

3 Understanding the Issue

3.1 Impacts from agriculture on waterways

Sediment erosion and nutrient loss from land are natural processes. In natural, unmodified ecosystems stream communities rely on regular inputs of nutrients to sustain life. In healthy native bush, catastrophic slip erosion occurs in response to climatic events, as do periodic floods and droughts. However, many agricultural practices accelerate natural processes leading to consistently higher levels of sediment, nutrients and surges of bacterial material being present in stream waters in agricultural catchments.

While it is true that most of our streams, rivers and lakes are healthy by international standards, there is no doubt that the quality of water and waterways in all but the most unmodified parts of New Zealand has deteriorated significantly since the bush was cleared and converted to farmland. In many areas the deterioration continues, where land use and farm practices are changing and becoming more intensive, as well as in waterways, especially shallow lakes and estuaries, where sediments and nutrients tend to accumulate.

3.1.1 Deforestation

Perhaps the greatest single source of pressure on the health of New Zealand's water and waterways has been the clearance of hill and riparian forests to create farmland. Today, New Zealand has 10 times more grassland than it once had and only a quarter of its original forests. Often the riparian vegetation was the first to be cleared because it was easy to access and because soils were fertile and water was available.

Removal of forests greatly reduces canopy interception of rainfall and absorption capacity compared to grassland. Hence runoff increases, both in terms of volume and velocity, so where forest has been removed surface run-off and flood waters are increased.

Several catchment studies have shown that vegetation change significantly affects river flows. Catchments near Rotorua with different vegetation covers were compared by Dons (1987). In the forested catchment 70–75 percent of rainfall was absorbed by vegetation compared to only 55 percent in the pasture catchment. Figure 2 shows runoff from the forested catchments as being half to two-thirds that of the pasture catchment. Consequently, the pasture catchment had higher average stream flows and flood flows.

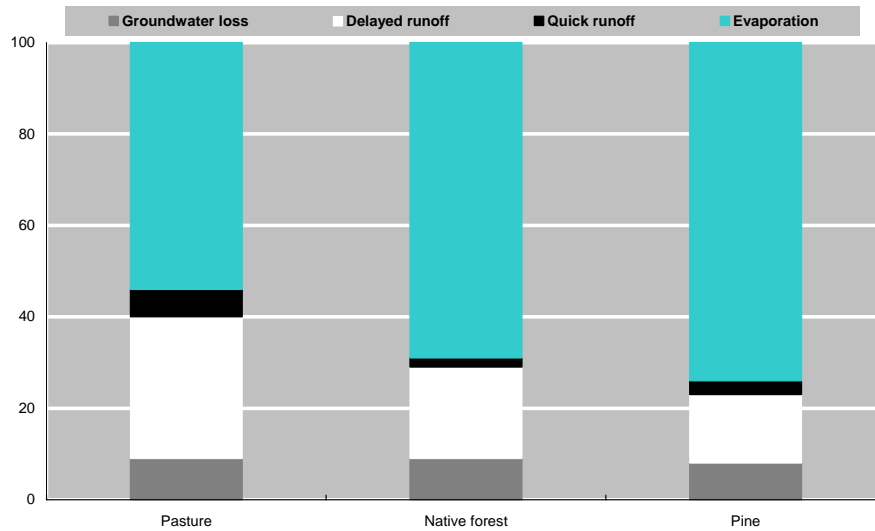


Figure 2: Patterns of water runoff from pasture, native forest and pine forest catchments at Purukohukohu, central North Island

Table 1 summarises the effects of the removal of native vegetation and its replacement with pasture. Many of the changes summarised in this table are discussed in later sections, and the variables outlined are revisited in later sections on management and restoration (Rutherford et al, 1997).

Table 1: Effect of replacing native vegetation by pasture on characteristics of hill-country streams at Whatawhata, near Hamilton (Rutherford JC et al, 1997)

Variable	Change	Mechanism	Effect
shade	reduced	reduced riparian vegetation	increased temperature, increased primary production, groundcover helps stabilise banks
runoff	increased	decreased interception, increased runoff rate	increased peak flows, increased catchment erosion and delivery
peak flow	increased	increased runoff	increased channel erosion
width	decreased	increased pasture encroachment, mass movement of soils	reduced streambed habitat
bank height	increased		increased water depth, increased bankside shading ^a
stock damage	increased	increased soil compaction, decreased groundcover, increased bank damage, voiding directly into stream	increased catchment erosion and delivery of sediment, increased nutrient supply
temperature	increased	increased solar radiation	loss of sensitive species, reduced dissolved oxygen saturation, increased respiration rates, increased plant growth rates
dissolved nitrogen	increased	increased catchment supply, reduced riparian removal, stock voiding into streams	increased potential primary production
fine sediment	increased	increased catchment erosion and delivery, increased channel erosion, increased bank damage by stock	reduced boundary layer flows, loss of fish and invertebrate habitat, reduced clarity

Variable	Change	Mechanism	Effect
clarity	reduced	increased fine sediment	degraded aesthetics, reduced visibility for animals
woody debris	reduced	reduced supply	reduced habitat diversity, reduced CPOM retention
coarse particulate organic matter	reduced	reduced litterfall, reduced retention	reduced food supply for shredders
primary production	increased	increased solar radiation, temperature and nutrient supply	increased food quantity for invertebrates, increased periphyton biomass ^c
periphyton biomass	increased ^b	increased primary production ^c	possible blooms, reduced boundary layer flows, reduced habitat diversity
invertebrates	altered	increased temperature and periphyton biomass, reduced habitat <i>quality</i> (increased fine sediment and reduced boundary layer flows, woody debris and CPOM retention), reduced habitat <i>quantity</i> (increased depth) of habitat	loss of sensitive species, increased snails, chironomids and oligochaetes, increased abundance and diversity

^a but insufficient to compensate for the loss of shade vegetation

^b biomass occasionally high but variable in space and time

^c sometimes counteracted by increased grazing and sloughing

3.1.2 Riparian deforestation

The significance and functions of riparian vegetation are covered in Sections 2.2.3, 2.2.4 and 5. The main instream effects resulting from riparian deforestation have been:

- more rapid and extensive changes in stream bed morphology
- increased contamination of waterways
- increased magnitude and intensity of floods
- changes in seasonal flow patterns (especially summer low flows)
- loss of indigenous aquatic plant and animal habitat due to increased summer maximum water temperatures and reduced shade
- increased sediment build up and decreased water clarity; increased nutrient content; and loss of necessary plant and animal food sources
- increased instream nuisance aquatic plants
- changes in the abundance and diversity of mahinga kai species
- desecration of the mauri of the water body.

The main effects on riparian zones have been:

- increased loss of land and soil due to streambank erosion, increased volume and speed of runoff, and flooding
- loss of indigenous plant and animal habitat
- loss or reduction of wildlife dispersal corridors

- increased exotic weeds and animal pests
- loss of riparian wetlands that play a key role in nutrient removal.

3.1.3 Drainage of wetlands

Of the wetlands existing prior to human colonisation approximately 85 percent have been lost to farming, flood control, urban development and the creation of hydroelectricity reservoirs (MfE, 1997). The extent of wetland loss varies from region to region. Unmodified wetlands have been reduced to about 37 percent of their original area in Southland, about 25 percent in the Waikato, 2 percent on the Rangitikei Plains, and less than 1 percent in the Bay of Plenty. The once massive 25,840-hectare Gordonton peat bog in the Waikato, for example, now consists of three 13- to 60-hectare remnants.

Furthermore the loss of habitat and resultant fragmentation and isolation of wetlands has led to a decline in wetland animal species, and as a result many species are under threat.

Wetlands are highly valued by Maori because of the mahinga kai associated with them.

Wetlands are of considerable value because they act as sponges, absorbing and holding water and releasing it slowly over long periods. As well as slowing down the speed of water, the long holding period means sediments and faeces largely settle out, some nutrients are used by the wetland plants and dissolved nitrate nitrogen is converted to atmospheric gases (denitrification).

3.1.4 Construction of farm drains and drainage networks

The construction and maintenance of drains and drainage networks has been essential for the development and improvement of farm operations throughout New Zealand. Tens of thousands of kilometres of drains have been created throughout the country.

Effective drainage management is a vital component of successful and sustainable agriculture in most regions throughout New Zealand. As a consequence, many regional and district councils are responsible for managing and maintaining an extensive network of primary drains and waterways, while many individuals maintain smaller networks throughout their farms. These drains are either natural streams or wetlands that have been substantially modified, or channels constructed specifically for drainage purposes. However, it is important to remember that these drains are not isolated systems; they are linked both physically and biologically to the wider catchment. Upstream activities on surrounding land affect drains, which in turn affect downstream systems. In almost all cases drains eventually flow into natural streams that connect to larger aquatic systems (eg, rivers, wetlands, lakes and estuaries).

The three main functions of farm drains are to:

- lower water-tables
- increase the rate of surface runoff
- reduce the impacts of floods.

Regular maintenance is invariably required to maintain the efficiency of drains. Traditional drain maintenance practices have focused on hydraulic efficiency. These practices have encouraged the maintenance of bare, channelised, unobstructed waterways – free of weeds and marginal or riparian vegetation. However, the most widely used methods, mechanical cleaning and chemical spraying, can have serious impacts on water quality and waterway habitats. Furthermore, our understanding of the efficiency of these methods in maintaining flow while reducing contaminant runoff, and environmental degradation of downriver ecosystems is incomplete (Harding and Hudson, in preparation).

It is increasingly recognised that drains and artificial waterways play important environmental and ecological roles. In particular, drains act as conduits for a range of agricultural chemicals and other contaminants (especially faecal bacteria, pesticides, herbicides, nutrients and sediment) from farmland into larger aquatic systems.

Drains are also important habitat for a range of native and introduced plants and animals. In particular, habitat for key conservation (eg, giant and banded kokopu, Canterbury mudfish, and bitterns), commercial (eg, eels and whitebait) and recreational species (eg, mallard ducks), as well as sources of mahinga kai for iwi (eg, watercress, eels, whitebait and lamprey).

In most regions, draining of wetland and clearing of riparian zones along streams and rivers has resulted in the significant loss of fish and wildlife habitat. As a result, drains and smaller waterways may provide the only alternative habitat within a region for important native species eg, brown mudfish and banded rail. Furthermore, because these drains are linked to larger systems they may provide refuge for native fish from floods and from larger introduced predatory fish species.



Photograph 2: A typically maintained drain, with loss of most fish and wildlife habitat.

3.1.5 Fertiliser and stock

The introduction of livestock along with associated farm activities have intensified the problems created by the removal of forest cover, particularly in relation to water quality.

From the 1950s until the 1980s, sheep numbers increased substantially and with them the volume of fertiliser applied, especially superphosphate. Sheep numbers and fertiliser application decreased through the 1980s as economic returns from extensive pastoral agriculture declined, and in the last decade there has been a corresponding increase in more intensive forms of agriculture. Between 1981 and 1995, sheep numbers fell by 30 percent, from a subsidy-driven peak of about 70 million to just under 49 million.

Cattle numbers, however, have risen to an all-time high of 9.3 million, largely reflecting the 40 percent increase in dairy cattle from 2.9 million to 4.1 million. Dairying has now moved into areas not previously recognised as dairy farming areas (for example, Otago, Taumarunui, the western side of Lake Taupo and irrigated land in Canterbury) and has expanded in areas such as Northland, Southland and Taranaki, where dairy farming has existed in the past. There has also been an increase in beef cattle numbers on hill country, and in some areas dairy farming has extended onto rolling hill country.

With the expansion in dairying has come an increase in nitrogen fertiliser use in an attempt to boost grass growth. Nitrogen fertiliser sales have more than trebled from 1994-2000, with most dairy farmers applying 25–100 kg of nitrogen as fertiliser per hectare per year, and some up to 200 kg. With the increased levels of application comes an increased likelihood of some of it reaching streams and groundwater.

3.1.6 Impacts on stream communities

The replacement of native vegetation with introduced vegetation and the increase in agricultural contaminants nearby our streams have significantly altered the plant and communities in our waterways.

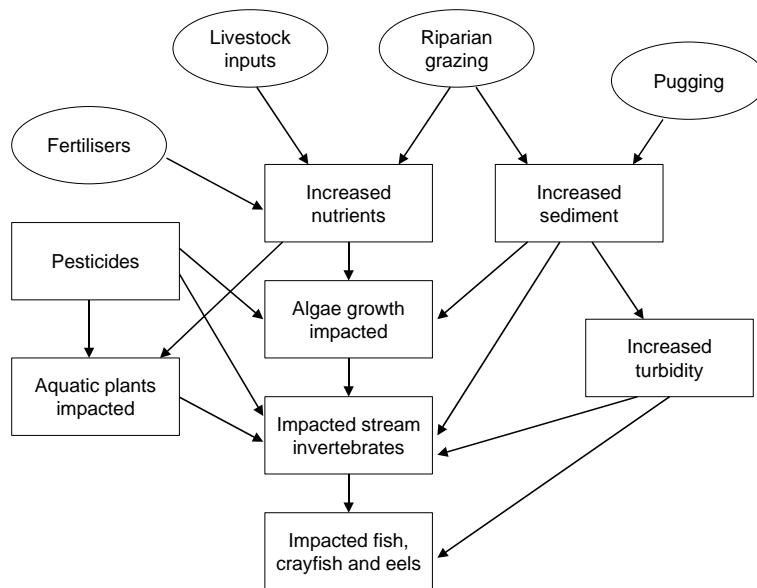


Figure 3: Summary of the effects of generalised agricultural activities on stream communities

Plants

Increased instream light levels and water temperature due to riparian vegetation clearance, and increased nutrient and sediment inputs from farmland have led to a significant change in the aquatic plant life of agricultural streams compared to native forest streams. The low light levels of forested streams encourage both the development of thin algal films on stones and the growth of mosses and liverworts on stable substrates, which in turn can provide important habitats for many aquatic invertebrates in small streams.

Invertebrates

Nationwide, the main threats to freshwater invertebrates come from habitat degradation by catchment clearance, removal of riverbank vegetation, wetland drainage, diffuse and point source pollution, channel engineering works, mining, and the regulation of flow regimes. Excessive summer water temperatures, in conjunction with high sediment inputs, nutrients and low dissolved oxygen levels all contribute to the degraded invertebrate communities found in many agricultural streams.

The number of invertebrates in pasture streams is often greater than in forested sites. This is caused by organic enrichment and high temperatures, supporting high abundances of pollution tolerant species, especially as snails, chironomids (midge larvae) and oligochaetes (aquatic worms).

Many of our pasture streams exceed 20°C during the summer, and temperatures this high are known to affect the survival of many invertebrate species.

Fish

Several of our native fish species are under threat, particularly from introduced species, forest clearance, contaminants from pastoral farming and drainage works.

All of our fish species are predators, feeding on invertebrates and other fish species. They are able to adapt to varying degrees to changes in food supply associated with altered riparian vegetation. However, some of the larger galaxiid fish (eg, giant kokopu and banded kokopu) depend on native forest for good breeding habitats. Removal of natural riparian vegetation, may have had direct effects on the presence of these species.

Of concern to Maori is the impact of the removal of natural riparian vegetation and the increased input of contaminants on eels, this is particularly important as eels are still harvested commercially. The longevity of eels means that over its life it is likely to accumulate contaminants found in the waterway in which it lives. Although scientists confirm that eels are a valuable bio-indicator, the level of contamination in larger eels and the resultant impact on the health of people who eat the eels is unknown.

Riparian vegetation and wetland habitats, are also important for our three species of mudfish and their distribution appears to have been severely impacted by habitat loss associated with pastoral development of catchments.

About half of our native fish species are migratory and require access to or from the sea at some stage of their life. Dams, weirs and elevated culverts which create barriers to fish movement can prevent these species completing their lifecycle.

3.2 Contaminants from agriculture: impacts on water quality

The impact of agricultural contaminants on water quality can be divided into two categories:

- **Point source contaminants** discharged from specific sites such as dairy sheds, piggeries, septic tanks, leachates from silage pits and farm dumps: In most New Zealand rivers, pollution from point sources has declined noticeably over the past 10–20 years. This is partly because the total number of point sources has fallen, and partly because waste treatment processes have improved.

In recent years, dairy farmers have been encouraged by regional councils to move to land-based methods of effluent disposal (eg, irrigation back onto pasture) as opposed to the standard oxidation pond system that has been used extensively since around 1975. This can reduce one point source of water pollution and replace it with another practice less likely to pollute waterways, although care also needs to be taken with land-based effluent disposal to avoid water contamination.

- **Diffuse or non-point source contaminants** arising generally from paddocks, forests and roads, and washing into streams as surface runoff: Although “traditional” sources of point-source pollution are declining, non-point source inputs from farm drains are still common. Drainage ditches frequently accumulate nutrients, sediment, herbicides and pesticides. Water from these drains frequently acts as “point-sources” of contaminants where they merge with natural waterways.

Most diffuse pollution is caused by rainwater washing organic matter, sediment and nutrients from land surfaces into streams, rivers and lakes. Diffuse pollution also occurs when nutrients or other contaminants are leached through the soil into groundwater. The development of mole, tile and novaflow drainage has decreased the

amount of surface water runoff from many farms, and increased subsurface flow enabling these contaminants to drain freely into drains and other waterways (Nguyen et al, 1998).

3.3 Nutrient enrichment

In natural, unmodified ecosystems inputs of nutrients and organic compounds (derived from vegetation decay) play a vital role in aquatic ecosystems. There are four main effects of enrichment (eutrophication):

- increased aquatic plant growth
- oxygen depletion
- pH variability
- changes in plant species quality and consequent food-chain effects.

The two nutrients most likely to cause excessive algal growths are nitrogen (particularly dissolved inorganic nitrogen), and phosphorus (especially as dissolved reactive phosphorus).

Excessive growths of algae and aquatic plants can cause problems in farm waterways by:

- changing the quantity and type of food available stream life
- altering the habitat for fish and invertebrates
- depleting the water's dissolved oxygen levels (through the decay of prolific growths)
- making them aesthetically unpleasant.

High nutrient levels will not always result in heavy growths of algae and other plants. Unsuitable substrate types, floods, low light levels (due to turbid waters or riparian shade), or high grazing rates (by instream invertebrates) will prevent the development of nuisance growths. However, unshaded, shallow lowland rivers with stony substrate are susceptible to algal proliferations. Aquatic plants are slower growing than algae and thus require stable flows and high nutrient concentrations over a longer period to reach nuisance, and are more likely in lowland rivers, lakes and estuaries with fine substrates.

3.3.1 Nitrogen

Agricultural non-point sources account for 75 percent of the total nitrogen loading to New Zealand surface waters (see Figure 4). The principal sources of high nitrogen levels on farmland are urine and dung from livestock, the application of nitrogenous fertiliser and nitrogen fixation by clovers.

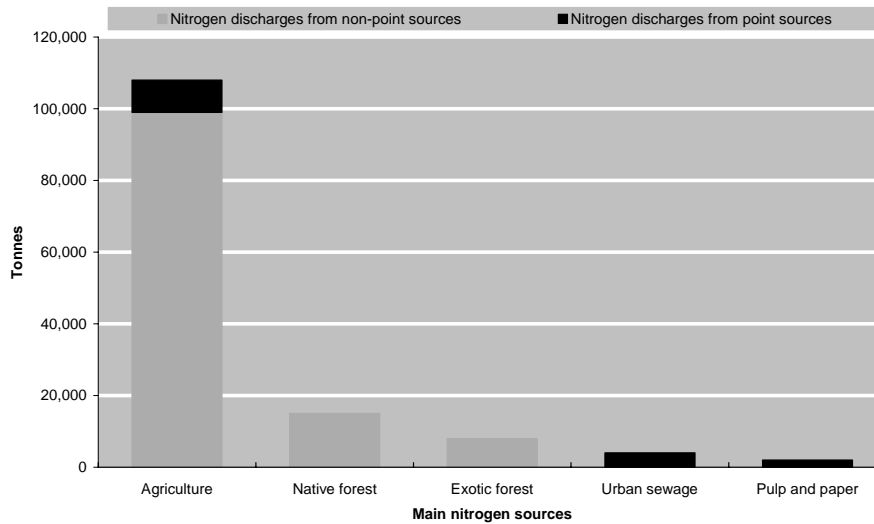


Figure 4: Estimated yearly nitrogen loadings to New Zealand surface waters (*MfE, 1997a*)

Nitrogen can be lost from pastures and cultivated land as surface runoff, or leached through the soil to groundwaters in the form of soluble nitrate nitrogen. On heavily grazed pasture, 100-200 kg of nitrogen per hectare per year could be lost from the soil, with most of it leached to groundwater (Ball, 1982). Nitrogen export from pasture hill catchments averages three to 10 times that of native forest (Cooper and Thomsen, 1988; Quinn et al, 1998). Figure 5 shows how nitrate loadings vary through the year, at different sites, in particular higher leaching rates are evident during the winter months.

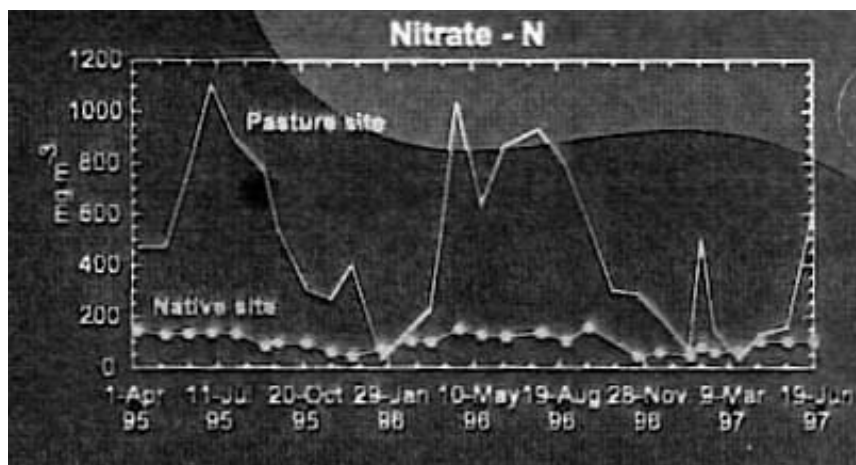


Figure 5: Hill-country farming effects, nitrate (*Quinn and Thorrold, 1998*)

The highest nitrogen fertiliser application rates, up to 400 kg/ha, have been recorded in market gardening areas. This is well in excess of the amount needed by plants to grow; the fertiliser not used by plants will be rapidly leached into the groundwater and end up in streams and rivers. Nitrogen fertiliser applications in excess of 200 kg/ha/year have been shown to significantly increase the nitrate contamination levels in groundwater. Table 2 illustrates losses under different land uses.

Table 2: Nitrogen losses in runoff to streams in the Purukohukohu experimental catchments (*Cooper and Thomsen, 1988*)

Nutrient indicators	Nutrient losses in runoff from: (kilograms/hectare/year)		
	Pasture	Pine forest	Native forest
Total (Kjeldahl) nitrogen ¹	10.76	0.76	0.83
Nitrate nitrogen (NO ₃ -N)	1.19	0.55	2.84
Total nitrogen ²	11.95	1.31	3.67

On hill country, nitrate-contaminated groundwater often surfaces in seepage zones just above river terraces or in stream banks. On flat and gently rolling land groundwater will often remix in the stream or drain channel itself, especially when the water table is high. Sites that are frequently irrigated often experience the worst nitrate contamination. When soil is porous (such as pumice or riverbed gravels) the problem can be at its worst (see *Case Study 2: Dairying and border-dyke irrigation along the Waikakahi Stream*).

The symbiotic nitrogen fixation of pasture clovers adds 1.1 million tonnes of nitrogen per annum to New Zealand pastures, over seven times the amount of nitrogen fertiliser applied deliberately to pastures each year (Hedley et al, 1990).

Animal urine contains high concentrations of nitrogen in the form of urea. When deposited on the soil, in a compact “urine patch”, this urea is rapidly converted to nitrate at concentrations considerably in excess of pasture requirements. At mid-Canterbury stocking levels, grazing stock deposit urea-nitrogen in their urine at a rate of 40–70 kg of N/ha per year (Quinn, 1979). Urea readily converts to nitrate, and because it is deposited in concentrated spots of about 500 kg N/ha, pasture cannot utilise it and it is rapidly leached through the soil and into shallow groundwater.

Direct dung and urine deposition in streams

Livestock with free access to waterways add concentrated nitrogen through their dung and urine. Cattle and deer like to congregate in the stream channel, especially in summer, to keep cool. This often coincides with periods of low flow. Sheep usually only stand in the water when there is no alternative water supply. As a consequence, their contribution to elevated stream nutrient levels is likely to be less than that of cattle.

Artificial drainage channels can cause drainage waters to bypass riparian zone soils. Because the concentrations of nutrients in groundwater are reduced within this zone, it is reasonable to assume that sub-surface drainage works have increased nutrient (especially nitrogen) levels entering our streams and rivers.

Many agricultural streams may not register excessively high nitrate levels, but this should not be used as an excuse to avoid improved nitrogen management. Consideration needs to be given to the downstream cumulative effects of nutrient contamination in rivers and especially in lakes and estuaries.

Spray application of dairy effluent

In many parts of New Zealand dairy farmers are being encouraged by regional councils to spray their cowshed effluent back onto the paddocks rather than leaving it to be processed in a series of oxidation ponds. Well managed land-based applications have less impact on surface and groundwater quality than the outflow from oxidation ponds. Maori are also likely to advocate for the investigation of land-based disposal options, due to the offensiveness of direct discharge of effluent directly to waterways.

For any detrimental environmental effects of land-based spray application to be minimised the method and volume of application needs to be carefully managed. It is important to note that if the nutrient component of the effluent applied is greater than the capacity of the pasture to process it, and/or if the volume of liquid applied at any one time is likely to create surface runoff, then the net effect could be worse than the outflow from oxidation ponds. If effluent is applied at a maximum loading of 150 kg N/ha per year, the need for nitrogenous fertiliser applications will be lessened.

Photograph 3: Irrigation, especially on porous soils, can greatly increase nitrate leaching to groundwater which in turn can lead to stream water contamination. The spraying of effluent onto pasture increases the risks further, especially when irrigators are poorly managed or maintained, as is the case in this photo.



Nitrogen contamination of streams is most likely to occur where:

- high levels of nitrogen, well in excess of plant needs, are present in the soil (particularly as a result of high fertiliser rates)
- soils are very porous
- irrigation water is applied excessively
- wetlands have been drained (and their denitrification properties lost)
- subsurface drainage (eg, mole, tile, or novaflow) systems bypass riparian wetlands
- too much fertiliser application adds nitrogen directly to waterways
- livestock, especially deer and cattle, have free access to streams.

Nitrogen effects

In addition to causing profuse plant and algae growth, sustained high levels of ammonia can be toxic to fish and in extreme cases, humans nitrates consumed by bottle-fed babies during the first six months of life may cause what is known as “blue baby” syndrome, which occurs when blood haemoglobin is converted to methaemoglobin reducing the oxygen carrying capacity of the blood. Contaminated water containing nitrates and nitrites can also be poisonous to livestock. The toxicity of a given concentration of ammoniacal nitrogen increases as the pH and temperature of the water increases.

The Ministry of Health (1995) has set the maximum safe level for nitrate nitrogen in domestic water supplies at 11.3 g/m³ (equivalent to 11.3 mg/L), and at 30 g/m³ for livestock consumption.

3.3.2 Phosphorus

The principal sources of elevated phosphorus levels on agricultural soils are application of phosphate fertiliser and dung from livestock. During periods of summer lowflow agricultural streams may have high phosphorus levels and support heavy growths of algae and other aquatic plants. In one trial catchment at Purukohukohu (Cooper and Thomsen, 1988), pasture lost 15 times more phosphorus than did the native forest and pine production forest catchments (see Table 3).

Table 3: Phosphorus losses in runoff to streams in the Purukohukohu experimental catchments (Cooper and Thomsen, 1988)

Nutrient indicators	Nutrient losses in runoff from: (kilograms/hectare/year)		
	Pasture	Pine forest	Native forest
Dissolved reactive phosphorus	0.37	0.04	0.02
Total phosphorus	1.67	0.1	0.12

¹ Total Kjeldahl nitrogen (TKN): organic nitrogen and ammonia

² Total nitrogen (TN): Total Kjeldahl nitrogen + nitrate nitrogen + nitrite nitrogen

Increased phosphorus contamination in streams is very closely related to increases in sediment concentrations (Rodda, 1998) (see Figure 6). This is because phosphates most commonly attach to clay and other soil particles which are then carried by water (as suspended sediment). Consequently, phosphorus loss from pasture to stream is greatest where surface runoff and erosion are most likely. Surface runoff occurs either because rainfall intensity exceeds soil infiltration rates, or because groundwaters rise and emerge at the soil surface (waterlogged or saturated soils).

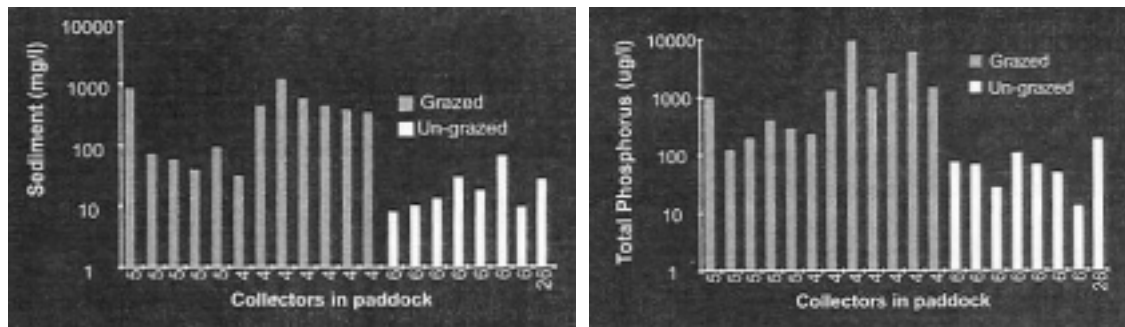


Figure 6: Diffuse source pollution (Quinn and Thorrold, 1998)

Recently-grazed pastures appear to have elevated levels of phosphorus and sediment loss compared to ungrazed pastures. The speed of water runoff (and hence its erosive capacity) is probably greater because there is less grass to intercept and slow down the passage of water and more soil is likely to be exposed. This is likely to be increased where pastures are overgrazed and where soils become waterlogged and pugged.

The greatest phosphorus runoff concentrations tend to occur directly after fertiliser applications and are generally substantially greater than those found in runoff from highly fertile soils. Thus careful management of the timing of fertiliser application is important.

Like nitrogen, phosphorus can also be introduced to streams as dung where livestock, especially cattle, have direct access to streams. In addition to dung, cattle encourage streambank erosion which accelerates sediment and hence phosphorus contamination. Cattle by their sheer weight tread and expose soil as they walk on and over river banks. Rain and elevated water levels erode the soil away where it is exposed and carry phosphorus with it.

Phosphorus contamination of streams is most likely to occur where:

- streams receive discharge from oxidation ponds
- low soil permeability encourages increased surface runoff
- soil erosion is a significant problem
- streambank erosion is occurring
- phosphatic fertiliser is applied to saturated soils
- high levels of phosphorus are present in the soil
- fertiliser is applied directly onto waterways
- subsurface drainage systems feed directly to waterways
- dung is deposited by livestock with free access to streams.

Phosphorus effects

The *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* provide DRP values, above which excessive algal (periphyton) growth may be promoted. Chapter 3 provides default DRP trigger values for lowland and upland

rivers. These guidelines are available in the Ministry's website at:
www.mfe.govt.nz/publications/water/anzecc-water-quality-guide-02/index.html

New Zealand Periphyton Guideline - detecting, monitoring, and managing enrichment of streams provides mean monthly DRP values for a range of average days of accrual. These guidelines are available on the Ministry's website at:
www.mfe.govt.nz/publications/water/nz-periphyton-guide-jun00.shtml

Phosphorus sorbed to soil particles, which generally enters stream water in surface runoff, can also contribute to increasing nutrient loadings and consequently lead to nuisance plant growth, especially on lake beds where nutrients accumulate in the deposited sediment. Phosphorus does not occur in our waterways in concentrations that are toxic to humans and other animal life.

3.4 Contaminants from agriculture: sediment

Estimates of rates of soil loss (Crossan, 1995; Pimental et al, 1995a, 1995b) suggest that six tonnes of soil per hectare are lost annually from pastureland, 13–17 tonnes per hectare from cropping, and only half a tonne from undisturbed forest. If we assume an average annual soil loss on New Zealand farm and exotic forest land of six tonnes per hectare then we are losing one 10-tonne truck full of topsoil every three seconds. This is six times higher than the average rate of soil formation.

Generally the greatest sources of sediment entering farm waterways come from accelerated erosion.

Suspended sediment levels are generally two to five times higher in streams draining pasture catchments than those draining native forests (Quinn, 1997). This has been attributed in part to the increased volume and velocity of surface runoff, a legacy of forest clearance on farmland; and in part to the impact of livestock and farm grazing and soil management practices. Where the bedrock is particularly erodable, the sediment loads may be even greater. Deforestation has the greatest impact of all and can increase sediment loads a hundredfold.

Surface soil loss to streams is likely to be most significant where:

- farm livestock, especially deer and cattle, cause soil compaction and treading damage to pasture, with the greatest impact being on steep and saturated soils
- excessive grazing of pasture and high stocking rates occur on wet, steep, and erosion prone land
- poorly drained and maintained tracks feed runoff directly to streams
- cultivation leaves soil bare for prolonged periods, especially over winter and spring.

3.4.1 Mass movement

The risk of mass movement (soil slip, earth slip, debris avalanche, earthflow, and slump erosion) increases with slope, degree of weathering of the underlying rock, and the relative impermeability of the subsoil. Consequently, there is considerable regional variation in susceptibility to mass movement, with areas of softer rock (such as that in parts of the east coast of the North Island) exhibiting severe erosion as a result of forest clearance and subsequent farming.

Mass movement can contribute large quantities of sediment to stream systems. At the Whatawhata Research Farm, west of Hamilton, one massive slip with an eroding surface area of 0.41 hectares put 11,000 tonnes of sediment into the stream over nine months.

3.4.2 Treading and pugging

Treading damage occurs when the soil surface becomes exposed through removal of pasture cover. Pugging refers to the destruction of surface structure of wet soils by stock or traffic. Both can result in reduced water infiltration capacity and increased surface runoff. The extent of soil damage and consequent sediment and nutrient runoff depends on the intensity of grazing, the weight of the animals, slope steepness and the ability of the individual soil type to withstand animal treading damage under wet winter conditions. On predominantly volcanic ash soils, soil damage due to treading on easy slopes (15–24°) had no effect on runoff of sediment and nutrients, whereas on steeper slopes (28–39°), treading damage generated greater losses of soil, phosphate and nitrogen (Nguyen and Sheath, 1998).



Photograph 4: High sediment concentrations in streams are far more likely to occur when pasture is damaged and pugging occurs, especially on slopes. Not only does it lead to soil loss but also to serious production loss. The pasture will take considerably longer to recover than pasture grazed in a more controlled fashion.

The heavier the animal the greater the potential damage. Therefore, bulls and steers are individually likely to cause more damage than cows and substantially more than sheep. The exception to this are deer. Although considerably lighter than most cattle, deer have a strong behavioural tendency to damage large areas of pasture, particularly in wet or water seepage zones, on erosion-prone faces and around fence margins. (This is dealt with in more detail in *Case Study 6: Deer farming and riparian management in Southland.*)

3.4.3 Roding and tracking

Farm tracks and roads can be a significant source of sediment (and nutrients) for hill-country streams. They are generally highly compacted and so water tends to flow along them as opposed to being absorbed. As essential arteries for the movement of livestock they accumulate manure, which is in turn carried down by runoff.

Roads and tracks tend to traverse slopes, so they intercept runoff from upslope and channel it; and frequently they lead to streams carrying the runoff that flows along them. There are several management practices available to reduce the impact of tracks on stream sediment and nutrient levels and these are discussed in a later section.

3.4.4 Streambank erosion

The removal of the original dense indigenous vegetation has left most agricultural streams more vulnerable to increased streambank erosion. This risk is further accentuated by increased flood flows, as there are no longer headwater forests to intercept rainfall and surface runoff.

Free access of livestock, particularly cattle, to streams and stream banks greatly accelerates streambank erosion:

- intensive grazing of streambanks reduces the ability of the bank to resist the erosive forces of flooded streams
- treading and pugging of banks exposes soil to erosion
- livestock accessing the stream for water tend to cut their own access tracks which can become drainage points for runoff and sources of sediment and nutrient to the stream
- the sheer weight of cattle, in particular, can accelerate streambank slumping.

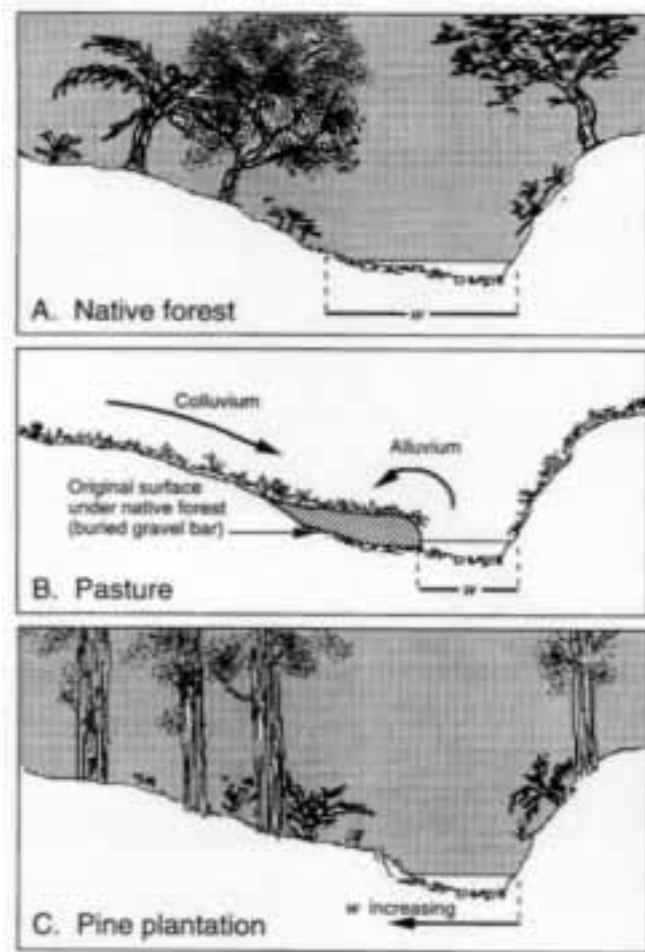


Figure 7: Conceptual model of the channel form of small streams at the same cross-section in different riparian vegetation. **A:** steady-state stream cross-section in native forest; **B:** steady-state stream cross-section in pasture; and **C:** stream-bank recession in a pasture stream planted with pines (pictured after canopy closure). Sediment stored in the pasture stream banks is indicated in Panel B. (Davies-Colley, 1997)

Cattle entering the stream channel over several days have been shown to increase the number of bank erosion sites by 66 percent and typically increased water turbidity from a background level of 5–15 NTU to levels of 65–85 NTU and on occasions as high as 230 NTU (Stassar and Kemperman, 1997).

Generally, stream channels flowing through pasture are narrower than those flowing through forest (native and exotic), and this is most pronounced in small streams where forest streams can be twice as wide as those in pasture. Pasture stream channels appear also to be more deeply incised (see Figure 7). As a result of the narrowed channel, and perhaps also because of increased floodflows due to deforestation upstream, pasture stream waters are faster flowing.

The replacement of riparian forest with exotic grasses has had an important impact on channel narrowing. Pasture grasses trap sediment derived from floodwaters and from catchment erosion and consolidate it into soil. The net result is new stream banks built inside the original active channel, the narrowing of the channel, and the accumulation of stored sediment which is highly erodible if exposed by livestock or bank undercutting. There is some suggestion that reforestation of narrow agricultural stream banks may lead to a reversion of the channel back to a forest shape, with erosion of the banks and channel widening, especially if streambank grasses have been shaded out (Davies-Colley, 1997).

3.4.5 Cultivation

Sediment contamination of streams is most pronounced on cropping and horticultural land where cultivation occurs close to the edge of streams and drains, and where depressions that serve as temporary drainage channels during rain are cultivated and left exposed to surface runoff (see Figure 8). The impact of these cultivation practices is magnified where cultivation takes place on a slope: the steeper and longer the slope the greater the erosive force of the runoff.

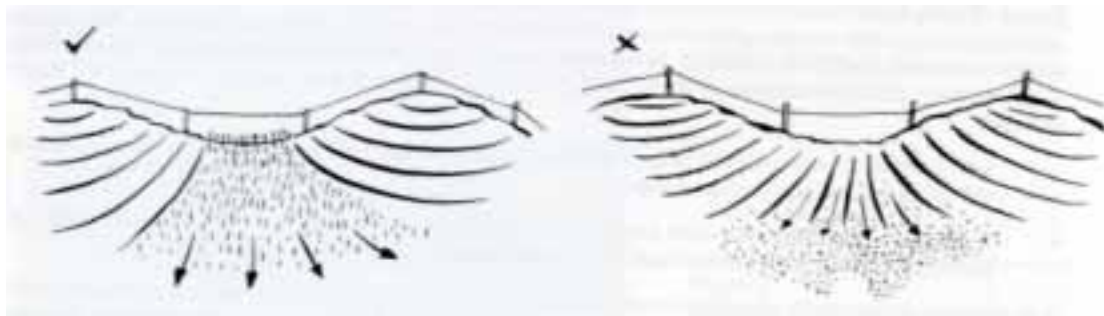


Figure 8: Grassed waterways – in hollows, not bare soil (Hicks, 1995)

Other practices that can increase surface runoff and/or sediment (and nutrient and pesticide) contamination of stream waters include:

- cultivation up and down a slope, as opposed to contour cultivation
- excessive cultivation, resulting in soil compaction and the development of pans and crusts
- soil cultivation when soil moisture levels are too high (wet or saturated soils) or too low.

3.4.6 Suspended solids – effects

High suspended solid levels impacts aquatic life in several ways:

- high turbidity can reduce photosynthesis and overall productivity of aquatic communities by reducing light penetration
- poor visibility can promote emigration and loss of animals from affected areas
- sediments can clog the food filtering or trapping mechanism of aquatic insects
- sediments can coat stone surfaces and clog the small spaces on the stream bed critical for stream plants and animals
- suspended materials may kill fish at very high concentrations:
 - reduce fish growth rate and disease resistance
 - prevent successful egg and fry development
 - modify movements or migrations, or reduce food availability
- fish efficiency in catching prey may also be reduced.

3.5 Faecal contamination

Faecal contamination is a serious problem because of the immediate risk it poses to human and stock health. Faecal material is a source of bacterial, protozoan and viral pathogens. Agricultural streams and rivers in the Wellington region were found to have faecal coliform levels 20 times greater than those draining indigenous forest catchments (Smith et al, 1993).

Faecal coliform bacteria, *E. coli* and enterococci bacteria are most commonly used in water monitoring as indicators of the potential presence of harmful pathogens. All are ordinary bacteria that live inside human and animal intestines and pass out in faeces; the assumption is that if they are present the more harmful micro-organisms are also likely to be present. If these bacteria are present at all, water is classified as unfit for human consumption (Ministry of Health, 1995). As bacterial density increases, water is progressively classed as unfit for shellfish harvesting (for marine waters above a measurement of 14 faecal coliforms per 100 ml of water), contact recreation (above 277 enterococci/100 ml¹) and sheep and cattle consumption (above 1000/100 ml for marine waters and 410 *E. coli* for fresh water).

Animal faecal material enters streams in four ways:

- directly by stock with free access to stream channels
- transport of dung in surface runoff
- oxidation pond discharges
- in localised cases, where shallow groundwaters beneath intensively farmed areas have become contaminated by leached faecal material.

Faecal contamination is likely to be greater where:

- stream water is the only source of drinking-water for stock
- stock must cross streams to reach pastures or milking sheds on the other side
- there is no alternative shade available to stock in the summer
- stocking rates are high
- there are cattle and deer
- streams are not fenced from stock.

¹ The Ministry of Health and MfE recently (November 1999) published the Recreational Water Quality Guidelines, which use *E. coli* as the indicator of choice for freshwaters and enterococci for marine waters.

Pathogen concentrations reaching and contaminating streams and rivers (and ultimately lakes and estuaries) may increase when:

- livestock are intensively farmed (ie, high stocking rates)
- surface runoff is high due to low soil permeability, overgrazing, soil saturation, steepness and long slope lengths
- riparian wetland areas and seepage zones have been drained
- no riparian vegetation remains to filter out contaminants from surface runoff
- heavy rain follows a period of dry weather
- sub-surface drainage systems have been put in place
- oxidation ponds discharge directly to streams.

When pathogens enter waterways through animal waste and human sewage, they pose a risk of illness to swimmers, recreational users and shellfish eaters.

Many animal pathogens may occasionally be transmitted animal to animal via water. In most cases water is not recognised as the main vehicle of transmission. A recent study the 'Bad Bugs programme' considered various pathogens, the criteria for selection in the study included potential transmission in water, and zoonotic potential. The main pathogens considered were: *Cryptosporidia* a protozoa which causes diarrhoea, *Salmonellae* a bacteria which cause stomach upsets and dysentery; *Giardia* a protozoa which can cause diarrhoea, stomach cramps, bloating, dehydration and nausea; *Fosciola* a parasite; and the bacteria *Leptospira* and *Campylobacter* which causes stomach ailments in people and abortions in sheep and cattle.

Faecal contaminants are also a potential health risk to livestock. Reduced growth, ill-thrift or mortality may result from the transmission of pathogens in contaminated waters.

The direct detection of pathogens in faecally contaminated waters is not feasible for routine assessment, as the pathogens occur intermittently, are diverse, and some are difficult or impossible to recover from waters. Tests for indicator bacteria levels can be carried out to determine the risk of pathogens being present, rather than testing for individual pathogens.

3.6 Chemical contamination

Pesticide contamination of waterways is most likely to occur next to land used for commercial cropping, market gardening, orcharding and other horticulture. Sheep dip sites also offer the threat of contamination. Pesticides can enter waterways in three ways:

- they can leach through the soil to groundwater
- they can be carried in surface runoff (bound to fine soil particles)
- from direct contamination due to spraydrift.

Modern agricultural chemicals (herbicides, insecticides, and fungicides) are generally less persistent and more specific in their activity than those used in the past. In contrast with the organochlorines used during the 1950s, 1960s and 1970s (such as DDT), most modern pesticides are not bioaccumulative.

But while modern pesticides are generally less persistent in the environment, many are highly toxic to aquatic and terrestrial organisms (including humans). Each class of pesticide has its own maximum acceptable value (set by the Ministry of Health), below which the water is considered to be of drinkable quality. Separate toxicity levels for aquatic organisms have also been developed for some chemicals.

3.7 Stream temperature and shade

Many streams running through pasture have a surprisingly high levels of shade (50–70 percent shade). This is largely provided by stream banks and by bank vegetation, but this is considerably less than in forested streams, which typically have shading of 95–98 percent. Open streams with low banks and a complete lack of riparian vegetation can be expected to have considerably lower than 50 percent shade (Collier et al, 1995; Rutherford et al, 1997). The amount of shading has a significant impact on water temperature with pasture streams having daily maximum temperatures that are 6–7°C higher than forest streams, and daily mean temperatures 2–3°C higher.

The temperature of farm waterways varies with climate, elevation, groundwater inputs, shade and flow, as well as from human activities such as farm discharges and water abstraction. Water temperature also varies from season to season and throughout the day.

Water temperature is an important determinant of habitat suitability for a wide range of aquatic flora and fauna. In particular, brown trout need water temperatures below 10°C (for rainbow trout, below 12°C) during the winter spawning season. Many important aquatic insects die when temperatures exceed 23°C. In many parts of the country, pasture stream temperatures often exceed 20°C during the summer, and can exceed 25°C.

Small streams heat up and cool down more rapidly than larger streams and hence may be more responsive to changes in riparian shade. A small stream (with a flow of, 0.013 m³ per second) passing from native bush into pasture may warm by up to 10°C within a few kilometres, while a larger stream (0.250 m³ per second) may take over 40 km to warm up by 10°C.

Computer modelling predicts that shade levels of about 75 percent are sufficient to maintain water temperatures comfortably below 20°C (Rutherford et al, 1997). In the very smallest streams, the shade from stream banks, the surrounding land and overhanging plants may be sufficient to maintain acceptable water temperatures, whereas in larger streams (flows of hundreds of litres per second) tall riparian vegetation is necessary to lower water temperatures.

As well as influencing water temperature, shade, by reducing light levels, has a direct impact on aquatic plant growth. A reduction in stream lighting will produce an

equivalent reduction in aquatic plant production. A major concern with open stream reaches is that algae and aquatic plants may grow to nuisance levels. This is more likely in agricultural catchments where waters are enriched by nutrients.

Generally, aquatic weeds require at least 30 percent of the light of an open site to sustain growth. Thus, shading of 70 percent or more can be expected to reduce growth of these plants. The complete elimination of macrophytes is, however, probably not desirable as they greatly increase habitat diversity and can be the main substrate for invertebrate colonisation in open streams with sandy bottoms and little woody debris. Fifty percent shading has been suggested to retain a desirable macrophyte level. Nuisance filamentous and mat growths of algae are also likely to be eliminated by shading of 70 percent or more, although shade levels of 90 percent are necessary to restore periphyton biomass to the low levels typical of forest streams.

Adequate stream shade is important to instream life because:

- it helps to keep summer maximum water temperatures below levels that can threaten the tolerances of fish and invertebrate life
- it can reduce nuisance growths of algae and aquatic plants.

Excessive shading may:

- eliminate macrophytes from streams (their retention can be important for stream function in soft-bottomed streams)
- result in loss of stream bank groundcover plants thus increasing bank erosion.

3.8 The impact of flow regime on water quality

The flow regime of a river will vary with the season and other activities such as abstraction, which in turn affect water quality. To learn more about this readers are referred to the Ministry for the Environment publication “Flow Guidelines for Instream Values” (Volumes A and B, 1998).