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FINE SEDIMENT PRODUCTION FROM TRUCK TRAFFIC, QUEEN CHARLOTTE FOREST, MARLBOROUGH SOUNDS, NEW ZEALAND

R.J. Coker, B.D. Fahey, and J.J. Payne

Manaaki Whenua – Landcare Research

P.O. Box 31-011, Christchurch, New Zealand

ABSTRACT

Fine sediment mobilised by 30-min simulated rainfall events on 10-by-4 m sections of forest road before, during, and after trucking was measured at two sites in Queen Charlotte Forest. One was on strongly weathered schist at 70 m elevation and the other was on moderately weathered schist at 460 m elevation. At the lower site, suspended sediment concentration from the fresh road surface reached 10 g L^{-1} of runoff, but fell to 3 g L^{-1} by the end of the test run. With simulated rainfall during trucking (20 passes), concentration peaked at 130 g L^{-1} but declined to about 12 g L^{-1} once trucking ceased. When the simulator was run immediately after 20 truck passes the maximum concentration was 21 g L^{-1}. This quickly fell to 6 g L^{-1}. At the higher site the sediment response was lower overall. Extrapolating this information to a 1-km length of road on strongly weathered schist with a 9-hour simulated storm, total suspended sediment production from a typical road surface without truck movements is estimated at 1.8 t. During trucking it rises to 10 t and after trucking it is only marginally higher (2 t). On moderately weathered schist at higher elevations suspended sediment production is only about half these amounts.

INTRODUCTION

Our recent estimates of erosion rates, and sediment production from forest roads at several sites in the northern South Island of New Zealand (Fahey and Coker, 1989, 1992) did not include the potential influence of truck traffic on sediment yields. Yields are increased during storms by the loose material generated from traffic. A few studies have addressed the role of truck traffic as part of a general assessment of forest road erosion. Reid *et al.*, (1981) for example, found that logging roads in western Washington that carried more than four trucks per day yielded more than 30 times the sediment derived from traffic-free roads. Burroughs *et al.*, (1984) found that sediment yields in the granite terrain of central Idaho doubled in response to increased road traffic.

This experimental study examines the increase in fine sediment production likely to be associated with logging traffic during the harvesting of Queen Charlotte Forest in the eastern Marlborough Sounds. Increased sedimentation could have a detrimental effect on water quality in the many coves and bays of the Sounds (Johnston *et al.*, 1981). The results are based on data collected during artificial runoff events generated by a rainfall simulator.

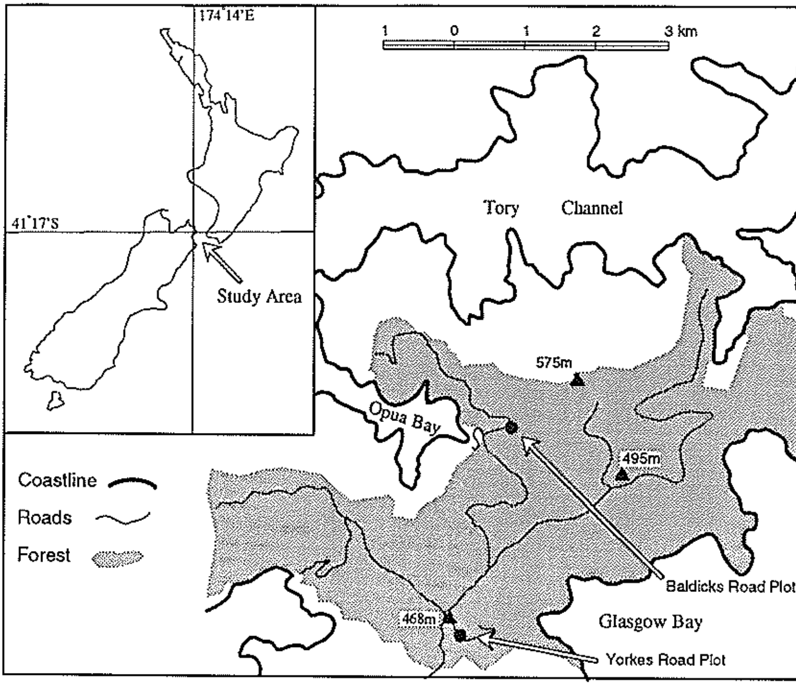

FIG. 1—Location map showing study sites

STUDY AREA

Queen Charlotte Forest lies 18 km east of Picton and covers about 4000 ha (Fig. 1). Low-grade schist has been strongly weathered below 200 m elevation to form a soft red, almost lateritic, regolith, which comprises clay and silt-size material and is an important source of fine sediment during runoff. (McQueen *et al.*, 1985, Laffan *et al.*, 1985). At higher elevations the schist is only moderately weathered.

In 1986 two 25-by-4 m sections of Yorkes Road at 460 m elevation (Fig. 1) were isolated to serve as runoff plots for measuring the quantity of coarse sediment (material in the sand and gravel-size range) mobilised by rainfalls over a 3-year period. A second site was established in 1987 on Baldicks Road, 70 m above Opua Bay (Fig. 1) to measure fine sediment production (material in the silt and clay-size range) over a 2-year period. This site and Plot 1 on Yorkes Road were used in the rainfall simulation experiments. Both sections of road were representative of average road dimensions and conditions in Queen Charlotte Forest (Fahey and Coker, 1992). Each has a down-slope gradient of about 5°.

INSTRUMENTATION AND METHODS

Rainfall simulators can seldom duplicate the raindrop size distribution, impact velocities, and kinetic energy of natural storms. However, they are useful in erosion research for comparing responses between or among treatments, provided that the volume of water and the method of application are the same for every trial (Meyer 1988).

We used a fixed-nozzle, single intensity device made up of a 3-m high frame of aluminium tubing that covered a 10-by-4 m (40 m^2) section of road (Fig. 2). Water was applied via 24 Fulljet GG3.6SQ nozzles (capacity, 1-2 Ls^{-1} at a spray angle of 45°) embedded in three rows of alkathene tubing strapped to the upper frame.

Water was pumped from a nearby stream into 400 L storage reservoirs, then pumped to the simulator via the alkathene hoses at moderate pressures (50–70 kPa). The flow was regulated by an in-line dividing breech. Shade cloth was draped over the exposed sides of the simulator to minimise wind drift, but trials were halted if wind deflected droplets beyond the area beneath the simulator. The amount and intensity of the simulated rainfall were estimated from water collected in plastic spouting laid diagonally beneath the simulator during pre-treatment trials (Fig. 2). This water was directed into tipping bucket raingauges and a calibration factor linking the area of the troughs to the number of tips was established to determine rainfall in a specified time. Estimated amounts of simulated rainfall over the 40 m^2 ground surface varied between 16 and 19 mm for each 30-min trial, which converts to an intensity of 32 to 38 mm h^{-1}. Although this is double the maximum rainfall intensity (18.9 mm h^{-1}) measured at the trial site between January 1987 and December 1988 (Fahey and Coker, 1992), because of the small raindrops generated by the simulator, it represents only a moderate-to-low intensity event.

After the trials finished, the simulator was tested to gain some idea of the kinetic energy and spatial distribution of the simulated rainfall. The latter was assessed by calculating the coefficient of uniformity (Moore *et al.,* 1983) from simulated rain water collected in 30 cans placed at intervals of 0.5 m in a 2-by-2.5 m grid beneath the frame. At the pressures used during the trial (50–70 kPa), the coefficient of uniformity was 80%. At higher pressures coverage was better, but drop sizes decreased to that of very light rain. However, even at the pressures quoted above, drop sizes were smaller than those associated with natural rainfall.

Empirical formulae for calculating the kinetic energy of a storm on the basis of its intensity are applicable only to natural events. Kinetic energy determinations for simulated events require a knowledge of drop-size distribution, fall heights, and fall velocities. Drop diameters for the simulator lie between 0.5 mm and 2 mm. Based on the 3-m fall height for the simulator and the nomogram from Law (1941), fall velocities were estimated to range from 2.5 m s^{-1} to 7 m s^{-1}. Using procedures outlined by Meyer (1958) and assuming a normal distribution for drop sizes, kinetic energy per mm of simulated rainfall was then calculated as 123 KJ ha^{-1}. This is only about 30% of that calculated for a natural event with the same intensity of about 38 mm h^{-1}. The lower energy output from the simulator is a function of its higher percentage of smaller droplets than that associated with natural rainfall.

Runoff entering the drainage ditch was channelled via a concrete apron through a series of pipes into a flow monitoring-sediment trapping system used in the original study at Baldicks Road (Fahey and Coker, 1992). A 200-L drum for catching coarse sediment was linked to a second drum immediately down-slope

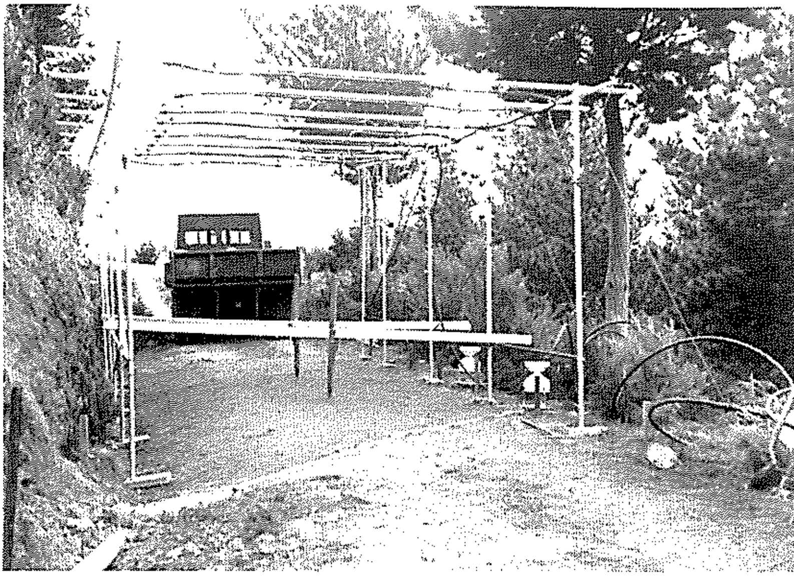

FIG. 2—Rainfall simulator at Baldicks Road showing the freshly prepared surface, the troughs for estimating amount of simulated rainfall, and the Nissan truck in background.

which had an 11° V-notch weir attached to its front and a Belfort-water level recorder for measuring runoff. Half-litre water samples were collected at the pipe outlet into the first drum every 2 minutes or at 10-minute intervals depending on the nature of the trial. Suspended sediment concentrations were calculated using standard vacuum procedures (APHA, 1976), and sediment-time curves were integrated with the runoff data to calculate the sediment yields for each event.

The response of the fresh surface to a simulated rainfall event was used as a standard to assess the response of the surface during and after trucking. A Nissan 8-t 2-axle 6-wheel dump truck with a tare weight of 3000 kg was used in the trial. Ten return passes through the plot were assumed to equal four return passes by an unladen logging truck (rigs normally have between 18 and 22 wheels). Because of differences of truck and tyre size the effective ground pressures in the trial were higher than for empty logging trucks but less than for loaded log trucks. However, the multiple passes were taken to be representative of heavy traffic.

At the beginning of each set of trials the road was raked to provide a fresh uniform surface. Each trial lasted 30 min, and used about 700 to 750 L of water. This volume approximated or was slightly more than that measured in the tipping bucket gauges, especially on windy days when spray from the nozzles occasionally drifted outside the test area. Each control run was replicated to ensure consistency in the response of the freshly-raked surface to drop impact and runoff.

The during-trucking response was established by subjecting the fresh road

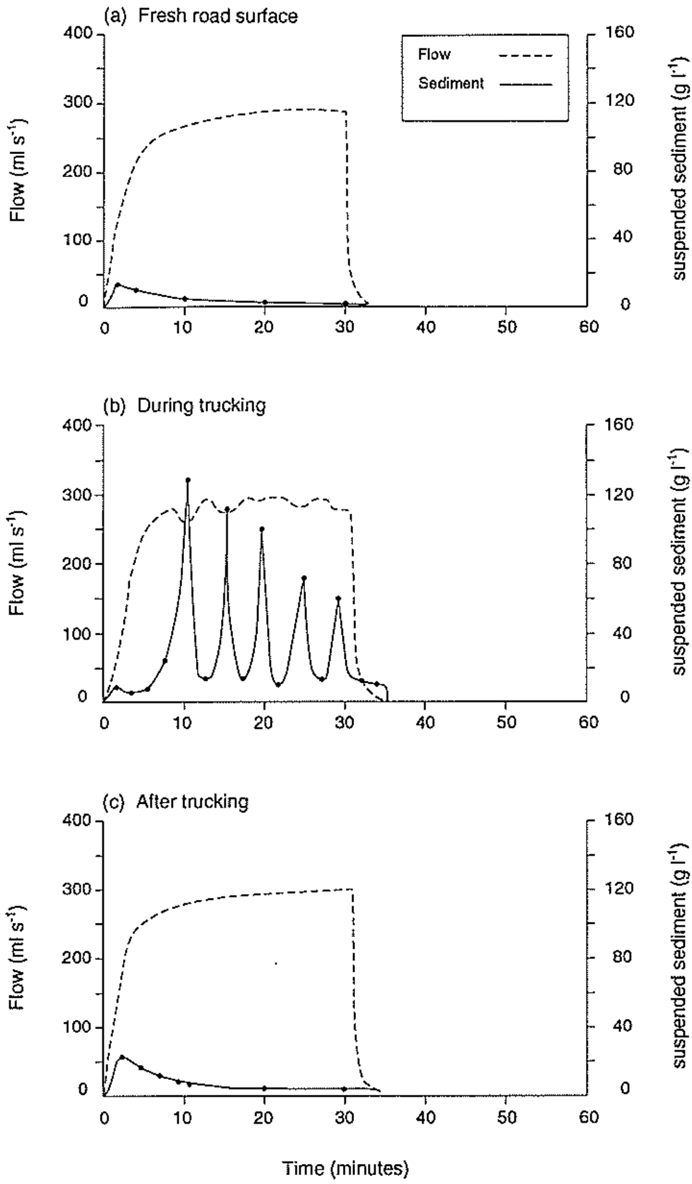

FIG. 3—Flow and sediment concentration responses at Baldicks Road to 30-minute simulated rainfalls with a constant application rate of approximately 38 mm h^{-1} for (a) the fresh road surface, (b) during trucking, and (c) after trucking.

surface to 10 return passes in groups of two while the simulator ran for 30 min. The same procedure was followed to assess the impact of trucking after a simulated rainfall event except that the simulator was turned on for a 30-minute period after 10 return passes.

RESULTS

Baldicks Road

During simulated rainfall of 760 L (19 mm) on the fresh 10-by-40 m road surface delivered over 30 min, about 500 L (66% or 13 mm) appeared as runoff in each treatment (Fig. 3).

For the trial without trucking (control), maximum fine sediment concentrations (10 g L^{-1}) occured immediately after runoff began, but these quickly declined to about 3 g L^{-1} then remained reasonably constant until the end of the trial (Fig. 3a). The total sediment yields for the initial and replicate test were 1.0 and 1.3 kg, respectively from the 40-m^2 section of road over the 30 min.

Before trucking began in the second trial (trucking during simulated rain) the sediment concentration followed a similar pattern, initially rising to 6.0 g L^{-1} then declining rapidly to half that value after 5 min (Fig. 3b). However, once the road surface had been disturbed by the first truck run 10 min into the trial, concentrations rose immediately to a maximum value of 130 g L^{-1}, but fell away rapidly to 12 g L^{-1} once traffic ceased (Fig. 3b). Peak sediment concentrations decreased during each sequence of truck passes. The total yield for the 30-minute trial was 20 kg. A replication showed a similar response and yielded 17 kg of fine sediment. The troughs in the hydrograph are believed to represent times when the truck deck intercepted some of the simulated rainfall.

When rainfall was simulated after ten return passes, the sediment concentration initially peaked at 21 g L^{-1} (Fig. 3c). However, within 10 min it had fallen to 5.0 g L^{-1}, and after 20 min, 3.5 g L^{-1}, similar to the sediment concentration in the control trial. The total sediment yield over the 30 min trial was 4.0 kg. A replication yielded 5.2 kg.

Yorkes Road

The same trials were conducted at Yorkes Road. The depth of runoff at Yorkes Road was equivalent to only 8 mm compared to 13 mm at Baldicks Road for the same simulated rainfall (19 mm) (Fig. 4), and is thought to be the result of the higher proportion of coarse material on the road surface causing higher infiltration and lower surface runoff. However the more exposed location could have led to some rainfall losses outside the plot boundaries.

Although the maximum sediment concentration in the trial without trucking at Yorkes Road was higher (15 g L^{-1}) (Fig. 4a) than that for Baldicks Road, the total 30-min yields for the two replications (0.7 and 1 kg) were much the same. The response during trucking (Fig. 4b) was not as dramatic as that for Baldicks Road, but still showed the same pattern of declining peak levels with successive truck passes. The maximum sediment concentration was 55 g L^{-1}, and the total yield was 5.5 kg. For the after-trucking trial sediment concentrations rose to 47 g L^{-1} after 2 min, but the total yield over 30 min was only 3.0 kg (Fig. 4c). The consistently lower total yields in the trials involving trucking reflect the lower levels of runoff from the Yorkes Road plot.

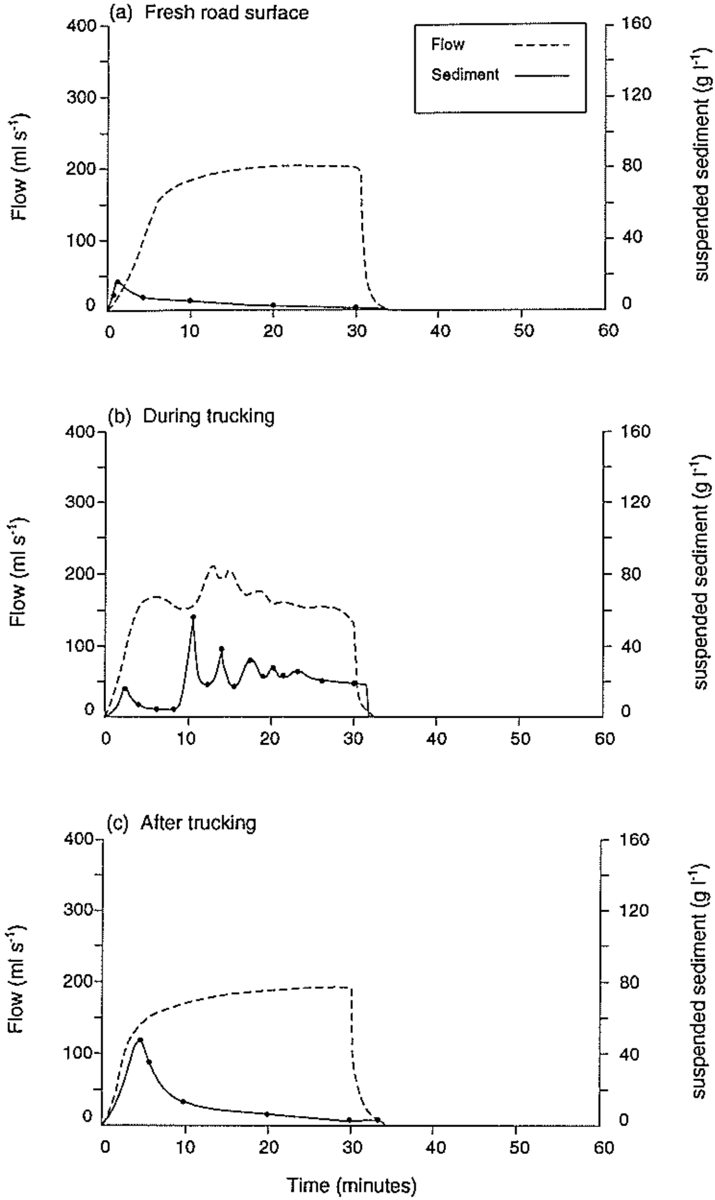

FIG. 4—Flow and sediment concentration responses at Yorkes Road to 30-minute simulated rainfalls with a constant application rate of approximately 38 mm h^{-1} for (a) the fresh road surface, (b) during trucking, and (c) after trucking.

Extrapolation of Results to 1-km Length of Road

Based on theoretical logging schedules in steepland terrain, approximately 10 return passes per day over the year would be needed to remove 250 t of logs. This is equivalent to a truck movement in each direction every 30 min between 7 am and 4 pm (9 hours). Assuming a 9-hour rain event with an average rainfall rate of 38 mm h^{-1} during trucking, and assuming that sediment concentration averages 60 g L^{-1} during each pass (2 min duration), and falls to 6.0 g L^{-1} between each sequence of passes (28 min), over the 9-hour event the total storm yield for a 10-m stretch of road with the same characteristics as Baldicks Road would be 86 kg, or about 10 t for a 1-km length. The yield from a 9-hour simulated event after trucking is estimated at 2.0 t km^{-1}, and for the fresh surface without trucking, about, 1.8 t km^{-1}.

For Yorkes Road, the quantity of sediment yielded by a 9-hour event would be lower. During trucking, for example, the estimated sediment yield per kilometre is estimated at only half that calculated for Baldicks Road.

Comparison with Yields from Natural Rainfall

Preliminary calculations and comparisons between yields extrapolated from natural events (Fahey and Coker, 1992) and those from the simulated experiments revealed major discrepancies. The extrapolated natural sediment yield from lightly travelled road surfaces formed in strongly-weathered schist below 200 m elevation in Queen Charlotte Forest using data collected at the Baldicks Road site was 9 t km^{-1} annually for roads with gradients of about 5°. The same calculations for the simulator data extrapolated to a 1-km length of road in strongly-weathered schist gave 1.8 t km^{-1} or about 20% of the annual yield of 9 t km^{-1} from a non-trafficked surface after only one 9-hour storm.

The reason for this discrepancy is in the very large volume of water delivered by the simulator despite the much lower kinetic energy. Using 9 hours as the average storm duration, the simulator would have delivered 342 mm of water to the road surface. Although the average duration of the 92 storms that generated runoff at Baldicks Road between 12 January 1987 and 29 December 1988 was also 9 hours, the average rainfall was only 18.8 mm. Thus fine sediment yields extrapolated from the simulator results are probably at least ten times higher than those from natural events, assuming about 40 storms per year. However, they clearly illustrate the magnitude of the increase in sediment yields likely to accompany truck traffic.

CONCLUSIONS

The passage of trucks beneath the rainfall simulator at both sites caused fine sediment concentrations in runoff from the road surface and drainage ditch to increase. There was a dramatic 10-to-15-fold increase in sediment concentrations after each truck pass during simulated rainfall at the Baldicks Road trial, and a less dramatic but still significant 7-fold increase at Yorkes Road. Concentrations increased by a factor of 2 to 3 at the two sites when rainfall was simulated after 10 return truck passes.

When these results are extrapolated to kilometre-lengths of road typical of those found in Queen Charlotte Forest, the increases in sediment production are signficant. While there is only a small increase after trucking compared with the yield from the freshly raked road surface, during trucking sediment production is likely to rise by an order of magnitude. Thus is would be prudent to delay trucking and other ground-based operations during prolonged rainfall to reduce sediment production and prevent the rapid deterioration of the road surfaces.

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