THE IMPACT OF FOREST ROAD EROSION IN THE DART VALLEY, NELSON

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ABSTRACT

A survey of erosion on a road system constructed in granitic terrain in the Dart Valley, Nelson, for production forest development has been carried out. Rates of sediment input into the stream system in 1978-9 averaged 255 $m^3/km/yr$ over the 25 km road system, but figures for individual roads varied widely, from 14 $m^3/km/yr$ for a 10-year-old valley bottom road to 1270 $m^3/km/yr$ for a 1-year-old mid-slope road which had suffered a number of large culvert or fill slope failures. Total rates of erosion on the road system were three times greater, but much sediment is fed on to vegetated slopes beneath the roads, and is stored there. Total sediment input from the road system into the stream system in 1978-9 was estimated as 12 000 t/yr, in comparison with an estimate for natural sediment yield from the catchment of 9600 t/yr. Much of the sediment has been stored in headwater channels (which are, however, probably subject to periodic flushing by major storm events), deposited upon point bars above the low-flow water level in the main river, or flushed out to sea in suspension. The impact of the road-derived sediment upon the Dart River is therefore probably limited. The estimated natural sediment yield of the Wangapeka is an order of magnitude greater than that from the Dart; sediment from the Dart Valley road is therefore unlikely to have had any significant impact upon the Wangapeka, or the Motueka downstream.

INTRODUCTION

During recent years, forestry operations in New Zealand have come under increasing public scrutiny. Aside from the general aesthetic considerations involved, a particular cause for concern has been the impact upon streams and rivers of the increased rates of erosion and sediment transport that are often associated with forestry (Graynoth, 1979). This has particularly been the case in the watershed of the Motueka River, Nelson, and fishing

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interests have expressed concern regarding the effects upon fish habitat of increased qantities of granitic sand coming from lands currently undergoing afforestation. For example, a Nelson fisherman states

> . . . . during the 1970s the Motueka system has been adversely affected by deposits of granite sand. This has not caused any weed growth, but it has covered large areas of gravel in both the main river and side streams. The trouble started with a large flood in April, 1976 which affected the west bank tributaries. Enormous quantities of material entered from slips which started on forestry roads and firebreaks. (J. A. Ring, written communication to E. Graynoth (MAF., Fisheries Research Div.), December 1979).

Attention has recently been concentrated upon the catchment of the Dart River, where erosion on roads newly constructed through granitic terrain is claimed to have caused a significant increase in the quantities of sand reaching the river. It is held that sediment is being deposited in the gravel river beds, choking spawning grounds and destroying fish habitat. Evidence for this has been qualitative and based upon recollection of earlier conditions; this is a notoriously unreliable basis for an assessment of the true situation. Futhermore, it does not take into account natural variations caused by floods, etc. It is necessary to measure or estimate both natural rates of erosion in the catchment under discussion, and the rate of erosion on the road system. In response to a request from Nelson Conservancy, N.Z. Forest Service, a survey was carried out of erosion in the area of the Dart catchment that is undergoing afforestation, in order to objectively assess likely impacts on the river system.

A large body of information, particularly in the U.S.A., demonstrates that the presence of forestry roads in an area may result in major increases in erosion rates with respect to natural or "geologic rates (Fredriksen, 1970; Swanson and Dyrness, 1975; Megahan, 1977). Increases in forest road-related erosion have been found to be particularly severe in the granitic terrain of the Idaho batholith (Megahan and Kidd, 1972; Gardner, 1979). Indeed, impacts upon the South Fork of the Salmon River, Payette National Forest, were so severe that a moratorium was imposed upon logging that remains in force today, and there is controversy regarding the advisability of production forestry in several other national forests located on granitic bedrock. Because of the similarity of the granitic terrain of Idaho and Nelson, the U.S. findings suggest that the possibility of environmental deterioration in Nelson as a result of road construction should be taken seriously, and warrants examination.

THE STUDY AREA

The Dart Valley is an 81 km^2 south-bank catchment of the Wangapeka River, much of it clothed in native forest (Fig. 1). Approximately 17 km^2 of the catchment adjacent to the main confluence has in the past been cleared, has reverted to scrub and rough grazing, and is presently undergoing exotic forest development. Some 25 km of road have been constructed to facilitate this development, and to provide access to a lookout tower.

Slopes are steep, commonly up to 35°, and incised by numerous side drainages. The watershed is underlain by the Separation Point Granite, a massive soda-alkali granite whose character, as revealed in road cuts, varies widely from unweathered to highly fractured and rotten. Some areas are naturally prone to deep-seated slumping, and hummocky slumped topography is evident in the lower catchment, with numerous mass movement scars

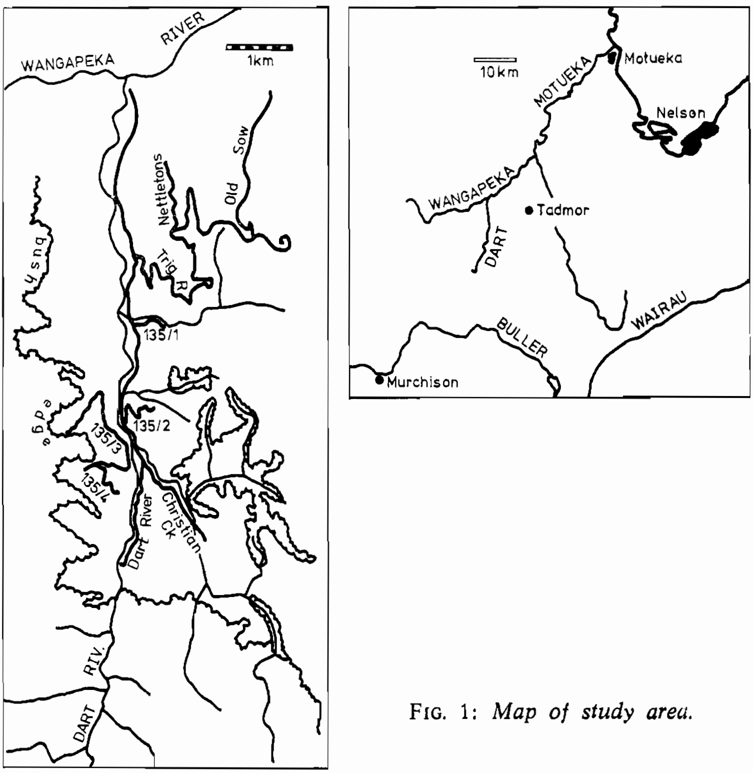

FIG. 1: *Map of study area.*

visible throughout the cleared area, commonly in gully heads. The whole catchment may be regarded as potentially highly erodible when the vegetation cover is disturbed.

Mean annual precipitation varies with relief and location, but is in the range 2000-3000 mm.

ROAD EROSION — ESTIMATION PROCEDURE

The entire road system in the Dart Valley (excepting roads 135/3 and 135/4, which are on the west bank of the river and were inaccessible owing to high streamflow) was traversed during the week of January 21-5, 1980. All signs of erosion on the road formation (cut slope, watertable/drain, road surface, fill slopes/sidecastings) were noted and described, and volumes of sediment removed were estimated by measuring by tape or pacing the dimensions (length, width and depth) of the erosional features remaining. Features such as slump scars, gullies and rills were easily measured; an attempt to estimate rates of surface lowering by sheet erosion (raindrop impact, etc.) was also made by reference

TABLE 1: ESTIMATES OF EROSION, DART VALLEY ROAD SYSTEM

Road	*Length (km)*	*Date Built*	*Erosion Rate on Road Formation (m^3/km/yr)*	*Rate of Sediment Supply to Drainage System (m^3/km/yr)*	*Total Sediment Supply to Drainage System (m^3/yr)*
Trig R (Dart Valley)	2.1	1970-1	20	14	30
Trig R (Sherry Lookout)	6.7	1970-1	200	110	740
Dart River (lower)	3.4	Feb. 78	210	124	420
Dart River (upper)	1.85	Feb. 78	460	182	340
Christian Ck	1.4	Feb. 78	1 330	675	960
Rd 135/1	0.55	Feb. 78	145	145	80
Rd 135/2	1.1	Feb. 78	1 650	585	645
Rd 135/3	2.25	Feb. 78	—	100	225
Rd 135/4	1.85	Feb. 78	—	500	930
Nettletons Rd	1.6	Jan. 79	4 130	1 270	2 030
Old Sow Rd	2.3	Jan. 79	140	0	0
	25.1		650 (weighted mean)	255 (weighted mean)	6 400

to pedestals protected by pebbles, and other visible evidence. The fate of the sediment (whether stored at the base of the slope as an alluvial fan, fed directly into the river system, etc.) was also determined, and volumes of sediment estimated by probing the deposits. This procedure is similar to that used in surveys elsewhere (Haupt, 1959; Haupt and Kidd, 1965).

Roads were built almost exactly ten, two or one years before the survey (Table 1); for the roads built in the last one or two years, erosion was assumed to have been spread evenly over the period. Although erosion would probably have been most rapid in the early stages, a major storm in late 1979 has probably had the effect of evening out erosion rates on the 2-year-old roads. Erosion on Trig R road has now, aften ten years, reached low levels, with sidecastings frequently well vegetated, but the major erosion scars that were noted have occurred in the last year, so estimated volumes are assigned to 1979 alone rather than to 1970-9. It is considered that erosion in earlier years would have been considerable, but that the resulting scars have now been revegetated.

Erosion rates on roads 135/3 and 135/4 have been estimated on the basis of visual comparison, at a distance, with those roads for which rates could be estimated directly.

RESULTS

The frequency distribution of size of erosion features observed is shown in Table 2; it will be noted that some massive failures of several hundred cubic metres have occurred. The data in Table 2 are to some extent misleading because the volumes of individual small features on areas of fill suffering rill and gully erosion were lumped to give a total sediment loss from the whole area. The table therefore summarises sediment loss data for both individual features and areas of slope; almost all entries with volumes greater than 200 m^3 were, however, specific features such as slump scars.

Table 1 summarises the estimated total volumes of sediment eroded from each section of road, and supplied from each section to the permanent drainage system. There is, of course, potential for error in these estimates, but without actual measurements of soil movement from plots they are the best available. There is a great range in rates of sediment loss from individual roads; the 10-year-old Trig R road along the floodplain of the Dart River has a very low rate of erosion of about 20 m^3/km/yr, whereas

TABLE 2: FREQUENCIES OF EROSION FEATURES BY VOLUME CLASS

Volume Class (m^3)	*Number*	
	On Road Formation	*On Road Formation: Volume Reaching Stream*
0 — 50	41	28
51 — 100	12	5
101 — 150	6	6
151 — 200	12	3
201 — 250	2	1
251 — 300	4	2
301 — 400	8	3
401 — 500	5	3
501 — 600	4	3
> 600	1	0

Note: Table includes both discrete erosion features (slumps, etc.) and areas of fill slope undergoing rill and sheet erosion. Most of the members of the larger volume classes are discrete features.

Nettleton's Rd, a newly constructed midslope road which cuts across a number of incised gullies high on a steep face, had a total rate of erosion of over 4000 m^3/km/yr. This latter figure seems high, but includes severe rilling and gullying of most side-cast slopes, frequent slumping and universal sheet erosion of cut slopes, and some massive failures of fills and embankments across culverted stream crossings (Fig. 2).

FIG. 2: *Slumping and gullying of road fill on Nettletons Rd associated with culverted crossings of steep headwater drainages.*

FIG. 3: *Fill slope on Dart Valley Rd; sediment eroded from the fill is redeposited on the vegetated slope immediately beneath.*

Nevertheless, rates of sediment entry into the river system are substantially lower, and average 255 m^3/km/yr for the whole road system. Two-thirds of the sediment removed from the road prism is redeposited immediately downslope in the dense undergrowth (Fig. 3), or as large alluvial fans on the main floodplain (Fig. 4).

Taking the whole road system into account, the estimated total annual input of sediment into the stream system in 1978-9 was 6400 m^3; assuming a specific gravity of 1.9 g/cm^3 this amounts to over 12 000 t/yr.

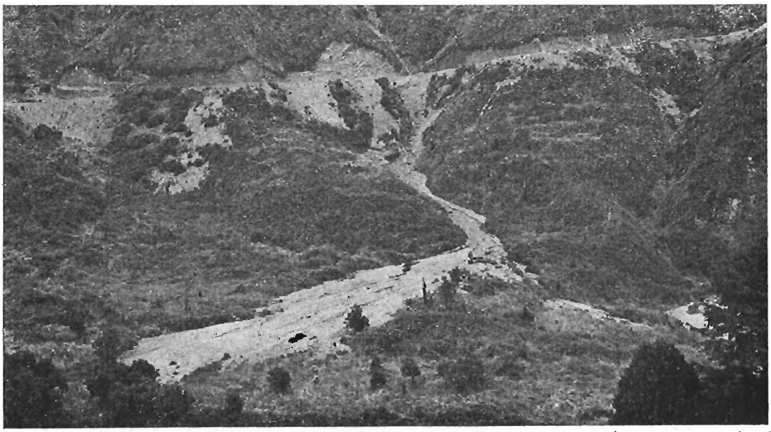

FIG. 4: *Sediment from a failure of a fill slope on Road 135/3 is redeposited as an alluvial fan on the floodplain of the Dart.*

ESTIMATION OF NATURAL EROSION RATES

To place the estimate for road-related sediment supply to the stream system into a broader context, some estimate of natural erosion rates is necessary. No runoff or sediment load data are available for the Dart or Wangapeka Rivers, but a recent study by Griffiths (1979) provides a usable basis for estimation of natural erosion rates in these catchments. Griffiths found a close relationship between sediment yield and precipitation for rivers draining the West Coast ranges which appears to be unaffected by other factors such as vegetation and lithology. The relationship is:

$$G = 9.02 \times 10^{-11} P^{3.65} \quad (1)$$

where G is sediment yield in t/km^2/yr and P is mean annual precipitation in mm. Limited data for the Motueka River indicate that the relationship may be used in this catchment also, particularly in the steep, forested headwater areas (G. A. Griffiths, pers. comm.)

TABLE 3: ESTIMATES OF EROSION AND SEDIMENT YIELD

	Mean Annual Precipitation (mm)	*Catchment Area (km²)*	*Suspended Sediment Yield (t/yr)– from Equation 1*	*Total Sediment Yield (t/yr) (incl. bedload)*	*Specific Total Sediment Yield (t/km²/yr)*
Dart	2 000	81	8 200	9 600	119
Wangapeka	3 100	240	120 000	140 000	583
Dart Valley roaded area— road system only		16.9		12 000	710

Mean annual precipitation has been estimated for the Dart and Wangapeka catchments from the 1:500 000 map issued by the N.Z. Meteorological Service, and entered into equation 1 (Table 3). The estimate of mean annual suspended sediment yield from the Dart River catchment is 8200 t. To be made more comparable with the estimate of erosion from the road system, which includes all material, whether moving as suspended load or as bed load, this figure should be increased. Data presented in Gregory and Walling (1973) suggest that in a river such as the Dart 15% of the total sediment load moves as bedload; adjustment of the estimate for sediment yield gives a total yield of 9600 t/yr.

DISCUSSION

Only one-third of the sediment eroded from the formation of the Dart Valley road system actually reaches a drainage channel, the remainder being discharged on to vegetated slopes beneath the roads, and held there. Sediment generally reaches the drainage system only where a road crosses a stream as in the case of mis-slope roads such as Nettletons Rd, or where a road runs beside a stream, as in the case of lower slope or valley bottom roads such as Upper Dart Valley road. Ridge-top roads such as Old Sow Rd present few problems, as far as sediment input to the drainage system is concerned.

Nevertheless, the estimated total sediment input of 12 000 t/yr from the road system into the drainage system in 1978-9 is 25% greater than the estimated natural sediment yield of 9600 t/yr from the whole catchment. The impact of this increase upon the Dart River and rivers into which it flows is difficult to assess, striking though the increase in sediment input appears. Large quantities of the sediment derived from the road system have been deposited in headwater stream channels downstream from road crossings; for example, over 100 m^3 (190 t) of sediment believed to have come from the failure of a fill slope on Trig R road is stored upstream from an embankment on Dart Valley Rd. Tributary streams are therefore acting as temporary storage areas which

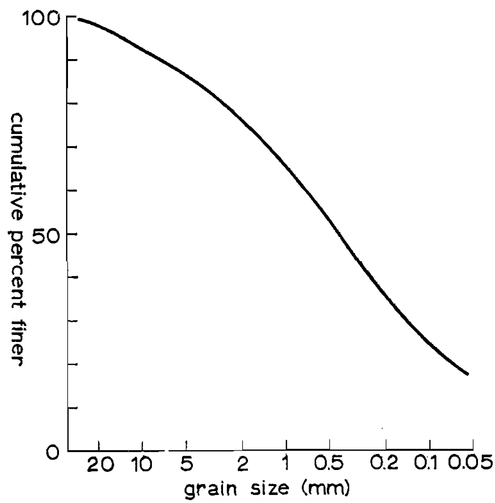

FIG. 5: *Size distribution of sediment composing a fill slope on the upper Dart Valley Rd.*

moderate the flow of sediment into the main channel; a similar effect has been observed in headwater channels in the Ruahine Range (Mosley, 1978). In some cases such sediment storage may be permanent, but under the climatic and geologic conditions prevailing in the Dart Valley steep headwater gullies can be expected to be periodically flushed clear of accumulated sediment, by debris torrents, during high intensity rainstorms (Miner, 1968: Swanston, 1974).

Forty percent of the sediment particles of which fill slopes along the upper Dart Valley road are composed have a diameter less than 0.25 mm (Fig. 5). Much of this fine sand, silt and clay would be caried out of the catchment in suspension if it reached the Dart River as a result of erosion along the road system, and therefore does not represent a problem for the channel of the Dart itself, nor for the Wangapeka or Motueka Rivers.

The 10-year-old Trig R road has well vegetated fill slopes, while cut slopes, water-tables and road surfaces appear generally stable. However, sheet erosion is still occurring on unvegetated surfaces, particularly the near-vertical cut slopes, and there has been recent slumping of fill slopes. Hence it appears that sediment losses from the newer roads should progressively decline in future years, as shown by Megahan and Kidd (1972) and Megahan (1974) in similar granitic terrain in Idaho (Fig. 6), but that sediment will

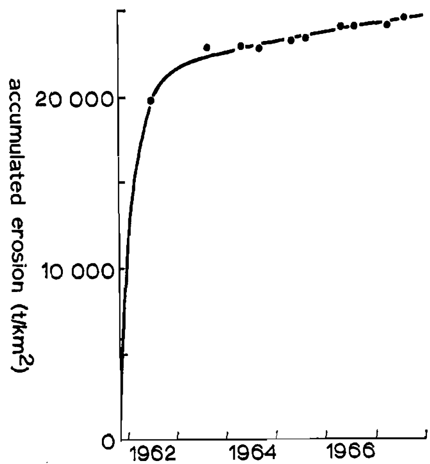

FIG. 6: *Accumulated surface erosion from a section of road in the Idaho batholith region (from Megahan, 1974, Fig. 3). The road was constructed in November 1961; sediment eroded from the road was collected behind a dam.*

continue to reach the stream system in quantities greater than would be the case were no road present. Megahan (1974) concluded that surface erosion rates on his study sites in Idaho will even after 40 years be 10 times greater than natural rates. The whole picture can, of course, be changed by the occurrence of major storm events; a single large event could interrupt a trend towards lower sediment yields and delay recovery for several years (Anderson, 1972). The important controlling influence of large storm events has already been demonstrated in forested areas in Westland and Nelson (O'Loughlin *et al.*, 1978), and on road systems elsewhere (Haupt *et al.*, 1963; Fredriksen, 1970; Hartsog and Gonsior, 1973).

Most sediment is transported during medium to large flow events (Wolman and Miller, 1960; Gregory and Walling, 1973). the risk of erosion on or failure of the road system is highest when natural stream turbidities and sediment concentrations are already greatest. During flood events, the location of maximum bed load transport in a river channel tends to coincide with the location of greatest current velocity and shear stress, over the point bars (Fig. 7), which are submerged during the period of high stage (Hooke, 1975). On the falling stage sediment is deposited on the point bars, that is, above the low flow channel. In addition, as already noted, 40% of the sediment — the particles finer than 0.25 mm

FIG. 7: *Sand deposited on a point bar in the Dart River upstream of the roaded area. Point bars downstream through the roaded area have a similar appearance.*

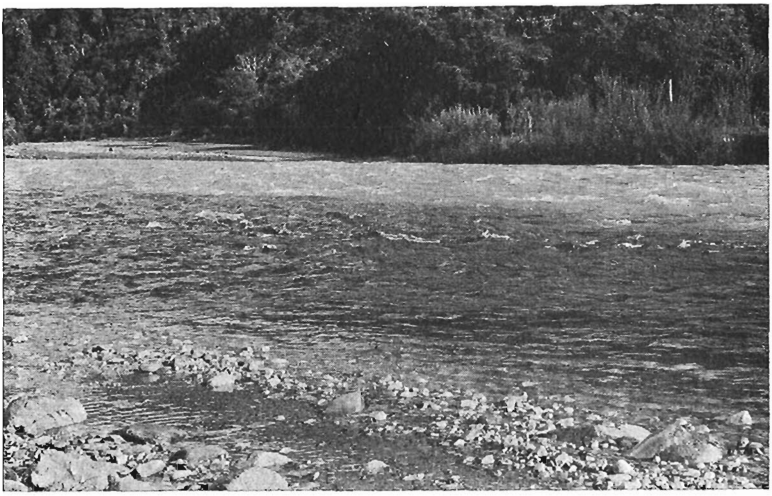

FIG. 8: *The confluence of the Dart and Wangapeka Rivers on January 25, 1980. The clear water of the Dart in the foreground contrasts with the turbid Wangapeka.*

— may be removed entirely from the catchment, as it travels in suspension at the same velocity as the water carries it. Hence the impact upon low-flow channel form of sediment supplied to the Dart River from the road system may be rather limited. If all the sediment eroded from the road system in one year were spread evenly over the bed of the Dart River and its major tributary Christian Creek, its depth would be 2.5 cm. Deposition of coarse material in headwater channels and on point bars and transport of fine material beyond the catchment leaves only a fraction — possibly small but unfortunately unmeasurable — to be deposited in the low flow channel.

Comparison of vertical aerial photographs taken in 1946 and 1974 clearly shows significant changes in the condition of the channel of the Dart River, particularly an increase in width in the lower reaches. Changes during that period could not have been a result of road constructon, and recently observed changes may similarly be merely the continuation of a pre-existing natural trend rather than a response due to road construction. Certainly, large quantities of sand are to be found in the bed of the Dart River upstream of the roaded area (Fig. 7); the character of the streambed or its sediment composition does not appear to change significantly downstream through the roaded area.

Table 3 indicates that sediment transport rates from the Wangapeka River are an order of magnitude greater than from the Dart. There are many natural erosion scars, often caused by landslides during earthquakes, in the Wangapeka catchment, which provide a ready source of supply of sediment to the river. Several local observers have noted that the water of the Wangapeka may be turbid when the Dart is quite clear, albeit with a brown organic staining (Fig. 8). Hence, it seems that the increase in sediment load caused by road construction in the Dart catchment has a small relative impact upon the already high sediment load of the Wangapeka.

CONCLUSION

Although the total quantity of sediment eroded from the Dart Valley forest road system and reaching the drainage network in 1978-9 exceeded the estimated natural mean sediment yield from the catchment of the Dart River, the preceding discussion suggests that its impact upon the Dart and Wangapeka Rivers may have been relatively limited. Sediment deposition has caused severe impacts upon headwater gullies immediately downstream from road crossings, but because of this deposition impacts decline downstream. Forty percent of the road-derived sediment reaching the main river has a diameter less than 0.25 mm, and has probably been flushed out to sea in suspension, and a large proportion of the coarser material has probably been deposited above the low-water line on point bars during the flood events that are responsible for most sediment transport. The impact upon the Wangapeka River of roading in the Dart Valley is probably slight, because natural sediment yields from the Wangapeka are so much higher than from the Dart, and impacts upon the Motueka River will be even further diluted.

The present state of the 10-year-old Trig R road, in combination with experience elsewhere, indicates that impacts are in any case relatively temporary: major sediment yield increases are limited to the first two or three years after construction. Nevertheless, tried and tested construction techniques such as end-hauling of spoil are available to minimise erosion along roads (Megahan, 1977) and experience indicates that, although they may increase the first cost of a road, long-term costs are lower because of reduced maintenance. Much of the sediment reaching the Dart Valley drainage system came from fewer than 30 locations where mass failure or gullying of road embankments or fill slopes occurred. Almost all of these were predictable on the basis of current knowledge of sites that present stability problems in road construction, and hence could have been avoided by according these locations more attention during planning and construction. In particular, full-benching and end-hauling to stable disposal sites of the spoil from a very small proportion of the total road length would have substantially reduced total sediment inputs to the drainage system.

Finally, proper evaluation of the impact of erosion on forest roads upon the Motueka River system requires consideration of its importance relative to other land uses. For example, land clearance for agricultural development in the Sherry River valley immediately to the east of Dart Valley has involved stripping of the vegetation from large areas of land, and qualitative observations suggest that the impacts upon physical water quality must be considerable. When assessing the advisability of land development for production forestry use, it should not be forgotten that, over the long term, sediment yields from forested areas have repeatedly been shown to be lower than from any other land use (Megahan, 1972). Increased sediment yields associated with initial development may therefore be out-weighed by a reduction in yields over the long term.

ACKNOWLEDGEMENTS

I thank Peter Kemp, Engineering Officer, Golden Downs State Forest, and John Handiside, N.Z. Forest Service, Nelson, for their assistance in this study, and Colin O'Loughlin, Forest Research Institute, for his review of the manuscript.

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