FOREST ROAD EROSION IN NEW ZEALAND: OVERVIEW

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ABSTRACT

New Zealand research relating to erosion impacts of plantation forest roads, tracks and landings has been carried out since the mid-1970s. Methods include paired catchment studies, storm-induced mass movement surveys, and surface erosion plot experiments from both natural and simulated rainfall–runoff. Road surface erosion data exist only for indurated conglomerate, granitic, schist and pumice terrains, with annual sediment yields up to 15 kg m$^{-2}$ for a range of treatments and source types including graded, ungraded and gravelled road surface-ditch, cutbank and sidecast. Sediment generated from infrequent storm-induced landslides over entire forest road networks range from c. 40 to 8000 t km$^{-1}$ road, or one to three orders of magnitude greater than combined surface road erosion processes. Young roads tend to have greater landslide susceptibility. Despite predicted increases in sediment yields from road surfaces during forest establishment and harvesting activities, annual sediment yields from catchments appear to be within natural levels. Copyright © 2001 John Wiley & Sons, Ltd.

KEY WORDS: research; erosion; road; plantation forestry; effects; stream

INTRODUCTION

This paper reviews 12 studies on forest road erosion in New Zealand (Table I). Located in eight regions (Figure 1), the studies have been conducted in first-rotation exotic plantation forests comprising mainly Pinus radiata, with the exception of one study in logged indigenous mixed beech/podocarp/hardwood forest (O’Loughlin, 1979; O’Loughlin et al., 1980). Table I summarizes forest road erosion type and source, type of study and erosion variables determined, geology, soils, slopes and rainfall characteristics of the study locations. The results of the various studies are assembled to show erosion rates at the plot, road network and catchment scale, and the relative magnitude of sediment yields between surface and mass erosion processes.

Forest road erosion studies were initially motivated by public concerns in the early 1970s when fish (Salmo trutta) deaths were associated with excessive erosion and sedimentation from forestry roads and firebreaks in the Nelson region (Graynoth, 1979; Mosley 1980). Most of the road erosion research has been carried out in this and the Marlborough Sounds region. In parts of the Marlborough Sounds, erosion of forest roads below 200 m altitude was a concern due to the presence of strongly weathered schist, and a perceived threat to marine mussel farming, high water quality, recreation and scenic values (Fahey and Coker, 1992). The establishment of small experimental basins from 1964 to 1975 (New Zealand’s participation in UNESCO’s International Hydrological Decade) later provided opportunities to examine the erosional effect of logging tracks (skid trails) and landings on stream water quality (O’Loughlin, 1979; O’Loughlin et al., 1980, Pearce and Hodgkiss, 1987; Hicks and Harmsworth, 1989).

Copyright © 2001 John Wiley & Sons, Ltd.
<table>
<thead>
<tr>
<th>Forest location</th>
<th>Author(s)</th>
<th>Erosion source and type</th>
<th>Type of study and variables</th>
<th>Geology</th>
<th>Soils</th>
<th>Slopes</th>
<th>Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glenbervie Forest, Northland</td>
<td>Hicks and Harmsworth (1989)</td>
<td>Landing – severe gully erosion of embankment</td>
<td>Paired catchment, SSC</td>
<td>Deeply weathered, shattered and sheared graywacke</td>
<td>Yellow brown earth, 16–28° hillslope 3 m thick regolith</td>
<td>15–25° fillslope</td>
<td>1900 mm a⁻¹, 2–10 RP storms from 160–210 mm in 24 h tropical cyclones can occur in summer-autumn Storm total 260 mm over 4 days; 32 mm h⁻¹ for 1 h duration</td>
</tr>
<tr>
<td>Tairua Forest, Coromandel Peninsula</td>
<td>Pearce and Hodgkiss (1987)</td>
<td>Landing failure</td>
<td>Volumetric survey of erosion scars and sediment deposits, paired catchment, SSC</td>
<td>Rhyolite</td>
<td>Volcanic sandy loams</td>
<td>15–25° hillslope 40° fillslope</td>
<td>1562 mm a⁻¹, slightly seasonal, high intensity summer storms 118–265 mm in 24 h</td>
</tr>
<tr>
<td>Kaingaroa Forest, Central North Island</td>
<td>Smith and Fenton (1993)</td>
<td>Track surface runoff</td>
<td>Plot (4; 2 × 10 m, 2 × 25 m), natural rainfall, bedload sediments</td>
<td>Rhyolite</td>
<td>Unweathered air-fall pumice tephra; gravelly to sandy</td>
<td>18–23° track</td>
<td>580–1200 mm a⁻¹ with infrequent cyclonic storms in summer – autumn 1000–1300 mm a⁻¹ pronounced winter maximum, common localized high intensity storms</td>
</tr>
<tr>
<td>East Coast</td>
<td>Phillips (1988)</td>
<td>Road failures</td>
<td>Volumetric Sandstone with interbedded mudstone</td>
<td>Limestone with soft sands and mudstone</td>
<td>Calcareous loams to sandy loam</td>
<td>15–35° hillslope</td>
<td>25–35° hillslope 70% of road ≤5°</td>
</tr>
<tr>
<td>Tangoio Forest, Hawkes Bay</td>
<td>Fransen (1998)</td>
<td>Road fill and batter failures</td>
<td>Volumetric erosion scar and deposits</td>
<td>Rhyolitic tephras and loess – silt loam to sandy loam</td>
<td>15–35° hillslope</td>
<td>25–35° hillslope 70% of road ≤5°</td>
<td></td>
</tr>
<tr>
<td>Queen Charlotte Forest, Marlborough Sounds</td>
<td>Fahey and Coker (1992)</td>
<td>Road cutbank spill, surface–ditch runoff, and sidecast</td>
<td>Plot (2 × 100 m²; 2 × 20 m²-sidecast) natural rainfall</td>
<td>Low-grade schist</td>
<td>&gt;200 m a.s.l. mod. weathered scree and colluvium; &lt;200 m a.s.l. silty clay loams or silty clays</td>
<td>25–35° hillslope 70% of road ≤5°</td>
<td></td>
</tr>
<tr>
<td>Dart Valley and Motueka-Golden Downs Forest, Nelson</td>
<td>Coker et al. (1993)</td>
<td>Truck-induced runoff</td>
<td>Plot (2 × 40 m²), simulated rainfall, SSC</td>
<td>Unweathered to highly fractured and weathered granite</td>
<td>Sandy loam to loam</td>
<td>35° hillslope 3.5–7.5° road</td>
<td>2000–3000 mm a⁻¹</td>
</tr>
<tr>
<td>Fahey and Coker (1989)</td>
<td></td>
<td>All road-related features</td>
<td>Volumetric survey of erosion and deposits</td>
<td>Unweathered to highly fractured and weathered granite</td>
<td>Sandy loam to loam</td>
<td>35° hillslope 3.5–7.5° road</td>
<td>2000–3000 mm a⁻¹</td>
</tr>
<tr>
<td>Graaf and Wagendonk (1991)</td>
<td></td>
<td>Road cutbank, surface–ditch runoff, and sidecast</td>
<td>Plot (6 × 100 m²; 4 × 20 m²-sidecast), natural rainfall, Volumetric survey</td>
<td>Rhyolitic loess to sandy loam</td>
<td>35° hillslope 3.5–7.5° road</td>
<td>2000–3000 mm a⁻¹</td>
<td></td>
</tr>
<tr>
<td>Coker and Fahey (1993)</td>
<td></td>
<td>Road-related mass movements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tawhai Forest, North Westland</td>
<td>O’Loughlin (1979)</td>
<td>Track surface</td>
<td>Erosion pin plots (6), paired catchment, SSC and bedload</td>
<td>Poorly permeable weathered conglomerates</td>
<td>Shallow permeable well drained</td>
<td>35° hillslope</td>
<td>2600 mm a⁻¹, evenly distributed; approx. max. 26 mm h⁻¹</td>
</tr>
<tr>
<td></td>
<td>O’Loughlin et al. (1980)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SSC = suspended sediment concentration
MATERIALS AND METHODS

A variety of methods and scales of study have provided information on the effects of forest road erosion in New Zealand (Table I). These include the following.

1. Paired catchment studies (1-6 to 23 ha basins) typically utilized weirs to monitor stream flow, automatic samplers to collect suspended sediments, and concrete-lined sediment traps behind weirs to collect bedload sediments.

2. Pace and/or tape measurements of the dimensions of road erosion features (surface wash pedestals, rills, gullies, mass movement scars) and associated deposits.

3. Plot-scale studies of which five types have been carried out.

(a). Erosion pins set into the surface of a skidder track on a range of slopes.

(b). Road surface plots. The Nelson and Marlborough Sounds road sites were either left ungraded or graded (road shaped). Additionally two graded plots were overlain by river-run gravel to represent local road surfacing procedures (Fahey and Coker, 1989). Natural runoff from the drainage ditch, and suspended sediment, was determined using a weir and settling tanks, and automatic samplers.

(c). Natural rainfall–runoff plots on road sidecast had grass, tree and shrub treatments.

(d). Rainfall simulator over unbounded plots to determine suspended sediment yields before, during and after truck passes to simulate an unladen logging truck (Coker et al., 1993). To generate sediment-laden runoff, water was applied at 32–38 mm h$^{-1}$ for 30 min. Two sites were selected at 70 m and 460 m elevation, respectively on strongly and moderately weathered schist, to determine the effect of particle size. The kinetic energy of the simulated rainfall was 30 per cent of a 38 mm h$^{-1}$ natural event. An 11 tonne truck was used on a fresh uniform road surface.

(e). Partially bounded plots established on a logging extraction track formed by bladework (Smith and Fenton, 1993).
Table II. Annual sediment yields from road, sidecast and track plots (Fahey and Coker, 1989, 1992; Smith and Fenton, 1993)

<table>
<thead>
<tr>
<th>Geology</th>
<th>Treatment</th>
<th>Gradient (%)</th>
<th>Other</th>
<th>Sediment yield (kg m(^{-2})) for year:</th>
<th>Sediment yield (g m(^{-2}) mm(^{-1})) for annual rainfall (mm) of:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Granite</td>
<td>Cutbank</td>
<td>bare</td>
<td>-</td>
<td>15.2</td>
<td>7.0</td>
</tr>
<tr>
<td>Granite</td>
<td>SD</td>
<td>graded &amp; gravelled</td>
<td>7</td>
<td>1.7</td>
<td>0.8</td>
</tr>
<tr>
<td>Granite</td>
<td>CSD</td>
<td>graded &amp; gravelled</td>
<td>6</td>
<td>2.8</td>
<td>4.0</td>
</tr>
<tr>
<td>Granite</td>
<td>CSD</td>
<td>graded</td>
<td>6</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Granite</td>
<td>CSD</td>
<td>ungraded</td>
<td>10</td>
<td>14.2</td>
<td>8.5</td>
</tr>
<tr>
<td>Granite</td>
<td>CSD</td>
<td>ungraded</td>
<td>13</td>
<td>1.7</td>
<td>2.5</td>
</tr>
<tr>
<td>Granite</td>
<td></td>
<td></td>
<td>8</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Schist</td>
<td>CSD</td>
<td>graded</td>
<td>9</td>
<td>470 m a.s.l.</td>
<td>0.6</td>
</tr>
<tr>
<td>Schist</td>
<td>CSD</td>
<td>graded</td>
<td>10</td>
<td>470 m a.s.l.</td>
<td>0.6</td>
</tr>
<tr>
<td>Schist</td>
<td></td>
<td></td>
<td>9</td>
<td>70 m a.s.l.</td>
<td>tr</td>
</tr>
<tr>
<td>Schist*</td>
<td>CSD</td>
<td></td>
<td>9</td>
<td>70 m a.s.l.</td>
<td></td>
</tr>
<tr>
<td>Granite</td>
<td>sidecast</td>
<td>control</td>
<td>55.5</td>
<td>3.1</td>
<td>2.5</td>
</tr>
<tr>
<td>Granite</td>
<td>sidecast</td>
<td>D. fir.</td>
<td>55.5</td>
<td>3.1</td>
<td>2.5</td>
</tr>
<tr>
<td>Granite</td>
<td>sidecast</td>
<td>D. fir.</td>
<td>55.5</td>
<td>11.3</td>
<td>2.4</td>
</tr>
<tr>
<td>Granite</td>
<td>sidecast</td>
<td>grass</td>
<td>55.5</td>
<td>4.6</td>
<td>0.2</td>
</tr>
<tr>
<td>Schist</td>
<td>sidecast</td>
<td>shrubs</td>
<td>82</td>
<td>40% cover by yr 3</td>
<td>8.2</td>
</tr>
<tr>
<td>Schist</td>
<td>sidecast</td>
<td>shrubs</td>
<td>82</td>
<td>15% cover by yr 3</td>
<td>5.7</td>
</tr>
<tr>
<td>Pumice</td>
<td>track</td>
<td>as used</td>
<td>40.5</td>
<td>10 m length</td>
<td>1.2</td>
</tr>
<tr>
<td>Pumice</td>
<td>track</td>
<td>as used</td>
<td>32.5</td>
<td>10 m length</td>
<td>0.4</td>
</tr>
<tr>
<td>Pumice</td>
<td>track</td>
<td>as used</td>
<td>40.5</td>
<td>25 m length</td>
<td>0.2</td>
</tr>
<tr>
<td>Pumice</td>
<td>track</td>
<td>as used</td>
<td>32.5</td>
<td>25 m length</td>
<td>0.9</td>
</tr>
</tbody>
</table>

C = cutbank; S = road surface; D = ditch; tr = trace. Gradients are for road and track surfaces, and sidecast slope. * Fine sediment production compared to coarse sediment production at other sites.
SEDIMENT YIELDS FROM PLOTS

Forest road surface erosion data for New Zealand are listed in Table II. Data from granite terrain comprises 63 per cent of the database, and schist and pumice the remainder. While the data provide a general indication of the magnitude and potential scale of forest road surface erosion in New Zealand, annual sediment yields cover a range of treatments and gradients with little replication. Annual sediment yields ranged from a trace to 15.2 kg m\(^{-2}\). Normalizing the sediment yield in terms of annual rainfall amount (where available) did not appear to reduce the year-to-year variability (Table II).

A bare cutbank plot in granite had the highest annual sediment yield in the first year, but rapidly declined within the next two years. The unprotected cutbank contribution was about nine times the combined contribution from a gravelled road surface and ditch (Table II). However, cutbanks did not contribute significant quantities of sediment at other plot studies where the combined yields of cutbank, road surface and ditch were measured. An ungraded road had the second and third highest annual sediment yield from road surface erosion. No clear relationships could be made about the effect of slope or road surface condition on sediment yield. On granite terrain, an ungraded road (that was relatively unstable) with 10 per cent gradient yielded five times more sediment than one with a 13 per cent gradient. Plots with graded and gravelled surfaces had similar sediment yields to graded-only and ungraded surfaces. On a 6 per cent gradient, sediment yields from a graded and gravelled road surface were marginally greater than a graded-only road surface. However, the graded and gravelled 7 per cent gradient road produced even lower and declining yields over three years of observation (Table II).

Sediment yields on schist and rhyolite pumice were an order of magnitude lower than for granite. The highly permeable raw pumice soils, especially where they are uncompacted, probably account for the low sediment yields on logging tracks. At low altitudes in the Marlborough Sounds, annual average fine sediment production was about five times greater than that for high altitude sites where 90 per cent of the sediment was greater than 2 mm.

Sidecast plot data show marked or significant decreases in sediment yield with time. Yields were comparable to the cutbank-road surface-ditch source area, and within an order of magnitude for schist and granite terrains. Grass-covered sidecast was more effective in reducing sediment yields than sidecast with tree cover.

The road trucking trial showed that 20 passes of a truck can produce as much sediment as that generated in a year by natural road surface erosion on lightly used roads. Fine sediment mobilized by 30 min simulated rainfall events on sections of forest road before, during and after trucking averaged 0.03 kg m\(^{-2}\), 0.46 kg m\(^{-2}\) and 0.12 kg m\(^{-2}\) respectively, on the strongly weathered site at 70 m elevation (Coker et al., 1993). However, on moderately weathered schist at 460 m elevation, suspended sediment production was three times lower.

ROAD NETWORK EROSION RATES

Sediment yield data from plots were tentatively used to estimate sediment production (expressed in t km\(^{-1}\)) from the forest road network, tracks and firebreaks before and during harvesting (Fahey and Coker, 1989, 1992).

In this paper, extrapolation of the plot data only extends to lengths of road with the same gradient (Figure 2), representing 62 and 70 per cent of the road network in Nelson and Marlborough Sounds forests respectively. Sediment generated from infrequent storm-induced mass movements are up to three orders of magnitude greater than combined surface road erosion processes (Figure 2). Sidecast failures contributed 80 per cent of sediment volume in the Nelson granites, equivalent to about 80 years of continuous road surface erosion with average storm conditions (Fahey and Coker, 1993). Sediment yield from surface erosion on steep ungraded roads in granite was similar to that from mass movements in tephric soils.

There are few data to relate storm parameters to road-related mass erosion rates. In July–August 1990, mass movements in the granite terrain were associated with four large storms, ranging from 87 to 350 mm;
the maximum 24 h rainfall was 212 mm. The storm-induced landslides in the ‘soft-rock’ limestone country of Hawkes Bay had wet antecedent conditions, with a maximum daily rainfall ranging from 97 to 183 mm over the forest watershed. At a forest road aged 15 years, the eroded volume in the granite terrain was half that in limestone terrain.

The volume of road-derived sediment generated from landslides generally declines with road age (Figure 2). However, in the granite terrain, erosion rates significantly increased on 24–30 year old roads that had been upgraded for harvesting (Graaf and Wagendonk, 1991). Erosion rates vary widely on individual road segments, ranging from 38 to 380 t km\(^{-1}\) a\(^{-1}\) for a section of 10 year old road, and 266 to 7600 t km\(^{-1}\) a\(^{-1}\) for a newly constructed road (Mosley, 1980); however, data included some mass failures of culverted stream crossings. Road failures associated with stream undercutting were omitted in the Motueka–Golden Downs study (Graaf and Wagendonk, 1991). Blocked culverts and sidecast accounted for 45 and 58 per cent respectively of 17 forest road-related landslides in the East Coast of the North Island (Phillips, 1988). Other factors that could contribute to the irregular relationship of mass erosion to road age are: the episodic nature of storms and timing of harvesting and planting activities; changing road construction and maintenance standards; road location; the representative lengths of roads surveyed; and variable geologic/soil conditions.

In Tangoio Forest, Hawkes Bay, landslips on an ungraded ridgetop road comprised 0 per cent and 17 per cent of the total landslide volume in 74 ha and 42 ha watersheds respectively. However, a recently graded mid-slope road contributed 71 per cent of the total volume of landslides in a 34 ha area in the lower catchment (Fransen, 1998).

Coker et al. (1993) extrapolated the sediment yield of a 9 h simulated storm from trucking trials to 1 km of road. Predicted total suspended sediment yields on strongly weathered schist increased from 1.8 t km\(^{-1}\) before, to 10 t km\(^{-1}\) while the truck passed, to 2 t km\(^{-1}\) after truck passage. On moderately weathered schist at higher elevations, suspended sediment production was estimated to be only half these amounts.
CATCHMENT EROSION AND SEDIMENT YIELD RATES

Sediment yields (expressed at t km$^{-2}$ a$^{-1}$) for catchments affected by road erosion are compared with those from measured yields in undisturbed control catchments, empirically derived yields (Griffiths, 1979, 1981; Adams, 1980; Griffiths and Glasby, 1985) or other land-use erosion rates (Table III). Large errors in catchment sediment yields can occur due to estimation procedures, large variations inherent from small basins, and short monitoring times (O’Loughlin, 1979; O’Loughlin et al., 1980). Nevertheless, results show that forest road-related mass movements can increase catchment sediment yields by up to three orders of magnitude. The increase in catchment sediment yield, as a result of severe gully erosion of a landing in Northland, represented about 70 per cent of the sediment yield from a 30 year production forest rotation (Hicks and Harmsworth, 1989). However, in the Hawkes Bay study, catchment erosion rates (for mass movement scars) under mature forest with no roads were similar to a nearby forested area affected by roads (Table III).

Estimates of the volume of mass-movement material retained on slopes range from half to two-thirds of eroded volumes (Mosley, 1980: Coker and Fahey, 1993; Fransen, 1998). At Glenbervie Forest, as landing failure scars and associated deposits stabilized over two to three years, suspended sediment and bedload yields diminished to pre-harvest levels (Hicks and Harmsworth, 1989). However, following large mass movements, fluvial remobilization of deposited sediment can maintain high and variable sediment yield rates. In the Tairua Forest study, increases in catchment sediment yield caused by landing erosion declined from 30–80-fold to two-fold over the first two years, but increased again to 15-fold in the third year (Pearce and Hodgkiss, 1987). Several storms in the second and third years of observation were actually larger than the one that caused landing failure in the first year. All storms had return periods of two years or less.

Surface erosion of new and upgraded roads at harvest times may potentially increase sediment yield five-fold compared to pre-harvest ungraded and lightly used roads. However, surface sediment yield rates for the road prism were an order of magnitude lower than the estimated background catchment sediment yields for the Nelson–Marlborough region (Fahey and Coker, 1992). The background rates of erosion are not strictly comparable with erosion rates for forest roads which represent potential sediment supply. The storage of road surface eroded sediment on slopes probably explains why catchment sediment yields are within natural levels. No precise information is available on either delivery ratios or residence times of sediment once it is

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Table III. Catchment sediment yields and erosion rates affected by forestry roads

<table>
<thead>
<tr>
<th>Region</th>
<th>Sediment erosion rates from</th>
<th>No roads* $(t \text{ km}^{-2})$</th>
<th>Road related* $(t \text{ km}^{-2})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glenbervie, Northland</td>
<td>Catchment - stream/landing erosion</td>
<td>7 (280)</td>
<td></td>
</tr>
<tr>
<td>Tairua, Coromandel</td>
<td>Catchment - stream/landing failure</td>
<td>0.5 (1350)</td>
<td></td>
</tr>
<tr>
<td>Peninsula</td>
<td>- stream, after 3 yrs</td>
<td>9 (90–255)</td>
<td></td>
</tr>
<tr>
<td>Tangoio, Hawkes Bay</td>
<td>Catchment - mass movement</td>
<td>(278–1620)</td>
<td>– (331–1706)</td>
</tr>
<tr>
<td>Marlborough Sounds</td>
<td>Catchment - regional estimates</td>
<td>300–600</td>
<td>–</td>
</tr>
<tr>
<td>Motueka-Golden</td>
<td>Catchment - regional/ mass movement</td>
<td>500 (1400)</td>
<td>– (2800)</td>
</tr>
<tr>
<td>Downs, Nelson</td>
<td>Road - mass movement</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Road - surface pre-harvest</td>
<td>–</td>
<td>45–62</td>
</tr>
<tr>
<td></td>
<td>Road &amp; tracks - surface at harvest</td>
<td>–</td>
<td>218</td>
</tr>
<tr>
<td>Dart Valley, Nelson</td>
<td>Catchment - regional/ mass movement</td>
<td>120 (266)</td>
<td>–</td>
</tr>
<tr>
<td>North Westland</td>
<td>Catchment - stream</td>
<td>33</td>
<td>396</td>
</tr>
<tr>
<td></td>
<td>Track - surface at harvest</td>
<td>–</td>
<td>246</td>
</tr>
</tbody>
</table>

* Values relate to yields for storm-induced mass movement event and field in parentheses survey. Values without parentheses are annual yields.
removed from roads, tracks and firebreaks (Fahey and Coker, 1992). However, in North Westland, logging
track erosion accounted for 60 per cent of the harvested catchment sediment yield which was 12 times greater
than an undisturbed forested catchment (O’Loughlin, 1979; O’Loughlin et al., 1980).

DISCUSSION

In Idaho granites, Megahan (1974) and Burroughs and King (1989) showed that surface erosion rates from the
entire road prism and from fill-slopes in the first one to two years after disturbance are high and decrease
exponentially over time. In New Zealand, three plot treatments showed that road erosion rates in the first year
were similar to the Idaho study, but for the other treatments/sites erosion rates were substantially less. Road
surface erosion rates also decreased with time in the New Zealand granite terrain, but were less pronounced
than the Idaho erosion trends. Megahan et al. (1991) noted that microscale mass erosion on unconsolidated
road fill explained the high erosion rates in the first year after construction. Average (three-year) annual road
surface erosion rates on New Zealand granites appear an order of magnitude higher, which may be attributed
to the greater annual rainfall than in Idaho.

Fahey and Coker (1989) found unprotected cutbank contribution was about nine times the combined
contribution from a gravelled road surface and ditch (Table II). Needle-ice activity and freeze–thaw on
cutbanks produced high sediment yields in winter. However, cutbanks did not contribute significant
quantities of sediment at other plots (in the same study) where the combined yields of cutbank, surface and
ditch were measured. In Idaho, Burroughs et al. (1984) found unprotected cutslopes and ditch contributions
were 6-3 times greater than sediment yield from the native road surface. On a gravelled road, unprotected
cutslopes produced 9-8 and 12 times more sediment with rocked ditch and unrocked ditches respectively.
These studies, and that of Swift (1984), show that cut (and fill) slopes are a significant source of surface
sediment from the road prism.

In Malaysia, on sedimentary rocks mantled with soils developed on volcanic parent material, Baharuddin
et al. (1995) reports logging road and skid trail surface erosion rates similar to those in pumice hill country in
New Zealand.

Grant and Wolff (1991) demonstrated the importance of episodic mass movements as controls on the
timing and magnitude of sediment yields in steep watersheds. Six years after road construction, storm-
induced mass movements contributed 90 per cent of the total sediment yield (21,000 t km$^{-2}$) over a 30 year
period, and more than 26 times the total sediment yields in forested control. After the storm event, sediment
yields were uniformly low.

While studies have indicated that road surface erosion rates are within natural background rates, and that
this sediment has a potential to cause adverse effects to the stream environment, no studies have confirmed
this. Sediment from forest road surface erosion has only indicated a potential to cause significant adverse
effects to the stream environment, though no studies have confirmed this. However, mass erosion related to
forest roads is of greater concern with the potential to damage stream environments. However, the claim that
erosion from forestry roads in the Dart valley caused fish deaths downstream in the Motueka River was not
supported by erosion surveys (Mosley, 1980). The increase in sediment loads to the Dart River caused by road
construction had a relatively small impact and was diluted by higher sediment loads of the Wangapeka River
which fed the Motueka River system. Sediment delivered to streams may represent up to half to two-thirds of
the total mass volume eroded, with the remainder retained on hillslopes. In addition, New Zealand stream
ecosystems are quite resilient, and infrequent storm events (five to 20 year return period), while significant
generators of sediment, do not necessarily affect stream ecosystems in the long term (Ryan, 1991).

FUTURE RESEARCH

Road erosion plot results for New Zealand have provided information on the relative erosion rates from
cutslope, road surface and ditch, and sidecast sources. However, there are insufficient data to draw a
clear relationship between erosion rate, road surface condition and gradient, or to derive nomograms that
could be used for road design and sediment estimation. Use of erosion prediction technologies is not widely practised. While models like the USDA WEPP (Water Erosion Prediction Project) appear promising for forest roads, their application will require new and extensive field trials to acquire the necessary input data to run these models. An alternative is to develop empirical models for local conditions. Research efforts should also focus on quantifying the effect of road-induced sedimentation on aquatic ecosystems relative to other sources (e.g. channel).

CONCLUSIONS

Infrequent road-related mass movements are major sources of sediment within forests and have the greatest potential to affect stream ecosystems. Mass-movement erosion rates were shown to decline with road age, but may increase to earlier levels when upgraded for harvesting activities. Road mass erosion rates are up to three orders of magnitude greater than surface erosion rates. High and also relatively low road surface erosion rates have been reported within the first and second years of new road construction compared to the third year of study. All studies indicate that cut-and-fill slopes contribute to the initially higher erosion rates compared to road surfaces. Heavy road use by logging trucks can add substantial amounts of sediment. Road extension and upgrading associated with harvesting activities may increase annual surface erosion rates, but are not expected to significantly affect the long-term natural erosion rates from forested catchments. Much of the sediment derived from the road prism is deposited on slopes and retained by slash and revegetation. Nevertheless, the New Zealand forest industry has acknowledged the potential environmental risks from roads, and employs a range of erosion prevention measures to reduce sediment yields. Better understanding of the effects that modern forestry roading practices have on the stream environment must focus on the fate of sediment from newly constructed roads and measuring sediment changes in-stream and on aquatic organisms.

REFERENCES


