The forest and water quality relationship

Colin O'Loughlin*

ABSTRACT

The projected strong growth over the next decade or more in the size of New Zealand's plantation forest estate and the area of annual forest harvest suggests that plantation forests will have increasing potential to influence water resources. The evidence from small catchment studies and broader-scale, water-quality monitoring programmes indicate that streams draining undisturbed indigenous and mature plantation forests have high water quality with low concentrations of dissolved nutrients, suspended solids and microbiological organisms. Forest activities such as harvesting and road or track construction can degrade water quality, at least in the short term, particularly by increasing the suspended sediment in streams. Management approaches such as application of modern harvest planning, low-impact harvesting techniques and development or retention of streamside buffer zones can effectively protect soils and slope stability and prevent erosion products from entering streams.

INTRODUCTION

The introduction of the Resource Management Act (1991) has placed increased emphasis on the sustainable management of surface and ground water resources in New Zealand. Embodied in the definition of sustainable management is the concept of ecological and environmental sustainability which, when applied to the management of water resources, can logically be taken to include the protection and maintenance of water quality. Although New Zealand is generally regarded as a land with abundant supplies of fresh water of high quality, expanding urbanisation, expanding industrial development, the heavy use of agricultural pesticides, weedicides and fertilisers and the large population of farmed and wild animals present major challenges to Regional and District Authorities and other land managers including foresters and farmers in their efforts to ensure that the water quality of streams, rivers, lakes and ground water are not degraded. To help achieve the goals of protecting or improving the quality of ground and surface waters through the various resource management planning processes and granting of consents, a sound knowledge of natural water quality, the relationships between management/development activities and water quality and the sources of pollutants is required.

Many of New Zealand's important surface and ground waters originate in forested terrain or are influenced by forests which occupy nearly 28 per cent of the country's land surface. The rapidly growing commercial forest industry is expected to continue to expand into the medium-term future. The current area of commercial exotic plantation (1.3 million hectares) is likely to increase at a rate of between 50,000 and 100,000 hectares per year over the next decade or more. Much of this expansion of the exotic forest estate will occur on pastoral land. Furthermore, the total area of forest harvesting (clearfelling) will also increase above the current level of approximately 20,000 hectares per year as the area of mature plantation available for wood production rises. These projections suggest that forests will have increasing potential to influence water resources. This paper attempts to summarise the accumulated knowledge about the relationships between forests and their management and water quality.

DEFINING STREAM WATER QUALITY

Hoare and Rowe (1992) pointed out that water quality is not easily defined. My understanding is that water quality depends on a number of water quality parameters which are measurable and combined to determine whether or not water is suitable for drinking, bathing in, a range of other domestic and industrial uses and supporting aquatic fauna and flora. The parameters of concern in this paper are:

- the concentrations of cations (sodium, potassium, calcium, magnesium, aluminium), and anions (chloride, nitrate, nitrite, ammonium, phosphate, bicarbonate), dissolved oxygen, complex organic compounds and heavy metals which determine the chemical water quality;
- the pH, temperature and electrical conductivity of the water;
- the biochemical oxygen demand of the water (BOD);
- the concentrations of suspended solids (sediment, organic materials) which can determine the clarity of the water or the turbidity;
- the concentrations of microbiological organisms such as bacteria and parasites such as Giardia.

The ways in which these water quality parameters are measured have been described in a vast range of publications and it is not my intention to outline the techniques in this paper.

To facilitate overall water quality assessments and enable comparisons between sites or between different rivers and streams, some Regional Councils have adopted a General Use Water Quality Index (WQI) (Smith 1987) which summarises temperature, dissolved oxygen, pH, turbidity, biochemical oxygen demand and faecal coliform concentrations. The WQI scores between 0 and 100. WQIs of 80 and above indicate very good water quality eminently suitable for general use and WQIs below 40 indicate very poor water quality requiring urgent attention.

WATER QUALITY OF STREAMS AND RIVERS ORIGINATING FROM INDIGENOUS FORESTS AND MATURE PLANTATION FORESTS

Generally, the highest natural water quality occurs in streams and rivers flowing from indigenous forests and from mature plantation forests which have not suffered major disturbances for a considerable period of time. For instance, the Wellington Regional Council Water Quality Monitoring Programme, which monitors water quality at 105 sites on 44 water courses, has consistently shown that the 10 sites with the highest water quality drain predominantly native forest catchments (Wellington Regional Council 1993). The WQI for these sites ranges from 89 to 98. Typically, undisturbed native forest streams and streams flowing from mature undisturbed plantation forests contain few suspended solids except at times of extreme floods and low concentrations of nutrients such as NO_3-N, NH_4-N and total P. Dissolved or colloidal organic material sometimes causes streams flowing from indigenous forests to appear "tea-like" in colour.

Water quality studies in small forest catchments (Cooper and Thomsen 1988, Hoare and Rowe 1992, McColl *et al.* 1977,

* *Dr Colin O'Loughlin, 10B Grosvenor Flats, 19 Cottleville Terrace, Wellington.*

Mosley and Rowe 1981, O'Loughlin *et al.* 1980, Rowe and Fahey 1991 and Landcare data as yet unpublished) confirm that ionic concentrations including NO_3-N and various forms of P and concentrations of suspended solids in streamwaters draining undisturbed forest catchments, are generally lower than the concentrations measured in streamwaters from pasture, urban and recently clearfelled forest catchments. The ability of forest ecosystems to cycle nutrients efficiently and prevent erosion and soil loss, generally ensures that the water quality of streams draining undisturbed forests is high. Overseas and New Zealand studies have indicated that undisturbed forest ecosystems often approach a cation balance situation where the outputs of cations in streamflow approximately balance the inputs in rainfall. Table 1 presents some comparative water-quality information for undisturbed forest and pasture catchments.

TABLE 1: Typical mean streamwater concentrations of nitrate, total P and suspended solids from forest and pasture catchments under baseflow conditions (after McColl *et al.* 1977, Mosley and Rowe 1981, Cooper and Thomsen 1988, Rowe and Fahey 1991 and Wellington Regional Council 1993).

	Pasture			Indigenous forest			Radiata pine forest		
	NO_3	TP mg/L	SS	NO_3	TP mg/L	SS	NO_3	TP mg/L	SS
Maimai				0.05	<0.01	<10			<10
Central NI	0.02	0.04		0.08	0.01		0.20	0.02	
Well. Region	0.02	0.06		0.03	0.01	<10	0.02	0.02	

Blank spaces indicate no information available

At Purukohukohu experimental basin near Rotorua, Cooper and Thomsen (1988) found that N and P exports in streams from maturing pine forest and from indigenous forest were similar but differed markedly from a pasture catchment stream. The pasture stream exported 15 times more P on an area basis than the forested catchments (pine and indigenous) and about three and ten times more N than indigenous and pine forest streams respectively. Elevated levels of N and P can contribute to excessive growth of benthic algae and the disappearance of pollution sensitive species.

Although water quality data for streams draining mature, undisturbed exotic forests is rather sparse, the information available suggests that streamwater quality from mature radiata pine catchments is generally high and comparable with the water quality from indigenous forests, given similar conditions of terrain, climate and geology.

Under high flow (stormflow) conditions, the concentrations of nutrients and especially suspended solids in pasture, urban and recently clearfelled forest catchments can rise dramatically compared to the concentrations under baseflow conditions. At high flows the differences between undisturbed forest stream nutrient and suspended sediment loads and the loads carried by streams draining pasture, urban, and recently clearfelled forest catchments generally increase markedly. These differences relate to the way in which stream stormflows are generated. In undisturbed forest subsurface processes are dominant while in pasture, other agriculture and urban catchments surface runoff tends to dominate and stormflow yields per hectare are higher than those in forested catchments (Fahey and Rowe 1992).

The fauna occurring in streams is strongly influenced by the stream environment including the quality of the water. In particular, macroinvertebrate communities (insects, worms, snails and crustaceans), many of which will not tolerate polluted water, are used by researchers and Regional Councils as a general indicator of long-term water quality. For instance, the Wellington Regional Council uses a Macroinvertebrate Community Index (MCI) (Stark 1985) which summarises the presence or absence of macroinvertebrate species, to provide a general indication of water quality. In the Wellington Region indigenous forest catchment streams yielded high MCIs (>135) and pollution intolerant species of mayfly (*Ephemeroptera*), stonefly (*Plecoptera*) and predatory *Tricoptera* groups were well represented, indicating high water quality. Streams with poor water quality draining urban and agricultural land have lower MCI scores and badly polluted streams where sewage or sediment severely degrades the water quality, support very limited invertebrate communities and MCIs fall below 100.

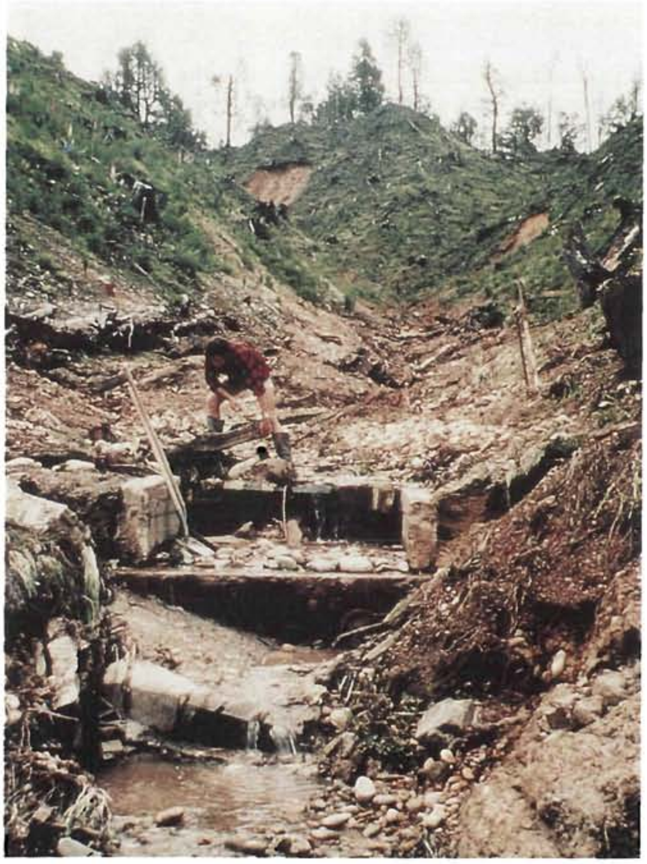
INFLUENCE OF HARVESTING, ROAD CONSTRUCTION AND OTHER FOREST MANAGEMENT ACTIVITIES ON STREAM WATER QUALITY

Forest harvesting can influence water quality, particularly the concentrations of suspended solids (sediment) in streamwater. If the deforested sites are revegetated with forest cover these changes are usually not serious and only temporary. Experimental catchment studies in north Westland (Maimai) and in Nelson (Big Bush) have shown that clearfelling of the indigenous forests followed by post felling burning raised concentrations of K, Mg, Ca, NO_3-N, NH_4-N, total N and total P markedly in the first 12 months after treatment but these concentrations rapidly declined in the second year after treatment as a replacement crop of radiata pine developed. Mean streamwater electrical conductivity at Maimai increased from approximately 22 uS/cm during the pre-treatment period to a maximum of 1010 uS/cm in a clearfelled and burnt catchment during a storm 18 days after the burn. Clearfelling without burning produced smaller initial changes in water chemistry. The catchment studies also showed that retention of narrow riparian forest reserves helped to reduce the impacts of felling and burning on water chemistry. Over an eight-year post-treatment period mean annual yields of NO_3-N from clearfelled and clearfelled and burnt catchments increased between two and five times NO_3-N yields from adjacent undisturbed control catchments (Rowe and Fahey 1992).

Clearfelling indigenous forests in the Big Bush experimental catchments produced much smaller changes in water chemistry than at Maimai and only NO_3-N and total N showed marked increases in concentrations after clearfelling (Landcare unpublished information).

The most serious consequences of forest removal on water quality in New Zealand are related to increased supply of sediment to streams after logging and road building. Clearfelling and burning of small catchments at Maimai raised the total sediment yields from an estimated 33m^3/ha/year for undisturbed forest, to 47m^3/ha/year in a cable logged catchment with no tracks and 264 m^3/ha/year in a skidder-logged catchment over the first two years after treatment. Streams flowing from undisturbed indigenous forest were clear (<20 mg/L suspended sediment) about 97 per cent of the total time. Over the first two years after clearfelling and burning, streams draining the treated catchments were clear only 88 per cent of the time (O'Loughlin 1980). Although the sediment yield and physical water quality data for the bulk of the Maimai and Big Bush catchments over the 14 years since the catchments were clearfelled have not been analysed, it is apparent that after the first two to three years of highly elevated sediment yields, yields gradually lowered over subsequent years as a replacement cover of radiata pine and other weed and native vegetation developed and protected the slopes. The most serious sediment sources were logging tracks in the skidder-logged catchments, shallow landslides on steep deforested slopes, stream bank collapse and erosion of stored sediment in the stream channels by stormflows.

High-quality stream water in a central North Island indigenous forest catchment.



An extreme debris flow event demolished the stream gauging station and sediment trap in a recently logged experimental catchment at Maimai, north Westland. The debris flow accounted for a large per cent of the total sediment yield from this catchment over the first three years after harvesting.

A principal source of stream water pollution on recently logged catchments; logging track surface runoff in the Big Bush experimental area, Nelson.

Sampling suspended sediment concentrations in stormflow from a mountain beech catchment in the Craigieburn Range, Canterbury.

In general, other overseas forest catchment studies of the effects of forest removal on water quality (Sopper 1975, Patric 1976, Likens *et al.* 1970 and Binkley and Brown 1993) show that water chemistry changes resulting from forest removal are usually small and short-lived except where severe post-harvest burning occurred. The most significant changes are usually in physical water quality where sediment from logging roads, tracks and landings and from landslides and other forms of slope erosion on steep deforested terrain raises the concentrations of suspended sediment in stream water. In several catchment studies the retention of riparian reserves of undisturbed vegetation has moderated the effects of harvesting on water quality.

The fertilisation of pine forests in New Zealand has not been shown to seriously increase the concentrations of N and P in streamwater except where fertilisers are applied directly to the forest stream channels (Neary and Leonard 1978, Dyck and Cook 1981). Other studies have shown that the aerial application of baits treated with sodium monofluoroacetate (1080) in forests for possum control have had no detectable influence on the levels of 1080 or fluoride in the streamwaters draining the treated forests (Eason *et al.* 1992, Wellington Regional Council 1994).

IMPLICATIONS FOR MANAGEMENT

Managing forests for the protection of water quality principally concerns maintaining or improving soil and slope stability and preventing the products of erosion entering stream channels. The most critical period of high risk is during forest harvesting (including track and landing construction), and during a four-five year post-harvest period when replacement crops are not sufficiently developed to reinforce soils effectively and track and landing surfaces are not fully stabilised and remain susceptible to collapse and surface erosion. About 35 per cent of the exotic forests to be harvested over the next three decades are located on moderately steep to steep slopes over 20 degrees in steepness. Many of these slopes in Northland, Coromandel Peninsula, East Cape, Hawkes Bay, Taranaki, Wellington, Marlborough Sounds, Nelson and north Westland are potentially unstable. Managing these steep terrain forests for soil protection as well as for wood production will require new approaches to harvesting based on the new technologies developed overseas and by the Logging Industry Research Organisation. Furthermore, account will need to be taken of the results of forest slope stability research by Landcare Research (formerly conducted by FRI) so that particularly sensitive slope areas can be recognised during the harvest-planning phases of large operations.

The application of the principles outlined in the revised New Zealand Forest Code of Practice (Vaughan 1990, revised by Visser and Smith 1993) will help forest managers to plan and executive forest operations in a sustainable manner. In particular, sections 4, 5 and 6 of the Code of Practice covering the values at risk, impact appraisal process and operations database respectively, provide essential information for managing forests without adversely influencing water and soil resources. The use of Geographic Information Systems to record and integrate a wide range of spatial data such as water course locations, terrain stability information, location of wetlands and areas of poor drainage, will probably be essential in future forestry planning exercises if the goal of protecting water resources on forest lands is to be met. The development of other strategies, involving the partial logging of steep slopes, small logging coups, staged logging, low-impact cable-logging techniques and construction of erosion-resistant logging roads and tracks, may also be necessary to comply with the requirements embodied in Regional and District Council plans.

Managing streamside and wet valley bottom areas presents some important challenges for the future. It is these locations which are often vulnerable to disturbance and, when managed poorly, they can seriously influence water quality. On the other hand, careful management of riparian areas for protection of streams, lakes and wetlands can moderate the impacts on water quality of forest activities on middle and upper slopes. The Resource Management Act (1991) recognises the benefits of riparian protection and provides a legal framework for the use of riparian buffers (Quinn *et al.* 1993).

The establishment of more or less permanent, self-sustaining vegetation streamside buffer zones may be the most effective way of protecting streams against inputs of sediment and other pollutants. Riparian vegetation can also maintain stream bank stability, provide shade which lowers stream temperatures, controls algae growth and provides a food source for aquatic life (McColl *et al.* 1981, Gilliam *et al* 1992, Smith 1992, Fenton 1992, Quinn *et al.* 1993). The development of streamside zone management strategies based on research and field trials is only in its infancy in New Zealand (and in many other countries). More applied research is urgently needed to provide a basis for managing riparian areas.

In steep unstable hill country where protection of water quality is a prime goal, the protection of water resources may require more than simply establishing narrow 10 or 20 m wide strips of protective scrub vegetation. For instance, in hill country catchments which supply water for Auckland, Wellington and Dunedin cities, there may be many long-term advantages if whole tributary headwater valley bottoms were zoned for protection use only and reverted to indigenous scrub or forest or some stable form of self-sustaining vegetation cover. In these circumstances production forest activities would be restricted to middle and upper slopes and any major disturbances would be kept well away from the stream channels.

The maintenance of the quality of New Zealand's important ground water resources has become a more important issue since a number of investigations and routine monitoring have revealed that some resources are contaminated by pesticides (Close 1992, Smith 1993) and nitrate nitrogen (Smith *et al.* 1993). Localised contamination of ground water by faecal coliforms and other bacteria and by high concentrations of iron and manganese also occurs in rural areas. Forestry as a landuse could play an important role in protecting ground water quality if forests were established in major ground water recharge areas. On the other hand, where ground water supplies are heavily utilised and under stress, forest vegetation may be regarded as undesirable because of its relatively high water use. For instance, Fenemor (1991) indicates that controls on exotic afforestation may be introduced in the Tasman District Council's District Plan to restrict reductions in stream flows and ground water recharge in the Moutere Valley.

CONCLUSIONS

- The potential for forestry activities to influence water quality will grow over the next decade or more as the area of actively managed production forests expands.
- The most serious influence of forests on water quality occurs during and after timber harvesting and road building and is related to increases in erosion rates and sediment supply to streams.
- The adoption of modern harvest planning techniques including the application of modern low-impact logging techniques and construction of erosion-resistant roads and the careful management of riparian zones are effective approaches for moderating the most serious influences of forestry activities on water quality.

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A stream gauging weir and sediment trap on a radiata pine stream in the Marlborough Sounds. This installation is part of a long-term experiment to evaluate the impacts of clearfelling radiata pine forest on stream water quantity, quality and sediment yields. Photo: Landcare