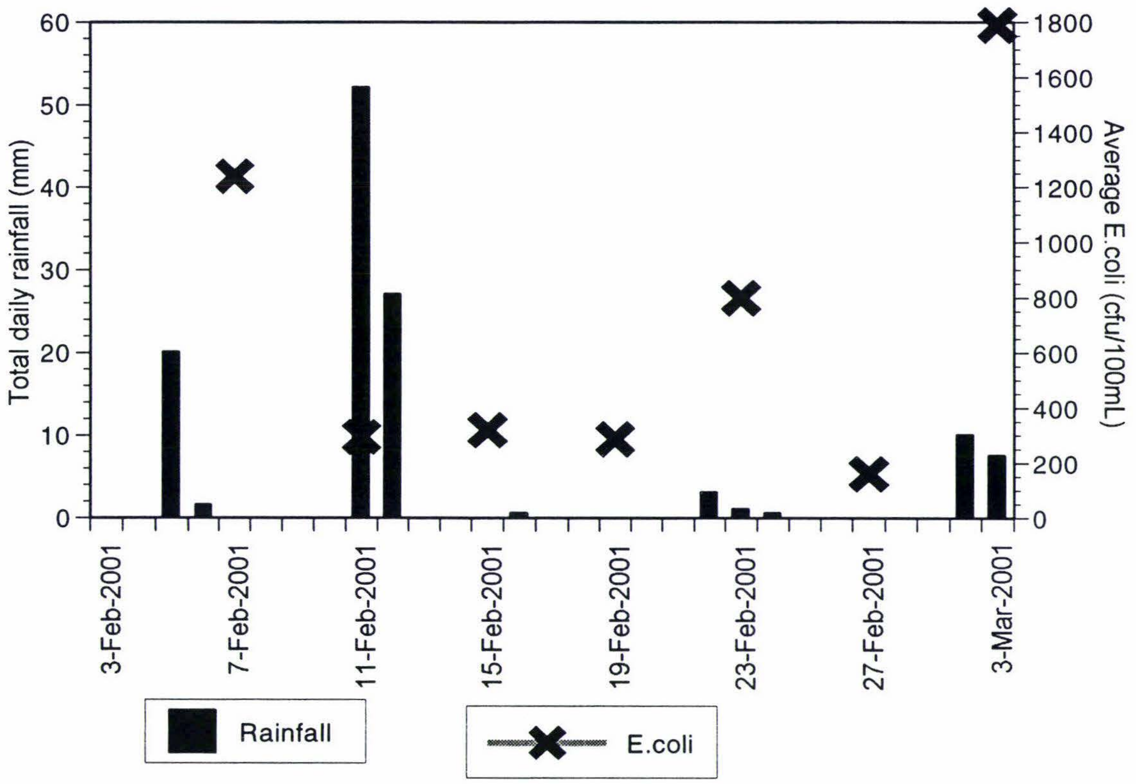

Figure 4.13: Average *E.coli* in the MangaAtua Stream (7 sites per date) shown with total daily rainfall from the catchment.

Periphyton

There did not appear to be a pattern between rainfall and periphyton levels (measured by chlorophyll-a) in the Otamaraho Stream. After a large rainfall event of 42 mm on the two-day period of 11th and 12th February 2001, the periphyton levels continued to increase, peaking on 14 February 2001. There was a rapid decrease in periphyton levels following this date, however this was not associated with a rainfall event.

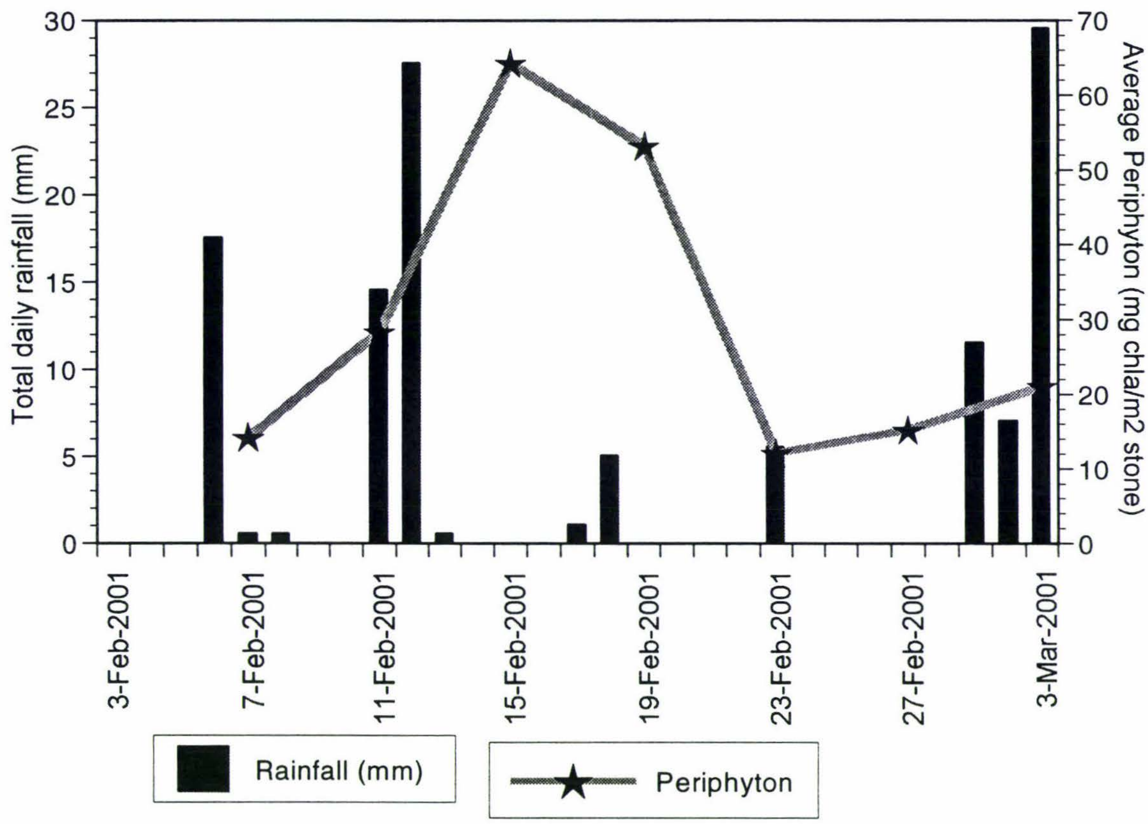

Figure 4.14: Average periphyton in the Otamaraho Stream (9 sites per date) shown with rainfall data from the catchment.

The MangaAtua Stream does show some influence of rainfall on periphyton. As can be seen from Fig 4.15, a large rainfall event occurred over 11 and 12 February 2001, after which low levels of periphyton were present. In late February and early March (a period with no significant rain in this catchment) levels of periphyton increased quickly.

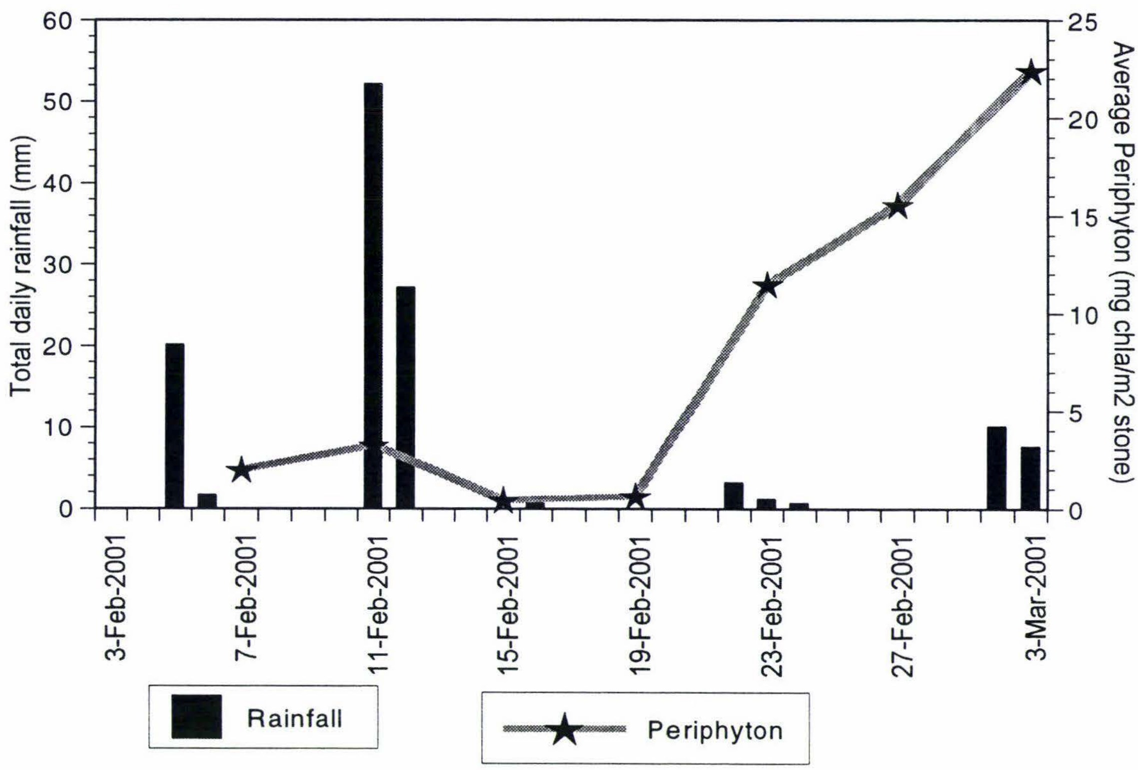

Figure 4.15: Average periphtyon in the MangaAtua Stream (7 sites per date) shown with rainfall data from the catchment.

DISCUSSION

Temporal variation

The time plots show a clear diurnal pattern in temperature as measured between 15 February and 3 March 2001. This is also demonstrated in the periodogram, with both 12 and 24-hourly cycles. The 24-hour cycle is consistent with Walling and Webb (1992) who note that the summer diurnal cycle is clearer than in winter. Wilcock and Nagels (2001) found that temperature, dissolved oxygen and pH had clear diurnal variation, the extent of which differed between catchments.

Temperature was the only variable to show a 12-hourly cycle, which was expected to correspond to the twice-daily washing down of the milking shed. It is unlikely that the 12-hourly cycle in temperature did relate to the wash down because of the long time lag and also because the same cycle was not seen in conductivity or oxygen levels. Unfortunately, discharge two was one of the discharges that did not produce an increase in conductivity (see Chapter 3). The 12-hour cycle in temperature is more likely due to midday heating by direct sunlight and slower heat loss to air at night resulting in asymmetry in the cycle.

Prior to transformation, the T-plot for temperature showed a general decrease over time. This could be due to a period of cooler weather, with air and water temperature having a strong linear relationship (Walling and Webb 1992), or possibly instrument calibration drift.

The diurnal pattern in dissolved oxygen is less consistent than temperature. Thus while there is a daily pattern apparent in Figure 4.3, it is subject to fluctuations. This is consistent with Walling and Webb (1992) who found that the amount of diurnal variation in oxygen levels fluctuates due to flow rate and temperature.

The clearest pattern in dissolved oxygen was a 256 hourly cycle (10.7 days) which does not correspond with a known cycle of events but could be due to instrument calibration drift.

The time plot of conductivity (Fig.4.5) shows levels remain relatively stable over time, but with two major fluctuations. These are not cyclical, but extreme results. The reason for the first increase is not known although it was noted that there was a high flow coming out of the effluent ponds just upstream of the hydrolab site on the 23rd February. Examples of factors that may cause extra discharge into the waterway are more water being used to wash down the shed than is usually required, higher rainfall on the previous day (in this case 5.5ml), or pond disturbance. The farmer had the dairy shed effluent ponds upstream cleaned out by mechanical digger at the time of the second peak, the disturbance causing an overflow into the stream. These 'extreme' events causing pulses of effluent to enter the stream shows that individual farm management can have an impact on the timing and severity of contaminants entering streams at specific sites in the catchment.

Conductivity measurements show no daily pattern. There is no clear 'pulse' of dairy shed effluent, of which conductivity is an indicator, entering the waterways twice per day as anticipated (Sukias 1996). The cowsheds are washed down with water after both morning and evening milking, which could cause ponds that are full to capacity to discharge the equivalent amount of treated wastewater from the pond to the stream. However even though the ponds above the hydrolab were relatively full there was no evidence of these pulses. This could be due to evaporation from the pond maintaining them below capacity (Sukias 1996), or leakage to ground (Ray et al. 1995).

These results would imply that in the Otamaraho Stream there is no need to schedule sampling to avoid temporal 'pulses' of contaminants flowing down streams, except during major disturbances to the pond system.

Spatial variation

Point-source discharges have a large impact on DRP and *E.coli* and increase the likelihood of a guideline being exceeded in these two catchments.

In the Otamaraho Stream, a single monitoring site for *E.coli* and DRP at the downstream end would show a high rate of samples exceeding guidelines, but not the extremely high peak levels found at some other locations further up the stream. Conversely a single monitoring station in the lower MangaAtua Stream would suggest severe impact in the catchment but, apart from the drain, the levels of *E.coli* and DRP are not as bad upstream.

Catchment variation

Comparing the study subcatchments to other streams and rivers in the Manawatu catchment showed that the Otamaraho Stream had much higher levels of nutrients than the rivers. In particular it was very high in nitrate, while the Mangatera Stream (a SoE site) had higher DRP which is as expected due to a discharge of sewage from the Dannevirke township. The high nitrate in the Otamaraho Stream is likely due to the groundwater influence as discussed in Chapter Two.

The MangaAtua Stream has relatively low levels of nutrients, especially nitrate which is lower than the Manawatu River into which it flows. This would indicate that monitoring in the Manawatu River, while picking up some level of eutrophication is not detecting the high levels of either DRP or nitrate in some of the smaller catchments (the Otamaraho and Mangatera Streams). It is likely that assimilation and dilution processes in the distance between the sampling points and the streams entering the Manawatu River account for this.

The smaller streams studied showed intermediate levels of conductivity – more than the Tamaki River but less than the Mangatera Stream and the Manawatu River.

Conductivity is generally seen as a good indicator of effluent and nutrients in streams (e.g. Hickey 1989, Sukias 2001), and the SoE monitoring is obviously detecting high levels in the Manawatu River. This higher conductivity in the Manawatu River is also likely influenced by the catchment geology on the east of the catchment.

The dissolved oxygen levels, while showing the study streams as being slightly poorer quality than the other sites monitored, are not significantly different. Therefore the SoE monitoring appears adequate for detecting overall levels in the smaller streams.

Influence of Rainfall

Biggs et al. (1998) describe rainfall as probably the single most important influence on stream life. The Otamaraho Stream generally had elevated levels of *E.coli* following rainfall. This catchment has very limited riparian margins and during rainfall there is little impedance to overland flow. Thus bacteria, such as from cow-pats remaining in the paddock or in stream beds could enter the waterway when high flow occurs (Sinner 1992). The MangaAtua Stream showed lower levels of bacteria in general and no peaks associated with rainfall.

The MangaAtua Stream, being a predominantly rain-fed waterway, appears to show an impact from high rainfall on periphyton sloughing. In shallow streams, such as the MangaAtua, the scouring effect on periphyton from higher flows is expected to be the most important limitation (Welch and Lindell 1992). This has implications for algae management in the MangaAtua Stream, with likely buildups when there is little rainfall. There were also large variations in periphyton in the Otamaraho Stream however these were not related to rainfall events.

Conclusion

There are a number of influences on stream water quality results. This chapter has addressed a number of potential influences. The hydrolab data showed diurnal patterns in temperature and dissolved oxygen, which are natural cycles. There was a 12-hourly pattern in temperature however this did not appear to be associated with twice daily wash down of the milking shed. Patterns over longer time frames were found for conductivity and dissolved oxygen, which appear to be a coincidence of unrelated events. Thus sampling to avoid the temporal fluctuations in dairy shed effluent discharges was not important but having consistent sample timing or multiple/continuous sampling may be more important. The variation down the catchment length shows impacts from point-source discharges as well as other fluctuations due to reasons not determined by this study. Therefore individual farm management appears to have a clear influence on results from specific sites and spot testing of water quality may not accurately describe water quality of the whole catchment. The monitoring undertaken in the SoE programme by the regional council is detecting similar levels of conductivity and daytime dissolved oxygen as measured in the study streams but different levels of nutrients depending on catchment and farm-specific characteristics. Rainfall influences the two catchments differently, indicating that knowledge of the catchments is important when interpreting results and managing the waterway and that riparian management can have major influences on water quality variability.

REFERENCES

Allan, J.D. (1995). "Stream ecology: structure and function of running waters." Chapman and Hall, London.

Anon. (1998). "Dairy statistics 1997/98." Livestock Improvement, Hamilton.

Biggs, B., Kilroy, C., and Mulcock, C. (1998). "New Zealand stream health monitoring and assessment kit: stream monitoring manual." *NIWA Technical Report 40*, NIWA, Christchurch.

Hickey, C.W., Quinn, J.M., Davies-Colley, R.J. (1989). "Effluent characteristics of dairy shed oxidation ponds and their potential impacts on rivers." *New Zealand Journal of Marine and Freshwater Research* **23**, 569-584.

horizons.mw. (2001). "Whanganui catchment water quality." *Report 2001/EXT/467*, horizons.mw, Palmerston North.

Manawatu-Wanganui Regional Council. (1998). "Manawatu catchment wter quality regional plan." Manawatu-Wanganui Regional Council, Palmerston North.

Ministry for the Environment. (2002). "Recreational water quality guidelines: guidelines for the management of waters used for marine and fresh water recreation and recreational shellfish-gathering." Ministry for the Environment, Wellington.

Ray, D. E., Barkle, G. F., Selvarajah, N., McLeod, M., and Balks, M. R. (1995). "Seepage from dairy farm effluent treatment ponds." In: *NZWWA Annual Conference and Expo - Water Solutions*, NZWWA, Auckland, pp.141-144.

Sinner, J. (1992). "Agriculture and water quality in New Zealand." *MAF Policy Technical Paper 92/17*, Ministry of Agriculture and Fisheries Policy, Wellington.

Sukias, J. P. S., Davies-Colley, R. J., and Tanner, C. C. (1996). "Dairy shed waste stabilisation ponds: a review of treatment processes, upgrading options and research needs." *NIWA Science and Technology Series 33*, National Institute of Water and Atmosphere, Hamilton.

Sukias, J.P.S., Tanner, C.C., Davies-Colley, R.J., Nagels, J.W., Wolters, R. (2001). "Algal abundance, organic matter, and physico-chemical characteristics of dairy farm facultative ponds: implications for treatment performance." *New Zealand Journal of Agricultural Research*, **44**, 279-296.

Walling, D. E., and Webb, B. W. (1992). In: *The Rivers Handbook: Volume I*, Calow, P. and Petts, G. E. (eds.), Blackwell Scientific Publications, Oxford, U.K., pp. 61-68.

Wilcock, R. J., and Nagels, J. W. (2001). "Effects of aquatic macrophytes on physico-chemical conditions of three contrasting lowland streams: a consequence of diffuse pollution from agriculture?" *Water Science and Technology*, **43**(5), 163-168.

Welch, E.B., Lindell, T. (1992). "Ecological effects of wastewater: applied limnology and pollutant effects." (2nd Ed.). Chapman & Hall, London.

5

Synthesis

This thesis has provided information on overall water quality and biotic integrity in two streams draining predominately dairy farming catchments in the Tararua District, New Zealand. In addition the impacts of effluent discharges to water quality have been quantified. There are a number of influences affecting water quality data including temporal and spatial scales that have been investigated.

Water chemistry monitoring has shown that currently accepted guidelines are generally not being met in these dairy farm catchments. This is consistent with previous studies (Smith et al. 1993, Wilcock et al. 1998, Wilcock et al. 1999). Although chapter three showed there was a significant impact on water quality from effluent discharges, chapter two shows that each catchment had poor water quality even at sites not subject to direct discharges. Removing the point-source discharges from waterways will improve water quality locally (Hickey and Rutherford 1986, Taranaki Regional Council 1995), however the problem of diffuse sources of contamination will also need to be addressed before the streams will meet current guidelines. Riparian management is one method of addressing overland runoff and has been shown to reduce the amount of nutrients and bacteria entering waterways (Syverson 2002).

There was disparity between water chemistry and biological data in this study, with water chemistry exceeding guidelines in chapter two, yet periphyton and macroinvertebrate communities not showing signs of excessive enrichment. This applied also to the results in chapter three, where effluent discharges into water had a significant impact on water chemistry variables but not on invertebrates, and periphyton was generally lower below discharges. Previous work has indicated links between water chemistry and biological communities (Boothroyd and Stark 2000, Stark 1985). However, the current study suggests that biological monitoring may be inadequate in detecting water quality problems. The likely explanation for the disparity between water chemistry and biological indicators was that these streams have a relatively steep fall or slope. High water velocities and bed instability may restrict periphyton levels (Biggs 2000). It may also create higher aeration, improving invertebrate survival ability and increasing downstream drift from uncontaminated headwaters. This highlights that stream-specific knowledge is important when analysing results, as using only one of these two types of monitoring may give misleading indications of the stream's state of 'health'. Turbidity, DRP and conductivity were strongly correlated with a composite measure of water quality derived from Principal Components Analysis. Any one of these could provide good indications of overall water quality in these streams if there was insufficient funding to test more variables, but would not reliably predict the state of the biological communities.

The results give some indication of important factors to consider when designing a sampling programme. Site selection is very important, as can be seen by the spatial variation of results in these catchments, and monitoring at limited numbers of sites may give results that are not indicative of the whole catchment. State of the Environment monitoring in larger waterways may not detect water quality problems in smaller streams, especially with regards to nutrient levels.

Continuous monitoring with a Hydrolab datasonde below one dairy shed effluent discharge into water showed no consistent effect of any twice daily 'pulse' of effluent entering the streams. Therefore sampling need not be arranged to avoid this. Likewise the location of cows relative to sampling points did not impact on results.

It is important to have some knowledge of the local hydrological influences on a stream when interpreting sampling results. Hydrological characteristics such as velocity, inflow of groundwater and flood dynamics may modify contaminant impacts on each stream differently, for example on periphyton sloughing and invertebrate migration.

Contaminated groundwater may also influence levels of nutrients in streams, as with the nitrate levels in the Otamaraho Stream. Steady inflow of groundwater to a stream may also even out flow levels.

The knowledge of these and other factors is important in assessing water quality and biotic information and when making management decisions. This confirms that the current trend in New Zealand of working towards catchment or even reach-specific management objectives and guidelines (e.g. ANZECC guidelines, 2000), is appropriate.

REFERENCES

ANZECC, Australian and New Zealand Environment and Conservation Council. (2000). "National water quality management strategy: The Australian and New Zealand guidelines for fresh and marine water quality." Australian and New Zealand Environment & Conservation Council, Canberra, Australia.

Biggs, B. J. F. (2000). "New Zealand periphyton guideline: detecting, monitoring and managing enrichment of streams." Ministry for the Environment, Wellington.

Boothroyd, I., and Stark, J. (2000). "Use of invertebrates in monitoring." In: *New Zealand stream invertebrates: ecology and implications for management*, Collier, K. J. and Winterbourn, M. J., (eds.), New Zealand Limnological Society, Christchurch, pp.344-373.

Hickey, C. W., and Rutherford, J. C. (1986). "Agricultural point source discharges and their effects on rivers." *New Zealand Agricultural Science*, **20**, 104-110.

Quinn, J. M., and Hickey, C. W. (1990). "Characterisation and classification of benthic invertebrate communities in 88 New Zealand rivers in relation to environmental factors." *New Zealand Journal of Marine and Freshwater Research*, **24**, 387-409.

Smith, C. M., Wilcock, R. J., Vant, W. N., Smith, D. G., and Cooper, A. B. (1993). "Towards sustainable agriculture: freshwater quality in New Zealand and the Influence of Agriculture." *Report No. 93/10*, MAF Policy, Hamilton.

Stark, J. D. (1985). "A Macroinvertebrate Community Index of water quality for stony streams." *Soil and Water Miscellaneous Publication 87*, National Water and Soil Conservation Authority, Ministry of Works and Development, Wellington.

Syverson, N. (2002). "Effect of a cold-climate buffer zone on minimising diffuse pollution from agriculture." *Water Science and Technology*, **45**, 69-76.

Taranaki Regional Council. (1995). "Discharges to land and water strategy background report: a review of agricultural nutrient discharge regulations in selected overseas countries." Taranaki Regional Council, Stratford, New Zealand.

Wilcock, R. J., Nagels, J. W., Rodda, H. J. E., O'Connor, M. B., Thorrold, B. S., and Barnett, J. W. (1999). "Water quality of a lowland stream in a New Zealand dairy farming catchment." *New Zealand Journal of Marine and Freshwater Research*, **33**(4), 683-696.

Wilcock, R. J., Rodda, H. J. E., Scarsbrook, M. R., Cooper, A. B., Stroud, M. J., Nagels, J. W., Thorrold, B. S., O'Connor, M. B., and Singleton, P. L. (1998). "The influence of dairying on the freshwater environment (the Toenipi study): volume I. Summary of Major Findings." *Report DRI60202*, NIWA, Hamilton, New Zealand.

Appendix 1

Raw data

(Note: Ox = Otamaraho Stream; Mx = MangaAtua Stream sites)

	E.coli (cfu/100ml)						
Site ID	**7-Feb**	**11-Feb**	**15-Feb**	**19-Feb**	**23-Feb**	**27-Feb**	**3-Mar**
O1	55	600	90	47	260	42	34000
O2	1900	500	400	270	6400	72	6400
O3	1100	1800	160	110	280	48	9800
O4	900	11000	100	130	550	280	6600
O5	350	6300	240	120	630	900	34000
O6	-	260	300	53	580	1700	9000
O7	30	96	64	10000	180	170	1000
O8	40	100	41	2100	150	280	2200
O9	-	130	120	230	450	760	780
O10	170	700	270	1500	600	180	4400
O11	-	140	70	150	340	98	920
M1	38	30	60	17	20	440	520
M2	1700	110	26	16	130	68	370
M3	180	60	100	47	220	17	1600
M4	150	120	360	130	100	110	330
M5	250	220	670	110	120	36	150
M6	270	250	240	350	110	58	1100
M7	560	1500	790	280	420	500	3000
D1	160	100	1000	620	630	54	450
D2	2300	3300	860	4000	6800	320	780
D3	4400	250	340	220	260	68	120
D4	3600	100	280	1400	5800	140	8900

	DRP (mg/l)						
Site ID	**7-Feb**	**11-Feb**	**15-Feb**	**19-Feb**	**23-Feb**	**27-Feb**	**3-Mar**
O1	0.268	0.006	0.005	0.000	0.000	0.006	0.079
O2	0.132	0.056	0.077	0.054	0.873	0.059	0.985
O3	0.287	0.050	0.082	0.067	0.235	0.057	0.625
O4	0.220	0.050	0.098	0.011	0.363	0.059	0.796
O5	0.000	0.047	0.094	0.077	0.287	0.053	0.463
O6	-	0.044	0.068	0.152	0.193	0.043	0.187
O7	0.028	0.008	0.006	0.172	0.013	0.013	0.009
O8	0.026	0.015	0.019	0.128	0.038	0.020	0.052
O9	-	0.027	0.039	1.080	0.046	0.034	0.354
O10	0.066	0.022	0.035	0.098	0.039	0.033	0.033
O11	-	0.019	0.077	0.638	0.027	0.024	0.028
M1	0.000	0.011	0.010	0.000	0.009	0.007	0.005
M2	0.005	0.014	0.018	0.000	0.012	0.009	0.005
M3	0.007	0.019	0.020	0.000	0.016	0.009	0.011
M4	0.011	0.018	0.053	0.033	0.015	0.016	0.010
M5	0.028	0.028	0.058	0.000	0.029	0.025	0.017
M6	0.320	0.039	0.059	0.010	0.033	0.034	0.027
M7	0.141	0.113	0.110	0.033	0.074	0.078	0.069
D1	0.000	0.007	0.009	0.000	0.007	0.007	0.008
D2	0.000	0.483	0.116	0.017	0.915	0.073	0.188
D3	0.080	0.053	0.126	0.054	0.088	0.063	0.060
D4	0.162	1.400	0.147	0.730	1.360	0.418	4.430

(A zero result is below detection limit of 0.002 mg/l).

	Nitrate (mg/l)						
Site ID	**7-Feb**	**11-Feb**	**15-Feb**	**19-Feb**	**23-Feb**	**27-Feb**	**3-Mar**
O1	0.150	1.300	0.000	0.640	0.190	1.200	0.970
O2	0.490	2.000	0.140	1.100	0.320	3.000	1.400
O3	1.200	2.200	0.260	1.300	0.770	3.900	1.800
O4	1.100	2.200	0.370	1.200	1.100	4.600	2.600
O5	1.800	2.300	0.410	3.300	1.000	4.400	2.800
O6	-	2.500	0.440	2.000	0.920	4.000	2.500
O7	2.400	2.900	0.520	2.200	0.490	2.500	1.700
O8	2.400	2.700	0.430	2.500	0.520	2.600	2.000
O9	-	2.500	0.330	2.400	0.510	2.400	1.900
O10	2.500	2.500	0.400	2.000	0.430	2.400	1.900
O11	-	1.900	0.250	2.300	0.350	1.800	2.500
M1	0.000	0.100	0.060	0.100	0.000	0.080	0.000
M2	0.000	0.110	0.070	0.160	0.020	0.240	0.000
M3	0.000	0.120	0.060	0.160	0.000	0.230	0.000
M4	0.000	0.100	0.070	0.180	0.000	0.280	0.000
M5	0.000	0.130	0.100	0.220	0.020	0.210	0.000
M6	0.000	0.190	0.100	0.190	0.040	0.300	0.140
M7	0.000	0.240	0.100	0.250	0.040	0.380	0.100
D1	1.100	3.000	0.510	3.500	0.650	3.100	2.200
D2	2.400	3.800	0.520	3.800	4.200	8.000	2.300
D3	0.000	0.000	0.060	0.000	0.000	0.000	0.000
D4	0.000	0.380	0.050	0.160	0.040	6.800	0.470

(A zero result is below detection limit of 0.02 mg/l).

	Ammonia (mg/l)						
Site ID	7-Feb	11-Feb	15-Feb	19-Feb	23-Feb	27-Feb	3-Mar
O1	0.000	0.000	0.030	0.030	0.000	0.000	0.140
O2	2.400	0.430	0.070	1.100	0.290	0.670	5.700
O3	0.480	0.040	0.080	0.090	0.450	0.000	4.800
O4	1.700	0.030	0.080	0.360	0.720	0.020	4.600
O5	0.520	0.000	0.170	0.190	0.500	0.180	2.800
O6	-	0.000	0.120	0.050	0.440	0.400	0.660
O7	0.030	0.000	0.110	0.050	0.000	0.280	0.000
O8	0.050	0.000	0.110	0.040	0.060	0.130	0.280
O9	-	0.030	0.120	0.070	0.020	0.030	0.030
O10	0.000	0.000	0.120	0.040	0.000	0.040	0.000
O11	-	0.000	0.110	0.050	0.000	0.000	0.000
M1	0.000	0.000	0.020	0.020	0.000	0.000	0.070
M2	0.000	0.000	0.030	0.180	0.000	0.000	0.000
M3	0.000	0.040	0.150	0.030	0.000	0.000	0.000
M4	0.000	0.000	0.030	0.020	0.000	0.000	0.000
M5	0.000	0.000	0.040	0.030	0.000	0.000	0.000
M6	0.030	0.000	0.060	0.100	0.000	0.000	0.000
M7	0.040	0.080	0.100	0.120	0.060	0.030	0.040
D1	0.000	0.000	0.210	0.530	0.150	0.220	0.390
D2	5.200	6.200	0.140	5.400	1.900	1.900	3.000
D3	0.000	0.000	0.060	0.050	0.000	0.000	0.000
D4	0.410	7.900	0.100	7.800	0.400	2.400	31.000

(A zero result is below detection limit of 0.02 mg/l).

	Turbidity (ntu)						
Site ID	7-Feb	11-Feb	15-Feb	19-Feb	23-Feb	27-Feb	3-Mar
O1	0.740	1.000	1.100	1.100	3.500	0.620	6.700
O2	6.300	1.800	3.600	2.200	19.000	1.700	21.000
O3	3.400	1.500	2.000	2.500	4.600	1.400	17.000
O4	4.700	1.600	2.500	2.900	5.300	1.500	19.000
O5	3.500	1.800	4.700	2.900	5.100	22.000	21.000
O6	-	2.200	3.400	4.000	7.000	7.900	14.000
O7	1.100	1.100	1.500	31.900	2.100	4.600	2.600
O8	1.900	1.300	1.800	9.400	2.600	4.800	6.900
O9	-	2.100	1.800	3.800	2.900	8.000	8.500
O10	2.600	2.500	4.100	4.100	2.100	4.300	6.300
O11	-	1.700	3.100	1.900	1.400	1.400	4.100
M1	4.500	1.000	4.100	1.800	1.700	0.970	11.000
M2	3.400	0.930	8.600	1.700	0.970	0.540	0.760
M3	3.500	1.000	8.400	2.200	0.980	0.600	0.850
M4	3.400	0.960	6.700	1.500	0.870	0.520	1.000
M5	4.600	1.000	8.500	1.800	1.900	0.950	1.500
M6	6.700	2.200	4.700	2.600	1.700	1.600	2.500
M7	6.200	2.900	7.300	3.100	2.500	12.000	5.800
D1	0.920	1.000	3.400	2.900	2.500	25.000	59.000
D2	16.100	19.000	8.800	48.200	37.000	14.000	126.000
D3	8.700	2.800	6.200	3.100	3.900	4.200	8.500
D4	10.200	31.000	6.200	25.000	31.000	8.400	95.000

	Temperature (°C)						
Site ID	**7-Feb**	**11-Feb**	**15-Feb**	**19-Feb**	**23-Feb**	**27-Feb**	**3-Mar**
O1	16.9	15.7	20.4	19.9	17.1	16.9	16.1
O2	16.3	14.8	17.3	16.9	15.2	15.3	15
O3	18.9	15.1	18.6	19.2	16.3	16.8	15.2
O4	19	15.1	18.6	19.2	16.4	16.7	15.2
O5	19.1	15.2	19.2	18.9	16.3	17.4	15.4
O6	.	15.4	19.1	18.4	17	18.3	15.3
O7	19.2	15.5	19.2	18.9	17	18.9	15.5
O8	19.2	15.5	19.2	18.9	17.1	18.9	15.5
O9	.	15.4	17.7	18	17.5	18.7	15.7
O10	18.8	16.1	19.2	18.7	17.9	20.5	15.6
O11	.	16.7	19.6	19.2	18.7	20.6	16
M1	17.3	17	19.5	18.8	18	19.5	15.4
M2	17.8	17.8	20.4	19.2	18.3	20.8	16.5
M3	18.1	17.8	20.4	19.4	18.4	20.8	16.5
M4	18	18.7	21.9	18.9	20.9	22.8	17.2
M5	16.5	18.6	22	18.6	20.8	22	16.6
M6	15.5	18.5	23.7	18.5	21.4	22.7	16.3
M7	15.9	18.5	24.1	18.5	21.3	22.8	16.4
D1	19.3	16.1	19.7	21.1	18.3	22.3	16.4
D2	20.6	16.9	20.7	21.8	19.1	22.2	16.5
D3	17.2	18.8	23.2	20.7	21.2	22.2	17.7
D4	17.4	19	23.2	20.6	21.6	22.8	17.5

	Conductivity (µS/cm)						
Site ID	7-Feb	11-Feb	15-Feb	19-Feb	23-Feb	27-Feb	3-Mar
O1	83.6	74.9	74.1	74.3	78.3	79.6	69.4
O2	144.8	91.8	102.2	99.2	248	97.9	148.9
O3	114.3	90.9	96.8	98.4	127	93.3	133.5
O4	134.3	90.9	98.2	107.9	145.1	93.4	146.7
O5	129.5	95.8	108.8	106.2	143.1	103.3	138.7
O6	.	95.9	103	106.7	139	107.7	113.7
O7	93	94	93.7	96.4	94.2	96.2	71.7
O8	101.7	94.9	96.5	98.6	102.7	98.5	77.3
O9	.	99.3	103	106.7	107.5	98.4	78.5
O10	108.4	99.2	102.9	104.6	104.7	98.3	89.4
O11	.	107.3	112.7	111.6	111.3	106.8	76.9
M1	91.8	98.8	91.3	96.7	98.5	101.7	103.5
M2	100.9	109.4	102.5	108.8	112.5	116.3	108.3
M3	101.3	110.2	103.1	109.3	113.2	116.6	109.4
M4	106	112.9	111.2	115.6	118.2	121.9	114
M5	141.8	124	130.1	128.9	130.3	135.6	125.6
M6	137.8	133.2	135.8	137.1	140.2	144.2	136.9
M7	140.7	139.9	139.9	140.6	145.8	150.2	142.6
D1	107.5	108.5	117.5	122.5	118	113.2	866
D2	267	245	147.1	230	382	130.4	1013
D3	362	417	292	345	372	386	354
D4	371	546	292	441	508	419	734

	DO (mg/l)						
Site ID	**7-Feb**	**11-Feb**	**15-Feb**	**19-Feb**	**23-Feb**	**27-Feb**	**3-Mar**
O1	7.3	8.8	8.6	8.5	7.9	6.6	6.8
O2	7.8	8.8	8.4	8.1	7.6	7.9	7.5
O3	8.2	9.5	8.3	8.8	8.6	8.8	7.5
O4	7.9	9.7	8.8	8.3	8.6	9	7.8
O5	7.6	9	6.7	8.2	8.3	7.8	7.3
O6	.	9.6	8.8	9.5	8.6	8.4	8.3
O7	8.8	9.9	9.3	9	8.7	8.5	9.1
O8	8.4	9.5	9.1	9.2	8.6	8.4	8.4
O9	.	9	9.5	8.7	8.7	8.5	8.6
O10	9.1	9.9	10	9.6	9.2	9.2	10
O11	.	9.4	8.8	9.3	8.9	8.6	9.5
M1	9.2	9	8.8	9	8.7	9.1	8.9
M2	9.6	9	8.7	9	9	9.5	9.1
M3	9	8.9	8.6	9.2	8.9	9.2	9.1
M4	9.3	9.2	8.3	9.4	8.3	9.3	9.2
M5	8	8.7	7.9	8.8	7.9	8.6	8.6
M6	9	8.4	7.4	8.8	8.1	9	8.7
M7	8.7	8.3	7.1	8.4	7.7	8.8	8.2
D1	5.7	5.8	5.2	4.8	5.5	5.5	5.4
D2	4	3.8	3.8	3.9	2.5	2.8	4.3
D3	4.8	7.5	5.1	4.2	8.2	9.6	6.9
D4	5.2	7.9	5.4	4.7	7.5	9.8	5

	DO% Saturation						
Site ID	7-Feb	11-Feb	15-Feb	19-Feb	23-Feb	27-Feb	3-Mar
O1	77	89.1	95.5	94.1	82.8	67.7	69.4
O2	80	87	87.5	84.1	76	79	75.6
O3	91	93.5	89.3	95.7	88.4	91.3	75.7
O4	89	93.9	94.4	90.5	88.4	92.8	78.2
O5	85	90.5	72	88.7	83.6	82	74.2
O6	.	96.6	95.7	102	90.1	89	83.2
O7	99	98	101.3	97.1	91.1	92.9	91.7
O8	94	95.8	98.4	98.7	88.6	91.5	85.2
O9	.	91	100.3	92.6	88.2	91.5	87.4
O10	101	100.1	108.7	104.3	98	102.3	100.5
O11	.	96	97.5	101.5	95.8	96.2	97.3
M1	95	90.7	96.3	96.4	92	100.3	89.6
M2	99.1	95.4	96.7	98	96.5	105.6	93.4
M3	95	93.3	96.1	100.2	95	103.7	94.3
M4	98	97.5	95.1	101.8	94.3	108	96.7
M5	82	91.4	90.8	94.3	88.5	99	88.7
M6	90.7	90	88.6	94.1	93	105.4	88.2
M7	89.3	88	85.3	89.2	87.7	103	84.2
D1	64	60.1	57	54.7	58.1	64.2	55.5
D2	46	39	42.6	43.9	26.7	33.4	45
D3	51	67.2	60	45.9	93.5	111.1	72.6
D4	55	71.5	63.8	52.9	84.9	114.2	46.5

	pH						
Site ID	**7-Feb**	**11-Feb**	**15-Feb**	**19-Feb**	**23-Feb**	**27-Feb**	**3-Mar**
O1	7.4	7.1	6.9	6.9	6.6	6.1	6.8
O2	6.1	7.2	6.4	6.5	6.6	6.1	7.1
O3	6.8	7	7.2	7.4	6.9	6.7	7.1
O4	7	7	7.1	7.1	6.9	6.8	7.1
O5	6.9	6.7	6.8	7	6.9	6.6	7.1
O6	.	7.3	7.3	7.4	7.4	6.9	7.8
O7	7.7	7.6	7.5	7.4	7.3	7.1	6.6
O8	7.5	7.8	7.5	7.3	7.2	7.1	6.9
O9	.	7.4	7.8	7.6	7.3	7.3	6.9
O10	7.8	8.1	8.2	7.6	7.5	7.7	8.4
O11	.	7.6	8.5	7.7	7	7.6	6.9
M1	7.7	7.8	7.3	7.9	7.8	7.7	8
M2	7.7	8	7.4	8.2	8.3	7.9	8.1
M3	7.7	8	7.5	8	8.1	7.9	8.1
M4	7.7	8.1	7.4	7.7	8	8.5	8
M5	7.8	8.5	7.9	7.7	8.1	7.9	8
M6	7.9	8.4	7.8	7.9	8	7.9	8
M7	7.9	8	7.6	8.2	7.7	7.8	8.8
D1	6.4	6.3	6.6	6.5	6.5	6.3	6.3
D2	6.6	6.7	6.5	6.3	6.9	6.3	6.3
D3	7.2	7.8	7.3	7.4	7.9	8	7.9
D4	7.4	7.7	7.3	7.2	7.5	8	7.7

	Periphyton (mg chla/m2 stone)[1]						
Site ID	**7-Feb**	**11-Feb**	**15-Feb**	**19-Feb**	**23-Feb**	**27-Feb**	**3-Mar**
O1	0.63	2.99	91.47	7.45	47.79	23.54	13.78
O2	1.09	1.66	2.90	2.20	2.98	1.45	3.11
O3	45.31	46.01	234.23	232.04	27.77	32.22	84.02
O4	19.02	54.25	101.62	88.22	9.78	7.96	27.79
O5	3.97	6.01	2.55	3.64	4.74	3.98	5.02
O6		7.38	10.99	3.99	4.62	7.55	10.52
O7	4.77	3.84	3.98	1.84	1.23	1.56	2.40
O8	7.56	6.20	7.66	2.78	2.68	1.63	5.10
O9		15.23	20.56	29.23	8.28	5.60	8.02
O10	17.92	11.42	15.81	4.11	7.47	11.60	5.67
O11		65.06	14.21	13.76	7.50	11.03	42.83
M1	0.15	0.53	0.55	0.83	0.64	8.45	16.76
M2	0.43	1.04	0.50	0.00	7.45	25.34	45.05
M3	0.24	6.94	0.39	1.91	15.94	15.28	25.94
M4	0.29	1.66	0.42	0.01	21.33	18.38	35.79
M5	0.27	2.01	0.49	0.49	1.46	20.46	9.40
M6	6.23	7.09	0.64	0.00	7.52	13.57	11.94
M7	0.00	0.86	0.00	0.11	1.04	1.21	0.06

1: Geometric mean of three samplings

Site		o1			o2			o3			o4			o5			o6			o7			o8		
Surber No.		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Species	**MCI**																								
COLEOPTERA																									
Hydora	6	17	287	196	45	62	50	82	83	62	134	26	110	187	58	158	223	213	86	350	252	273	175	117	108
Staphylinidae	5																								
DIPTERA																									
Paralimnophila	6		1					1		1															1
Aphrophila	5							2			1									1	1				
Austrosimulium	3	6	1	6	617	36	8	7	3	5	24	28	3	11	2	6		8		4	1	1	3	6	13
Eriopterini	9		1																						
Maoridiamesa	3		1		1			44	2				1					2				1	7		
Orthocladiinae	2	90	4	6	70	6	14	27	3	2	17	12	13	10	8	10	30	15	8	6	1	3	4	2	6
Chironomus	1				1		1																		
Polypedilum	3			2	2	1	1							1		1									
Tanytarsus	3	2	2	2	3			1			1		3	1											
Tanypodinae	5	1									1		1				5		1				1		
Corynoneura	2															1									
Paradixa	4			1	1																				
Culex	3				1								1												
Tabanidae	3						1																		
Psychodidae	1				9	5	10																		
Empididae	3			1													1								
Brachydeutera	4				7																				
Ephydrella	4				1																				
EPHEMEROPTERA																									
Austroclima	9	4			511		18	13		9	3			19			13		21	8	7	15	63	15	17
Coloburiscus	9				1	2		1		1				1		1	4	7	3	2	1	3	6		3
Deleatidium	8	176	163	473	172	328	118	52	51	90	84	52	26	186	178	234	50	30	3	172	130	203	48	119	212
Mauiulus	5				22	67									7	6	1	9	2				2		
Nesameletus	9	5	1	1																					
Zephlebia	7															2					2				
PLECOPTERA																									

Site		o1			o2			o3			o4			o5			o6			o7			o8		
Stenoperla	10												1												
Zelandobius	5										1														
Megleptoperla	9				2	1	1							1	1	1	13	4	6						
TRICHOPTERA																									
Plectrocnemia	8										1	3	1												
Aoteapsyche	4		1		2			21	1	3	10	2		35	14	32	34	101	9	42	20	41	77	36	76
Beraeoptera	8																								
Costachorema	7																			1		1		1	2
Helicopsyche	10									1					2	2	2	3		1	2	4	10	5	5
Hudsonema	6								2	3	2	1	5	4	7	1	6	2	14			3	4	3	3
Hydrobiosis	5	8	12	24	97	26	10	15	10	22	31	10	11	12	9	14	10	16	4	11	7	10	17	9	6
Olinga	9	1		1		1	1	8	1	2		1	3	1	4	2	14	4		5	3	3	8	3	7
Psilochorema	8	6	4	3	18	9	6	12	1	12	11	6	9	14	11	12	29	8	8	3	4	4	26	8	7
Pycnocentria	7		3	7	11	8	3	7	4	16	18	9	3	16	8	4	24	13	20	29	14	30	101	29	13
Pycnocentrodes	5	39	33	49	16	16	6	115	159	141	172	159	87	149	123	289	126	156	35	164	70	114	401	149	172
Triplectides	5																1	1							
Oxyethira	2			1									1		1		4	1	1			1			
Polyplectropus	8											1					1	1							
Oeconesus	9							1		1					1		1					1	1		
Archichauliodes	7	1				1		2		1						1									2
Sigara	5																								
CRUSTACEA																									
Amphipoda	5	71	35	29	62		16							5					1	4	8	42	51	23	2
Ostracoda	3										1		1	11	1		2				2	2	2	1	
MOLLUSCA																									
Ferrissia	3				1			8	2	3	6	18	5	2	1	1	7	10	7	1		1	3		6
Physa	3																			1	1				1
Potamopyrgus	4	2	2	2			2	575	204	244	243	503	126	34	114	107	36	59	164	5		5	70	20	133
Sphaerium	3																	1							
Hirudinea	3								1	1				5											
Nemertea	3																					1			1
OLIGOCHAETA	1	9	16	40	158	320	272	18	15	36	17	17	59	96	34	88	6	3	3	10	5	19	3	6	14
PLATYHELMINTHES	3	2		8			1													1	2	8	2	2	5

Site		**o9**			**o10**			**o11**		
Surber No.		**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Species	**MCI**									
COLEOPTERA										
Hydora	6	109	53	87	31	15	7	250	382	511
Staphylinidae	5							2		
DIPTERA										
Paralimnophila	6									
Aphrophila	5	1	1					2	1	1
Austrosimulium	3	10	54	14	50	44	17	6	14	4
Eriopterini	9									1
Maoridiamesa	3	13	8	2	3	73	50	1	1	1
Orthocladiinae	2	9	2		65	583	298	5	7	3
Chironomus	1							1		
Polypedilum	3									
Tanytarsus	3				2	2			2	
Tanypodinae	5							1	1	
Corynoneura	2									
Paradixa	4									
Culex	3									
Tabanidae	3									
Psychodidae	1									
Empididae	3									
Brachydeutera	4									
Ephydrella	4									
EPHEMEROPTERA										
Austroclima	9	9	8							
Coloburiscus	9	3	5						2	1
Deleatidium	8	6	4	2				51	110	99
Mauiulus	5			5					2	
Nesameletus	9									
Zephlebia	7								4	
PLECOPTERA										

CONTINUED...	Site	o9			o10			o11		
Stenoperla	10									
Zelandobius	5									
Megleptoperla	9									
TRICHOPTERA										
Plectrocnemia	8									
Aoteapsyche	4	321	232	135	159	62	44	27	324	43
Beraeoptera	8									
Costachorema	7	6	4				2			
Helicopsyche	10	1		1						
Hudsonema	6									
Hydrobiosis	5	2	6	2		2		6	23	11
Olinga	9	2								
Psilochorema	8			1				1	2	2
Pycnocentria	7	5	5	2	4		1	5	31	24
Pycnocentrodes	5	97	58	69	29	11	11	35	132	53
Triplectides	5			1						
Oxyethira	2				1		2			
Polyplectropus	8									
Oeconesus	9									
Archichauliodes	7	1	6			3		2	7	5
Sigara	5	1						1		
CRUSTACEA										
Amphipoda	5	1			23	58	12		1	
Ostracoda	3				1					
MOLLUSCA										
Ferrissia	3	11	4	3	11	4	4			1
Physa	3			3	1		1			
Potamopyrgus	4	2	5	161	30	6	16	3	6	6
Sphaerium	3			1	2					
Hirudinea	3									
Nemertea	3				1					
OLIGOCHAETA	1	6	12	14	6	13	1	2	1	3
PLATYHELMINTHES	3		1		18				1	1

Site		M1			M2			M3			M4			M5			M6			M7		
Surber No.		**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Species	**MCI**																					
COLEOPTERA																						
Hydora	6	11	8	76	96	66	67	24	112	129	105	113	146	193	137	138	1180	587	227	375	462	932
Staphylinidae	5														7	1						
DIPTERA																						
Paralimnophila	6																					
Aphrophila	5																					
Austrosimulium	3	1				12	6		2	2	1		3	3	2	6	19	27	44	14	16	14
Eriopterini	9	4	5	6	3	1		2	4	2	3	4	7	2	3	1	5			1		
Maoridiamesa	3																					
Orthocladiinae	2	1							3	2	2		1					2				
Chironomus	1																					
Polypedilum	3																					
Tanytarsus	3																					
Tanypodinae	5										1											
Corynoneura	2																					
Paradixa	4																					
Culex	3									1												
Tabanidae	3																					
Psychodidae	1																					
Empididae	3																					
Brachydeutera	4																					
Ephydrella	4																					
EPHEMEROPTERA																						
Austroclima	9																					
Coloburiscus	9						1										6	11	22	1	1	20
Deleatidium	8	29	10	47	88	55	198	102	111	108	35	34	61	68	92	78	181	221	273	61	110	312
Mauiulus	5																		1			1
Nesameletus	9																					

CONTINUED....	Site	M1			M2			M3			M4			M5			M6			M7		
Zephlebia	7																					
PLECOPTERA																						
Stenoperla	10																					
Zelandobius	5																					
Megleptoperla	9																					
TRICHOPTERA																						
Plectrocnemia	8																					
Aoteapsyche	4		1		1	1	3	1	1	1			4		2	2	29	17	34	12	2	33
Beraeoptera	8																					
Costachorema	7																					
Helicopsyche	10																					
Hudsonema	6						1					1										
Hydrobiosis	5	1	1		1	2	5	4	6	3	2	1		2		1	2	6	1	2		5
Olinga	9				2										2							1
Psilochorema	8	2		6	4	3	6	5	4	7		3	1		4	2		2	3	2	3	1
Pycnocentria	7				1			1	1								1	6	4			8
Pycnocentrodes	5			1	5	1	3	8	18	4	3		7			3	2	11	11			87
Triplectides	5														1							
Oxyethira	2																					
Polyplectropus	8																					
Oeconesus	9																					
Archichauliodes	7													2	1	2		2	1			
Sigara	5																1					
CRUSTACEA																						
Amphipoda	5																		1	2	2	3
Ostracoda	3																					
MOLLUSCA																						
Ferrissia	3																					
Physa	3																1			1		
Potamopyrgus	4					1	1						4				14	14	1	1	1	34

CONTINUED....	Site	M1			M2			M3			M4			M5			M6			M7		
Sphaerium	3																					
Hirudinea	3																					
Nemertea	3																					
OLIGOCHAETA	1	1	1		3		1										5	5	1	4	1	31
PLATYHELMINTHES	3																3	3	1		1	22

Appendix 2

Taxon correlation coefficients

Taxon	MCI	r1	r2
Hydora	6	-0.46	-0.76
Staphylinidae	5	-0.43	-0.38
Paralimnophila	6	0.12	0.72
Aphrophila	5	0	0.85
Austrosimulium	3	**0.79**	-0.00
Eriopterini	9	-0.71	-0.61
Maoridiamesa	3	0.17	0.91
Orthocladiinae	2	**0.81**	0.74
Chironomus	1	**0.77**	0.05
Polypedilum	3	**0.90**	0.11
Tanytarsini	3	**0.82**	0.56
Tanypodinae	5	0.22	0.35
Paradixa	4	**0.86**	0.13
Culex	3	0.42	0.15
Tabanidae	3	**0.77**	0.05
Psychodidae	1	**0.77**	0.05
Empididae	3	0.36	0.11
Brachydeutera	4	**0.77**	0.05
Ephydrella	4	**0.77**	0.05
Austroclima	9	**0.90**	0.49
Coloburiscus	9	-0.17	-0.18
Deleatidum	8	0.18	-0.62
Mauiulus	5	**0.71**	-0.08
Nesameletus	9	0.36	0.11
Stenoperla	10	0.14	0.33
Zelandobius	5	0.14	0.33
Megleptoperla	9	**0.77**	0.05
Plectrocnemia	8	0.14	0.33
Aoteapsyche	4	-0.56	-0.28
Beraeoptera	8	**0.77**	0.05
Costachorema	7	0.36	0.11
Helicopsyche	10	-0.09	0.727
Hudsonema	6	-0.02	0.79
Hydrobiosella	5	0.88	0.403
Olinga	9	0.46	0.791

CONTINUED....			
Taxon	**MCI**	**r1**	**r2**
Psilochorema	8	0.63	0.782
Pycnocentria	7	0.50	0.644
Pycnocentrodes	5	0.45	0.688
Oxyethira	2	0.92	0.18
Polyplectropus	8	0.14	0.326
Oeconesidae	9	-0.09	0.727
Archichauliodes	7	-0.02	0.565
Sigara	5	-0.43	-0.381
Amphipoda	5	0.90	0.033
Ostracoda	3	0.81	0.194
Ferrissia	3	0.72	0.813
Physa	3	-0.42	-0.715
Potamopyrgus	4	0.01	0.587
Hirudinea	3	-0.09	0.727
Oligochaeta	1	0.79	0.374
Platyhelminthes	3	0.58	-0.358