1983/13. The erosion of granite-derived soils in eastern and north-eastern Tasmania, with reference to forestry operations. Part 3: Proposed forest development in far north-east Tasmania.

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Abstract

Areas of proposed clear-fell logging operations in the north-east of Tasmania have been inspected. Most areas have low slopes and an undulating topography, and consequently few erosion problems are envisaged provided that the Forestry Commission Guidelines (1981) are implemented during and immediately after logging ceases. Low lying areas with high water tables require attention to ensure proper drainage, especially where traversed by access routes.

Steeply sloping areas in some coupes have been defined as having a moderate to high erosion potential, and consequently careful planning is required. The sensitive areas outlined have slopes between about 12° and 24° and may require modified erosion control measures, particularly near water catchment areas at major population centres such as St Helens.

An outline of monitoring methods is included. Sediment dams are favoured for erosion control and as monitoring stations, providing an overall measure of sediment run-off from a particular catchment. Water sampling should be undertaken on a paired catchment basis, with sampling of catchments at the same time and as frequently as possible. Monitoring should be conducted for a period of time before logging to enable catchment calibration.

Monitoring is essential to provide a quantitative evaluation of the effects of logging in relation to accelerated erosion, and to also evaluate the effectiveness of erosion control measures.

INTRODUCTION

Proposed areas of forestry operation in far north-east Tasmania were inspected in order to comment on the erosion potential, and in particular, on those areas where clear-felling is proposed during the next five years. Current areas of erosion were examined and assessed together with the topography of each coupe, and granite-derived soils were sampled for laboratory grain size analysis. The erosion potential of the area was assessed from observations made at coupe EL1 (Sloane, 1983*a*) and a review of literature on erosion studies elsewhere (Sloane, 1983*b*). To determine their adequacy, the Forestry Commission 'Guidelines' and the Environmental Impact Study recommendations were then related to the overall assessment of the region.

Areas of proposed forestry development in north-east Tasmania are shown on Figure 1. The majority of the area is of low undulating relief, with an increase in altitude towards the west and south-west. The altitude of coupes near the coast is between 100 m and 140 m, those towards the centre of the region are between 160 m and 200 m, while those towards the western and south-western margins range between 200 m and 400 m with locally higher areas in the west to 700 m. Rainfall in the north-east region occurs on an average of 140 days annually and ranges from about 750 mm near the coast to 1500 mm in areas of high relief to the west. Short periods of extreme rainfall occur, especially during the later months of the year.

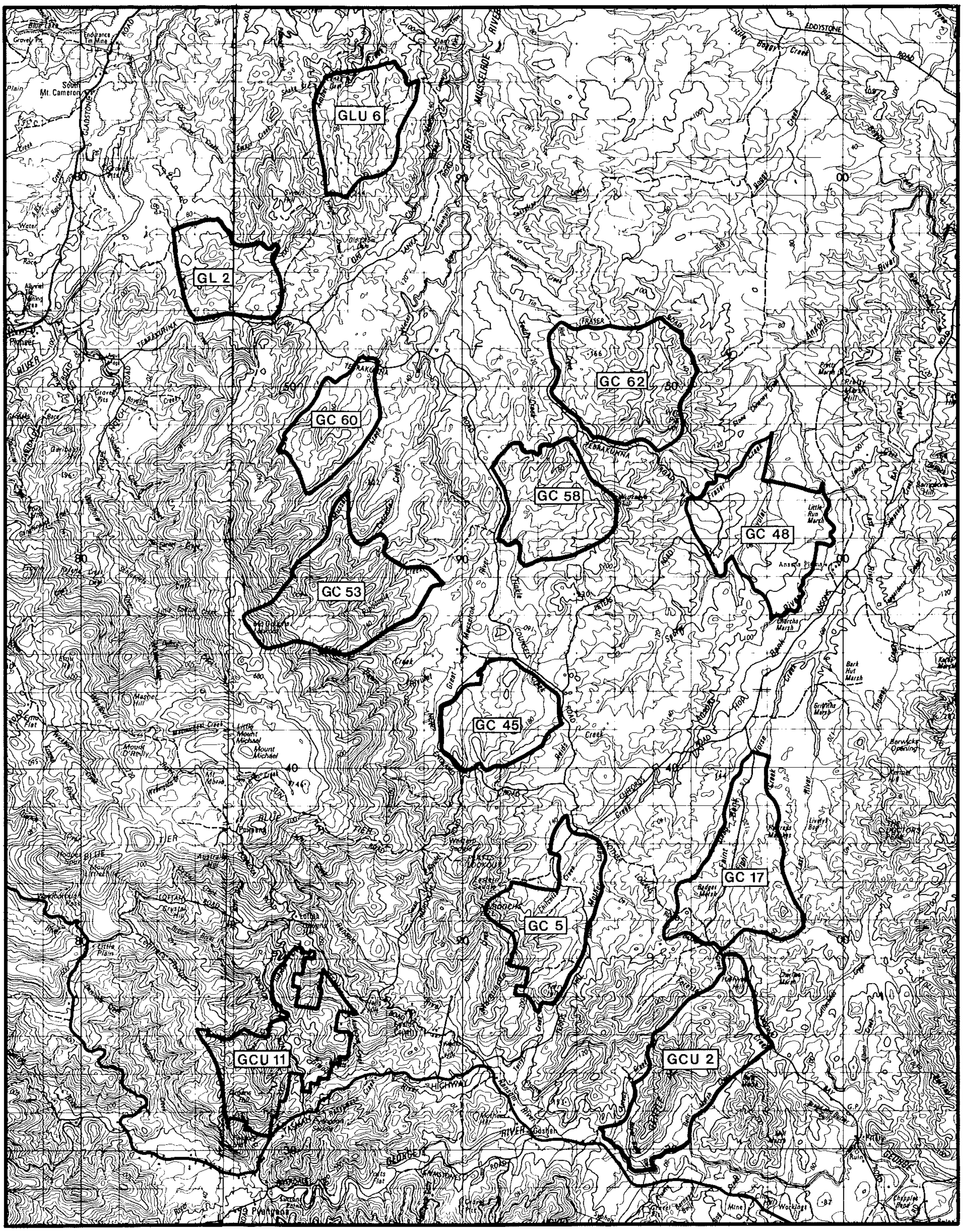

Figure 1. *Location of proposed forestry coupes, north-east Tasmania.*

The region is largely underlain by two Devonian granite types (fig. 2), a porphyritic biotite granite and adamellite, and a biotite hornblende adamellite and granodiorite (McClenaghan and Williams, 1981). There are some compositional differences between the granite types and one of the aims of this brief investigation was to determine if these differences were reflected in the soil type, depth of weathering, and consequent susceptibility to erosion. Erosion within the region was examined and the cause and location assessed in relation to soil depth and type, and topographic location.

The overall assessments in this study were made in relation to experience derived from coupe EL1 and information from a literature search of investigations elsewhere (Sloane, 1983*a*, *b*).

EROSION POTENTIAL OF THE FAR NORTH-EAST

Visual inspection of exposures in gravel pits and road cuttings indicates that there are no major differences between soils developed on the different granite types of the region. Thus the whole region must be considered as having highly erodable granite-derived soils.

Gradational soils occur over most of the area. Where observed these have developed to depths of up to 1.5 metres. At such depths weathered granite bedrock can be distinguished by relict texture, quartz veins, and infilled joints. Soils are characterised in many places by a high percentage of relatively undecomposed primary minerals, especially in lower horizons. The A_1 (topsoil) horizon is generally thin, between 0.1 m and 0.2 m in thickness but locally reaching 0.4 m, and is composed of medium to fine quartz sand with minor silt and angular quartz gravel. The topsoil contains organic matter and the loose and friable nature and grain size distribution renders it extremely susceptible to erosion (fig. 3).

The clay content generally increases with depth below the A_1 horizon to a mottled yellow-brown and yellow-orange gravelly and clayey sand. Iron concretionary material is occasionally present. Mottled brown, orange-brown, grey-brown, and yellow-brown gravelly and sandy clay occurs at depth.

In some areas the soil profiles approach the duplex type, where there is a sharp contrast in clay content between the upper and lower soil horizons. This soil type is generally developed on isolated patches of Tertiary sediments and in low lying depressions underlain by granite.

There is little difference between the soil types in terms of erosion potential. All soils have sandy and gravelly, loose to friable, easily eroded topsoil of varying thickness. The soil is generally thicker on the lower to middle slopes and thinnest towards ridge crests and in steeply sloping areas where granite crops out and where granite boulders are present in the soil.

The rainfall in the coupe area can be considered as virtually uniform, with a slight increase in the steeper regions to the west and south-west. Periods of extreme rainfall do occur during late summer and mid to late autumn. These short periods of extreme rainfall can cause severe erosion. Light, frequent rainfall is not as damaging, as most of the water infiltrates. The granite soils are considered to have a moderately high infiltration capacity. In summary, the region has highly erodable gravelly and sandy soils subject to periods of high intensity rainfall.

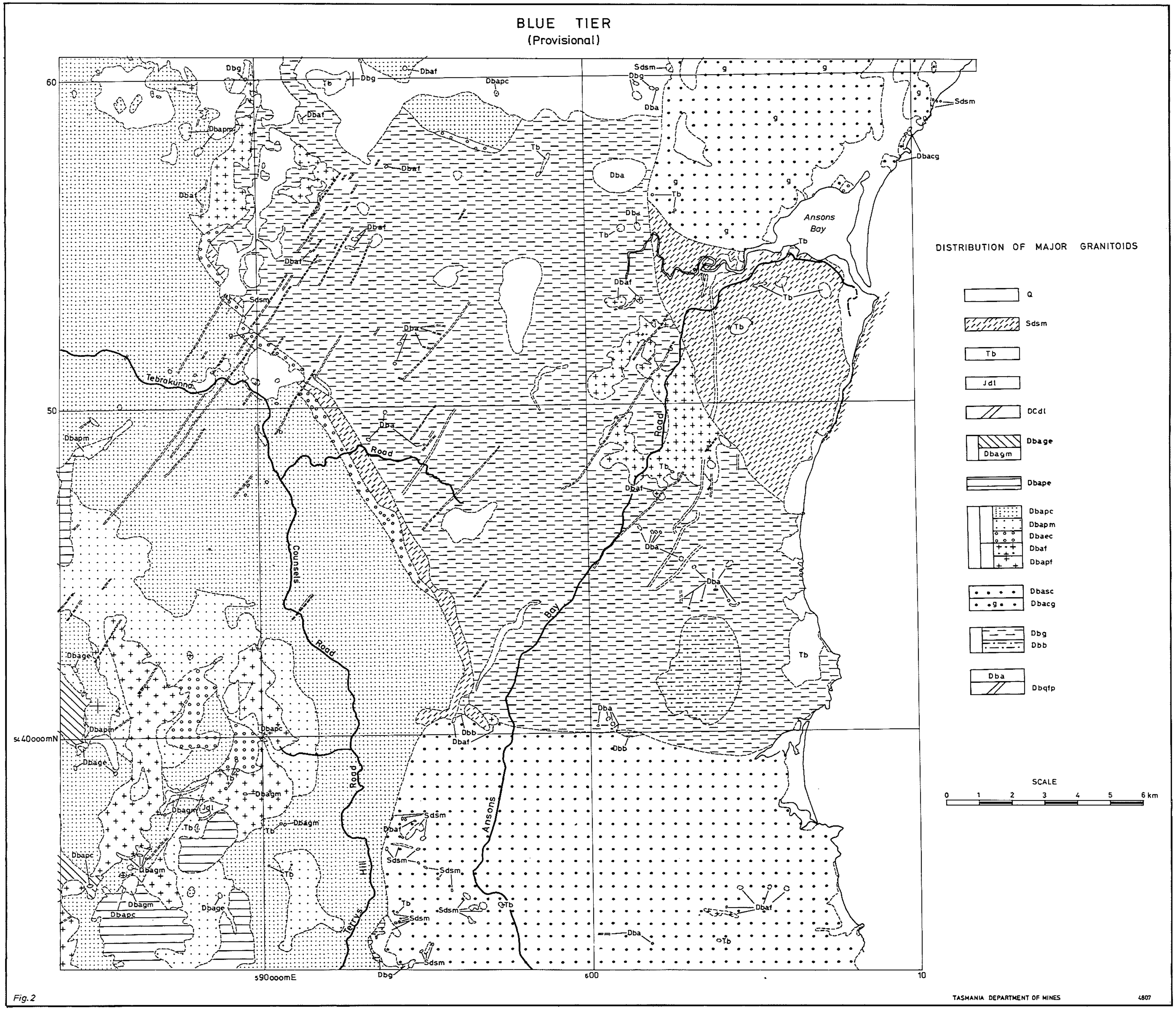
BLUE TIER
(Provisional)
DISTRIBUTION OF MAJOR GRANITOIDS
Q
Sdsm
Tb
Jdl
DCdl
Dbage
Dbagm
Dbape
Dbapc
Dbapm
Dbaec
Dbaf
Dbapf
Dbasc
Dbacg
Dbg
Dbb
Dba
Dbqfp
SCALE
0 1 2 3 4 5 6 km
Ansons Bay
Tebrakunna
Road
Counsels Road
Ansons Bay Road
Terrys Hill Road
590000mE
600
10
5440000mN
50
60
Fig. 2
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Figure 2.

Figure 2. *Geology of the Blue Tier Quadrangle (from McClenaghan and Williams, 1981).*

LEGEND

Q	Quaternary and Tertiary deposits, consisting of alluvium and marsh deposits, beach sand, mobile dune sand and older alluvium. The Tertiary deposits are sand, gravel, granule conglomerate, silcrete and ferricrete.
Sdsm	Contact metamorphosed quartzwacke and mudstone sequences. Mathinna Beds.

IGNEOUS ROCKS

Tb	Tertiary alkali-olivine basalt.
Jdl	Jurassic dolerite.
DCdl	Probably Devonian deuterically altered dolerite dykes.

Devonian Granitoid Rocks

Dbage	Fine to medium-grained biotite and white-mica bearing alkali-feldspar granite. Equigranular varieties.
Dbagm	Fine to medium-grained alkali-feldspar granite with large pale-brown mica aggregates. Pegmatitic patches frequent.
Dbape	Porphyritic to equigranular fine-grained greisenised adamellite with small feldspar phenocrysts (<15 mm) and larger than average quartz grains in porphyritic varieties. Muscovite dominant over biotite in equigranular varieties.

Medium to coarse-grained biotite, minor muscovite adamellite varieties:

Dbapc	with K-feldspar phenocrysts of approximately 25 mm mean size.
Dbapm	with K-feldspar phenocrysts (<25 mm mean size), plagioclase phenocrysts and quartz phenocrysts in medium-grained matrix.
Dbaec	Equigranular.

Fine-grained biotite-muscovite adamellite varieties:

Dbaf	Equigranular.
Dbapf	with small plagioclase (<15 mm) and quartz phenocrysts.

Coarse to very coarse-grained biotite adamellite varieties:

Dbasc	with very abundant K-feldspar phenocrysts (>30 mm mean size) or with seriate texture.
Dbacg	containing garnet.

Granodiorite bodies:

Dbg	Medium to coarse-grained biotite hornblende granodiorite.
Dbb	Medium to coarse-grained biotite granodiorite.

Minor granitic intrusions:

Dba	Aplite
Dbqfp	Quartz-feldspar porphyry.

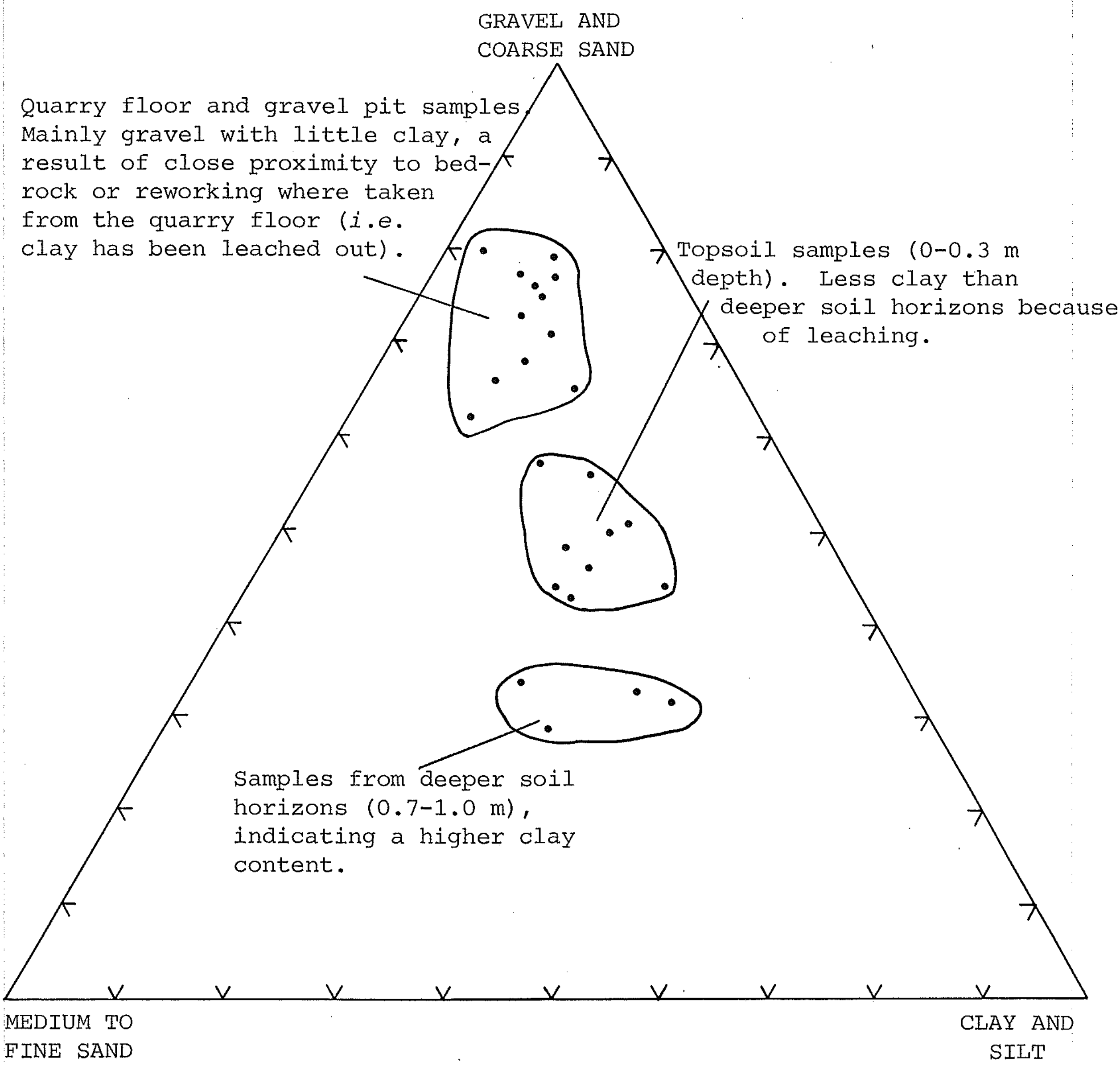

Figure 3. *Grain size analysis of soil and gravel samples, north-east Tasmania. Samples show a variation in depth and/or reworking, rather than a variation between granite types.*

Perhaps the most important consideration concerning erosion potential is the topography of the individual coupes. The area is generally of low undulating relief, but there are some areas with steep slopes (>15°). Where underlain by granite soils, these areas are prone to erosion because of reduced infiltration due to thin soils and steep slopes, both factors being related to infiltration rate. The steep slopes can also result in increased runoff velocities, with a consequent increase in the erosive potential of the runoff water.

An inspection of the Lands Department 1:50 000, 20 m contour interval maps of the region indicates that of the coupes where logging is proposed during the next five years, coupes GC6, 17, 45, 48, 58, 60, 62, and emergency coupe GL2, contain few steeply sloping areas. Provided the 'Guidelines' (1981) are adhered to, few problems can be envisaged, apart from the possibility of deep rutting by machinery in low lying, poorly drained areas. Roads and tracks should skirt these areas or, if access is essential, it is preferable to construct tracks by building up with filling. This prevents alteration of the natural drainage which has occurred in some cases, where permanent ponding of bodies of water has occurred.

Construction of roads in such a way does tend to cause some sediment introduction to water courses, but this is considered to be a minimal effect and far less detrimental than the drainage alteration which may otherwise occur. Some small local areas of moderate to steep slopes may not be readily recognisable from the topographic base maps of the region. Such areas can only be assessed in the field and appropriate measures taken.

Areas of steep slope and high erosion potential occur in coupes GCU2, GC5, GCU11, and GC53. The western section coupe GC5 has steep north-east facing slopes along the flanks of Marguerita Ridge and Murdochs Hill (fig. 4). There is evidence of gully erosion along old logging tracks, especially on the midslope and footslope regions of the steeper area. Soils tend to become thinner towards the ridges, with occasional granite outcrops and boulders evident. Slopes in the steeper region are commonly up to 20° with locally steeper areas to 25°.

Coupe GC5 has topographic similarities to EL1 (Sloane, 1983*a*) and roading and snig track systems can be planned in a similar way, with major access roads along the foot of the slope and ridge location of major snig tracks.

Coupe GC53 has a high potential for erosion, with a large part of the coupe having steep (150°) slopes on the north-east facing flank of McGoughs Lookout (fig. 5). The area also has steep slopes to the west, below the peak of McGoughs Lookout. Slopes are low and gently undulating towards the centre of the coupe, but steepen again towards the eastern margin. This coupe is assessed as having the highest potential for erosion of all the proposed areas because of the large proportion of steep slopes. However a topographic advantage is the area of low slope which occurs near the centre of the coupe. Runoff and sediment yield from the steep western section can be dispersed on this flatter tract.

Main access roads to the western slopes should be restricted either to the two main ridges or along the base of the main slope. Major snig tracks should be located along ridges and careful attention to the 'Guidelines' must be taken, especially regarding the drainage of snig tracks and machinery ruts. The location of major ridge snig tracks should

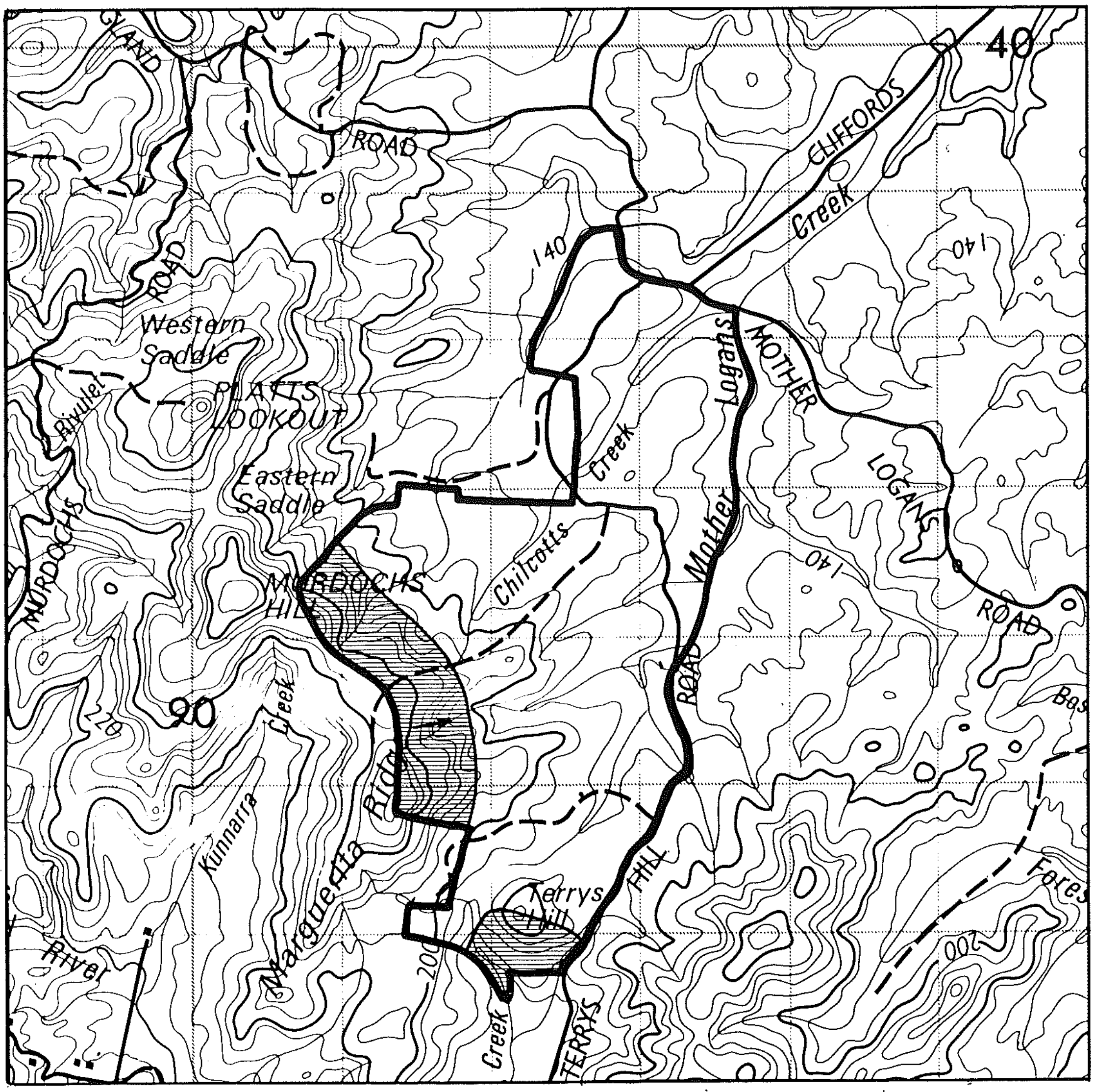

Figure 4. *Forestry coupe GC5. This coupe contains areas of moderate erosion potential on the flanks of Terrys and Murdochs Hills and Marguerita Ridge. Regional slopes are about 14°.*

Scale 1:50 000, contour interval 20 metres.

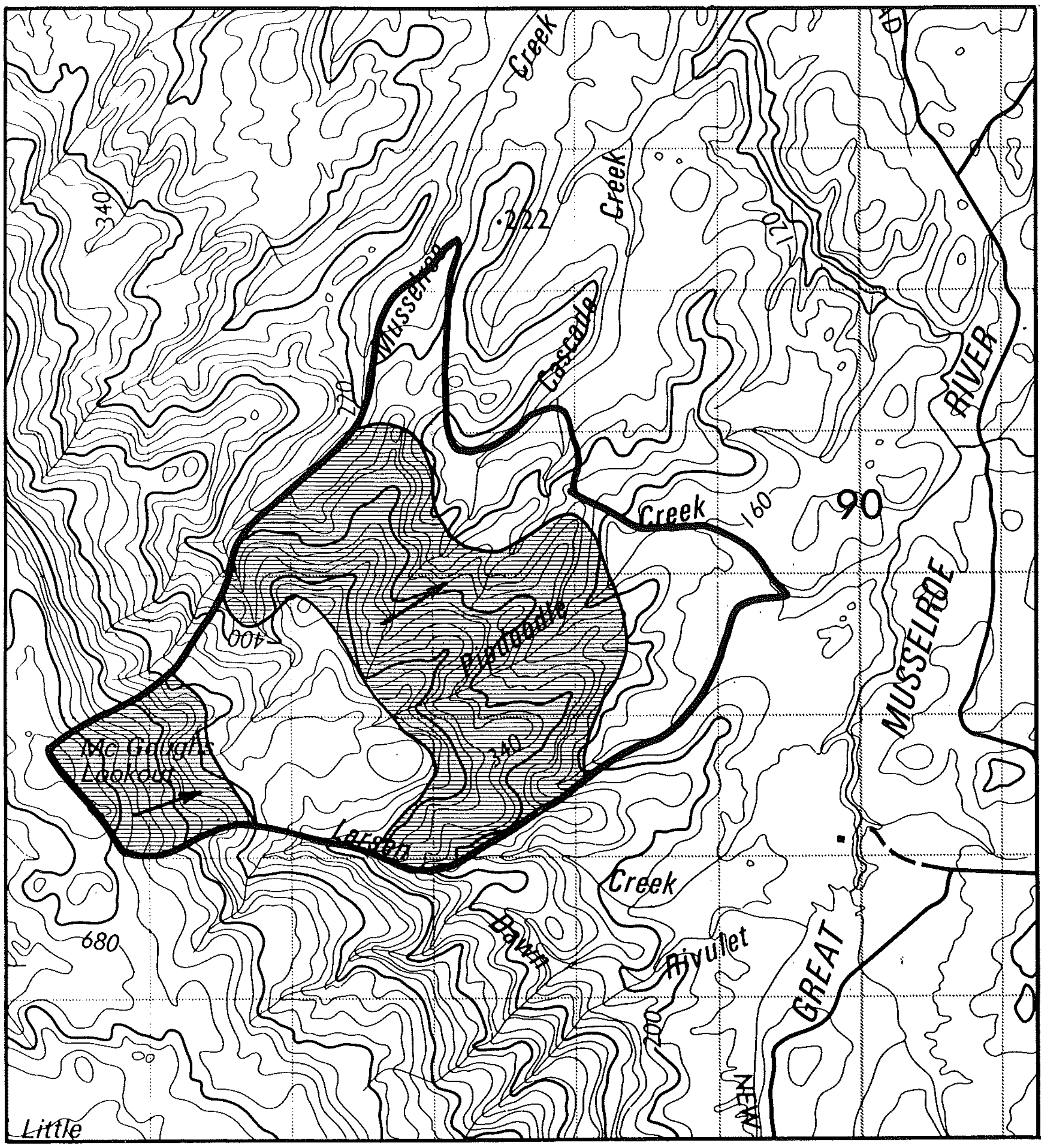

Figure 5. *Forestry coupe GC53. Moderately steep 14°-16° slopes with a moderate to high erosion potential are indicated. The flank of McGoughs Lookout is a sensitive area, as is the long sloping area towards the centre of the coupe.*

Scale 1:50 000 Contour interval 20 metres

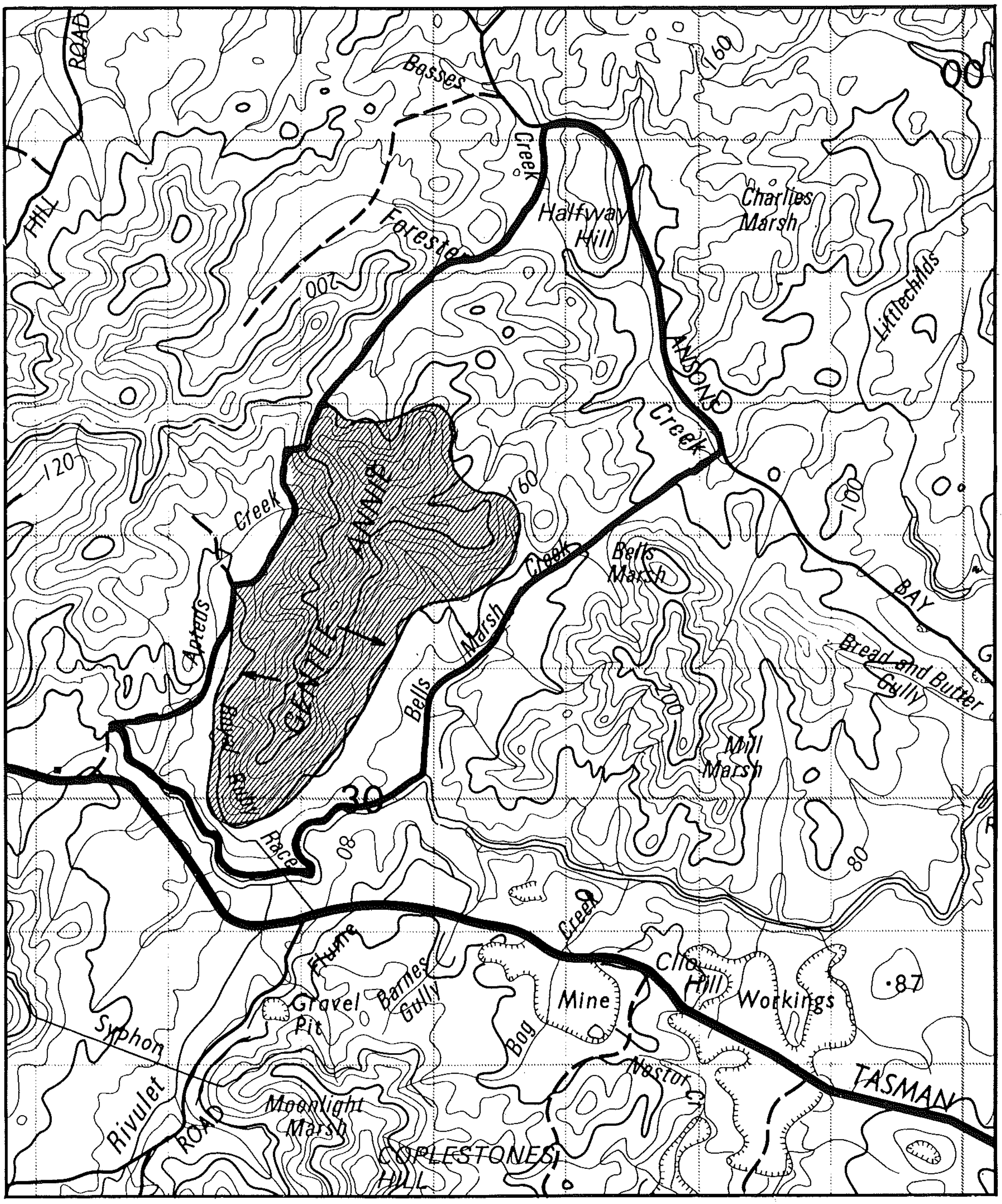

Figure 6. *Forestry coupe GCU2. Areas of moderate to high erosion potential are indicated along the flanks of Gentle Annie. This is a sensitive area due to the proximity of the George River. Regional slopes are about 18°.*

Scale 1:50 000 Contour interval 20 metres

also fit in well with the Environmental Impact Study recommendation restricting maximum snigging distance to 600 m. The steep slopes in the eastern part of the coupe should be dealt with in a similar way, due to the presence of three main ridge spurs in this area.

If consideration is given to the snigging of logs up and across contours to the major snig tracks or roads located along the ridges, gully erosion could be prevented provided, of course, that the 'Guidelines' are followed. The flatter central region should be clear-felled using an uphill snigging pattern. This will disperse any runoff from the adjacent steep slopes to the west.

It is essential that careful planning and control of operations is exercised in this coupe. Good planning, strict adherence to the 'Guidelines', with implementation during and immediately after clear-felling, together with regular inspection and maintenance should control runoff and erosion and thereby preserve the area for future harvesting.

Coupes GCU11 and GCU2 have areas of potentially severe erosion due to steep slopes. The southern half of coupe GCU2 (fig. 6) has Gentle Annie, a central ridge with moderate to steep flanks and a south-west to north-east orientation. The coupe is close to the Tasman Highway and drains almost directly into the George River.

The granite underlying this area is perhaps a little coarser than elsewhere and as such should give rise to coarser grained soils and perhaps a thick footslope 'wedge' of eroded material at the base of the ridge. Erosion in this area, resulting in runoff containing a high sediment yield flowing to Apteds and Bells Marsh Creeks and Royal Ruby Race, would have a detrimental effect on water quality and sediment yield of the George River.

The area is close to private land and to the Tasman Highway. When planning operations, extreme caution is required to ensure that no erosion occurs. Access roads must either be placed along the ridge itself or around the base. Midslope roading is not advised in this coupe. Here again snig tracks must be restricted to ridges, with no snigging permitted adjacent to drainage depressions or small valleys.

There is an absence of defined creeks on the 1:100 000 topographic map and it is considered that retention strips could be located along some of the most obvious drainage channels evident in the field and 'defined' stream length reduced to a distance of one kilometre. It is essential that extra streamside retention areas be included in the operation plans of the coupe. If an access road is placed along the ridge, then consideration should be given to uphill snigging on the upper slopes. The lower slopes can be logged on a downhill snig pattern to access roads at the slope base.

Very careful attention to snig track drainage is essential. Frequent scoops could also be used in this area as well as small sediment dams on major drainage channels. Every attempt must be made to prevent erosion and if sediment movement does occur, then it must be contained in as small an area as possible. Control measures as indicated in the 'Guidelines' must be implemented both during and immediately after clear-felling operations.

The inspection of the region has done little more than confirm that easily erodable granite soils of varying depth occur over the majority of

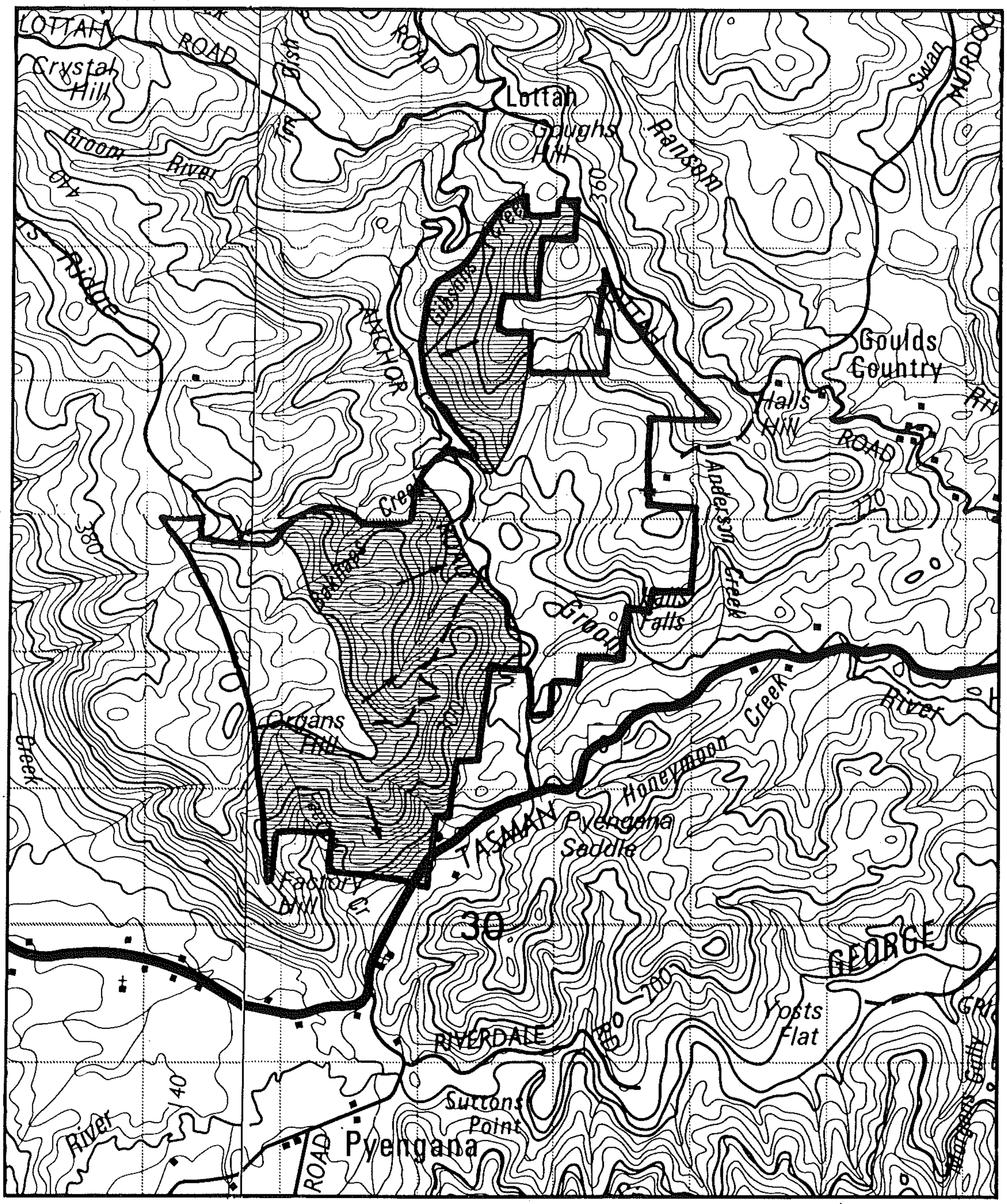

Figure 7. *Forestry coupe GCU11. Steep 18°-23° slopes with a moderate to high erosion potential occur around the flanks of Organs Hill. This area is sensitive as it is close to the George River.*

Scale 1:50 000 Contour interval 20 metres

the area, that no great differences could be observed between soil types developed on different granite types, and that all such soils should be considered equally susceptible to erosion. Steep parts of the region are undoubtedly more susceptible to erosion than flatter parts. Erosion has previously occurred in the region, mainly due to disturbance by machinery tracks.

The above statements appear obvious, but perhaps the major point of the investigation is to stress that serious erosional consequences can result unless personnel are aware of potential problems and take appropriate preventative action. Little erosion will occur if all aspects of clear-felling operations are carefully planned, if comments in this report are carefully considered, if the 'Guidelines' are conscientiously implemented at all stages both during operations and after operations cease, and if regular inspection and maintenance occurs after the region has been harvested and replanted.

Adjacent areas of tin sluicing operations provide examples of the effects of erosion and extreme ground disturbance. Large areas of the old tin workings are virtually unrestorable, millions of tonnes of topsoil and subsurface sand, gravel and clay having been lost. Sluicings have been discharged into streams and the resultant effect can be seen from the sediment choked George River and Golden Fleece Rivulet.

One of the effects of such sedimentation is an increase in flooding of these streams. Other streams in the region obviously carry high bedloads. The Great Musselroe and Ansons Rivers are examples, with large amounts of gravel and sand along their courses. It is essential that sediment yields of these streams are not increased as a result of clear-felling operations. Careful attention to the 'Guidelines', plus frequent inspection after clear-felling, will ensure this.

Coupe GCU11 is another proposed logging area which has steep slopes, especially around Goughs Hill to the north and Organs Hill to the south (fig. 7). These areas drain towards the Groom River, a major tributary of the George River, which dissects the coupe. Previous comments on erosion sensitive areas apply to this coupe, especially that area to the south-west of Anchor Road. Ridge roading and snig tracks, extra stream-side retention areas, careful implementation of the 'Guidelines' *etc.* are all essential in this coupe. The retention of contour vegetation strips could also be considered in the sensitive sections of GCU2 and GCU11. These strips not only reduce the visual impact of operations adjacent to areas of population and highways, but also act as filter strips reducing runoff velocities and acting as sediment traps, similar to the ways that contour ploughing and strip cropping are used in agriculture to prevent erosion.

SUMMARY AND CONCLUSIONS

One of the main effects of clear-felling operations in a previously forested region is an increase in runoff for a period of up to five years after operations cease. This increase is related to a reduction in infiltration, interception and evapotranspiration, compaction of soils, and alteration of drainage due to ground disturbance. This increase in runoff, together with the removal of vegetation and ground disturbance, can result in increased erosion with a deterioration of water quality in adjacent streams and an increase in sediment yield. The Forestry Commission's 'Guidelines' are designed to minimise such detrimental effects of clear-felling operations.

From an inspection of areas previously clear-felled and regenerated at coupe EL1 at Chain of Lagoons (Sloane, 1983*a*), several important factors related to erosion can be observed. The surface soils and underlying weathered parent materials of the granite bedrock are highly susceptible to erosion, especially on steep slopes during periods of high intensity rainfall to which the area is subject. Soils are thinnest towards the crests of steeper slopes, with granite outcrops and boulders evident. Midslope to footslope areas have thicker soils, often up to two metres or more in depth. Such areas are prone to erosion, confirming our understanding of runoff models, and gullying to depths of two metres can be observed. Both sheet and gully erosion occur, with gully erosion perhaps the most obvious and more dominant form.

From the observations at EL1 and the work of others (Sloane, 1983*b*), the main sources of erosion and sediment yield to streams are caused by ground disturbance, particularly from roads, access tracks, and snig track ruts. Erosion which has occurred at EL1 is related to such features and has been accelerated by a delay between the cessation of logging operations and the implementation of erosion control. It is highly important in areas underlain by granite soils that careful attention is paid to the drainage of areas of disturbance, both during logging and immediately after logging operations cease.

Careful planning of roads and snig track systems is essential, roads preferably being located along ridges or at the base of slopes. Midslope and upper footslope locations are not advised due to their sensitivity to erosion. Scoops could be a useful addition to the other drainage provisions of the 'Guidelines' (1981). These scoops are easily constructed and have been used in some areas at the ends of road drains, where they act as settling ponds or sediment traps. Logging debris can also be used on the downstream side of scoops to act as a barrier and sediment trap for any overflow.

The granite sand and gravel surface of roads is considered to be a major source of sediment and therefore scoops or small sediment dams should be constructed on road drains. Grip drains are considered to be essential in snig track drainage, provided they are constructed correctly and attention is given to their direction of drainage. Logging debris can be used in conjunction with grip construction, but such debris is not suitable as a sole means of intercepting runoff. Deep rutting caused by machinery must also be drained in a similar way to snig tracks.

Both uphill and contour snigging of logs are considered to be desirable methods on highly erodable granite soils. These methods may be impractical in some steep areas due to the limitations of machinery and undesirable ground disturbance on steeper sections. Even so, uphill snigging should be used wherever possible with areas of downhill snigging perhaps separated by areas of uphill snigging. This system is advantageous even on the low slopes at the foot of steeper areas, as the network of tracks distributes any runoff from the steeper areas in a divergent pattern.

Elsewhere, on moderate to steep slopes, major snig tracks or access tracks should be restricted to a ridge system and consideration should be given to a system where logs are dragged up and across contours to the ridge tracks. Downhill snigging will no doubt be the only practical method in many steep areas and therefore the drainage of these tracks becomes of major importance.

The convergent system of tracks is considered difficult to drain efficiently, especially close to the logging landing. Drainage of such areas must be maintained and inspected regularly, particularly during the first five years after logging.

Consideration should be given to reducing the length of a 'Defined Stream' to a distance of one kilometre, particularly in areas with slopes greater than 10°. In some particularly sensitive areas, such as the steeper parts of coupes GCU2 and GCU11, the defined length could be reduced even further. Consideration should also be given to the retention of 30 m strips of vegetation along the contours at intervals of approximately 200 m. These modifications should be considered due to the prevalence of steep slopes in GCU2, GCU11 and GC53, and the close proximity of these slopes, particularly in GCU2 and GCU11, to major water courses, private property, and a major highway. The areas considered to be of high erosion potential in the proposed area of operations north of St Helens have been outlined in this report. The majority of the region has low slopes and is gently undulating and thus few problems are envisaged. Steep slopes on the flanks of Murdochs Hill and Marguerita Ridge in coupe GC5, the slopes of McGoughs Lookout in coupe GC53, and the southern and south-western parts of GCU2 and GCU11 are potentially high erosion areas and as such must be carefully managed. Implementation of the 'Guidelines' (1981) and other suggestions in this report have been already discussed. It is important that frequent inspection and assessment of these areas is made, particularly after operations cease. There may be a necessity for maintenance and modified interpretation of the 'Guidelines' and the suggestions given in this report, in view of local problem areas.

Soil is the most important basic resource of the forest and conservation is highly important in order to minimise erosion and preserve the capacity of the area for reafforestation and further harvesting. Erosion of a region may not only reduce the forest-bearing capacity but may reduce access, increase restoration costs, and generally make further operations more difficult and expensive.

The 'Guidelines for the Planning and Control of Logging in Native State Forests' (1981), produced by the Forestry Commission of Tasmania, is considered to be very thorough and comprehensive as regards Section 3.2, Soil Erosion and Control Measures, and only minor modifications and suggestions have been presented in this report.

Previous operations may have tended to lull personnel into a false sense of security as regards the effects and potential for erosion in the granite soil regions, due mainly to the fact that most regions previously logged are located on rock types with soils of low erosion potential. In these areas, other problems such as slope instability may predominate, and operations have been adjusted and modified to allow for such eventualities. It cannot be stressed strongly enough that the granite soils of the regions of proposed operations in far north-east Tasmania are highly erodable and that consideration of erosion control must be given during planning and implemented during logging and immediately after logging operations cease. Soil disturbance resulting in some erosion is virtually inevitable during forestry operations. The purpose of the 'Guidelines' is to minimise disturbance and to contain its effects as far as possible within the confines of the logging coupe.

From discussions with Forestry Commission personnel and speaking at a Foresters meeting in the north-east, it is considered that there is a good appreciation of the potential erosion problems, the effects of erosion, and its control. Personnel appear completely capable of assessing localised problems which may occur in the field. If problems are quickly assessed and prompt remedial action taken, adherence to the 'Guidelines' and suggestions in this report should cover virtually all situations adequately.

Contractors are becoming educated to the problems, the purpose, and the need for implementing erosion control procedures. This process of involvement and information should continue. In the long term the measures that are being taken at this stage preserve the area for future harvesting operations and reduce the costs of any redevelopment and restoration which may be required in the future.

This investigation has largely confirmed that present operations and guidelines are generally sufficient and that only minor modification and stricter adherence is required. This series of reports has discussed the erosion problem in some depth. The first section (Sloane, 1983*b*) has been prepared as background knowledge to assist in an understanding of runoff and erosion. Knowledge of these processes is important. The literature search agrees with our intuitive knowledge and understanding of the problem but confirms it in a more quantitative way. The search indicates the results of studies often conducted over a long term and in detail. We are currently restricted as to the type of investigation we can conduct and thus the applicability of these studies to similar problems in similar areas is quite pertinent.

MONITORING AND MEASUREMENTS

Any approach to erosion and sedimentation studies must include an assessment of the site differences such as the geology, climate, topography, soils and vegetation, as well as the method of logging. Consideration of the logging methods includes the silvicultural system, skidding methods, and erosion control measures implemented both during and after logging operations.

Site differences result in variations in erosion even in an undisturbed forest and have a major role in governing the reactions of areas. The methods involved in the total harvesting and reafforestation programme are important in governing the amount of accelerated erosion. Most studies use sedimentation data to provide an index of the effect of logging on erosion and the data provide an integrated measure of the erosion over an entire watershed, including channel erosion. There is also an important need to identify source areas by observation.

Measurement of the processes operating is essential to substantiate and quantify relationships between the forms observed and processes involved. A great number of processes and parameters are available for selection and data may be collected by a wide variety of techniques and instruments. Clearly defined objectives are required but cost may be a deciding factor regarding techniques and instruments to be used.

Important measurements include the input of precipitation, the interactions within, and the output of water, sediment and solutes from the selected catchment area. Point and continuous measurement techniques may be employed, although point measurements are the more practical in relation to any proposed erosion studies in north-east Tasmania because of the lower capital expenditure.

The measurement technique is also directly related to the problem of sampling in both space and time. Observations which are based on a set time interval may miss many of the extreme events associated with a parameter which varies markedly with time. It may also require a long time interval of data collection to provide valid conclusions about the magnitude and frequency of specific events and processes. Problems of sampling in space are equally relevant as, apart from measurements of the output of channel flow and sediment and solute yields from a catchment, most data collected pertains to small areas or points within the catchment.

The initial input is precipitation, the quantitative assessment of which is a primary measurement. Problems related to measurement lie in assessing the possible errors inherent in the values obtained from the technique used. Other problems are related to the extrapolation of point measured results to the whole basin.

Measurement of surface runoff may be made by installing a trough on the watershed slope and collecting the intercepted water in a container or recording apparatus. Runoff plots may be constructed by surrounding the area with a cutoff wall, the downslope boundary being shaped to convey the surface runoff to an outlet point where it can be measured. In this method the interruption of the flow by a collecting trough does not materially influence the flow, as the flow is driven by surface gradient only. Runoff plots are often used to document soil erosion as well as runoff production. Measurement of subsurface flows is much more difficult, as any interruption to the site by digging of trenches *etc.* considerably modifies the hydraulic conditions.

Rainsplash erosion is usually difficult to measure, as it involves assessing the movement of particles in the zone above the soil surface. The simple gravimetric approach uses trays of soil or small field plots surrounded by metal frames or troughs to catch the splash material. Soil splash is a component of sheet erosion and as such it is often convenient to measure the overall effects of sheet erosion, generally by trapping entrained sediment in collectors, essentially the same as those used for collecting overland flow.

An alternative approach to the assessment of sheet erosion involves measuring the rate of lowering of the ground surface and calculation of the volumes removed. Values so obtained provide a useful check against direct measurements of removal rates. Surface elevation changes can be measured by levelling and relevelling a line between known bench marks. Erosion pins or the changes in the exposure of metal stakes driven into the ground can be used (Schumm, 1964). Other workers have used nails, with washers below the head, which are driven into the ground so that the washer is flush with the surface (Leopold, Emmett and Myrick, 1966). Subsequent measurements of the gap between the nail head and the washer, or accumulation above the nail head, provide an indication of surface lowering or accretion respectively. Sections of brass welding rod have also been used as erosion pins. A large number of these pins is required in order to obtain a representative result.

Rill and gully erosion assessment can be approached by measuring the amount and rate of discharge of sediment from a gully outlet, which can then be related to the overall volume of erosion. Check dams can be constructed to provide observations on rates of sedimentation. Alternatively the development of a rill and gully system may be documented by periodic surveying, both in plan and section, together with calculation of the amount of material removed. Repeated aerial photographs are also valuable in demonstrating the development of the erosion system.

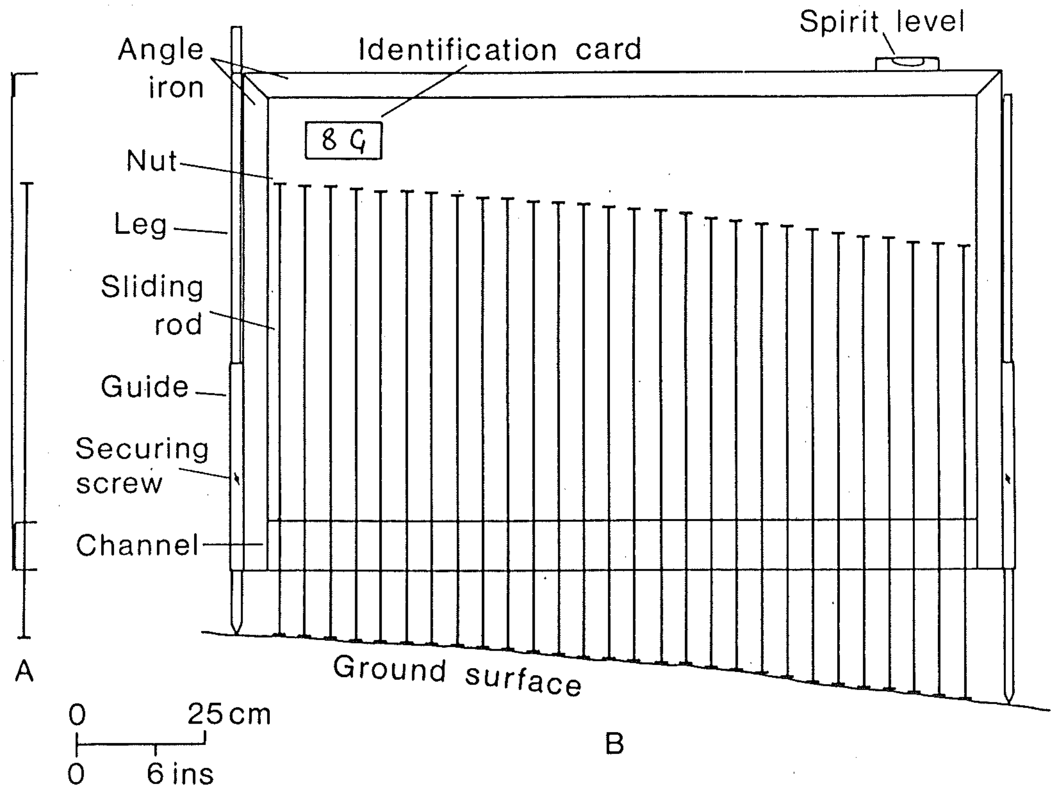

Figure 8. *Slope profiles (after Mosley, 1975, p.5). A = side elevation, B = front elevation. Horizontal lines on the backboard are omitted for clarity.*

Erosion measurement by surveying gully profiles has already been attempted by the Tasmanian Forestry Commission. The method entails measurement from a horizontal rod, placed on reference pegs on either side of a gully site. This enables the periodic plotting of profiles across erosion features. A similar method of slope profiling has been developed by Mosley (1975) and is shown in Figure 8. Sliding vertical rods follow the ground profile and are photographed, to be later scaled and plotted, enabling rapid profile recording.

Measurements of the suspended sediment concentration of discharging streams are of primary importance, as most assessments of this type of sediment transport are based on such values. Concentrations vary within a stream cross-section, so sampling devices are required which will provide representative samples. These devices must be designed so that the flow velocity of the sampler intake must be the same as the stream velocity. The sampler should also cause little flow disturbance at the sampling point and must be oriented into the flow in both vertical and horizontal planes. The subsequent laboratory analysis of suspended sediment samples obtained in the field is an integral part of the sampling method.

Bedload transport is extremely difficult to assess because the pattern of flow and transport is often altered by the sampling device. Other problems include the difficulty of positioning the measuring apparatus on an uneven and variable channel floor, sampling efficiency, and the irregular movement of bed material.

Several different types of measuring apparatus are used, including slot traps, collecting basins, basket samplers, tray samplers, pressure difference samplers, and acoustic and pressure sensitive devices. The slot type sampler has been used by the Tasmanian Department of the Environment in an attempt to monitor bedloads of the Meredith and Macquarie Rivers.

Its function is self explanatory and on small streams the pit can contain a removable collecting box. The practical application of a slot trap involves considerable problems in terms of construction, emptying and overfilling. A collecting basin or sediment dam is similar in concept except that a structure is built across the stream to form a pool in which the bedload will be deposited. The simplest form of measuring device is the basket sampler, a mesh box which is lowered to the bed and oriented with the entrance upstream.

The sediment yield of a drainage basin or catchment is the result of the processes of erosion, transportation and deposition operating on that catchment and its magnitude reflects the sediment delivery ratio. The sediment yield may be estimated by evaluating the individual processes but generally direct measurements are made of the total sediment load by measurement at the outlet of the watershed over a long period of time. Techniques available include reservoir sedimentation studies, fraction collectors, and sediment sampling. Reservoirs and artificial ponds can provide good data, because measurements of the rate of accretion of deposited sediment directly reflect the sediment yield of the tributary watershed.

Other methods of observing sediment transport by running water relate to the visual examination and recording of forms which are assumed to result from these processes. For example, overland flow may be indicated by flattened vegetation or vegetation debris draped around obstructions such as plant stems. If debris has been transported, evidence of deposition may be seen in small hollows or adjacent to obstructions which interrupt the flow of water. Rainsplash may be shown by the formation of small pedestals capped by stones.

The assessment of dissolved loads or solutes within a catchment is extremely difficult, due to the need to isolate natural processes from man-induced influences. In some areas the dissolved load of a stream may be many times greater than the solid load. Laboratory analysis can provide data on many parameters of chemical quality, but the concentration of total dissolved solids (TDS) in milligrams per litre (mg/*l*), specific conductance or conductivity (μS/cm) and the concentrations of individual ions (mg/*l*) are of most interest.

D. Polya of the Department of Mines (pers. comm.) who has conducted water quality studies, considers that water quality data are valuable as direct measurements of nutrient losses and also in estimating catchment disturbance. The concentration and major element chemistry (HCO_3^-, Cl^-, SO_4^{2-}, SiO_2, Ca^{2+}, Mg^{2+}, K^+, Na^+ and pH) of both total suspended solids (TSS) and total dissolved solids (TDS) should be determined. Analyses for some minor chemical components such as NO_3, phosphate, boron, and dieldrin may also be of value.

Polya also considers (pers. comm.) that monitoring of TSS in runoff may be used to estimate denudation rates if discharge values are known. Such estimates are generally lower than the actual values because significant amounts of material may be removed in very short periods of time that may occur within the sampling interval.

In many areas TSS may be expressed as an empirical function of discharge so that close monitoring of discharge can lead to a reliable average denudation rate. Polya also considers (pers. comm.) that in contrast to TSS, the TDS content of runoff remains relatively constant at unusually high discharges. TDS is the main indicator of increased catchment disturbance and gives an insight into the nature and extent of chemical interaction between precipitation and the land. Meaningful interpretation of TDS analysis is dependent on correct sampling technique (Brown *et al.*, 1970). It is also preferable that both pH and HCO_3^- are measured directly on sampling in the field.

The extent to which the various techniques are incorporated into a particular catchment study will depend on the scope and objectives of the project. The required equipment and instrumentation will depend on the character of the watershed, the approach, and the funds available to the researchers. Studies may be largely observational or may contain a varying amount of instrumentation. The techniques used may vary as calibration is required to determine the normal response of a catchment before the changes are introduced, and to predict the pre-treatment response. With a single catchment the 'before and after' technique involves calibration of the catchment against climatic variables for a number of years before the treatment is carried out and the deviations from the predicted response are assessed.

The paired catchment procedure involves the use of an untreated control catchment with similar characteristics to the experimental catchment which is to be treated. The paired catchments are initially calibrated for some years before treatment of one is undertaken, the effects of treatment being measured as departures from the predicted behaviour of the treated basin.

The methodology and evaluation of monitoring procedures for an erosion study has been summarised in Appendix I.

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[3 May 1983]

APPENDIX 1

Monitoring programme

DECIDE ON AIM

- how much erosion?
- where is erosion occurring?
- contribution of processes?

Gives
- outline of areas of varying erosion potential.
- indication of erosion control measures required.
- effectiveness of erosion control measures.

DECIDE ON TECHNIQUES AND INSTRUMENTATION REQUIRED

Observational approach
- erosion forms *e.g.* gullies, rills *etc.*
- depositional forms *e.g.* sediment fans.

Need regular inspection
- plotting on maps or enlarged air photos of suitable scale.
- periodic air photo runs of selected areas.

Gives
- development and extent of erosion and deposition both in space and time.

MEASUREMENT AND/OR INSTRUMENTATION

Runoff plots
- quantity sheet erosion and runoff volumes.
- careful selection of representative sites.
- may need numerous sites.
- problems as only point sample.

Erosion pins
- quantity rates of surface lowering by erosion and also accretion.
- may be incorporated with runoff plots.
- need many sites which must be representative.
- only a point sample - problems with extrapolation.

Gully and rill monitoring
- snig track gullies *etc.* can be profiled at selected representative points.

Gives
- idea of where most erosion and deposition is occurring in association with gullies.
- estimate of volumes removed and rate of removal perhaps in comparison with results from runoff plots.
- may also be applied to road drains.

Sediment Dams
- can be used for road drains, snig tracks, gullies *etc.* especially at major discharge points.
- simple to construct, easy to monitor. Can be monitored using deposition and erosion pins.
- also acts as erosion control feature.

Gives
- good overall measure of sediment yield from combined processes.

Chemical and Suspended Sediment
- requires accurate measurement of discharge at same time of sampling.
- requires accurate sampling technique.
- frequent monitoring as large scale events may be missed.
- laboratory analysis of samples.

Appendix 1 (continued)

- require 'before and after' monitoring over long period on 'paired catchment' technique.
- above are requirements for *meaningful* results.
- expensive and time consuming considering means available.
- perhaps best monitoring - paired catchments sampled at same time.
- one control catchment and one treated.
- need calibration before treatment to check similar responses.

Gives - qualitative idea as to effects of treatment and an estimate as to the magnitude of treatment effects.