Effects of dairying on water quality of lowland streams in Westland and Waikato

R. J. DAVIES-COLLEY and J.W. NAGELS
National Institute of Water and Atmospheric Research (NIWA), P. O. Box 11-115, Hamilton
r.davies-colley@niwa.cri.nz

Abstract

Several New Zealand studies suggest that pastoral land use causes appreciable water quality degradation particularly in lowland streams. The water quality of eight NZ lowland streams, three near Morrinsville in the Waikato Region and five south of Hokitika in Westland, was sampled monthly for 13 months. Three of the five Westland streams are spring-fed streams on dairy-farmed alluvial plains of large rivers, and have high and steady flows and visually clear water, contrasting with two nearby reference streams in forested land which are more flow-variable and have humic-stained water. The catchments of the three Waikato streams, with the exception of a forested headwater area, are intensively grazed, mostly by dairy cows. Median conductivity, phosphorus and nitrogen concentrations, and (to a lesser extent) faecal contamination (as indicated by *Escherichia coli* concentrations), were all elevated in streams draining dairy pasture, often exceeding water quality guidelines. The most intensively-farmed Waikato stream (Toenepi Stream) has very high concentrations of nutrients and fairly high faecal contamination. At the other extreme, Dunlop Creek (Westland) has very low concentrations of nutrients and faecal contamination, consistent with its minimally-disturbed native forest catchment. The optical variables: humic concentration, turbidity and (inversely related) visual water clarity, show less of a pattern with land use across stream sites, apparently because of the influence of other factors, such as soil characteristics. The area-specific yields of streams in Westland dairy land were comparable with those in the Toenepi Stream, reflecting high rainfall driving runoff and leaching in Westland. However, the concentrations of contaminants mobilised by dairy farming were generally higher in Waikato than in Westland because of dilution in high water flows in the latter region. The water quality degradation of streams draining dairy land will need to be addressed by the dairy industry.

Keywords: dairying, faecal contamination, nitrogen, nutrients, phosphorus, turbidity, water quality

Introduction

There is increasing recognition that pastoral farming is a major source of water pollution in New Zealand (MfE 1997; Parkyn *et al.* 2002). Some of this water pollution, notably that associated with dairy shed waste treatment lagoons (Sukias *et al.* 2000), may be regarded as a "point" source. However, most of the contaminant yield in streams draining farmland is typically "diffuse" pollution, arising as runoff or leaching from extended areas of the catchment (MfE 1997; Vant 2001) or from livestock trampling and waste deposition in channels (Nagels *et al.* 2002; author's unpubl. data). Lowland pastoral streams in New Zealand are further degraded (Parkyn *et al.* 2002) owing to modified hydrology (artificial drainage) and riparian vegetation, in combination with high intensity farming, which mobilises large quantities of contaminants (Wilcock *et al.* 1999).

This paper reports the water quality of streams in dairy-farming catchments in two regions: Waikato and Westland, based on monthly sampling over 13 months. We hypothesised that concentrations of land-derived contaminants (sediment, nutrients, and faecal microbial contaminants) would tend to increase with land use intensity, but would differ between regions owing to climatic and hydrological differences. The Waikato Region lacks suitable unimpacted reference streams for comparison with streams draining dairying land. However, in the Westland Region, streams in native forest catchments provided a baseline for gauging the water quality impact on nearby streams in dairying catchments.

Some of the water quality data presented below has already been reported as part of a study of invertebrate and plant communities in these same eight lowland streams (Duggan *et al.* 2002). Here we give a more detailed analysis of the stream water quality, considering nutrient yields and comparing concentrations with published water quality guidelines.

Methods

Study sites

The eight study streams are listed in Table 1 and some general features of the catchments are given. In the Waikato, three streams in the Piako Catchment near Morinsville were sampled in one of the most intensively dairy-farmed areas of New Zealand. The headwaters of one of these streams (Piakonui) is in native forest, and the remainder of the catchment is used mainly for dairying, but with some deer farming. Water quality of the Toenepi Stream, in an intensively dairy-farmed catchment, has already been reported in considerable detail by Wilcock *et al.* (1999) based on an earlier sampling programme. The Piako River, a larger lowland stream with dairying as the predominant land use, was sampled near Kiwitahi where a level recorder station is located (downstream of the Piakonui site). In Westland, south of Hokitika, three streams (Murray, Berry and Chinn Creeks) were sampled on alluvial plains that are almost completely developed for dairying (Table 1). The streams in dairy pasture in both regions had high aquatic plant biomasses (Duggan *et al.* 2002). We also sampled two lowland streams in relatively undeveloped catchments in Westland for comparison: Dunlop Creek, with a near-pristine native forest-scrub catchment, and Fergusson Creek with a catchment mainly in native scrub and bog vegetation, but with a small proportion (17%, Table 1) used for beef cattle grazing (Duggan *et al.* 2002).

Water quality sampling

Each site was visited monthly for 13 months (November 1998 to November 1999). Monthly sampling is recommended for stream water quality characterisation (Ward *et al.* 1990), because it is "pseudo-random" (*sensu* Gilbert 1987) and provides insight into seasonal patterns, but suffers minimally from the serial correlation that affects more frequent sampling. Although a longer sampling programme would have been better for calculating yields (Robertson & Roerish 1999), we considered a year of data to be a reasonable compromise between cost and increasing redundancy of extra data for water quality characterisation.

On each monthly visit a flow estimate was obtained from standard current meter gauging or estimated from an established rating curve. Visual water clarity measurements were taken on site using the black disk method of Davies-Colley (1988).

Water samples were obtained from each site on each visit in 100 ml sterile vials for enumeration of the favoured faecal indicator bacterium *Escherichia coli*, by the Colilert most probable number (MPN) method (IDEXX Laboratories, USA). These samples were transported in insulated bins (dark, chilled) to the NIWA Laboratory in Hamilton, Waikato Region (by overnight courier from Westland), and were analysed or preserved within 24 hours of arrival.

A pair of 1-litre water samples was also taken from each site on each visit in acid-washed polyethlyene bottles for other water quality analyses. These water samples (handled the same way as the bacterial samples), were analysed within 24 hours of receipt at the laboratory for: electrical conductivity as an index of ionic content (Radiometer CDM 83 meter), dissolved humic matter as the absorption coefficient at 440 nm of filtrates (0.2 mm membrane filter, Shimadzu 1600UV spectrophotometer), and turbidity as an indication of water cloudiness (Hach 2100AN nephelometer). The following nutrient analyses were conducted: dissolved reactive phosphorus (DRP) by automated molybdenum blue-ascorbic acid

Table 1 Summary of lowland stream site characteristics.

	Westland Region					Waikato Region		
	Forest		Dairy pasture			Mostly dairy pasture		
Stream name	Dunlop	Fergusson	Murray	Berry	Chinn	Piakonui	Piako	Toenepi
Access	Off Hwy 6	Bold Head Rd	Municipal Rd	Wanganui Flat Rd	Off Waitaha Rd	Off Paratu Rd	At Kiwitahi	At Tahuroa Rd
River system	Duffers Creek	N/A	Hokitika	Wanganui	Waitaha	Piako	Piako	Piako
Map reference	I34 199 954	I33 228 034	J33 494117	I34 1921 9886	I34 243 951	T14 427 768	T14 398 856	T14 356 848
Catchment area (km^2)	1.8	2.1	3.4	5.0	1.6	27	105	15
% Pasture	0	17	99	96	99	53	85	100
% Native forest + scrub	100	83	1	4	1	47	14	0
Cows/km^2	0	0	220	200	200	160	200	300
Median flow (m^3/s)	(0.049)	(0.03)	0.21	0.91	0.20	0.20 (0.16)	0.56 (0.52)	0.031 (0.037)
Mean flow (m^3/s)	(0.22)	(0.26)	0.23	1.32	0.33	0.36 (0.25)	1.38 (0.77)	0.38 (0.068)
Specific flow ($m^3/s/km^2$)	(0.12)	(0.13)	0.068	0.26	0.22	0.013 (0.0092)	0.013 (0.0073)	0.026 (0.0045)
Runoff (m/yr)	(3.7)	(4.0)	2.2	8.3	6.8	0.41 (0.29)	0.41 (0.23)	0.80 (0.14)
Gradient (m/km)	21	10	2.9	2.7	5.7	3.8	1.7	2.5

[1] Flow statistics for the Waikato streams were calculated from the continuous level recorder on the Piako River at Kiwitahi.
[2] Parentheses indicate approximate flow statistics for the more flow-variable sites as calculated from 13 monthly visits.

colorimetry, total phosphorus (TP) by acid persulphate digestion followed by molybdenum blue colorimetry, ammoniacal nitrogen (Am-N) by automated phenol-hypochlorite colorimetry, nitrate plus nitrite nitrogen (NO_x-N) by cadmium column reduction (to nitrite) followed by diatolization with sulphanilamide, and total Kjeldahl nitrogen (TKN) by acid digestion followed by indophenol blue colorimetry. TP and TKN were measured on unfiltered, frozen, subsamples, and DRP, Am-N, and NO_x-N on frozen, subsamples that had been membrane-filtered (0.45 mm). Analyses followed methods detailed in APHA (1998), sometimes with minor modifications.

Dissolved inorganic nitrogen (DIN) was estimated as Am-N + NO_x-N. Organic nitrogen (OrgN) was estimated as TKN – Am-N, and total nitrogen (TN) as TKN + NO_x-N (= OrgN + DIN).

Water flow and yield calculations

The hydrograph for the Piako River, estimated from the level recorder at Kiwitahi, was used to simulate flows at the other two Waikato stream sites using the regression of flows gauged at times of sampling on the simultaneous flows in the Piako River (correlation coefficients were 0.97 and 0.93 for the Toenepi and Piakonui sites respectively). Annual yields of nutrients in the Waikato streams were calculated from these hydrographs by the regression method (Robertson & Roerish 1999). This involved synthesising a massflow time series from the continuous flow hydrograph using the regression on flow, and integrating the massflow with time for the year of study. Yields were calculated for DRP, TP and TN for which plots versus flow were well-fitted by simple power law expressions, but not for DIN which had a complex relationship to flow that would have required non-linear modelling (needing more than 13 data points).

There were no suitable continuous flow records for the Westland streams, so yields were simply calculated from 13 instantaneous estimates. Such estimates are imprecise for flow-variable streams, and usually much too low because yield-dominating high flows are not often sampled. However we expect that these estimates are meaningful for the spring-fed streams on dairy-farmed river flats in Westland (Murray, Berry and Chinn Creeks) that are all very flow-steady streams in which nutrient concentrations were unrelated to flow.

Storm-sampling is often done to improve estimates of yields, because the floods that typically dominate yields are not often encountered in short-term sampling programmes. However “storm-chasing” can give excessive *bias* when there is a strong hysteretic relationship between concentration and flow as is typical for nutrients and sediment (Robertson & Roerish 1999), so no storm sampling was done in this study. No attempt was made to estimate yields for *E. coli*, which increases markedly (c.1000-fold) in floods (Nagels *et al.* 2002) (floods were not encountered in our programme of monthly sampling for one year).

Results and discussion

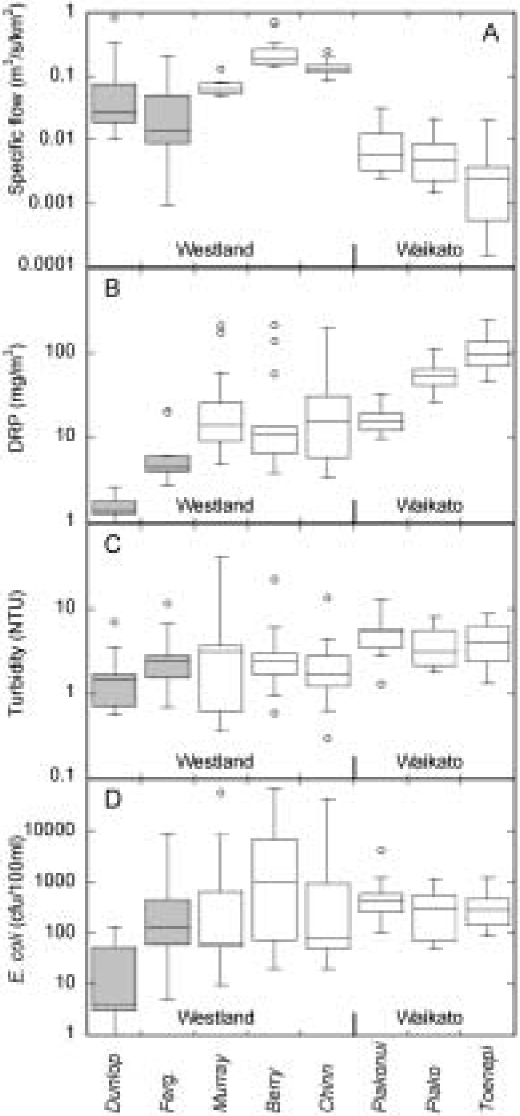
Major differences in climate and geological factors are reflected in the catchment hydrology of the study streams (Table 1). The study area in Westland has a much higher rainfall than the Morrinsville area of the Waikato (about 3000 mm and 1100 mm respectively), which probably accounts for the much higher (>10-fold) catchment area-specific flows in the former region (Table 1). Water yield (expressed in m/yr) in two of the Westland dairy streams is implausibly high compared with rainfall, probably because much of the stream-flow comes from groundwater flow from *outside* the (surface) catchment. The hydrology of the alluvial plain streams (Murray, Berry and Chinn Creeks) contrasts with that of the neighbouring forested streams (Dunlop and Fergusson Creeks) in Westland. The box plots in Figure 1A show that the Westland flood plain streams have very high catchment area-specific flow, and also very *consistent* flow (low flow variability) as indicated by the small box spans. The flow-steady character of these river flat streams is also emphasised by the close numerical similarity of their median and mean flows (Table 1). The two reference streams were appreciably more flow-variable (Figure 1A). Despite hydrological differences, all of the Westland streams had gravel-cobble substrates contrasting with the sand-silt substrates of the Waikato streams (Duggan *et al.* 2002).

Table 2 summarises water quality in the eight study streams in terms of median concentrations. (A similar summary, for a smaller range of variables, was given by Duggan *et al.* (2002) in a report on the invertebrate animal communities in these same streams.) Water quality data for the Toenepi Stream as reported earlier by Wilcock *et al.* (1999) (based on a more complete sampling programme) is given for comparison with our data for the Toenepi. Also given in Table 2 are New Zealand water quality guidelines for dissolved nutrients (DRP, DIN, to prevent nuisance algal growths, MfE 1992), for visual water clarity as measured by black disc visibility and (inversely-related) nephelometric turbidity (to protect contact recreation, MfE 1994), and for *E. coli* (also to protect contact recreation, MfE 1999).

Figure 1 gives box plots for selected water quality variables. Despite the very steady flows in the spring-fed streams on dairy-farmed river flats in Westland, their water quality was appreciably variable (comparable to more flow-variable streams) – apparently in response to rainfall events driving runoff and leaching.

Major nutrients (forms of nitrogen and phosphorus) were generally low in the Westland reference streams,

Figure 1 Box plots of A. specific flow at times of water quality sampling, B. dissolved reactive phosphorus (DRP), C. Nephelometric turbidity and D. *E. coli*,. for eight lowland streams in Westland and Waikato. Two wholly or predominantly forested streams in Westland (shaded) provided a reference for comparison with water quality in dairy pasture streams in both regions (unshaded).



higher in the Westland streams in dairy land, and higher again in the Waikato streams. The Westland dairy farming streams (Murray, Berry and Chinn Creeks) had much higher dissolved nutrients than the large mountain-fed rivers (Hokitika, Waitaha, and Wanganui Rivers respectively) that recharge the aquifers providing baseflow to these streams. (These rivers had DRP ~ 3

Table 2 Summary of water quality characteristics of the study streams (median values).

Variable	Units	Dunlop	Ferg	Murray	Berry	Chinn	Piakonui	Piako	Toenepi[2]	Water quality Guidelines[3]
DRP[1]	mg/m^3	1.4	4.5	14	11	16	16	54	97 (66)	15-30
TP	mg/m^3	5	13	23	19	21	32	76	150 (134)	
Am-N	mg/m^3	3	6	7.3	15	23	23	20	22 (70)	
NO_x-N	mg/m^3	13	50	370	190	330	280	910	820 (2210)	
DIN	mg/m^3	18	56	370	230	370	350	1040	1230	100
OrgN	mg/m^3	60	190	67	100	90	210	350	490	
TKN	mg/m^3	63	200	73	120	150	260	360	510 (710)	
TN	mg/m^3	86	290	550	480	560	590	1400	1700 (3040)	
Conductivity	µS/cm[1]	33	31	79	100	110	94	150	210	
g_{440}	/m	1.31	6.9	0.17	0.17	0.30	1.76	2.37	3.15	
Turbidity[1]	NTU	1.5	2.5	3.2	2.5	1.7	5.3	3.2	4.0	2.0
Black disc vis.	m	4.5	1.9	6.6	3.3	8.6	1.25	1.5	1.28	1.6
E coli[1]	cfu/100 ml	4.1	130	62	1030	77	440	310	280 (420)	126

[1] Variables for which box plots are given in Figure 1.

[2] Values for the Toenepi Stream given in parentheses are as reported by Wilcock *et al.* (1999).

[3] Guidelines for water quality – values for DRP and DIN (to prevent nuisance growths of algae) from MfE (1992), for turbidity and black disc visibility (to protect contact recreation) from MfE (1994), and for *E. coli* (to protect contact recreation) from MfE (1999).

mg/m^3 and DIN ~ 40 mg/m^3, showing that the great majority of the dissolved nutrient in the streams on their alluvial plains is attributable to dairying.) Figure 1B gives box plots for DRP, which ranged 70-fold from the forested reference site, Dunlop Creek (1.4 mg/m^3), to the most nutrient-enriched Toenepi Stream (97 mg/m^3). Total phosphorus (TP) ranged 30-fold, and total nitrogen (TN) 20-fold (Table 2), with the same broad pattern. This pattern was also seen for conductivity, which correlated with the nutrients (e.g., Spearman Rank Correlation of DRP and conductivity, $R_s = 0.64$).

All of the sites, except Fergusson, showed seasonality in total nitrogen, particularly the dissolved inorganic nitrogen (DIN) component, with much higher values in winter-spring than in summer-autumn. This seasonal pattern, although present in the Westland streams, was particularly strong in the Waikato streams with very low DIN (mostly nitrate) in warmer and dryer times of the year. Seasonality of DIN has been reported previously for the Toenepi Stream (Wilcock *et al.* 1999) and attributed to lower soil leaching combined with greater uptake by plants (pastures, wetland and stream plants), in summer-autumn. Quinn & Stroud (2002) found similar strong seasonal patterns of DIN in hill country streams near Whatawhata in western Waikato.

Nitrogen partitioning contrasts strongly between the forest reference streams and the dairy land streams. In Dunlop and Fergusson Creeks, nearly 70% of the total nitrogen occurs in organic form (OrgN). By contrast, in the streams in developed land in both Westland and Waikato, organic N was appreciably lower (medians ranging from 12-36% of TN). This pattern of low proportions of organic nitrogen (and correspondingly high proportions of DIN) has recently been interpreted as a general feature of streams draining intensively-farmed land characterised by mobilisation of large quantities of N in mainly inorganic form (van Breemen 2002).

Dissolved reactive phosphorus (DRP) in the Westland dairy streams was close to the guideline for nuisance growths – consistent with modest algal biomasses in these streams (Duggan *et al.* 2002). DRP greatly exceeded the guideline in the Piako and Toenepi Streams, but algal growth is restricted by lack of suitable substrate in these (silty-bedded) streams. Median DIN greatly exceeded the guideline for nuisance algal growth in all of the streams in developed land, however DIN typically fell below guidelines during summer, due to rapid uptake by plants combined with reduced soil leaching in this season.

Coloured organic content (aquatic humus or "yellow substance") of the stream waters was indicated by absorption coefficients of filtrates at 440 nm (g_{440} values, Table 1). Davies-Colley & Close (1990) have suggested that g_{440} < 0.1/m indicates "low", and > 1/m indicates "high" humic content. On this basis, Dunlop Creek has high, and Fergusson Creek very high humic content. Humic staining is a feature of many lowland waters in Westland (e.g., Moore 1989; Moore & Jackson 1989) and may be attributed to the low levels of aluminium and ferric iron (that would otherwise complex these organic acids) in strongly-leached soils in this region. The low to moderate humic content of the Westland streams on the alluvial plains of large rivers reflects the rather low humic colour of these mountain-fed rivers (g_{440} ~ 0.15/m, author's unpublished data). The three Waikato streams have moderately high humic staining, reflecting their rather high organic productivity.

Figure 1C gives box plots of turbidity. The Westland pasture streams have low turbidity (and correspondingly high visual clarity, Table 2), again reflecting their spring-fed source and, probably a comparative lack of (strongly light-scattering) fine particles in soils. The Westland forest streams have similar or slightly lower turbidity than the pasture streams, but also have *lower* visual clarity because of light attenuation by humic matter. The Waikato streams are moderately turbid with rather low visual clarity. Although the suspended sediment concentration and yield of these streams is quite low (142 kg/ha/yr in the Toenepi, Wilcock *et al.* 1999) much of this suspended matter probably comprises (intensely light-scattering) plate-shaped clay mineral particles eroded from the clay-rich soils. The visual clarity guideline for contact recreation recommended by MfE (1994) is 1.6 m, corresponding to a nephelometric turbidity of about 2 NTU (Nagels *et al.* 2001). On this basis the Waikato dairy streams, although not very turbid in absolute terms, are frequently (more than 50% of time) unsuitable for contact recreation.

Faecal contamination, as measured by *E. coli* (Figure 1D), showed a broadly similar trend to that of nutrients and conductivity. However, *E. coli* concentration was much higher in Fergusson Creek than in Dunlop Creek (and comparable to levels in dairy farming streams), probably reflecting the 17% of the catchment of the former stream in dry-stock farming (Table 1). The faecal contamination in Fergusson Creek may be exacerbated by scrub and forest shade over most of the channel length, which is expected to reduce *E. coli* die-off by reducing exposure to the strongly bacteriacidal ultra-violet component of sunlight (Sinton *et al.* 2002). The very high faecal contamination in Berry Creek is attributed to the discharge into this stream of dairy shed effluent (Trevor James, West Coast Regional Council, pers. comm.) that is typically high in *E. coli* (Sukias *et al.* 2000). Somewhat higher faecal contamination in the Piakonui Stream compared to the other two Waikato streams may reflect wallowing by farmed deer in side channels immediately upstream of the sampling site. The median *E. coli* levels of the dairy streams approached or exceeded the guideline (median of 126 cfu/100 ml) for contact recreation, implying a health-risk associated with contact recreation in these waters.

Catchment area-specific average annual yields of contaminants present a different picture from concentrations in the study streams (Table 3). Note that specific yields in the Waikato streams, calculated as simple averages of 13 simultaneous flow and concentration measurements, are generally much lower than estimates using continuous flow hydrographs by the regression method (Table 3). However, as stated earlier, we believe that specific yields calculated as simple averages in the Westland dairying streams (but not the forested streams) are reliable because these streams have very steady flows (Figure 1A) and their nutrient concentrations are essentially uncorrelated with flow. The specific yields of nutrients are particularly high in the Westland dairy streams, presumably because there is limited opportunity for interception and processing by plant tissue and soil before entry to streams. The moderate *concentrations* of nutrients in the Westland dairy streams are evidently a consequence of dilution of high yields into large flows of water.

Specific yields of nutrients in the Waikato streams trend strongly with intensity of land use (Table 3) – and more so than concentrations (Table 2). Specific yields are rather low in the Piakonui, higher in the Piako, and very high in the Toenepi – as noted by Wilcock *et al.* (1999). (Our yields of nutrients in the Toenepi Stream are somewhat higher (2-fold for TN) than reported by Wilcock *et al.* (1999) for a more-detailed record and empirical, rather than simulated, continuous flow data). The reason for the much greater yields in the Toenepi Stream compared to the Piakonui Stream (with intermediate values in the Piako R.) seems to be that the Toenepi Stream is much more flow-variable (and has a higher specific flow – Table 1) and high flows dominate yields. The yields of N in the Westland dairy land streams are broadly comparable to those in the Toenepi, but P yields are much higher. The yields for N and P from Westland streams, and for N from the Toenepi, are well outside the range reported previously in New Zealand studies (Table 3), highlighting the nutrient mobilisation characterising intensive dairying.

General discussion and conclusions

This study has shown that streams in dairy-farmed catchments in very different regions have degraded water quality by comparison with reference streams in native forest. This finding is consistent with a growing body of work recently summarised by Parkyn *et al.* (2002) showing general degradation of water quality and stream

Table 3 Catchment area-specific yields of selected forms of nutrients (kg/ha/yr) in the study streams.

Variable	Dunlop	Ferguson	Murray	Berry	Chinn	Piakonui	Piako	Toenepi	*Toenepi*[4]	*NZ studies*[4]
DRP	(0.08)	(0.71)	1.02	6.6	6.7	**0.07** (0.05)	**0.21** (0.12)	**0.9** (0.13)	*0.54*	*0.04-0.3*
TP	(0.60)	(2.1)	1.5	10.0	10.5	**0.17** (0.10)	**0.42** (0.22)	**1.35** (0.21)	*1.16*	*0.3-1.7*
DIN	(0.68)	(1.2)	9.3	21	20	(2.1)	(4)	(3)	*30*	*1 to 5*
TN	(7.1)	(22)	13	48	50	**9** (3)	**27** (5)	**70** (4)	*35*	*4 to 19*

[1] Regular type indicates yields calculated as the average of 13 monthly observations.
[2] Parentheses indicate yield estimates, so calculated, that are subject to large error (usually an under-estimate) in the more flow-variable streams.
[3] Bold type indicates yields for Waikato streams calculated from the regression method using the continuous flow record for the Piako River at Kiwitahi (see text for details).
[4] Italic type indicates yields for the Toenepi stream reported by Wilcock *et al.* (1999), and the range reported in NZ studies by Wilcock (1986) and Vant (2001).

'health' by pastoral agriculture. In the streams studied here, the high intensity of dairying land use mobilises large quantities of nutrients (N and P), faecal microbial contaminants, and (sometimes) fine sediment causing reduced visual clarity. These impacts are exacerbated if cattle are permitted access to streams, disturbing the streambed and banks by trampling, and depositing their waste products directly into the stream channel (Nagels *et al.* 2002; author's unpubl. data). The water quality degradation is not very severe in terms of exceedance of water quality guidelines, but being diffuse it is widespread, and therefore represents a large total impact.

Mobilisation of fine sediment by pastoral agriculture, with consequent optical effects, can sometimes be masked by geological/hydrological variability. In the present study, the dairy farming streams in Westland had fairly high visual clarity, which we attribute to the spring source of water from ground water recharged by large mountain-fed rivers combined with the coarse-grained character of the soils. By contrast, the higher turbidity in pastoral streams in the Waikato, despite rather low sediment yield (Wilcock *et al.* 1999), may be attributed to livestock disturbance of clay-rich soils.

A recent paper focussed on invertebrate communities in the same eight lowland streams (Duggan *et al.* 2002) reported that regional differences between Westland and Waikato tended to mask land use differences, forest versus pasture. However, regional influences on water quality appear not to over-ride land use, and in this study water quality was comparably impacted by dairying in two contrasting regions.

The water quality degradation in streams draining dairy land reported by this study and others (reviewed in Parkyn *et al.* 2002) suggests that we may expect a general decline in water quality in New Zealand as the national dairy herd increases unless measures are instituted to reduce stream contamination. The first direct evidence that such a decline is actually occurring has recently been obtained. Statistical analysis of water quality data for rivers in Southland where dairying is expanding rapidly show a trend of increased dissolved N concentrations (Keith Hamill, Environment Southland and Graham McBride, NIWA-Hamilton). A major challenge for the dairy industry will be to develop and adopt measures such as riparian fencing and planting (Meals 2001), bridging of raceways, and interception of contaminants in artificial drains (Long Nguyen, NIWA, Hamilton pers. comm.), in order to reduce diffuse pollution of streams.

ACKNOWLEDGEMENTS

We thank staff of the NIWA-Greymouth office, Paul Lambert, Doug Griffin, and John Porteous, for fieldwork. Ralph Morse of NIWA-Hamilton assisted with sampling the Waikato streams, and Mike Crump, Denise Rendle, and Marieke Van Cooten of the NIWA-Hamilton laboratory conducted numerous water quality analyses. Trevor James of the West Coast Regional Council provided local information and contact with landowners, and helped Bob Wilcock and Kevin Collier choose the study sites. Bob Wilcock made helpful comments on the manuscript, which was further improved following constructive comment by the referees. The study was funded by FoRST through programmes CO1X022 and CO1X010.

REFERENCES

APHA 1998. Standard methods for the examination of water and wastewater. 20th edition. America Public Health Association, American Water Works Association, Water Pollution Control Federation. Washington D.C.

Davies-Colley, R. J. 1988. Measuring water clarity with a black disc. *Limnology and Oceanography 33*: 616-623.

Davies-Colley, R. J.; Close, M. E. 1990. Water colour and clarity of New Zealand rivers under baseflow conditions. *New Zealand Journal of Marine and Freshwater Research 24*: 357-366.

Duggan, I. C.; Collier, K. J.; Champion, P. D.; Croker, G.F.; Davies-Colley, R. J.; Lambert, P.W.; Nagels, J. W.; Wilcock, R. J. 2002. Ecoregional differences in macrophyte and macroinvertebrate communities between Westland and Waikato: are all New Zealand lowland streams the same? *New Zealand Journal of Marine and Freshwater Research.* In press.

Gilbert, R. O. 1987. Statistical methods for environmental pollution monitoring. Van Nostrand Reinhold. New York, NY, 320pp.

Meals, D. W. 2001. Water quality response to riparian restoration in an agricultural watershed in Vermont, USA. *Water Science and Technology 43*: 175-182.

MfE 1992. Water quality guidelines No. 1: Guidelines for the control of undesirable biological growths in water. Ministry for the Environment, Wellington. 77pp.

MfE 1994. Water quality guidelines No. 2: Guidelines for the management of water colour and clarity. Ministry for the Environment, Wellington. 77pp.

MfE 1997. The state of New Zealand's environment. Ministry for the Environment, Wellington. 648pp.

MfE 1999. Recreational water quality guidelines. Ministry for the Environment, Wellington, 16pp.

Moore, T. R. 1989. Dynamics of dissolved organic carbon in forested and disturbed catchments, Westland, New Zealand. i. Maimai. *Water Resources Research 25*: 1321-1330.

Moore, T. R.; Jackson, R. J. 1989. Dynamics of dissolved organic carbon in forested and disturbed catchments, Westland, New Zealand. ii. Larry River. *Water Resources Research 25*: 1331-1340.

Nagels, J. W.; Davies-Colley, R. J. ; Smith, D. G. 2001. A water quality index for contact recreation in New Zealand. *Water Science and Technology 43*: 285-292.

Nagels, J. W.; Davies-Colley, R. J.; Donnison, A. M.; Muirhead, R. W. 2002. Faecal contamination over flood events in a pastoral agricultural stream in New Zealand. *Water Science and Technology 45 (12)*: 45-52.

Parkyn, S.; Matheson, F.; Cooke, J.; Quinn, J. M. 2002. Review of the effects of environmental effects of agriculture on freshwaters. NIWA client Report FGC02206. 45pp.

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

Robertson, D. M.; Roerish, E. D. 1999. Influence of various water quality sampling strategies on load estimates for small streams. *Water Resources Research 35*: 3747-3759.

Sinton, L. W.; Hall, C. H.; Lynch, P. A.; Davies-Colley, R. J. 2002. Sunlight inactivation of fecal indicator bacteria and bacteriophages from waste stabilization pond effluent in fresh and saline waters. *Applied and Environmental Microbiology 68*: 1122-1131.

Sukias, J. P. S.; Tanner, C. C.; Davies-Colley, R. J.; Nagels, J. W.; Wolters, R. 2000. 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.

van Breemen, N. 2002. Natural organic tendency. *Nature 415*: 381-382.

Vant, W. N. 2001. New challenges for the management of plant nutrients and pathogens in the Waikato River, New Zealand. *Water Science and Technology 43*: 137-144.

Ward, R. C.; Loftis, J. C.; McBride, G. B. 1990. Design of water quality monitoring systems. Van Nostrand Reinhold. New York. 231pp.

Wilcock, R. J.; Nagels, J. W.; Rodda, H. J. E.; O'Connor, M. B.; Thorrold, B. S.; 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*: 683-696.