1983/11. The erosion of granite-derived soils in eastern and north eastern Tasmania, with reference to forestry operations Part 1: Hydrologic cycle, erosion, and previous investigations

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Abstract

A basic knowledge of the hydrologic cycle and fluvial processes is required in order to understand and avoid potential erosion problems following the clear-felling of forested catchment areas.

Overland flow is the most potentially erosive component of the cycle, particularly in areas of Tasmania which are underlain by granite.

Large scale erosion can occur when overland flow is concentrated into discrete channels by ground disturbance. The greatest amount of erosion tends to occur between the middle and the foot of slopes, where the soil mantle is thick, and where there is a predominance of sand-sized particles in the soil.

Previous investigations elsewhere in the world have indicated that forestry roads and snig tracks are the major locii of erosion, contributing most of the sediment carried by overland flow. The result may be accelerated erosion and sedimentation causing on-site and/or off-site damage.

Careful planning, operation execution, and follow-up procedures are required to ensure erosion control. Erosion control measures are most beneficial when applied during and immediately after ground disturbance by logging operations.

HYDROLOGIC CYCLE AND FLUVIAL PROCESSES

To understand potential erosion problems associated with clear-felling a catchment area, some understanding of natural fluvial processes and the hydrologic cycle is required. The effect of induced changes on these processes can then be established and any detrimental effects can be assessed and remedial action taken. A broad outline will be presented in an attempt to avoid confusion, as the subject matter is large and classical theories are being modified as research progresses. This outline of processes is presented for field foresters who have expressed interest in information on this subject, especially with reference to forestry operations on areas underlain by highly erodable granite soils.

The initial input to the hydrologic cycle is falling rainwater, which is divided into several components as it reaches the ground surface (fig. 1). Initially some of the falling rainwater is intercepted by vegetation which prevents direct raindrop impact on the ground surface beneath. Some water is held on the foliage surfaces, from where it may be evaporated, some drops to the ground after a delay, and some runs down the stems and branches to reach the ground at the plant or tree base.

The water which reaches the ground surface either directly or indirectly may infiltrate into the ground, may be stored temporarily in small surface hollows as depression storage, again available for evaporation, or may be diverted downslope as overland flow across the ground surface. That proportion of rainfall which infiltrates into the ground may partially

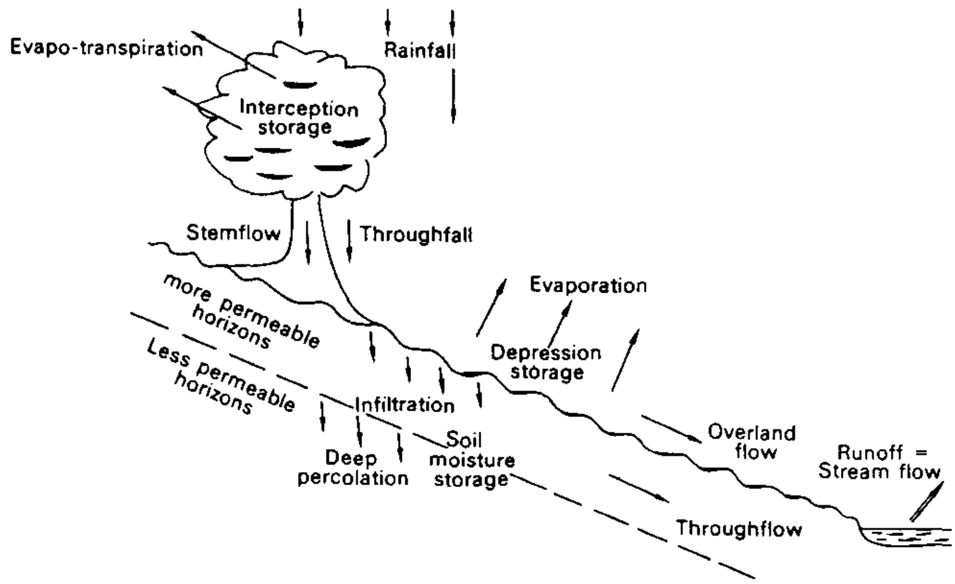

Figure 1. *Simplified diagram showing components of the near-surface hydrologic balance (from Carson and Kirkby, 1972).*

remain to increase soil moisture content, or may continue to percolate to the water table.

In many cases, soil profile development has resulted in a reduction of soil permeability with depth or, where soils are thin, the bedrock is less permeable than surface soil horizons. As the surface soil horizons are of higher permeability, some of the water percolating down from the surface is frequently diverted laterally as throughflow. The following figures quoted by Carson and Kirkby (1972, p.47) can be used as rough working estimates for the various components of the near-surface water balance.

Interception: the first one millimetre of rainfall and 20% of the subsequent rainfall for full tree cover.

Interception stemflow: 1% to 5%

Depression storage: 2 mm to 5 mm of rainfall

Infiltration: varies from zero to over 100 mm per hour of rainfall.

These figures should be considered as very approximate, as interception, interception stemflow, and evaporation are related not only to the density of vegetation cover but also to the type of vegetation.

Many factors are also related to the infiltration rate and capacity of the soil. Infiltration decreases rapidly from the beginning of rainfall. Infiltration is related to soil grain size or, more strictly, to the pore size or the open spaces within the structure of the soil mass. Infiltration is also related to the soil moisture at the start of rainfall, and also to the density and type of vegetation cover which influences infiltration by affecting soil structure, and by providing protection from rain impact. Holtan and Kirkpatrick (1950) report a reduction of six to ten times in the infiltration rate into old permanent pasture compared with that into bare ground.

There are many variables which must be balanced against rainfall intensity to determine the likelihood of rainfall excess flowing over the ground surface as overland flow. This flow occurs when rainfall intensity exceeds the rate at which water can be stored or absorbed as infiltration. The greatest single factor is high rainfall intensity, but sparseness of vegetation cover is also important. Both must be taken into account when considering proposed operations in the far north-east of Tasmania. Not only are soils highly erodable but clear-felling and high intensity rainfall compound the problem.

Considering its potential as a direct erosive agent, overland flow or runoff is the most important component of the system with which we are concerned. Runoff should be a term applied to stream flow which is not only contributed to by overland flow but by throughflow and groundwater as well.

There are two main theories concerning overland flow. Horton (1945) originally put forward the theory of *Horton* overland flow; overland flow occurred when rainfall intensity exceeded the surface depression storage and infiltration capacity of the soil. Recent investigations have shown that this theory is not strictly correct, and that overland flow can occur when the infiltration capacity has not been exceeded, especially when surface soil horizons are saturated and rainfall intensity is greater than the rate of throughflow. In simple terms, the Horton model states that 'overland flow will occur when rainfall intensity is greater than the infiltration capacity of the soil'.

Considering a uniform hillslope, infiltration capacity can be considered as uniform over a small area and therefore the rainfall excess is more or less constant over the slope. The overland flow discharge therefore increases linearly downslope with distance from the drainage divide. The greatest amount of overland flow occurs at the base of a slope due to uniform contributions from all areas upslope.

The second major theory of overland flow is a little more complex. To recall, the *saturated* overland flow occurs when rainfall intensity exceeds the *subsurface throughflow* rate, and it therefore tends to occur in situations which favour the saturation of soils. Such conditions usually occur towards the base of a slope, especially where it is adjacent to a stream, and also in areas where soils are thin and in areas of flow concentration produced by slope concavity or contour curvature. These areas exist only on certain parts of the hillside and vary with rainfall intensity. Discharges are very difficult to measure or estimate because of this areal variation.

With both models, infiltration rate is related to soil moisture content, in that drier soils absorb water faster than soils that already have a high moisture content. Horton overland flow therefore occurs more readily during a period of rainfall when the soil is already moist.

A similar effect occurs in the throughflow model. When the existing soil moisture content is high, there is less space for further moisture and consequently during rainfall the saturated throughflow zone increases rapidly in thickness. There is therefore a greater probability that the water will seep out on the surface to produce overland flow. Generally, there is a greater probability of overland flow occurring when the existing

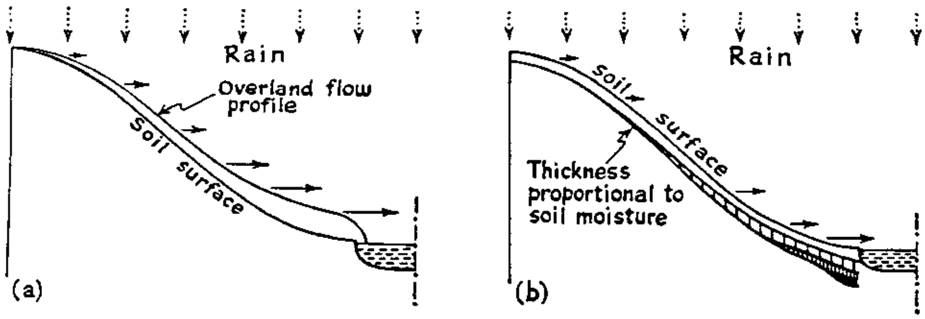

Figure 2. *Patterns of hillslope flow during Horton overland flow and throughflow. Arrow lengths show relative discharges over or through the soil (from Chorley, 1969, p. 119).*

(a) Horton overland flow (After Horton, 1945, p. 316). Thickness of water layer on surface is drawn proportional to actual thickness.
(b) Throughflow. Thickness of water layer below surface is drawn proportional to soil moisture content. Soil moisture from progressively earlier rainfalls is shown by progressively darker shading. The subsurface layer does not indicate the depth of infiltration into the soil.

moisture content of the soil is high.

Vegetation not only increases the shear strength of the soil mantle by root binding but it also reduces the effect of surface water forces by two main components, the litter cover and canopy cover. The canopy serves a dual purpose. Firstly some rainfall is lost through evaporation from the canopy and hence the potential runoff is reduced, and secondly the canopy protects the soil from the full impact of raindrops. This protection varies with the type of vegetation, and a good example is the protection afforded by pine forests. The dense needle canopy has a very large surface area which has an extremely high interception and protection effect.

The vegetation litter also protects the soil from raindrop impact and reduces the force of overland flow. Flow is reduced by increasing surface roughness, which also allows an increase in infiltration. Vegetation is considered to be a major element in reducing soil loss.

Summary

The amount of overland flow is inversely correlated with the ability of a hillside to absorb water. In the Horton model, overland flow occurs when rainfall intensity is greater than the infiltration capacity of the soil mantle. Infiltration capacity depends largely on soil porosity and the initial moisture content. New work indicates that Horton's overland flow model may be considered as an expanded form of the throughflow model. Throughflow can occur when infiltrating water reaches an horizon of lower permeability, above which saturated throughflow may occur. If a storm is of sufficient duration and intensity, the saturated throughflow horizon may expand in thickness until it intersects the surface and water seeps out. This is commonly observed where soils are thin, and on the lower parts of slopes.

EROSION

There is an important distinction between geological erosion and 'accelerated' erosion. Geological erosion is the normal rate at which the land is eroded without the effects of disturbance. 'Accelerated' erosion refers to an increase in the rate of erosion which often arises when man alters the natural system by various land use practices.

Erosion rates are measured in terms of sediment yield from a particular drainage basin and are commonly measured in tonnes/km^2/annum. The sediment yield is often measured by analysing the amount of sediment suspended in flowing water. Erosion rates are affected by numerous variables including rock type, climate, vegetation type and density, and drainage basin characteristics. Basin characteristics include area, relief, drainage density, steepness, and length of slopes.

Soil erosion by water involves the detachment of particles and their subsequent transportation. The two main agents involved are raindrops and flowing water. Raindrop erosion results from the detachment of particles by raindrop impact and particle movement by splashing. Overland flow erosion generally involves the transportation of particles previously detached by raindrops, but may also involve particle detachment. Transportation is by turbulent water flowing as sheets, in rills, or gullies.

Investigations have shown that the amount of soil carried in runoff increases rapidly with raindrop energy. The detachment and movement of soil particles as a result of raindrop impact is a fundamentally important and often initial stage of soil erosion. Erosion can therefore be reduced by preventing raindrop impact and this protection can be provided by vegetation. Soil splash varies with the nature of the soil surface, in particular the detachability and transportability of soil particles. The slope of the soil surface is also important as rain splash on a sloping surface will result in a nett downslope movement of a detached soil particle. Raindrop impact may therefore detach soil particles and move them in a downslope direction, consequently reducing soil nutrients and in some cases reducing infiltration by dispersing clay particles in such a way as to form a surface crust upon drying.

Horton's model of surface runoff provides a basis for an understanding of the causes and control of runoff erosion. To reiterate, in simple terms, precipitation equals infiltration plus runoff. As runoff occurs a thin layer of water develops on the ground surface as overflow from depressions takes place. Initially the water does not have enough energy to transport and detach soil, but as it proceeds downslope the force increases until there is sufficient energy for erosion to begin. Upslope from this critical or threshold point, no runoff erosion occurs and rain splash is the main erosive force. Below the critical point rilling and gullying may be initiated. Generally, for slopes of less than 20°, the width of the belt of no runoff erosion increases as rainfall intensity decreases and as surface roughness increases.

In summary, the variables that determine runoff erosion and which must be modified to reduce erosion are:-

- rainfall intensity and infiltration capacity expressed as runoff intensity,
- length of overland flow,
- angle of slope,
- surface roughness.

Once the flow of water has passed the critical threshold point, there will be enough energy to incorporate sediment, and the erodability of the ground surface will determine the amount of erosion occurring.

The erodability of the surface can be expressed in terms of particle size and flow velocity. Figure 3 shows the relationship concerned, based on the Horton runoff theory.

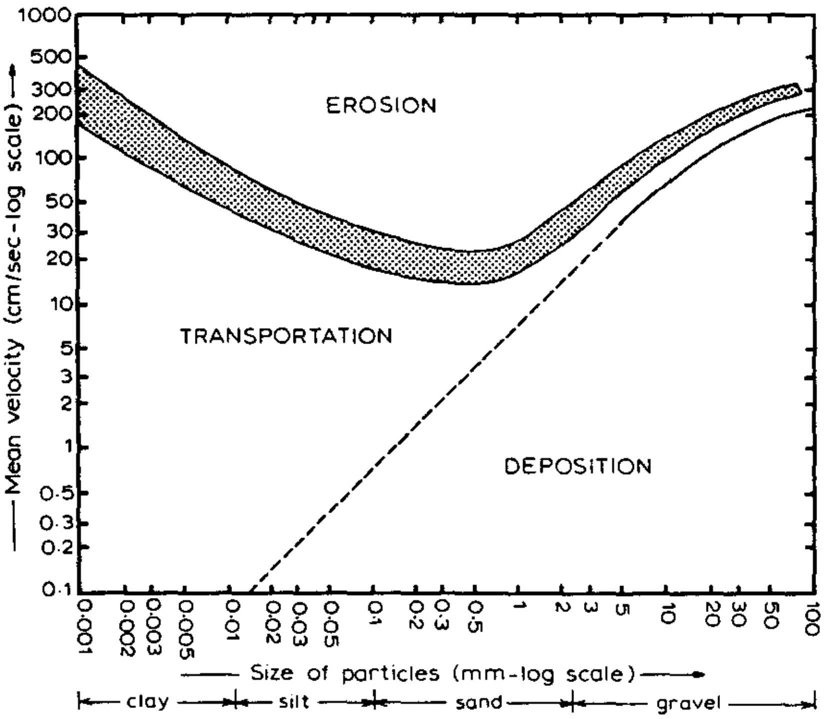

Figure 3. *Relations between particle size, erosion velocity, and settling velocity for uniform sediments (from Cooke and Doornkamp, 1974, p. 34).*

One of the salient features of this relationship is that the most easily moved particles are between 0.5 mm and 0.1 mm diameter, in the medium to fine sand size range. Runoff follows the lines of least resistance and becomes concentrated in rills and gullies, forming eroded channels. The depth and velocity of the water increases with this concentration, as does the ability to detach and transport sediment particles.

The water and sediment mixture is extremely erosive, the mixture scouring the base and sides of a channel. Waterfall erosion occurs at the head of the channels with the formation of plunge pools and undercutting, and slumping occurs due to undercutting and steepening at the sides of channels. Patterns of rill and gully formation may be guided by pre-existing structures such as culverts, snig tracks, and wheel ruts.

In the case of the saturated throughflow model, the important controls are soil characteristics, distance downslope, slope angle, and intensity of rainfall. The attainment of fully saturated conditions occurs most readily on concave slopes or in hollows where soil is thin and impermeable. Erosion due to the surface appearance of seepage from saturated throughflow involves the upslope extension of existing channel systems and is independent of the distance from the slope crest. As with the Horton model, the erosive force of the runoff increases downslope and increases with increasing slope angles. On a slope with a convexo-concave profile, the erosive forces reach their maximum on the steepest, and often central, part of the slope profile. Most of the erosion occurs downslope of the central part of the slope, initiating gullies and channel flow. Overland flow and throughflow are likely to be two extremes of a continuous sequence of possible conditions for erosion and gully development, with throughflow being more common in humid areas and overland flow more likely in semi-arid areas.

Consideration of these flow theories give a basic outline of the causes and effects of erosion and sediment yield caused by precipitation runoff. The aim of erosion control is to reduce soil loss so that soil productivity is economically maintained and deterioration of regional water quality is prevented. The purpose of implementing controls is to restore equilibrium, so that the rate of loss is equal to the rate of regeneration, *i.e.* to reduce 'accelerated' erosion to 'geological' erosion.

Soil conservation practices fall into three main groups; crop management practices, supporting erosion prevention practices, and practices designed to restore eroded land. All these relate to the manipulation of one or more of the variables in the precipitation-erosion system.

Crop management practices are generally used in agriculture and do not apply to any great extent in forestry operations. However, consideration should be given in erosion sensitive areas for the possible planting of cover crops to protect the soil quickly after clear-felling until protection by tree growth can be established. Specific applications include the mulching and seeding of road embankments and quarries and the sowing of road surfaces and snig tracks after harvesting operations cease.

Supporting erosion-prevention practices include contour farming, strip cropping, and terracing in agriculture. In forestry operations, these practices can include the correct planning and design of road and snig track systems as well as road drainage. The purpose of these practices is to disrupt surface water flow by reducing flow velocity, dispersing the water, or by increasing the surface roughness, as well as restrict the locii for rill development, and conserving water.

Restoration of previously eroded areas includes covering waterways with grasses or encouraging natural vegetation. Gullies may also be converted to stable artificial channels with dimensions more appropriate for the water discharge carried. Water discharge may be reduced by conservation techniques in catchment areas, by diversion into artificial channels, and by reducing flow by the building of spills and inlets to dissipate flow energy.

SOME PREVIOUS INVESTIGATIONS OF FOREST HYDROLOGY AND EROSION

A continuous cover of mature forest is probably the best protection that a water supply catchment can have to minimise erosion and turbidity. The role of forests in protecting against erosion has been accepted for a long time. Swanston and Swanson (1976) consider that accelerated erosion due to poor forest land management activities may result in reduced productivity of forest soils over sizeable portions of effected watersheds, in damage to roads, bridges and other structures, and have adverse impacts on stream environment downstream.

Australian research in forest hydrology has not been extensive, although a wide range of subjects have attracted interest. The published reports give a good summary of the problems in particular areas. The greater number of overseas reports, particularly those from the United States of America, are of more value in evaluating the effects of forests on water yields, floods, erosion and turbidity. Areas of concern within Australia are summarised by McArthur and Cheney (1965) who note that 'most forest practices such as roading, logging, control burning, and plantation clearing will produce increased erosion and sedimentation if carried out in an unplanned and haphazard manner without due regard to the primary objective of management, which is to prevent any reduction in water yield and quality. With careful prescriptions the amount of sediment originating from areas where forest operations are in progress can be frequently reduced to lower values than from undisturbed areas'.

A major effect of clear-felling is an increase in runoff, and it has generally been found (Boughton, 1970) that when only part of a catchment is cleared, the resulting increase in runoff is less than would be expected if the whole catchment was cleared, and is in proportion to the percentage of the area cleared. The Melbourne and Metropolitan Board of Works has opposed the logging of mature forests from water supply catchments, not because of the increased runoff after clear-felling, but because they considered that in the long term the reseeded forest will take about 25% more water than the mature trees they replace (O'Shaughnessy *et al.*, 1979). There is not a lot of evidence to support this view from other areas, however the theory seems plausible, especially if the regrowth density is greater than the mature forest. Evidence is based on hydrological data from the Maroondah catchment (Langford, 1974) where 69% of the *Eucalyptus regnans* forest was killed and regenerated by the 1939 bushfires. Stream flows in this catchment are still 24% less than the pre-1939 levels. Evapotranspiration is certainly related to these findings and Douglas (1967) reported that reducing stand density reduces evapotranspiration and consequently, in the case of the Melbourne catchments, the reverse is possibly a contributing factor. Brookes and Turner (1963) agree with the Melbourne catchment studies in concluding that ....'there is some evidence for the view that in a young forest of this type (*Eucalyptus regnans*) the water yield decreases with an increase in stand density'. Boughton (1970) concluded that 'while there have been many studies directed towards interception, infiltration rates, and other components of the hydrological cycle affected by forests, there is no discernible pattern in the results available to suggest any dominant factor other than of difference in root depth'. Whatever mechanisms are operating, the main effect on the hydrological cycle that occurs is that clear-felling produces an increase in runoff.

Turbidity and erosion

Generally, within Australia, turbidity or suspended sediment load problems have occurred in catchments providing town water supplies and has been a source of conflict between forestry and water supply authorities in many areas. In a report on turbidity problems of Canberra's water supply, Teakle (1966) considered that there was '.... no doubt that the main sources of turbidity are areas of exposed soil, roads, firebreaks, earth-works, newly cleared land, eroded stream banks etc.'

Soil type and the type and amount of ground cover were identified as the prime factors in determining turbidity, and soils on granodiorite and volcanic rocks were stated to be readily dispersible in water and therefore more prone to release turbid water either as surface flow or seepage (Teakle, 1966). Work in the United States by Anderson (1954) confirms that the most erodable and highest sediment-producing soils were developed from intrusive igneous parent rocks. Packer (1967) also reached the same conclusions from work in Montana and northern Idaho. Wallis and Willen (1963) demonstrated that soils on acid igneous rocks were considerably more erodable than those formed from other parent materials. Soils on granite and granodiorite parent rocks, similar to those in north-east Tasmania, were considered to be the most highly erodable of all soils inspected.

Boughton (1970) considered that apart from fire, there were three principal sources of turbidity and erosion problems associated with forestry practices and activities within Australia. These include the construction of roads through forests for general access, for fire control purposes, and for the extraction of timber; logging activities, particularly where work is carried out around water courses or where skid trails are used to haul logs to loading areas; and the clearing of large areas of native vegetation for the establishment of a plantation forest.

The construction of roads involves the removal of plant and litter protection and the exposure of soil and weathered parent bedrock over a significant portion of a forested area. Road construction costs are a substantial proportion of the costs of the total forestry operation. Boughton (1970) considered that 'planning of road layouts to minimise erosion and protection of exposed soil surfaces by mulching or seeding is virtually non-existent in Australian forestry practice'. This may have been the case in 1970, but perhaps the comment is a little harsh considering operations today. Nevertheless, this comment stresses a vital aspect of operations, especially in areas of high soil erodability.

Boughton's review also quotes numerous studies relating to the deleterious effect of forest roads on turbidity and sediment yield, with turbidity increasing up to nine times in some areas during the first rain storm following road construction. A study by Copeland (1965) on granite soil areas of central Idaho attributed high sediment yields not only to the high erosion hazard presented by granite-derived soils, but also to the lack of adequate road drainage facilities.

The other major erosion source other than roads is associated with the problem of hauling the log from where it is cut to the point of loading on to trucks for transport to the mill. The amount of soil disturbance varies with the method used. The worst disturbance is caused by skid trails or snig tracks along which logs are hauled on the ground, and the least disturbance is caused by sky balloons or high wires which can lift a log clear of the ground for movement.

Numerous studies have been conducted comparing methods of log retrieval, and which confirm the above mentioned disturbance effects.

Dyrness (1965), Garrison and Rummell (1951), Wooldridge (1964), and Fowells and Schubert (1951), have all conducted studies on this matter. Trimble and Weitzman (1953) showed that erosion from poor skid trails with no gradient limits or waterbars yielded eight times as much sediment than skid trails having gradients of less than 10% and drained by waterbars as required.

The Tasmania Department of the Environment has conducted water quality and bed-load monitoring on the Meredith and Macquarie Rivers (1978, 1981). In 1976, eight silt traps were installed in a number of small streams in the headwaters of these rivers in an attempt to determine the principal sources of stream bed-load. In 1977, a water monitoring programme was started on the Macquarie River to sample suspended sediment. Conclusions reached again confirm the results of studies conducted elsewhere by others, in that snig tracks and roads were major sources of sediment and sources were generally due to improper drainage practices or the absence of erosion control measures. Water monitoring indicated that levels of suspended and dissolved solids reached peak levels as the Macquarie River flowed through farming areas, a result not consistent with the allegation that woodchipping is the principal source of dissolved and suspended sediment in the river. This is a consistent finding throughout the literature, a fact often overlooked by opponents of the woodchip industry. While the Tasmanian investigations were by no means conclusive, the observations were consistent with studies elsewhere.

Nearly all the studies mentioned so far, together with many others, indicate the erosion potential of roads and skid trails, especially where they concentrate water, intersect other skid trails or roads, and encroach on stream channels. The large amount of soil disturbance associated with the forestry operation will not necessarily be reflected in a deterioration of water quality, provided that the potential for erosion from these features is recognised and attempts made to reduce or nullify their effects.

A consistent theme of the literature, indicated by Boughton (1970) and others, is that there is a period of between two to four years from the time of reseeding to the time when the new forest offers adequate protection to the soil. A good yardstick would be a period of five years, by which time runoff has decreased to previous levels from its initial increase after clear-felling. Water quality shows the greatest deterioration over a period of about two years after clear-felling, by which time quality has once more become close to previous levels.

American literature generally stresses the importance of planning and attention to erosion control procedures after harvesting. This theme is highlighted by Haupt and Kidd (1965) from a study area at the Boise Basin Experimental Forest which is underlain by Idaho Batholith quartz monzonites, and has slopes of between 35% (19°) to 55% (29°). The effects of erosion and higher stream sediment yields were reduced because of careful advance planning, close supervision of logging, and application of intensive measures to control erosion promptly after harvesting.

Several precautions, believed to be good logging practices, were taken before and during logging operations. These are listed below.

(1) Secondary roads carefully located and constructed during the same year as logging;

(2) Road grades generally less than 9%, but locally steeper;

(3) Roads and landings kept above drainage bottoms to retain at least a three metre buffer strip of undisturbed vegetation between the foot of the fill slope and the channel that would help to trap surface sediment from the road;

(4) Road channel crossings kept to a minimum. Crossings cleared after logging to remove road-fill material from stream flow paths;

(5) Repeated use of the same skid trails where possible;

(6) No skidding down channels and no skidding across channels unless imperative;

(7) Skid trails grass seeded after use and logging slash barriers placed at intervals across skid trails. Slash barrier interval of 15 m (50') for less than 16% slope, 9 m (30') for 16% to 30% slope, and 3 m (10') for slopes greater than 30%. Where slash was sparse, cross ditches (grips) were dug instead of placing slash barriers;

(8) Roads cross ditched, harrowed, and seeded with a grass mixture after operations ceased.

Areas of subsequent erosion were recorded, together with areas of sediment deposition and lengths of surface sediment flows. Settling ponds were constructed along stream channels at the margins of the area prior to the commencement of operations. The surface of these sediment traps were surveyed before, during and after logging operations in order to determine the amount of sediment movement from the area.

Haupt and Kidd (1965) divided sediment runoff into two types; surface sediment which could be identified as originating from a single point source in a defined sediment trail, and channel sediment made up of surface sediment which has reached a drainage channel or originated directly from road or skid trails intersecting the watercourse. Little erosion was found to originate from the skid trails due to the erosion control methods used. Haul roads were found to be the major source of surface sediment due to sediment flows from road cross-ditches. As the grasses planted on the roads became established, erosion and sediment yields became negligible.

Little correlation was found between the amount of logging disturbance and sediment yield. Haul road disturbance could be more directly correlated with sediment yield, and the width of the buffer strip between the road fill embankments and watercourses was also important.

Megahan (1978) also studied the erodability of granitic road fills in central Idaho and concluded that the erosion is grossly dependent upon the erosion potential of rain storms and that small planted trees caused a reduction in erosion of approximately 50%. Haupt and Kidd's (1965) study indicated that providing skidding precautions and rehabilitation measures were taken, no serious loss of soil need be expected from areas disturbed by skidding. Haul roads require careful location and prompt and particular rehabilitation measures. Despite this, surface sediment can be expected from roads, but by careful treatment can be minimised or eliminated.

Similar conclusions were reached by Patric (1976) in a review of forest soil erosion in the eastern United States. Patric again stresses that .... 'responsibly managed timber harvest causes only minor increases in forest soil erosion, usually from channels and logging roads, but irresponsible timber harvest can increase erosion of particulate matter to unacceptable levels'. He also agrees that forest logging roads require special consideration and that they are undoubtedly the source of most of the soil lost from non-channel portions of managed forest land. Sediment yield is considered to originate from point sources rather than uniform soil loss. These points along roads and channels are considered to be the only sources of polluting particulate matter.

Patric (1976) also indicates the erosive power of rare catastrophic storms, resulting in rearrangement of drainageways in the short term and incision of channels in the long term. A pertinent conclusion of his review states 'it is naive to suggest that forests and forestry are not contributing to erosion problems in the Eastern U.S., but the overwhelming weight of evidence supports the view that soil losses from responsibly managed forest land are slight compared to those that accompany most other land uses'. This comment agrees with other studies which indicate high sediment yields from agricultural areas.

Cook and Hewlett (1979) also consider that poor design and location of logging roads is a major cause of erosion of the roads and subsequent sedimentation of streams. Kochenderfer (1970) found that the most severely disturbed portions of a logging area, that is the skid trails and logging roads, were the main areas of serious erosion. The compaction and hardening of trafficked areas prevents infiltration, with all runoff going to the road drains and skid ruts. Unless these drains are properly designed, with frequent outlets, water will stay in them, building up in quantity and velocity as it moves downhill. The end result of a poorly designed road is increased erosion and sedimentation, which may render the road unsuitable for further use.

Kochenderfer (1970) agrees with the findings of many others in that any operation needs comprehensive planning of the entire access system, construction of roads several months before use, good topographic location, design of features that remove water from the road surface, and revegetation following use. As also advised for road systems in north-east Tasmania, Kochenderfer favours roads with a ridge shoulder location that avoid water courses, intersect few seepages, and generally need little cut and fill.

Kochenderfer (1970), Cook and Hewlett (1979), and Hewlett and Douglass (1968) all favour the use of the 'broad based dip', constructed on forestry roads to reduce the velocity and volume of stormwater. The dip is essentially a six metre section of reverse grade built into the basic road grade and slightly outsloped at the bottom. Kochenderfer considers that broad based dips add little to road costs and are considered to work for years after road abandonment, thereby preserving the roadbed for future harvests.

Kochenderfer also stresses the need for the planning of road systems and in particular the planning of both skid trails and haul roads at the same time. Careful planning minimises the amount of disturbance and, combined with well planned and efficient logging, reduces erosion. Kochenderfer favours uphill snigging away from streams, the location of landings as far from streams as possible, and the retention of filter strips around streams.

The maintenance of logging roads, which is basically a problem of water control, is advocated as well as the immediate provision of additional protection against erosion after logging in the form of waterbars on the most heavily used skid trails and roads. Logging slash can be used as a supplement to waterbars where the erosion hazard is high. Grass seeding is considered to be an important supplement to mechanical erosion control on logging roads in areas of high erosion hazard.

Megahan (1972) again indicates the overwhelming impact of roads in relation to erosion and sediment runoff in the United States (Tables 1, 2).

Table 1. ESTIMATED EFFECTS OF CUTTING PLUS SKIDDING AND OF ROADS ON FACTORS INFLUENCING SURFACE EROSION (FROM MEGAHAN, 1972)

Erosion factor	Effect relative to undistrubed lands[1]	
	Cutting+ skidding	Roads
Detachability	None to small+	Mod.+ to large+
Force applied		
a. Raindrops	None to mod.+	None to mod.+
b. Wind	Small+ to mod.+	Small+ to mod.+
c. Surface flow	None to small+	Large+
d. Gravity	None	Small+ to large+
Surface cover	Small+ to mod.-	Large-
Overall erosion hazard	Small+	Mod.+ to large+

[1]Comparison made immediately after logging.

Table 2. MEAN SEDIMENT PRODUCTION DUE TO SURFACE EROSION FOR A 6-YEAR STUDY PERIOD[1] (FROM MEGAHAN, 1972)

Type disturbance	Sediment rate[2] (tons/year/mi)	Ratio to undisturbed lands
Undisturbed watersheds[2]	25	1.0
Disturbed watersheds[2]	1130	45.3
Cutting + skidding[3]	40	1.6
Roads (surface erosion)[2]	5500	220.0

[1]W.F. Megahan and W.J. Kidd. Unpublished manuscript, Intermountain Forest and Range Experiment Station, Boise, Idaho.

[2]Values expressed per unit area of watershed.

[3]Values expressed per unit of area disturbed.

Figures quoted for small watersheds in the granite areas of central Idaho indicate that log cutting and skidding increased surface erosion 1.6 times, while surface erosion due to roads increased 220 times. The combined effect of cutting, skidding, and roads increased the sediment yield 45 times for the entire area.

Vegetation regrowth tends to reduce surface erosion with time and in central Idaho erosion has been found to reduce rapidly during the first two to three years after disturbance. The studies in the Idaho Batholith region are very pertinent to proposed areas of clear-felling in north-east Tasmania. The Idaho study areas are underlain by highly erodable granite soils on a variety of slopes and are similar to those in north-east Tasmania.

An extensive report was prepared in Australia in 1978 by the Senate Standing Committee on Science and the Environment, entitled 'Woodchips and the Environment'. Section 4 of this report, entitled 'Earth, air and water' is considered to be essential reading and provides a very good review of erosion and sedimentation problems within Australia. Here again, many of the findings confirm previous studies mentioned in this report. It is considered worthwhile to report the essential findings in order to stress the important factors involved with the effects of forest clear-felling.

Here again, as with most of the reviewed literature, a submission from the N.S.W. Forestry Commission ....'emphasised the importance of carrying out erosion control work immediately after logging as it was the first [erosive] rain after soil disturbance which usually caused the greatest damage'. They also suggested that ....'the heavily travelled snig tracks are generally the only part of a coupe subject to the risk of erosion'.

The report also highlights the fact that logging roads are the main areas of soil loss as a direct result of exposed soil in road fills and cuts and concentrated runoff due to poor drainage. Section 4.1.5 of the report indicates, concerning anti-erosion specifications, 'in particular, drains are required to be constructed on all snig tracks and minor roads immediately logging has ceased, to prevent concentrated runoff and so minimise erosion'.

With reference to road systems and the provision of 'scoops' or sediment traps, the Parliamentary Committee considered that 'the erosion damage arising from roads and road construction is a recurring theme arising throughout the inquiry....' and recommended that roads should be located along ridges or contours with frequent dispersal drains incorporating silt traps. The report also recommends further attention to the sowing of grass and mulching of road embankments and other areas of severe disturbance. The Committee also considered that despite the inference that could be drawn that the direct forest operations, as distinct from the associated road construction, are not considered a particularly serious cause of erosion, concern was expressed at the steady but cumulative attrition likely to result from regular operations and which may not be fully recognised. Constant surveillance and attention to detail is required in order that effective long term erosion prevention can be achieved.

The Committee found that no forestry authority conducted formal training in how or why erosion control work should be done. Recommendations were made for the revision of snig track drainage specifications, formal training for forest contractors, financial incentives for correct anti-erosion work by contractors, and the establishment of teams of personnel from the forestry authority who are properly trained and equipped for anti-erosion work.

Siltation of streams, rivers, and lakes follows naturally from erosion, resulting in a reduction of water quality which may affect the spawning grounds of fish such as trout or the Australian grayling. The latter, present in the Douglas River of eastern Tasmania, is extremely sensitive to an increase in suspended sediment yield. An increase in bed load may also cause stream flooding in the long term, siltation of dams, water reservoirs and lakes.

The correct application of anti-erosion measures are, of course, the first line of defence against siltation. Filter strips of vegetation retained along defined water courses are designed to prevent siltation. The Parliamentary Committee considered that a shortcoming of the restrictions is related to the way in which watercourses are defined. The Committee considered that because of the large number of ephemeral streams within Australia '.... any definition of a watercourse which relies on some concept of 'permanent' water inevitably becomes imprecise'. The Committee advocate a broad interpretation coupled with attempts to minimise disturbance to all gully vegetation. They consider that a great deal depends on the knowledge and commonsense of the forest operators and their supervisors. This will also be commented on in a later report, concerning the north-east Tasmanian operations. It is an important comment and indicates the need for training, information, and education in these matters. The Committee concludes that '.... woodchipping operations are contributing to siltation, that the amount is unknown, probably relatively small, but not insignificant in the long term, and that the degree of siltation is a function of the quality of the harvesting techniques employed'.

Summary

From this short review of some pertinent literature from within Australia and the United States, several consistent themes are apparent. We can draw on the conclusions and results of these often extensive, long term studies and compare them with our field observations and intuitive ideas on erosion and sediment yield problems of the highly erodable granite soil areas of north-east Tasmania. Megahan (1972), in his review of forestry operations in the Eastern United States, summarises the salient features well.

(1) Timber harvesting including cutting and skidding, and especially roads, do tend to accelerate erosion and sedimentation which may cause on-site or off-site damage or both.

(2) Erosion hazards vary greatly with location.

(3) The construction of logging roads contribute a disproportionate share of the problems, perhaps up to 90% in most areas.

(4) Accelerated erosion and sedimentation often continues after logging operations cease. Surface erosion rates highest immediately after operations cease but decreases rapidly with time. The greatest effect probably occurs within two to three years after operations. After this period new vegetation has begun to afford some protection to erosion.

(5) Care taken and controls implemented during harvesting operations can have a considerable influence on the impact of results.

Guidelines for minimising erosion and sediment problems are essential. Suggestions include the stratification of land according to the erosion hazard and that access roads, skid trails and the cutting sequence should be planned accordingly, with specific reference to this hazard. The amount of the area disturbed by road construction should be kept to a minimum. Proper planning, operation execution and follow-up procedures are required to ensure erosion control. Erosion control procedures include streamside retention areas, provision and maintenance of road drainage and silt traps, the construction of waterbars on snig tracks, and the seeding of road areas and embankments. There may be differences in the erosion control measures required for specific local problems and these measures should be decided by those familiar with local situations. Erosion control measures are most beneficial when applied immediately after the disturbance due to the logging operations has occurred.

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