NIWA

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Review of the Environmental Effects of Agriculture on Freshwaters

NIWA Client Report: FGC02206
April 2002

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Prepared for

Fish and Game NZ

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Executive Summary

In this report we review the relevant information from scientific studies and Regional Council State of Environment reports to assess the effects of agriculture on both water quality (including faecal indicator bacteria for contact recreation) and the ecology and habitat of New Zealand waterways. We focus largely on information gained since the last major review of agricultural effects on waterways published by MAF "Towards sustainable agriculture: freshwater quality in New Zealand and the influence of agriculture" (Smith et al. 1993).

The conclusions we can draw on the state of water quality in New Zealand streams and rivers are similar to those by Smith et al. (1993). Lowland rivers in agriculturally developed areas are in poor condition due to high nutrients, turbidity and faecal contamination. However, there is now considerably more data to back up these conclusions, and therefore this report firmly establishes the link between agricultural land use and poor water quality, stream habitat and impacted biotic communities.

The vast majority of scientific studies on cause/effect relationships published since Smith et al. (1993) conclude that agriculture, as typically practiced in New Zealand, has a detrimental impact on water quality. These studies have shown that high levels of sediments, nutrients and bacteria are generally found in waterways in agricultural areas, and water quality guidelines are often compromised, particularly where farming activity is intensive. Proportion, intensity, and types of farming within a catchment have all been shown to be factors that affect stream health. In particular, streams in areas of dairy farming are in poor condition. Often this has been related to poor practices of dairy shed effluent disposal, but the intensification of farming associated with dairying has also been related to increasing levels of nutrients, sediments and faecal bacteria.

There have been many more studies into the ecology of New Zealand streams since 1993. Land use change and impacts of farming have clearly been shown to significantly alter the habitat (light condition, water temperature, woody debris cover, sediment etc.) and subsequently the nature of biotic communities living there.

Most regional councils implicate agriculture and intensification of farming as the main cause of poor water quality and habitat in the waterways of their region. Across the country, streams within or near native forest generally had good water quality, and there were many examples of forested headwaters that had healthy invertebrate communities that changed to communities of poor diversity and high pollution tolerance downstream, with increasing pastoral development in the catchment.

Although dairy farm oxidation ponds are important sources of pollution they are nowadays generally considered of less concern than diffuse sources of pollution because of the greater ease of regulation and improvements in waste treatment technologies. Other important areas contributing to pollution are farm drains (open or subsurface) and livestock access to waterways, particularly cows and beef cattle. The degradation of riparian areas has also been highlighted as a factor causing poor stream habitat and water quality.

Fencing stock out of streams and replanting riparian margins to restore shade and ecological function have generally shown improvements in stream health over time. Relatively immediate benefits to streams can be seen once stock are excluded from streams, particularly with respect to reducing levels of faecal bacteria. Half of the Regional Councils in New Zealand have some kind of riparian management funds available indicating how widely accepted the impacts of farming on streams are. For example, Environment Waikato has a riparian fund where $10 million will be distributed over 10 years for fencing and planting streams, and a programme that advocates planting from the headwaters downstream. Riparian management in conjunction with sustainable land management practices should improve the condition of New Zealand's streams in agricultural areas.

1. INTRODUCTION

In 1993, MAF produced a report entitled "Towards sustainable agriculture: freshwater quality in New Zealand and the influence of agriculture" (Smith et al. 1993), which assessed the quality of New Zealand's freshwater resources and the effects that agriculture has on these resources. The major conclusions from that review included:

- Lowland river reaches in agriculturally developed catchments were in poor condition
- Nitrogen and phosphorus concentrations were often excessive and waters were often turbid during steady flows in these rivers
- Faecal contamination was a widespread problem with many lowland river reaches unsuitable for contact recreation
- Small streams in dairying areas were in very poor condition[1]
- Eutrophication was the cause of a number of water quality problems in New Zealand lakes, and development in the lake catchments (primarily agricultural) was almost certainly responsible, due to increased nutrient loads.

In this report we update the relevant information from studies since 1993 to assess the current knowledge on the effects of agriculture on both water quality (including faecal indicator bacteria for contact recreation) and the ecology and habitat of New Zealand waterways. We also requested Regional Councils and Unitary Authorities to provide their latest State of the Environment reports and other published material that would assist us to review trends in water quality and river health as a function of livestock farming. We focus on data from New Zealand, but have also conducted a wide search of international literature to support our findings.

In a recent MAF report outlining expected changes to New Zealand land use (Ward 2002), deer farming is expected to show an 88% increase in land area, but dairying is forecast to experience the largest increase in land area (additional 265,600 ha) between 2000 and 2010. Dairying is expected to increase most rapidly in Canterbury, Southland and Otago.

In this report we identify research and data that address issues concerning the effects on streams of differing types of agriculture and intensification of land use.

[1] However, this conclusion was limited by data availability.

2. EFFECTS OF AGRICULTURE ON WATER QUALITY

2.1 Water quality guidelines

Since the report of Smith et al. (1993), considerable effort has gone into developing guidelines that define the suitability of a water body for a particular use. A summary of these guidelines is given in Table 1 of the Appendix. Our assessment of the literature post-Smith et al. (1993) is referenced to these guideline values.

2.2 Evidence for agricultural effects on water quality - *Scientific Research*

2.2.1 Studies comparing streams in native forest and agricultural catchments

The traditional approach to investigations of agricultural effects on water quality was to conduct comparisons of streams in native forest versus pasture catchments. Results from early studies of this type are detailed in Smith et al. (1993). The results of post-1993 studies are summarised in Table 2 (Appendix). Overall, studies of this type have shown that:

1. Pasture catchments have higher runoff, water yield and storm flows than native forest catchments (Davoren 1986, Dons 1987, Cooper and Thomsen 1988) as a result of pasture vegetation (e.g grasses) having lower interception and evapo-transpiration rates than forest (Fahey and Rowe 1992), and also compaction of the soil by livestock lowering infiltration rates (Trimble and Mendel 1995, Nguyen et al. 1998);

2. Pasture streams have higher amounts of suspended sediment, higher turbidity and lower water clarity than native forest streams (Dons 1987, Smith et al. 1993, Quinn et al. 1997, Quinn & Stroud 2002) due to increased runoff, erosion and bank instability (Trimble and Mendel 1995);

3. Pasture streams generally have higher amounts of nitrogen (N) and phosphorus (P) nutrients than native forest streams (Cooke 1979, Wilcock 1986, Cooper et al. 1987, Cooper and Thomsen 1988, Quinn et al. 1997, Quinn & Stroud 2002). This is due to increased runoff, eroded sediment and subsurface leaching losses carrying excess nutrients from fertilizers, nitrogen fixation and stock excreta on pastures and also due to direct inputs resulting from fertilizer drift and stock excreta where animals have free access to waterways (Quinn & Stroud 2002).

4. Pasture streams have higher numbers of faecal coliforms (Smith et al. 1993), *E.coli* and pathogens (Donnison and Ross 1999) than native forest streams.

5. In many cases, the levels of contaminants (sediments, nutrient and/or bacteria) found in pasture streams exceed water quality guidelines.

2.2.2 Studies relating the proportion of catchment area in agriculture to water quality

Other recent studies have linked the proportion of catchment land in agriculture to downstream water quality. Using data from Smith et al. (1993), the Ministry for the Environment have shown that poor lake water quality in New Zealand is linked to pastoral land use (MfE 1997). In pasture-dominated catchments (50% or more of the land is pasture as opposed to forest or tussock), most lakes have clarity levels and nitrogen and phosphorus concentrations that breach water quality guidelines. Similarly, for streams, Davies-Colley and Smith (1995) have shown that the characteristic level of bacterial contamination in streams increases with the proportion of catchment in pasture. After analysing the first 2 years of physico-chemical data from the National River Water Quality Network, Maasdam and Smith (1994) concluded that the most important factors affecting water quality were the degree of pasture development and associated variables (negligible to moderate erosion, high mean annual water temperature, high percentage of recent soils and low mean catchment elevation).

2.2.3 Studies on the effects of specific agricultural land uses

Other recent studies focussing on the environmental effects of specific land uses have also yielded valuable information. The New Zealand Dairy Industry funded research investigating the effect of intensive dairy farming on stream water quality and ecology in the Toenepi catchment, Waikato region (Wilcock et al. 1999). This research supports the conclusion drawn by Smith et al. (1993) that New Zealand streams in areas of dairy farming appear to be in poor condition. Specific yields of total nitrogen and nitrate were much higher than previously reported for New Zealand pasture catchments although yields of total phosphorus and dissolved reactive phosphorus were more aligned. Faecal bacteria concentrations were also much higher than is commonly observed in New Zealand lowland streams and could be accounted for by discharges from dairy ponds or stock access to streams. In the Manawatu-Wanganui region, a study was undertaken to determine the impact of dairy shed waste discharges on two streams (Mangaatua and Otamaraho) at the small catchment scale (<20 km^2) (Horizons.mw 2001b). The study showed that a number of water quality guidelines (*E.coli*, clarity and dissolved reactive phosphorus) were breached in the streams and that the dairyshed discharges were the major cause.

On the West Coast, the regional council has been monitoring the state of streams in dairy farming areas since 1997 (T. James, pers. comm.). In the 20+ sites monitored they found that 77% exceeded contact recreation guidelines for faecal contamination and more than 50% exceeded the less stringent stock water guidelines. They report that dairy shed effluent may be the most important source of faecal pollution at contaminated stream sites because the levels of bacteria are low in winter except where winter feed pads are located close to streams. Similarly, a study of the Little Waihi Estuary Catchment in the Bay of Plenty has shown that stream and canal waters entering the estuary are contaminated with enterococci bacteria that exceed contact recreation guidelines and are derived from dairy farming activity in the catchment (Deely et al. 1999). Also in the Bay of Plenty region a study was undertaken at Galatea to assess the impact of dairy shed effluent disposal on waterways. The study showed farming activity increased the nutrient and bacterial content of streams on the plain. Enterococci bacteria levels exceeded contact recreation guidelines (median 215 cfu/100ml) (McIntosh 2000).

2.2.4 Studies on the effects of stock access to waterways

The effect on water quality of stock having direct access to waterways has been illustrated in recent studies. On a deer farm in Southland, measurements of suspended sediment, ammonia and faecal coliforms were taken upstream and downstream of a stock access point (Environment Southland 2000). Downstream levels were 19-35 times higher than upstream. Moreover, faecal coliform levels exceeded the recommended guidelines for stock water, and ammonia concentration was at levels toxic to fish life. Similarly in hill country pasture in the Waikato, Quinn et al. (1998) showed that turbidity levels downstream of cattle wading in a stream increased dramatically from <10 to 50-250 NTU. A recent study on the Sherry River, Tasman District, showed a 50% increase in suspended sediment and a 400% increase in *E. coli* after a herd of cows crossed a stream to and from the milking shed (Davies-Colley et al. 2001). This increase was associated with the disturbance of the streambed and banks, and defecation, as the 246 cows deposited about 37 kg of faeces on two crossings of the stream.

2.2.5 Studies on the effects of increasing agricultural intensity

A number of recent studies in New Zealand have shown that increased farming intensity will, or is likely to, result in greater nutrient enrichment of waterways. Vant (1999) has found that the nitrogen yield in eight large Waikato catchments is strongly correlated to dairy cow stocking density. In a study of eight lowland rivers in the Westland and Waikato regions, Nagels and Davies-Colley (1999) found strong trends of increasing nutrients (nitrate and DRP) and faecal bacteria (*E.coli*) with an increasing ratio of stock number to water yield. Similarly, studies overseas have shown that nutrient (nitrate and orthophosphate) concentrations (Banasik et al. 1999) and faecal bacteria concentrations (Gary et al. 1983 and Tiedemann et al. 1988 cited in Stafford 2002) in streams and rivers increase with the intensification of agricultural land use.

A modelling tool recently applied by NIWA scientists to the Waikato River basin appears to be a useful method that could be used to predict the effect of land use change on nutrient loads (Alexander et al. in press). The SPARROW modelling technique takes spatial data of the location of different nutrient sources (diffuse and point source) and incorporates in-stream attenuation of nutrients. The resulting model predicts the annual average nutrient load at any location in the catchment and the relative contribution of different nutrient sources.

2.2.6 Studies on the performance and effects of farm oxidation ponds

Farm oxidation ponds are important point sources of nutrients and faecal pollution to New Zealand streams and rivers. However, they are generally of less concern than diffuse sources because of improvements in waste treatment technologies and the greater ease of regulation (Wilcock 2000). The effect of oxidation pond effluents on freshwater quality is dependant on the degree of dilution. In the Toenepi catchment, oxidation pond effluents were on average diluted by a factor of approximately 400 with stream water and added increments of DRP and ammonium to the stream that exceeded water quality guidelines (Wilcock et al. 1999). The authors cautioned that during summer low flows the dilution factor was likely to be much reduced (<100) and discharges could have an even greater effect. There is also the potential for cumulative effects to occur as a result of several discharges or in combination with diffuse inputs (Wilcock 2000).

A study on the performance of farm oxidation ponds that meet the larger size guidelines specified in recent dairy industry guidelines found that only half of the ponds consistently achieved effluent quality standards despite biological oxygen demand (BOD), ammoniacal nitrogen, total N and faecal coliform levels being improved by 20-70% (Sukias et al. 2001). To meet guidelines for visual clarity and contact recreation, discharges from these farm ponds require dilutions of around 500 and >850 fold respectively. To meet nutrient guidelines, dilutions in the range of >370-925 fold are required. Two recent studies in the Bay of Plenty region showed that only 30-48% of dairy pond discharges to surface water complied with consent conditions on first visits (Pickles 1999, Larsen 2000).

In early 1999 the West Coast Regional Council conducted an intensive study of the effects of dairy effluent discharges from eight farms in the region (T. James pers. comm.). They found that 7 of the 8 treatment systems studied seemed to be causing significant adverse effects on surface water quality. Some of the systems were causing very significant effects and three of the farms would probably be required to reduce faecal bacteria loadings by 1000 to 10000 times in order to comply with water quality guidelines.

It is noteworthy that the dairy industry has recognised the short-comings of existing farm oxidation ponds and has actively been pursuing cost-effective options for improving effluent quality. These include aerating ponds (Sukias et al. 2001) and reconfiguring ponds to an Advanced Pond System (APS) design (Craggs et al. submitted). The APS in particular has been very effective at reducing faecal bacteria concentrations to meet water quality guidelines upon discharge to receiving waters.

2.2.7 Studies on the effects of farm drains

Farm drain networks can potentially contribute high levels of sediments, nutrients and faecal bacteria to streams and rivers. These networks include surface drains such as open ditches or grassed waterways, and subsurface drains such as mole and tile drains and high-density polyethylene corrugated (HDPE) pipes. Drains transport runoff waters rapidly across the landscape minimizing contact with soil and reducing the potential for remediation in riparian zones. Research in New Zealand has shown that nutrient and faecal bacteria *(E.coli)* concentrations in farm drains can be high compared to normal stream levels and water quality guidelines (Wilcock 2000, Stafford 2002) and that waters derived from farm drains may dominate the flow and composition of small rural streams (Nguyen pers. comm, cited in Wilcock 2000). Concentrations of *E.coli* measured in farm drains (open drains and HDPE pipes) and 800 m downstream of a pond discharge outlet in the Waikato region were up to 1000 cfu/100ml and 20000 cfu/100ml, respectively (Nguyen 2001). These results are supported by a study in Canada where average bacterial levels in 12 tile drains were very high (total coliform, faecal coliform and faecal streptococci counts were 81000, 9400 and 2500 cfu/100 ml, respectively) (Thornley and Bos 1985 cited in Stafford 2002). In the United Kingdom, degradation of water quality (increased biochemical oxygen demand (BOD), ammonium and dissolved reactive phosphorus (DRP) occurred between dairy farm reaches and was most apparent where there were point-sourced drainage inputs from farmyards (Hooda et al. 2000).

2.2.8 Studies on the effects of agriculture on groundwater and the implications for surface water quality

Like farm drain networks, shallow groundwater aquifers can also be a major contributor to stream and river flows in some areas. For example, up to 95% of the Waikato region's surface water flows are contributed by shallow groundwater flows (Hadfield 1990 cited in Ritchie 1999a). Some shallow groundwater aquifers in the Waikato region are contaminated with high concentrations of nitrate (e.g., 15 g N m^{-3})

that exceed guidelines for domestic supply (11.3 g N m^{-3}). This contamination is attributed to agricultural activities, principally the use of nitrogen-fixing plants (legumes) and animal excretion at high stock densities (3-4 cows ha^{-1}) (Selvarajah et al. 1994 cited in Wilcock and Nagels 2001). Ledgard et al. (1999) studied the nitrogen balance of four dairy farmlets in the Waikato region, with varying stock densities (3.3 and 4.4 cows/ha) and fertiliser addition rates (0 , 200, 400 kg N/ha/yr). They found that nitrate leaching was the major process responsible for N loss from the systems, and in particular, cow urine was the main source. Larger leaching losses with increasing rates of fertiliser application were also noted with around 19 – 28% of the applied N lost on farms with high rates of fertiliser application. A study conducted in USA also implicates agricultural activities as a principal source of groundwater nitrate contamination. High concentrations of nitrate in groundwater in Florida were derived mostly from animal wastes from farming operations (49-53%) and fertilizers (39-45%) (Katz et al. 1999).

2.3 Evidence for agricultural effects on water quality – *State of the Environment*

Regional Councils in New Zealand monitor a range of parameters in freshwaters in their regions to determine water quality status. The parameters monitored include: 'black disk' clarity (or visibility), suspended sediments/solids, ammonia, nutrients (nitrate, dissolved reactive phosphorus and/or dissolved inorganic nitrogen), dissolved oxygen, temperature and faecal bacteria (faecal coliforms, *E.coli* and/or enterococci). In this section, we summarise the information reported in the most recent State of the Environment (SOE) reports for each region relating to agricultural effects on water quality. In addition a summary table (Table 3, Appendix) shows for each region where agriculture has been implicated, in isolation or in conjunction with other activities, as having a detrimental effect on water quality.

Southland

The regional council reports that excessive faecal contamination is a problem in many rivers (Environment Southland 2000). Headwaters and the Fiordland lakes are safe for contact recreation but lowland rivers are not. Waterways in catchments with high intensity land use (drystock and/or dairy farming) have more faecal contamination than waterways in low intensity land use catchments. Nutrient levels (nitrogen and phosphorus) are increasing in all major catchments. Headwaters of the region's major rivers contain little nitrogen but excessive concentrations are common in lowland areas. Most of this nitrogen comes from non-point sources associated, in particular, with the following activities: cropping, intensive grazing and fertilizer usage. While water clarity has improved in some rivers (lower Waiau, upper Oreti, upper Mataura) due to soil conservation efforts it has stayed the same (lower Aparima, lower Oreti, lower Mataura) or deteriorated (lower Mararoa) in others possibly as a result of runoff and high stocking rates. Groundwater quality in Southland is generally good but in some areas quality is reduced as a result of naturally occurring variations or intensive land use. Nitrate levels increase where land use intensity is highest with the major source likely to be leaching from dung and urine deposited by grazing animals along with land disposal of effluent, fertilizer application and septic tanks.

Otago

Otago Regional Council reports on the freshwater quality of their four principal sub-regions: the Clutha catchment, the Taieri catchment, the North Otago area and the Coastal and Southern Otago area (Otago Regional Council 2001). The Clutha River is in excellent condition apart from occasionally high faecal coliforms, and in the upper catchment, turbidity is the only issue. Runoff from agricultural land is reportedly contributing to low-level pollution in the Manuherikia and Lindis rivers. In most southwest Otago rivers, suspended solids, turbidity and faecal coliforms levels are high. High levels of faecal coliforms and nitrogen associated with animal waste and agricultural practices have sometimes been found in the Crookston Burn, Heriot Burn and Wairuna waterways. While groundwater quality in the Alexandra basin is generally high, there are problems with high faecal coliforms in the Wakatipu basin probably as a result of stock grazing, septic tanks and/or poor wellhead protection. Similarly, faecal contamination and rising nitrate levels in groundwaters of the Queenstown basin may be associated with farming activities.

In the Taieri catchment, river water quality declines in a downstream direction. This is attributed to a combination of natural changes as well as the influence of agriculture (dairy shed effluent and other agricultural wastes). Faecal coliform levels have increased at a number of sites. At one site (Henley Ferry Bridge) water typically has faecal coliforms in excess of guidelines levels. The Taieri floodplain is intensively farmed, mostly by dairying, and drainage water from its southwest part is pumped from the 'main drain' to Lake Waipori, contributing to its poor water quality.

In North Otago water quality is strongly influenced by the nature and intensity of surrounding land use. The water quality of the Kakanui and Shag rivers, which pass mostly through farmland, is generally good but deteriorates with distance downstream. In isolated instances faecal coliform levels exceed guidelines and there are sometimes algal blooms.

In Coastal and Southern Otago, river and groundwater quality are typically of a reasonable to good standard despite impacts from industrial and processing operations and farming. The Catlins River drains mostly forested areas and elevated suspended solids and turbidity are attributed to natural causes. However, the presence of faecal coliforms, sometimes above guideline levels, may come from farming. The lower Tokomairiro River has elevated suspended solids and nutrient concentrations and high faecal coliforms above contact recreation guidelines. The lower river is fed by streams draining farmland where stock have free access to stream margins and this may be contributing to the degraded water quality. However, the Milton sewage scheme is also a contributor. Groundwater in the Tokomairiro basin has been subject to limited sampling but faecal coliforms have been present at four sites. The catchment contains a significant proportion of land grazed by stock.

Canterbury

In the Canterbury region, groundwater quality is generally very high across the region, particularly in deep aquifers. In shallow aquifers, bacterial contamination derives from natural and human-induced sources. The latter includes septic tank systems and land-based animal effluent disposal systems (Canterbury Regional Council 1996). In the rivers of this region, concentrations of nutrients and faecal coliform bacteria typically increase with distance downstream due to the impact of point and non-point source contaminants (Hayward 2001) including runoff from agricultural land and animals in the riverbed and catchment (stock and wildlife) (Canterbury Regional Council 1996). Weathering of rocks may also contribute to increased nutrient levels with distance downstream. In general streams and rivers draining predominantly pastoral catchments (Selwyn, Ashburton and Opihi rivers, and Lyell Creek) have a tendency for slightly higher mean concentrations of total nitrogen than those with high country/alpine catchments and less intensive farming.

Three major rivers within the Canterbury region have been the subject of more detailed study, the Rangitata, Hurunui and Ashburton rivers. Poor bacterial quality of the Rangitata river, especially its lower reaches is attributed to land use and large populations of birds inhabiting the river bed (Hayward and Meredith 2000). The Hurunui River has high water quality in its upper reaches as a result of a high proportion of natural land cover in its catchment. Elevated nutrients and bacteria in the lower reaches of the Hurunui River are again attributed to intensive land use in the middle catchment area (tributaries draining intensively stocked land and irrigation bywash discharges) and birds inhabiting the riverbed (Hayward 2001). In the Ashburton River high faecal contamination is attributed mostly to black-backed gull colonies inhabiting the river bed but other potential sources are sheep and cattle grazing on the river bed, Canada geese, water race discharges and irrigation by-wash discharges (Main 1999).

Tasman

The district council reports that the water quality of the Takaka River and its tributaries is generally good although nutrient enrichment is evident at some sites (Tasman District Council 2000). The bacterial quality of freshwater bathing sites in the district is generally excellent with only occasional breaches of contact recreation guidelines. However, surveys in 1997 and 1998 have shown that the Motupipi river has high levels of suspended solids, nutrients and bacteria and excessive growth of aquatic plants and algae as a result of agricultural activities (dairy shed pond effluent discharges, runoff from land-applied dairy shed effluent, dairy factory wastewaters and general runoff from pastoral land). The district council reports that landowners are now controlling the direct discharges to the Motupipi river. They conclude that a large proportion of the sediment and nutrients entering Tasman's waterways originate from non-point sources with dairying and horticulture being major contributors. In relation to groundwater quality, this is generally good except for the Waimea Plains aquifers where the main causes of contamination are poorly designed septic tanks and land-based waste disposal systems.

Wellington

In the Wellington region, river sites within or near to forested catchments have good water quality. Rivers with the poorest water (elevated turbidity, DRP, ammonia, BOD and/or faecal coliforms) are impacted by runoff from urban and/or rural areas and generally experience lower flows than other waterbodies. The highest median levels of faecal coliforms were found at small urban sites. Small rural sites also recorded high faecal coliform levels while forest park sites recorded the lowest levels (Warr 2001). Wellington Regional Council has also recently released a report on the recreational water quality of the Wairarapa area that includes 10 freshwater sites (Watts and Sevicke-Jones 2001). The report finds that freshwater quality for the purposes of contact recreation is generally acceptable. However, higher *E.coli* and faecal coliform counts were found at two sites (Double Bridges and Te Ore Ore) and were apparently linked to runoff. The lowest bacterial counts were associated with sites in or near forest park boundaries.

Manawatu - Wanganui

In the Manawatu - Wanganui region, surface water quality is affected by the activities of agriculture and cities (Horizons.mw 1999). Water quality in the region ranges from good in several headwater catchments to poor in Lake Horowhenua but most areas have reasonable quality and are relatively unchanged since 1999. High water quality was reported for the upper Rangitikei and Mangwhero catchments. This is not surprising as these catchments are dominated by native vegetation. However, water quality was also good in the Mangatainoka catchment despite it being in intensive dairying country (Horizons.mw 2001a). Bacterial contamination is high at a number of river sites and contact recreation guidelines are exceeded at sites where there are no obvious point discharges such as sewage. Seepage of waste from pastures or septic tanks and livestock eroding riverbanks and wading and defecating in rivers are possible sources of contamination at these sites (Horizons.mw 1999). Discharges of dairy shed effluent to water have been identified as one of the principal causes of degraded water quality in the region and the Manawatu catchment in particular

(Horizons.mw 2001a). Groundwater quality is reasonably good in the region although there are some areas where it is degraded locally. Groundwater quality meets drinking water guidelines in many deep, confined aquifers in the Wanganui and Palmerston North areas but shallow groundwaters are contaminated with high levels of nitrate in the Horowhenua and Tararua areas (Horizons.mw 1999, 2001a). Intensive land use is identified as the probable cause of nitrate contamination in the latter regions (Horizons.mw 1999).

Taranaki

In Taranaki, the Regional Council reports that the water quality in the upper reaches of catchments is good to excellent with low numbers of faecal coliform bacteria (median <50/100ml). Good water quality in the mid-reaches of the Hangatahua River is attributed to protection from stock access. Generally though, nutrient and bacterial levels in the mid-lower reaches of catchments increase as a result of point source and agricultural non-point source runoff and direct stock access to surface water. In the lower reaches of some rivers and streams, particularly in intensive dairy farming catchments, numbers of faecal coliforms are high (>200/100ml). Phosphorus levels are elevated in ring plain rivers and streams as a result of weathering of volcanic rock but also from point and non-point sources on the intensively dairy farmed ringplain. Rapid rises and falls in surface water dissolved reactive phosphorus (DRP) concentrations are observed below point source discharges such as farm dairy treatment ponds. Nitrate concentrations in rivers increase with distance downstream and are highest in rivers and streams where dairy farming is most intensive (Punehu and Waingorongoro). In the Punehu stream, turbidity and bacteria levels are also elevated and this is attributed to farming activity and stock access. Elevated ammonia levels in some rivers result from cumulative point source discharges and pasture runoff. Compliance with bacterial water quality guidelines is reportedly variable in the region, particularly in the mid to lower reaches of dairying catchments (Taranaki Regional Council, in prep.).

Dairy farms in the Taranaki Region have become larger over the last 5 years with the average farm size having increased from 71 hectares in 1996 to 78 hectares effective area in 2001 and the average herd size having increased from 162 cows to 212 cows over the same period. A greater number of cows per hectare has led to a higher loading of dung and urine on pasture and increased potential for nutrients, organic matter and bacteria to enter both surface water and groundwater. The Taranaki Regional Council seem to suggest that cow densities may be linked to the elevated nutrient levels of ring plain streams, particularly in lower catchment areas.

Hawkes Bay

Hawkes Bay Regional Council monitors 27 different water quality variables in their State of the Environment monitoring programme but four key variables (faecal coliforms and the nutrients, nitrate, soluble reactive phosphorus and ammonium) are commonly used to assess the water quality state of their rivers. In the latest State of the Environment update (Hawkes Bay Regional Council 2001) they report that nutrient concentrations and distributions in the region's rivers reflect local catchment influences (geology and associated land uses) and do not show a clear gradient of low concentrations in headwaters and higher concentrations in lower reaches. In contrast, generally more faecal coliforms were found in lower river reaches compared to upper river reaches resulting from increased runoff from surrounding land uses. In another report, high faecal bacteria in one reach of the Tukipo River are likely to result from stock impinging on the riparian margins of tributary streams (Wood 1998).

Bay of Plenty

In the Bay of Plenty region freshwater quality has been monitored at 44 sites since 1989. Increasing nitrate concentrations have been documented in some of the pumice catchments around Lake Rotorua and the areas between the lakes and the coast, probably resulting from pastoral development. Increasing concentrations of bacteria have been found in rivers and streams across large parts of the region. Pastoral farming, the most widespread land use in the region, is a major contributor along with industrial and urban sources (Taylor and Park 2001). Lake water quality in the region is variable and while some lakes have improved, others have declined. The major pressures on lake water quality are the effects of the expanding small communities (i.e. septic tanks) and intensification of farming. Groundwater quality is monitored at 55 sites in the Bay of Plenty region. Elevated nutrients and bacteria in some shallow aquifers are attributed to contamination from some land-use activities (Environment Bay of Plenty 2001).

Waikato

In the Waikato region, water quality is monitored at 109 river and stream sites including 9 on the Waikato River. The water quality of regional rivers is largely suitable for supporting aquatic life but less suitable for swimming. Water quality is best in Lake Taupo tributaries, good in the Coromandel zone but poor in the lowland Waikato tributaries. Water quality of the Waikato River is good in its upper reaches with 90-94% compliance with water quality guidelines but poor in its lower reaches with 31-72% compliance. Land use upstream of the sampling sites has a significant effect on water quality with poor water quality generally found downstream of areas where land has been developed for agriculture and urban development. A large portion of the sediment and nutrients in the regions waterways can be attributed to non-point sources mainly from agricultural land use. Although the overall water quality of Lake Taupo is high, increasing nitrate concentrations are thought to be linked to land use intensification in the surrounding catchment. The water quality of peat lakes and Lower Waikato River lakes is poor. Land management changes including drainage, vegetation clearance and agricultural development have impacted upon the water quality of almost all of these lakes (Environment Waikato 1998).

Groundwater quality in the Waikato region has declined in areas of intensive land use especially where shallow aquifers are vulnerable to contaminants. Excessive nitrate concentrations in groundwater in the region are related to land use activities that include pastoral farming, market gardening, application of nitrogenous fertilizers and industrial and sewage effluent disposal. Nitrate concentrations can exceed drinking water guidelines in the intensively farmed Hamilton-Mangaouna area. The groundwater quality can also impact upon surface water quality in this region. In the Hamilton Basin up to 85% of the base flow of small streams comes from groundwater. A study in the Toenepi catchment indicates that a high proportion of nitrate found in the stream could result from nitrate leached from grazed pasture systems (Environment Waikato 1998).

Auckland

In the Auckland Region, the vast majority of streams have been modified for rural uses, flood control or urban development. In most instances stream modification has been accompanied by varying degrees of water quality degradation ranging from moderate to severe (Auckland Regional Council 1999). Streams in urban areas or in mixed land use catchments with a major urban component have the poorest water quality, a native forest stream has the best water quality and streams in agricultural catchments are intermediate. Of seven lakes monitored in the region, two (Lake Spectacle and Lake Kuwakatai) have very poor water quality (turbid and nutrient-enriched) due to intensive agricultural land uses in their catchments (Wilcock and Stroud 2000). One lake (Kereta) has high concentrations of faecal bacteria from waterfowl and from stock grazing near the shoreline.

Northland

In the Northland region, water quality varies greatly, being pristine in upper native forest catchments to highly impacted in modified lowland catchments. The lakes monitored in the region (Lake Taharoa and Lake Ngatu) have excellent water quality for contact recreation. However, most lowland rivers and streams are unsuitable for swimming. Some sites exceed the less stringent guideline for stock drinking water. Higher levels of bacterial contamination *(E.coli)* are found in catchments with high intensity land use and probably result from non-point sources, septic tanks and/or livestock (runoff from agricultural land or livestock wading in streams). Dissolved inorganic nitrogen concentrations are high enough to promote excessive algal growths in most catchments and concentrations are regularly high in developed catchments and extremely high in some rivers (Mangere and Mangahahuru). A significant proportion of the nitrogen is likely derived from point and non-point agricultural sources. High ammonia concentrations in the Mangere River are linked to the cumulative effect of dairyshed discharges and runoff. Nitrate concentrations in the Mangere and Wairua rivers exceed the stock drinking guideline and probably result from agricultural activities (dairy shed effluent discharges and non-point source agricultural runoff). Specific studies have shown that waterways in both the Ruawai and Te Kopuru areas are degraded as a result of intensive agricultural activity with waterways in the Ruawai area being severely degraded. Just over half of land in the region is used for pastoral agriculture and it is the most significant source of non-point source pollution (Northland Regional Council, in prep.).

2.4 Evidence for agricultural effects on water quality – *Conclusion*

The vast majority of scientific studies on cause/effect relationships published since Smith et al. (1993) conclude that agriculture has a detrimental impact on water quality. These studies have shown that high levels of sediments, nutrients and bacteria are generally found in waterways in agricultural areas, and water quality guidelines are often compromised, particularly where farming activity is intensive. Regional Council SOE reporting is not so unequivocal. This is to be expected because most Regional Council SOE monitoring occurs in larger river basins of mixed land-use where it is difficult to discern a cause-effect relationship. However there is still abundant evidence from the Regional Council information that intensive agricultural practices are the principal cause of poor water quality throughout New Zealand.

3.0 AGRICULTURAL EFFECTS ON AQUATIC ECOLOGY AND HABITAT

3.1 Evidence for agricultural effects on stream life – *Scientific research*

The review of agricultural effects on freshwater by Smith et al. (1993) highlighted the need for further research into the ecology of freshwaters and the impact of land use on biological communities. Since the time of that review there has been considerable work on land use effects on stream communities. There are a number of factors that are altered when land is cleared and grazed that contribute to the changes in stream communities (Table 4, Appendix). The main changes include: reduction of shade leading to algal proliferations and increased temperature (Quinn et al. 1997, Rutherford et al. 1997, 1999); reduction in organic matter inputs (leaves) that are habitat and food sources (Scarsbrook et al. 2001); increased nutrients adding to instream plant growth, increased sediment inputs (Quinn & Stroud 2002); changes to stream morphology and wood inputs (Davies-Colley 1997); deepening and straightening of channels that increases stream gradients, reduces stream length and habitat diversity (Williamson et al. 1992); increased flow yield, variability and surface runoff (Dons 1987, Fahey & Rowe 1992).

3.1.1 Benthic communities

Evidence for pastoral effects on streams was first noted in the New Zealand scientific literature by Allen (1959), who observed that thin, brownish algal films on the streambed were replaced by filamentous and mat-forming algal cover over a 20 yr period of increasingly intensive agricultural development in Horokiwi Stream, Wellington. This was followed by a change in the invertebrate community to fewer mayfly and caddisfly taxa, but an increase in abundance of snails, elmid beetle larvae, and chironomids.

Hopkins (1976) also found that total invertebrate production was higher in a pasture stream reach, but community composition changed to greater numbers of worms and a reduction in mayfly and stonefly species. Smith et al. (1993) documented that low-level inputs of nutrients and Biological Oxygen Demand (BOD) from agricultural land may have a beneficial impact on the natural aquatic community by increasing primary and secondary production (increasing invertebrate densities) without substantially altering the community structure. However, at higher loadings indications of ecosystem stress develop. Problems to aquatic life were identified as sedimentation, profuse growths of autotrophs/heterotrophs, excessive ammonium (NH_4), and low dissolved oxygen (DO).

Quinn & Hickey (1990) surveyed 51 medium-large rivers and showed that rivers in catchments with >30% pastoral development showed stress effects that were indicated by changes to the invertebrate fauna. Typically, fewer Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) (EPT) taxa were recorded and there was an increase in species that consume algae. These changes were associated with increases in summer maximum temperature, organic nitrogen concentration, and periphyton biomass. Periphyton proliferations in rivers were common in many regions of New Zealand (Biggs 1985) and high biomass of periphyton in a study of 100 rivers occurred in catchments that were at least partially developed into pasture (>20%; Biggs 1990).

A guideline for managing periphyton biomass in streams (Biggs 2000) outlines the maximum levels of chlorophyll *a* (a measure of periphyton abundance) in streams that should not be exceeded in order to retain benthic faunal biodiversity (50 mg/m^2), limit filamentous algal growths and maintain trout habitat and angling opportunities (120 mg/m^2). Agricultural land use affects the growth of periphyton communities through increasing light levels, from removal of forest trees, and through increasing nutrient delivery to streams. Biggs (2000) suggests guideline levels of soluble inorganic nitrogen and soluble reactive phosphorus that should not be exceeded in order to prevent periphyton biomass from reaching levels that inhibit benthic faunal biodiversity. These levels are generally less than 10 mg/m^3 (nitrogen) and <1 mg/m^3 (phosphorus) in stable, unshaded streams. However, there are a number of other factors that influence the growth of periphyton, namely light, flood events, and grazing. Where control of nutrient levels to those stated above is unlikely to be achieved, other mitigation measures such as riparian shading may be useful.

Land use changes between native forest and pasture have also shown marked differences in invertebrate communities in headwater streams in Otago (Townsend et al. 1997), North Canterbury (Harding & Winterbourn 1995) and Waikato (Quinn et al. 1997). In general, pasture sites had higher total invertebrate numbers, but fewer EPT individuals and species, and much smaller proportions of species that can feed on leaf litter. Gravel bed streams showed similar changes in invertebrate abundance and species composition between forest to pasture in Southland (Scott et al. 1994). Less study has been done on sandy-bottomed, lowland streams although Quinn (2000) presents data from the central North Island that shows large differences in invertebrate community composition between pasture sites and forested sites. Pasture streams that received drainage from farm tracks where cows travel to milking sheds were in particularly poor condition.

Quinn (2000) explains these changes to communities in terms of a subsidy-stress conceptual model. With low levels of pastoral development certain aspects of agricultural development may benefit stream invertebrates up until a critical level where they will begin to have negative effects, e.g., increasing light and nutrients can increase primary production so there is more food for invertebrates that feed on periphyton, but light and nutrients can become a stressor when high enough to cause algal blooms and high water temperatures. Freshwater crayfish can benefit from warmer stream temperatures by growing faster, but the lack of riparian trees can adversely affect their habitat stability by removing the flow refuges that their roots provide during floods (Parkyn 2000).

In their native condition most New Zealand rivers had forested headwaters and were well shaded until the channel width exceeded about 10m after which forest streams became increasingly open to sunlight (Davies-Colley & Quinn 1998). Forest removal, particularly of headwater areas, has resulted in a homogenising of stream habitat conditions and consequently loss of stream biodiversity, especially those species adapted to the high shade and cool temperatures of forested headwaters (Quinn 2002).

3.1.2 Temperature

Many invertebrate and fish species are sensitive to high temperatures (Quinn et al. 1994, Cox & Rutherford 2000). Mayflies and stoneflies are impacted by water temperatures greater than c.20°C and guidelines used by regional councils suggest that > 25°C can impact upon trout. Daily maximum temperatures in pasture streams often exceed these levels in summer. Wilcock & Stroud (2000) report that of 16 streams in the Auckland region, 4 streams had maximum daily temperatures of >25°C and maximum temperatures consistently below 20°C were found in only two streams, both in forested catchments. Similarly, 5 of 33 streams and rivers in the Manawatu-Wairarapa region had daily maximum temps that exceeded 25°C and some waterways showed increases of 2-3°C when flowing from native vegetation to farmland (Horizons.mw 2001a).

3.1.3 Native fish

Land use change has been held partly responsible for reduced viability and species diversity of indigenous freshwater fish, especially in the case of the extinction of the southern grayling, and apparent decline in whitebait abundance (McDowall 1990). Forest removal, intensive agriculture, wetland drainage, damming and water abstraction, and effluent discharges have all been identified as factors that impact on native fish fauna (McDowall 2000).

Land use affects on fish populations can differ according to species. Hicks and McCaughan (1997) found that eels were abundant in pastoral streams, particularly shortfinned eels, but that other species such as banded kokopu were only present in forested sites. Similarly, Hanchet (1990) surveyed 55 sites in the Waikato region and found that the diversity of native fish species declined in pasture sites compared to native forest possibly due to a reduction in suitable habitats (e.g. woody debris) and increased siltation.

3.1.4 Sediment and turbidity

At the time of the Smith et al. (1993) review very little work had been done on the effects of sediment in streams apart from a literature review (Ryan 1991) that identified that their needed to be more research that was specific to New Zealand species to be able to establish guidelines. Recent studies have shown that increased suspended sediment affects stream communities by reducing water clarity (affecting light for photosynthesis and vision for sight-hunting fish), by physically abrading biota, and by smothering the substrate, which affects habitat and food resources for fish and invertebrates (Davies-Colley et al. 1992, Quinn et al. 1992a, Rowe & Dean 1998, Dunning 1998 cited in Death 2000). Silt deposition generally leads to a change in invertebrate communities, with a loss of stonefly (Plecoptera) and mayfly (Ephemeroptera) species and an increase in animals such as chironomids (midge larvae) and oligochaetes (worms) that can burrow into silt (Suren 2000).

In recent years there have been studies investigating how increased turbidity can affect the foraging and migratory behaviour of fish (Rowe & Dean 1998; Rowe et al. 2000). Sensitivities to turbidity for native fish can range from thresholds of 20 NTU (banded kokopu) to > 160 NTU. Changes in trout behaviour can occur when turbidity reaches 30 NTU (Dave Rowe, NIWA, pers. comm.).

3.1.5 Agricultural intensification

From studies of invertebrate communities in gravel-bed streams in Southland, intensive grazing by cattle (c.15 su/ha) was associated with greater changes in invertebrate communities than extensive grazing by sheep or cattle (<10 su/ha). Small streams were more at risk from impacts of riparian grazing than larger streams due to the greater impact of reduced stream shade and higher sedimentation from bank trampling by stock (Quinn et al. 1992b).

A research project in the Pomahaka catchment of Otago strongly implicated the effects of farming on river water quality, particularly the elevation of turbidity, resulting in a decline in the condition of the trout fishery (Hayes et al. 1999 cited in Otago Regional Council 2000b). Harding et al. (1999) investigated the effects of agricultural intensity on water quality and invertebrate communities in the Pomahaka River. They found that increases in turbidity down the length of the river were out of proportion with that observed in longitudinal studies of a forested river. They concluded that agricultural intensity, rather than % of differing land uses, was a more useful indicator of impacts within rivers and suggested that, in the Pomahaka catchment, there was a threshold stocking intensity of c. 6 – 8 stock units ha^{-1}. Above this intensity, significant reductions in water quality were observed and contributed to the high nutrient and sediment levels, and changes to the macroinvertebrate assemblages observed in the lower river.

3.2 Evidence for agricultural effects on stream life – *State of the Environment*

Biological monitoring is undertaken by a number of regional councils throughout New Zealand. Benthic macroinvertebrate communities can be used as indicators of water quality and habitat in streams and rivers, as studies have shown that invertebrates differ in their tolerance to pollution. The invertebrate community is also an integrated long-term measure of all the factors affecting that particular site and indices have been derived from tolerance scores of taxa to determine the water quality status of a site e.g., Macroinvertebrate Community Index (MCI) and variations (QMCI, SQMCI) (Boothroyd & Stark 2000). Generally, mayflies, stoneflies and caddisflies (EPT taxa) are sensitive to pollution, while chironomids, worms, and snails are often more tolerant to pollution. Many regional councils use a combination of these indices to analyse the biological monitoring of streams and rivers in their regions.

3.2.1 Benthic communities

Environment Southland (2001) reports that 51% of sites monitored within their region had good or excellent ecosystem health and 33% of sites had poor ecosystem health. The sites with poor health were generally down-stream of effluent discharges or small streams with agricultural catchments. The amount of algae exceeded guidelines for maintaining trout habitat at 15% of sites and benthic biodiversity at 30% of sites. Well-vegetated riparian margins are the major factor affecting the abundance and distribution of aquatic biota in small Southland streams (Ryder 1997 cited in Environment Southland 2000). Environment Southland (2000) concludes that agricultural development has had the most impact on riparian vegetation in Southland. Economic pressures to create additional pasture led to the removal of much of the riparian vegetation along the margins of many rivers and streams in Southland. Stock access to riverbanks and riparian margins continues to be a problem.

The Otago Regional Council (2000a) reports that in the northern and coastal areas of their region, forested catchments had invertebrate communities indicative of good water and habitat quality whereas the lower reaches of rivers in farming areas that experienced periods of low flows were affected by algal proliferations and consequently changes in the invertebrate fauna. Communities were dominated by species tolerant of algae-smothered habitats and the recovery of sensitive taxa in the Kakanui river after a drought was very slow. The mid reaches of the Kakanui River, and the lower reaches of the Kakanui and Shag Rivers showed moderate quality invertebrate communitities and frequent heavy algal proliferations, due to a combination of prolonged low flows and farmland influences.

In the Taieri catchment, riverbed invertebrate communities are 'poorer' in the lower catchment than in the upper catchment, largely because of natural physical habitat changes determined by gradient and velocity (Otago Regional Council 1999). However, water quality degradation, such as nutrient enrichment, occurring in the upper catchment above Middlemarch was attributed to a moderate decline in the quality of the invertebrate fauna.

The Otago Regional Council has reported that both dairyshed effluent and diffuse source nutrient enrichment from pasture were significantly affecting water quality in a study done in 1994 (Otago Regional Council 2000b). Large industrial discharges to the lower Clutha River/Mata-Au have the potential to affect river biota because of the high organic loading of dairy and meat processing wastes, however, agricultural diffuse source and point source nutrient enrichment (and other agricultural activities) have the greatest influence on stream water and habitat quality in the tributaries of the Clutha river/Mata-Au system. This is particularly true in the lower catchment.

The West Coast Regional Council has been regularly monitoring the State of the Streams in dairy farming areas and other land uses since 1997. Poor invertebrate communities have been found to exist commonly in smaller creeks such as upstream reaches of spring fed creeks that receive dairy farm effluent discharges. These streams are often characterised by high ammonia concentrations and low dissolved oxygen.

In the Wellington region, biological monitoring revealed that 11 of 15 forest park sites had faunal assemblages consistent with good water quality, only 3 of 17 rural streams and rivers, and only 2 of 7 urban streams. Several of the rural and urban sites had faunal compositions indicative of severe pollution (Warr 2001).

Taranaki Regional Council (in prep) has been regularly monitoring macroinvertebrate communities at 32 sites since 1995. MCI results show a gradual decrease in scores from the National Park downstream to the coast. This decrease has been attributed to a combination of factors including the natural consequence of the changing physical habitat downstream, the effects of agricultural land uses on water quality and habitat such as nutrient run-off, loss of riparian vegetation, and increased sedimentation as a result of erosion of the stream margins. These effects represent the cumulative impacts of non-point source run-off and point source discharges through intensive dairy farming catchments and centres of human population.

In the Hawkes Bay, macroinvertebrate communities characteristic of good habitat and water quality conditions, were found mostly in the headwaters of the regions main rivers, generally in forest parks. The good water quality was attributed to minimal catchment disturbance, filtering of any faecal or nutrient run-off, and good stream habitat from riparian shading. Typically deterioration in macroinvertebrate communities was observed further down the river systems due to the cumulative effects of runoff from surrounding land uses (agriculture and urbanisation). Runoff from intensive land uses that is not well filtered by vegetation has elevated contaminant levels and resulted in poorer water quality (Hawkes Bay Regional Council 2001).

Environment Waikato (1998) surveyed 198 sites in the region. Nearly half the sites in developed catchments (agriculture, horticulture, urban) were either moderately or severely degraded according to biological monitoring results. Three of the streams classed as severely degraded were found in agricultural catchments and provided very poor habitats for invertebrates because of large loads of silt on the stream bed.

Macroinvertebrate communities have been assessed at 21 sites throughout the Northland region since 1996 (Northland Regional Council in prep). Generally ecosystem health was excellent in forested headwaters, but declined further downstream. At all other sites ecosystem health was moderately poor to poor. Lowland streams, especially in agricultural and urban areas had poor ecosystem health. Collier (1995) studied lowland streams in Northland and found that composition of the invertebrate fauna improved, particularly the number of EPT taxa and the Macroinvertebrate Community Index, with increasing substrate size and percentage of native forest upstream or in the riparian zone.

3.2.2 Fish

Environment Waikato (1998) report that a range of native and exotic fish species are present in the Waikato Region and factors that may adversely affect fish in some areas were identified as; barriers to dispersal (e.g., small dams, culverts, summer low flows), lack of riparian vegetation and high silt load. Native fish were surveyed in the Manawatu-Wanganui region (Phillips and Joy in prep) and healthy fish communities and some rare species such as shortjaw kokopu were found in forested streams. Streams in modified rural catchments were not so healthy with many fish species absent that were expected to occur on the basis of stream size and elevation. However, even some forested sites had fewer native fish species than expected and barriers to migration were identified as an important factor.

3.2.3 Trends

Environment Bay of Plenty (Wilding 2001) has been conducting biological monitoring since 1991 at 17 sites. Percentage of pasture in catchments was related to decreases in stream "health" scores of MCI and QMCI and to increases in the percentage of filamentous periphyton. Trend analysis of this data revealed that only the Ngongotaha stream showed a significant improvement over time, with increasing QMCI values, EPT and taxa richness from 1992 – 2000. This improvement was related to extensive riparian planting in the 1980's (see also Williamson et al. 1996).

Trend analysis of 66 sites in New Zealand's National Rivers Water Quality Network (a monitoring programme run by NIWA; Scarsbrook et al. 2000) have shown improvements in MCI over the period 1989-1996 in baseline sites, but only a weak improvement in impacted sites. Impacted sites were in areas downstream of agriculture, exotic plantation forestry, industry and urbanisation, whereas baseline sites were situated where there was no diffuse or point source pollution. The weaker trend at impacted sites suggests that climatic influences on in-stream conditions, rather than a change in river or catchment management, may be responsible.

Trend analysis is still very new due to the length of time required to establish data sets. However, trend analysis will be a useful tool in the future to identify the long term changes in stream communities, especially if studies are designed to collect information on farming type and intensity within catchments.

3.3 Evidence for agricultural effects on stream life – *Conclusions*

Since the time of the Smith et al. (1993) review of agricultural effects on waterways, there have been many more studies into the ecology of New Zealand streams. Land use change and impacts of farming have clearly been shown to alter the habitat (light condition, water temperature, woody debris cover, sediment etc.) and subsequently the nature of biotic communities living there. Furthermore, agricultural intensity, rather than percentage of differing land uses, has been linked to impacts within rivers particularly increases in nutrients and sediments (Harding et al. 1999).

State of Environment reports from around the country appear to have a number of commonalities with regard to the health of each regions streams:

- Forested headwaters have healthy invertebrate communities that change to communities of poor diversity and high pollution tolerance downstream in relation to the increasing amount of pastoral development in the catchment.

- A number of regions noted severe pollution of small streams and streams receiving dairy shed effluent

- The degradation of riparian areas has been highlighted as a factor causing poor stream habitat and water quality.

4.0 MITIGATION – THE WAY FORWARD

As a result of the evidence for the impact of agriculture on streams there have been many improvements in our understanding of how riparian management can be a useful tool to mitigate these effects. Riparian management is widely accepted by scientists and regulatory authorities as an effective means to improve water quality and stream habitat in rural areas. Research by NIWA in the late 80's and early 90's led to the publication of the DOC-NIWA guidelines: Managing Riparian Zones (Collier et al. 1995). Recently, MfE (2001) published guidelines for New Zealand rural waterways, and a number of regional councils have produced their own guides to implementing riparian management (e.g., Auckland, Wellington, and Taranaki Regional Councils). Half of the regional councils in New Zealand have some kind of riparian management funds available indicating how widely accepted the impacts of farming on streams are. For example, Environment Waikato has a riparian fund where $10 million will be distributed over 10 years and a "clean streams" project that advocates planting from the headwaters downstream. There are also many streamcare and landcare groups that are involved in planting stream riparian margins. For example, by 1999 landcare groups in the Waikato Region had fenced 95.5 km of stream banks (Ritchie 1999b).

Fencing stock out of streams and retiring riparian margins from agricultural land use are particularly important practices to improve stream water quality. Buffer zones can filter contaminants and sediments from overland flow before water enters the stream. Plantings, especially through provision of shade, can improve the ecological functioning of streams. The benefits of fencing animals out of streams were demonstrated by a study in Reporoa, Central North Island, where suspended solids and peaks in enterococci bacteria decreased dramatically following stock exclusion (Ritchie 1999a). A study on the effects of riparian retirement in the Ngongotaha catchment showed that this practice can result in substantial reductions in the amount of sediment and nutrients in streams (Williamson et al. 1996). Similarly, Environment Bay of Plenty (Wilding 2001) has found a positive trend for improvement in the invertebrate community at this stream in surveys from 1991 to 2000.

Riparian management can be viewed as a last line of defence for filtering out contaminants before entering the stream. Improved land management together with riparian management, are most likely to achieve improvements in water quality and stream habitat. Examples of improved land management include: avoiding overstocking and pugging of soils, retiring steep and erosion-prone land, protecting wetlands, diverting road and track runoff, avoiding fertiliser application directly to streams or when the water table is high or heavy rain is likely.

The New Zealand Fertiliser Manufacturers' Research Association (1998) has developed a code of practise for fertiliser use that advocates background testing of available nutrients before fertiliser application, and timing applications to maximise uptake and minimise adverse environmental effects. Summit-Quinphos (NZ) Ltd and NIWA have developed a model for phosphorus loss (the P Loss Risk Index) to identify high-risk areas of P loss and the factors contributing to this high risk at the level of an individual farm (Hart et al. 2002). The Index is calculated using knowledge of water movement, sediment and P loss transport mechanisms, as well as site-specific information such as average rainfall intensity, soil type and background soil P levels. The Index can be therefore be used to assess appropriate farm management practices to reduce this risk.

5. CONCLUSIONS

The conclusions we can draw on the state of water quality in New Zealand streams and rivers are similar to those by Smith et al. (1993). Lowland rivers in agriculturally developed areas are in poor condition due to high nutrients, turbidity and faecal contamination. There is now considerably more data to back up these conclusions, and therefore, this report firmly establishes the link between agricultural land use and poor water quality, stream habitat, and impacted biotic communities.

Virtually all studies we have reviewed in which a cause/effect relationship was studied, point unequivocally to livestock farming as a cause of deteriorating water quality and stream health. The proportion, intensity, and types of farming within a catchment have all been shown to be factors that affect stream health. In particular, streams in areas of dairy farming are in poor condition. Often this has been related to poor practices of dairy shed effluent disposal, but intensification of farming has also been related to increasing diffuse sources of pollution, such as nutrients (from animal wastes and leaching of fertiliser), sediments and faecal bacteria.

Although farm oxidation ponds are important sources of pollution they are generally considered of less concern than diffuse sources because of the greater ease of regulation and improvements in waste treatment technologies. However, many Regional Councils still report that a high proportion of pond systems are not achieving effluent quality standards. Other important areas contributing to pollution are farm drains (open or subsurface) and livestock access to waterways.

Since the time of the Smith et al. (1993) review of agricultural effects on waterways, there have been many more studies into the ecology of New Zealand streams. Land use change and impacts of farming have clearly been shown to alter the habitat (light condition, water temperature, woody debris cover, sediment etc.) and subsequently the nature of biotic communities living there.

Most Regional Councils implicate agriculture and intensification of farming as the main cause of poor water quality and habitat in the waterways of their region. Several regions identify dairy farming as a significant source of pollutants to some of their waterways. Across the country, streams within or near native forest generally had good water quality, and there were many examples of forested headwaters that had healthy invertebrate communities that changed to communities of poor diversity and high pollution tolerance downstream, in relation to the increasing amount of pastoral development in the catchment.

Poor water quality, particularly high levels of faecal bacteria, nutrients, and sediment, was generally attributed to agriculture (point source discharges of effluents, diffuse sources, and intensification of stocking rates) in the State of Environment reports. However, other factors may also be locally important such as sewage discharges, water abstraction, bird faeces, septic tank leakages, catchment geology, urban development, and horticulture. The reports highlight that discharges of dairy shed effluent, degradation of riparian areas and livestock access to streams, all have substantial impacts on water quality and aquatic ecology.

Despite the wealth of information obtained from Regional Council State of Environment reports, there has been little assessment by these councils (with a few exceptions) of whether water quality and stream health were improving or deteriorating in the regions. This may be because SOE reporting is relatively new and the period of record is insufficient for such conclusions to be made. However it does point to the need to standardize SOE monitoring (both within a region and nationally across all regions) so that good quality data is available for trend analysis. This would assist in national collation and public reporting of the state of New Zealand's environment. With the predicted levels of increasing intensification of dairy and deer farming in the future, we recommend that trend analysis of SOE data be conducted in relation to the type and intensity of farming, in order to evaluate the effects of land use changes on streams.

Fencing stock out of streams and replanting riparian margins to restore shade and ecological function can be expected to improve stream health over time. Riparian management in conjunction with sustainable land management practices, such as improved grazing practices and wise fertiliser use, will be necessary to improve the condition of New Zealand's streams.

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8.0 APPENDIX

Table 1. Guidelines for water quality and periphyton parameters

Parameter	Water use	Guideline
Suspended solids	Aesthetics/contact recreation	< 4 g m^{-3} [a]
Turbidity	Aesthetics/contact recreation	< 2 NTU [a]
Clarity (black disc)	Aesthetics/contact recreation	> 1.6 m [a]
Total nitrogen	Possible adverse ecosystem effect	>0.614 g m^{-3} [c]
Dissolved inorganic nitrogen (nitrate + ammonium)	Aesthetics/contact recreation Preventing algal growth	<0.040-0.100 g m^{-3} [b]
Nitrate	Public water supply	<11.3 g m^{-3} [a]
	Stock water supply	<30 g m^{-3} [a]
	Aesthetics/contact recreation	<0.100 g m^{-3} [a]
	Possible adverse ecosystem effect	<0.444 g m^{-3} [c]
Ammonium	Possible adverse ecosystem effects	>0.021 g m^{-3} [c]
Total phosphorus	Possible adverse ecosystem effect	>0.033 g m^{-3} [c]
Dissolved reactive phosphorus	Aesthetics/contact recreation Preventing algal growth	<0.015-0.030 g m^{-3} [b]
Ammonia	Aquatic ecosystems	Varies with temperature and pH e.g. <0.75 g m^{-3} 1 hr at 20°C and pH 9 [a]
Faecal coliforms	Contact recreation	<200/100 ml [a]
	Stock water supply	<1000/100 ml (geometric mean) with no more than 20% >5000/100 ml [a]
E.coli	Contact recreation	<126/100 ml (median) <235-576 (single sample, depending on extent of contact [a]
Enterococci	Contact recreation	<33/100 ml (median) <61-151 (single sample, depending on extent of contact) [a]
Temperature	Fish	<25ºC
	Invertebrates	<20ºC
Periphyton (filamentous)[d]	Aesthetics/recreation	< 120 mg chlorophyll *a*/m^2
	Benthic faunal diversity	< 50 mg chlorophyll *a*/m^2
	Trout habitat and angling	< 120 mg chlorophyll *a*/m^2

[a] Source: Smith et al. (1993)
[b] Source: Ministry for the Environment (1997)
[c] Source: ANZECC and ARMCANZ (2000)
[d] Source: Biggs (2000)

Table 2. Summary of studies post-1993 comparing water quality in native forest versus pasture streams.

Type of study	Author	Type of agriculture implicated	Water quality parameter measured	Water quality guideline	Result
Nested catchment study	Quinn et al. (1997)	Hill country pasture	Dissolved reactive phosphorus (DRP)	<0.010 g m^{-3}	No different to native forest (0.033 g m^{-3})
			Nitrate	<0.100 g m^{-3}	5-fold higher than native forest
			Dissolved inorganic nitrogen	<0.100 g m^{-3}	Significantly higher (~0.80 g m^{-3}) than native forest (~0.15 g m^{-3})
			Stream suspended sediment/solids	<4 g m^{-3}	~12 g m^{-3} in pasture, 3-fold higher than native forest
			Stream turbidity	< 2 NTU	~10 NTU in pasture, sig. higher than native forest
			Water clarity	>1.6 m	~0.8m in pasture, significantly less than native forest
	Quinn & Stroud (2002)	Hill country pasture	Suspended sediment load	Not available	~1050 kg^{-1} ha^{-1} yr^{-1} in pasture, 3 times higher than native forest
			Suspended solids	<4 g m^{-3}	~10g m^{-3} pasture compared to ~4 g m^{-3} native forest
			Nitrate	<0.100 g m^{-3}	~0.45 pasture compared to ~0.1 native forest
Comparison of stream sites in farmland versus forest control	Donnison and Ross (1999)	Dairy farm	Pathogen – *Campylobacter jejeni*	Should not be present	Present in 3/4 river water samples at two dairy farm sites but not in forest control site samples (0/3)
			Pathogen – *Yersinia enterocolitica*	Should not be present	Present in 1/5 river water samples at two dairy farm sites but not in forest control site samples (0/3)
			E.coli	<126 cfu/100 ml	Higher in river water at two dairy farm sites (90 & 130/100 ml) than at the forest control site (30/100 ml)

Table 3. Review of Regional Council State of Environment and associated reports to determine whether agricultural activities are reported to have a detrimental effect on water quality parameters (including macroinvertebrate community monitoring) in the regions freshwaters (streams, rivers, lakes and/or groundwater). A = agriculture is the only activity responsible, B = agriculture is responsible along with other activities.

Regional council or unitary authority	Water quality parameter						Source documents
	Sediment	Turbidity	Clarity	Nutrients	Bacteria	Macro-invertebrates	
Northland	NO	NO	NO	YES (B)	YES (B)	YES (B)	Northland Regional Council (in prep.)
Auckland	NO	YES (A)	NO	YES (A)	YES (B)		Auckland Regional Council (1999), Wilcock and Stroud (2000)
Waikato	YES (B)	NO	NO	YES (B)	NO	YES (B)	Environment Waikato (1998)
Bay of Plenty	NO	NO	NO	YES (B)	YES (B)	YES (B)	Taylor and Park (2001), Environment Bay of Plenty (2001)
Hawkes Bay	NO	NO	NO	NO	YES (A & B)	YES (B)	Hawkes Bay Regional Council (2001), Wood (1998)
Taranaki	NO	YES (A)	NO	YES (B)	YES (A & B)	YES (B)	Taranaki Regional Council (in prep.)
Manawatu	NO	NO	NO	YES (B)	YES (B)		horizons.mw (1999), horizons.mw (2001a)
Wellington	NO	YES (B)	NO	YES (B)	YES (B)	YES (B)	Warr (2001), Watts and Sevicke-Jones (2001)
Tasman	YES (A & B)	NO	NO	YES (A & B)	YES (A)		Tasman District Council (2000)
West Coast						YES (B)	West Coast Regional Council letter
Canterbury	NO	NO	NO	YES (B)	YES (B)		Canterbury Regional Council (1996), Main (1999), Hayward and Meredith (2000), Hayward (2001)
Otago	YES (B)	NO	NO	YES (A & B)	YES (A & B)	YES (B)	Otago Regional Council (2001)
Southland	NO	NO	YES (B)	YES (B)	YES (A)	YES (B)	Environment Southland (2000)

Table 4. Effects of agriculture on stream attributes (Table modified after Belsky et al. 1999; see also, Rutherford et al. 1999).

Attribute	Responses	Mechanisms	Impacts	Selected references
Riparian vegetation and soils				
Tree and shrub cover	Generally reduced (fragmented) Altered spp. composition	Livestock browsing, Livestock damage to roots and stems Exposure to wind and sun – drying	Exposure and desiccation Reduced shade, incr. temp. Reduced channel stability Reduced food supply to the stream Weed invasion	Trimble (1994) Kauffman & Krueger (1984) Fleischner (1994) Trimble & Mendel (1995) Sansom (1999)
Herbaceous cover	Reduced Altered spp. composition	Livestock grazing and browsing	Reduced shade, incr. temp. Reduced cover for fish Weed invasion	Kauffman & Krueger (1984) Petit et al. (1995) Trimble & Mendel (1995) Sansom (1999) *Quinn et al. (1992b)*
Native biodiversity	Reduced	Livestock grazing and browsing and mechanical damage to vegetation	Reduced conservation value	Fleischner (1994) *MfE (1997)*
Soil condition	Degraded	Increased bare ground, Compaction and reduced infiltration	Greater surface runoff, Soil erosion Increased delivery of contaminants	Trimble & Mendel (1995) Belsky et al. (1999) Sansom (1999) *Cooper et al. (1995)* *Nguyen et al. (1998)*
Channel morphology and physical habitat				
Channel stability	Reduced	Streambanks disturbed by livestock	Bed siltation, local widening Reduced in-stream habitat quality	Kauffman & Krueger (1984) Platts (1991) Trimble & Mendel (1995) *Williamson et al. (1992)*
Channel width	Reduced * (increased locally)	Pasture grasses armour against fluvial erosion and trap sediments Channel width may *locally* increase at livestock crossings	Reduced benthic habitat Reduced *quality* of benthic habitat	Sweeney (1993) Trimble (1994) Trimble & Mendel (1995) *Davies-Colley (1997)*
Bed sediment texture	Decreased	Siltation of the streambed by fines	Reduced interstitial water exchange Reduced epilithic food quality Reduced benthic habitat quality	Myers & Swanson (1996) *Ryan 1991* *Quinn et al. (1997)*

Attribute	Responses	Mechanisms	Impacts	Selected references
Water temperature	Peaks increase	Reduced riparian shade (in part by browsing, most through deforestation)	Elimination of cool-water organisms (incl. some fish and some inverts) Increased growth of nuisance plants	Platts (1991) Li et al. (1994) *Rutherford et al. (1997)* *Cox & Rutherford (2000)*
Contaminants degrading water quality				
Sediment load & turbidity **... Visual clarity**	Increased ...Reduced	Trampling and grazing leading to bank erosion and sediment suspension Hillslope instability Reduced entrapment in riparian vegetation	Bed siltation, reduced interstitial water exchange, Altered habitat for sighted animals Reduced epilithic food quality	Trimble & Mendel (1995) Waters (1995), *Quinn & Stroud (2002)* (see Wood & Armitage (1997) for review) *Rowe & Dean 1998*
Nutrients (N & P)	Increased	Voiding in stream channel Runoff from contributing areas in catchment Reduced entrapment in riparian vegetation	Proliferation of nuisance plants in streams Eutrophication of downstream waters	Duda & Finan (1983) *Smith et al. (1993)* *Cooper et al. (1995)* *Williamson et al. (1996)* *Quinn & Stroud (2002)*
Faecal microbes	Increased	Defaecation in stream channel Runoff from contributing areas in catchment Reduced entrapment in riparian vegetation	Health risk to humans Health risk to domestic livestock Increased water treatment costs Contamination of shellfish in downstream estuaries	Stephenson & Rychert (1982) Larsen et al. (1994) *Smith et al. (1993)* *Donnison & Ross (1999)*
Stream life				
Nuisance plant growths	Increased	Increased lighting and nutrients	Nuisance growths pH and dissolved oxygen excursions	Li et al. (1994) *Biggs (1985)* *Wilcock et al. (1995)*
Macrophytes		Trampling and grazing	Reduced in-stream nutrient attenuation	Belsky et al. (1999)
Invertebrates	Altered community	Higher water temperatures Bed sedimentation and reduced food quality Higher algal biomass	Lower IBI Less mayflies, stoneflies and caddis flies	Weigel et al. (2000) *Quinn et al. (1997; 1992b)* *Quinn (2000)*

Attribute	Responses	Mechanisms	Impacts	Selected references
Fish	Altered spp.	Generally degraded habitat, Reduced cover Higher water temperatures Higher turbidity and bed sedimentation Altered invertebrate food	Reduced salmonid production Reduction in diversity of native spp (possible local extinction) Increase in pollution tolerant fish (e.g. eels)	Platts (1991) Li et al. (1994) Armour et al. (1994) Rinne (1999) Kauffman & Krueger (1984) *Hicks & McCaughan (1997)* *Hanchet (1990)* *Rowe et al. (2000)*
Amenity values				
Scenery & recreational appeal	Degraded	Damaged vegetation and slumped banks Reduced native tree and shrub cover Deposits of faecal matter	Reduced scenic quality Reduced recreational values	*Mosley (1989)* *MfE (2001)*

International references are major reviews or landmark papers *(New Zealand references given where available/known)*
* Channel width is increased by ungulate grazing damage in the semi-arid American West. However, in naturally forested humid areas, channel width tends to be decreased in grazed pasture owing to armouring by grass turf - with the exception of livestock crossing areas which may be widened (Davies-Colley 1997; Trimble & Mendel 1995)