SEDIMENT YIELDS AND STREAM CATCHMENT VARIATION IN SOUTH-EASTERN TASMANIA

By

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Except as stated herein this thesis contains no material which has been accepted for the award of any other degree or diploma in any other university, and that, to the best of my knowledge and belief, the thesis contains no copy or paraphrase of material previously published or written by another person, except when due reference is made in the text of the thesis.

L.J. Olive

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ABSTRACT

The study is an examination of the sediment loads and erosion rates of three small catchments in south-eastern Tasmania. Only that part of the load known as the wash load has been considered. Also, the suspension and solution load components of the wash load have been determined. The bed load has not been examined because of the absence of any accurate method for its determination.

The previous literature on sediment yields is examined showing the dominance of work carried out in the United States of America in this field. Only a small number of studies have been carried out in Australia, with no previous studies in Tasmania. A review of methods used in sediment studies revealed a wide range, many of which proved unsatisfactory for this study. The method used in this study, involving the use of ashless filters, was the most accurate known to the author at the time of the study although it is subject to some limitations.

A description of the environment of the area is given. The landforms, geology, vegetation and climate of the three catchments are similar varying only in the proportions of each catchment which are made up of the various lithological and vegetational units.

The wash load of the streams was sampled over a period of twelve months while the suspension and solution loads were examined for only three months. From the information obtained sediment rating curves and daily sediment yields were determined. The computed daily sediment yields revealed the dominance of individual run-off episodes

where up to 20 per cent of the annual load was removed in one episode. These episodes were separated by long periods of basal flow when sediment transport was minimal. It also illustrated the importance of the solution load which made up 65 to 85 per cent of the total wash load. This high figure is due to some degree to the inability of the laboratory method to separate colloidal material from the solution load. The solution load was much more constant than total wash load with individual run-off episodes not being so dominant. The suspension load however was extremely concentrated in individual run-off episodes with only negligible transport during basal flows.

Erosion rates were also determined ranging from 140 to 156 tons per square mile. These fall into a similar range to those found elsewhere in Australia. A linear relationship was found between erosion rates and rainfall in Australia. This contrasts with results obtained in America where erosion rates increased with rainfall to a maximum at 12 inches per annum and then decreased as rainfall increased. These differences are due to differences in vegetation with the American vegetation changing with climate while that in Australia is relatively constant.

An examination of the influence of various catchments revealed significant relationships with lithology and vegetation. Erosion rates were greatest on sandstone and mudstone areas and lower from dolerite areas. Also, a greater proportion of the sandstone and mudstone was carried in suspension while the dolerite was transported in solution or colloidal suspension. Wash load was also greater from forest areas than from the other vegetational types. This is due to the lack of ground cover in the forest area.

TABLE OF CONTENTS

		Page
Chapter 1	THE PROBLEM	1-19
	Bed load	1
	Suspension load	5
	Solution load	13
	Wash load	18
Chapter 2	THE STUDY AREAS	20-39
	Previous studies :-	20
	1) the world	20
	2) Australia	25
	The Study Area	27
	The Physical Environment	30
	1) Geology	30
	2) Climate	33
	3) Topography	34
	4) Soils	36
	5) Vegetation	38
Chapter 3	METHODS AND TECHNIQUES	40-60
	Streamflow measurement	40
	Wash load sampling	46
	Laboratory analysis of sediment	55
	1) Wash load	56
	2) Suspension and solution loads	58
Chapter 4	BROWNS RIVER	61-85
	General environment	61
	Rainfall and runoff	67
	Sediment Data	73
	1) Wash load	75
	2) Suspension load	81
	3) Solution load	82
	Denudation Rates	83
	Summary of Results	84

		Page
Chapter 5	SNUG RIVULET	86-112
	General environment	86
	Rainfall and runoff	91
	Sediment data	99
	1) Wash load	99
	2) Suspension load	107
	3) Solution load	109
	Denudation Rates	110
	Summary of Results	110
Chapter 6	MOUNTAIN RIVER	113-136
	General environment	113
	Rainfall and runoff	119
	Sediment data	124
	1. Mountain River below the tributary	124
	i) Wash load	124
	ii) Suspension load	131
	iii) Solution load	132
	iv) Denudation rates	133
	2. Mountain River tributary	133
	3. Mountain River above the tributary	134
	Summary of results	135
Chapter 7	DISCUSSION OF RESULTS	137-171
	Rainfall and runoff	137
	Sediment data	139
	1) Wash load	139
	2) Suspension load	148
	3) Solution load	152
	Comparison with other studies	155
Chapter 8	CONCLUSIONS	172-177
Bibliography		178-184
Appendices		185-196

MAPS AND DIAGRAMS

			Page
Figure	1	Vertical distribution of varying sediment sizes	8
	2	Vertical distribution of sediment	9
	3	Transverse distribution of sediment	11
	4	Variation of sediment with changing bed form	12
	5	Catchment variables	14
	6	Location of the study area	29
	7	Rainfall of south-east Tasmania	35
	8	V-notch weir rating curve	42
	9	Mountain River rating curve	43
	10	UNE sediment sampler	48
	11	Relationship between sampler intake velocity and water velocity with constant depth	52
	12	Relationship between sampler intake velocity and depth	54
	13	Browns River catchment area	62
	14	Browns River geology	64
	15	Browns River vegetation	66
	16	Browns River hydrographs	71
	17	Browns River double mass curves	74
	18	Browns River runoff episode 15th-30th May 1969	79
	19	Browns River sediment rating curves	80
	20	Snug Rivulet catchment area	87

Page

21	Snug Rivulet geology	89
22	Snug Rivulet vegetation	92
23	Snug Rivulet hydrographs	96
24	Snug Rivulet double mass curve	97
25	Snug Rivulet - Browns River rainfall double mass curve	99
26	Snug Rivulet - Browns River discharge double mass curve	100
27	Snug Rivulet runoff episode 15th-30th May 1969	105
28	Snug Rivulet sediment rating curves	106
29	Mountain River catchment area	114
30	Mountain River geology	116
31	Mountain River vegetation	118
32	Mountain River hydrographs	123
33	Mountain River runoff episode 15th-30th May 1969	128
34	Mountain River sediment rating curves	130
35	Wash load rating curves of the three streams	144
36	Suspension load rating curves of the three streams	150
37	Solution load rating curves of the three streams	154
38	Variation of sediment concentration with annual precipitation in the United States	158
39	Relationship between sediment yield and precipitation in Australia	162

		Page
40	Relationship between sediment yield and precipitation in the United States	163
41	Relationship between solution load and runoff in the United States	171

TABLES

		Page
1.	Browns River rainfall data	69
2.	Browns River wash load data	77
3.	Browns River suspension and solution load data	78
4.	Snug Rivulet rainfall data	94
5.	Snug Rivulet wash load data	102
6.	Snug Rivulet suspension and solution load data	103
7.	Mountain River rainfall data	120
8.	Mountain River wash load data	125
9.	Mountain River suspension and solution load data	126
10.	Mountain River tributary and the Mountain River above the tributary - wash load data	127
11.	Denudation rates in Australia	159
12.	Siltation rates in Australian reservoirs	160
13.	Denudation rates in the Unites States	165
14.	Suspension load data for Australia and the United States	167
15.	Solution load data for the United States	170

CHAPTER 1

THE PROBLEM

Sediment can be transported in a stream as bed load, suspension load or solution load. Generally these three types are related to different variables and in many ways operate in distinctive ways. Although three types of transport have been proposed there are no distinct boundaries between them and it is possible for particular sediment particles to fluctuate between two types. Relatively fine bed load material may pass into suspension if stream velocity is increased. Also colloid particles which are theoretically part of the suspension load are often difficult to separate from the solution load due to their weak electrical bonds with the water. A further type of sediment load known as the "wash load" has been proposed by Einstein[1]. This load is that which can be carried by the stream independent of the stream velocity and is made up of the solution load and the greater proportion of the suspension load. It is the wash load that this thesis is primarily concerned with.

BED LOAD

The bed load is that part of the sediment load which is moved slowly by the stream by rolling, sliding or saltating on or very near the bed. It generally constitutes the bed of the stream and has a

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1. Einstein, H.A. (1964) "Sedimentation, Part II, River Sedimentation", Section 17-II in the Handbook of Applied Hydrology, V.T. Chow (ed.), McGraw-Hill, New York.

size range the same as the bed material. Although transport is usually slow, it is spasmodic, with long periods of little movement followed by short periods of relatively rapid movement associated with floods or periods of high flow. Once in motion larger grains tend to move faster and more easily than smaller ones and round particles move more easily than flat or angular ones.

The grains often move by rolling or sliding for short periods. Saltation will occur if the instantaneous hydrodynamic lift is greater than the weight of the particle, while deposition will occur when the flow conditions will not re-entrain them. Morisawa[1] has stated a number of ways in which a grain can be entrained: water velocity can differ over the grain creating a drag; differences in velocity direction can create a similar drag; or upward velocity components of an eddy can also lift a grain from the bottom. Regardless of the way in which a grain is entrained, the force required is known as the critical tractive force.

While there is general agreement on the physical principles involved in the movement of the bed load a large number of theories has been proposed to relate bed load movement to the stream variables. Little work was done to find out the factors controlling bed load movement until Gilbert carried out a number of flume tests in 1914[2].

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1. Morisawa, M. "Streams their dynamics and morphology", McGraw-Hill, New York, 1968, p. 47.

2. Gilbert, G.K. "Transportation of debris by running water", US Geol. Surv. Prof. Paper 86, Washington, 1914.

He aimed to relate bed load quantity to the discharge, stream slope and degree of comminution of the debris. No empirical relationship between the bed load and each variable was found but he did conclude that the tractional load was related to the controlling stream conditions in a highly complex manner and the laws of control were qualified by all other conditions.

Since Gilbert's work a great deal of research has been carried out and many hundreds of papers published on the relationship between the bed load and stream variables but as yet there is no agreement on the relationship which exists. Bagnold[1] has written "During the present century innumerable flume experiments have been done, and a multitude of theories have been published in attempts to relate the rate of sediment transport by a stream of water to the strength of water flow. Nevertheless, as is clear from the literature, no agreement has yet been reached upon the flow quantity discharge, mean velocity, tractive force, or rate of energy dissipation - to which the sediment transport should be related". What is agreed upon is that the movement of the bed load is related solely to internal stream variables and catchment variables have no influence.

Because of the complexity of the problem many workers have disregarded the theory of the controls of bed load movement and have concentrated on practical problems rather than scientific explanations.

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1. Bagnold, R.A. "An approach to the sediment transport problem from general Physics", US Geol. Surv. Prof. Paper 422 I, Washington 1966, p. 37.

This has been the case particularly with hydraulic engineers who solve their problems by empirical reasoning of past experience of like conditions. This has led to the derivation of a large number of formulae, each of which approximates the correct answer over a different limited range of conditions. Leopold, Wolman and Miller[1] have stated that "estimates of the rate of sediment transported in natural channels based on existing equations, however, may be as much as 100% in error". They sum up future bed load studies by stating that "because of the variables involved it appears likely that major advances will be made primarily through advances in theory and critical experiments rather than by amassing volumes of additional data"[2].

Similar problems exist in calculating bed load movement in the field. As yet no reliable sediment sampler has been designed to give an accurate assessment of movement in a stream. A number of direct methods has been proposed with the two main types being a sediment trap or slot extending across the stream bed or several samples being taken with a portable sampler usually in the form of a grab. Both these methods leave much to be desired and large errors are common. The most commonly used method is the use of an empirical formula with the particular hydraulic variables being substituted. As stated above these are rather restricted and are also subject to large errors.

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1. Leopold, L.B., Wolman, M.G., and Miller, J.P. "Fluvial Processes in Geomorphology", Freeman, San Francisco, 1964, p. 184.

2. Ibid, p. 184.

Because of the lack of understanding of the mechanics of bed load movement and the variables involved, and the lack of a reliable sampling method the bed load was not considered in this study. The bed load of all three streams was made up of large rounded boulders of periglacial origin which moved only during periods of extremely high flow. For this reason they were not thought to constitute a significant proportion of the total sediment load. Also as the bed load is related solely to stream variables and is independent of the catchment variables it is outside the scope of this study.

SUSPENSION LOAD

The suspension load consists of particles finer than the bed load which are supported by the fluid and carried along above the layer of laminar flow. The settling velocity of these particles is less than the upward velocity due to turbulence and vortices, and once these particles are entrained little or no energy is required to transport them. They can be carried by a current with a lower velocity than that required for their entrainment. Also the suspended load decreases inner turbulence of the water so frictional losses of energy are reduced and the stream is more efficient.

A large number of theories has been proposed to explain the suspension of sediment in flowing water but only recently has a plausible analysis been developed. Lane and Kalinske[1] were the first to recognise

1. Lane, E.W. and Kalinske, A.A. "The relation of suspended to bed materials in rivers." Amer. Geophys. Union, Trans, Vol. 20 Pt. 4, pp. 637-41, Aug. 1939.

that the suspension of sediment is related to the turbulence of the water. In turbulent flow the current at a given point fluctuates rapidly and haphazardly and although there is a general forward motion there are also fluctuations in horizontal and vertical directions which do not follow any definite sequence. Also the velocity of the water fluctuates above and below the mean value in an irregular manner.

Sediment in suspension is acted upon in a vertical direction by currents moving upwards and downwards in the stream, and, as the water level in the stream is constant, these movements must be equal. A particle caught in a current moving upward at a velocity greater than the settling velocity will move upwards, but, if it is suspended in water moving downward or moving upward at a velocity less than the settling velocity, the particle should move downward. If the downward currents carried as much sediment as the upward currents then after time all the sediment would settle on the bottom. Due to the settling velocity however, sediment is concentrated towards the bottom so the upward currents have a greater sediment concentration than those moving downward, and more sediment is acted upon by the rising currents than the falling ones. The interaction of the settling action and the upward and downward currents tends to produce a balanced suspension of sediment.

For sediment of uniform density the settling rate increases with size but not proportionately. The settling rate of particles less than 0.062 mm (silt) varies approximately as the square of the particle diameter, while the settling rate of coarse sand varies approximately as the square root of the diameter. As a result, the distribution of suspended sediment in streams varies with the depth below the stream surface, with the highest concentration near the bottom and decreasing rapidly towards the surface. The point with the highest concentration coincides with that of maximum turbulence and for a set grain size the concentration through the stream vertical depends on the settling velocity of the particles and the amount of turbulence. Past work has shown that set patterns of distribution of suspended sediment concentration exist for different grain sizes. Sand grains are concentrated close to the bottom because of their larger size and so their greater settling velocity. The concentration of silt tends to be relatively even throughout all the stream depth with local concentrations due to eddies. An example of the vertical distribution of varying sediment sizes is shown in Figure 1. The United States Sub-Committee of Sedimentation[1] has collected data for a large number of stations in the United States and other countries and plotted mean ratios of spatial sediment concentrations near mid-depth and near the bottom of those near the surface (Figure 2). The sediment concentrations at mid-depth and near the bottom were almost always greater than those at the surface and those near the bottom greater than those at mid-depth.

The horizontal distribution of suspended sediment tends to be relatively uniform in long reaches of uniform channel. However, water from a tributary tends to stay on its side of entry into the channel for considerable distances down-stream and if the sediment concentrations of the main stream and the tributary differ significantly, the sediment concentration may not be uniform for some distance below the junction.

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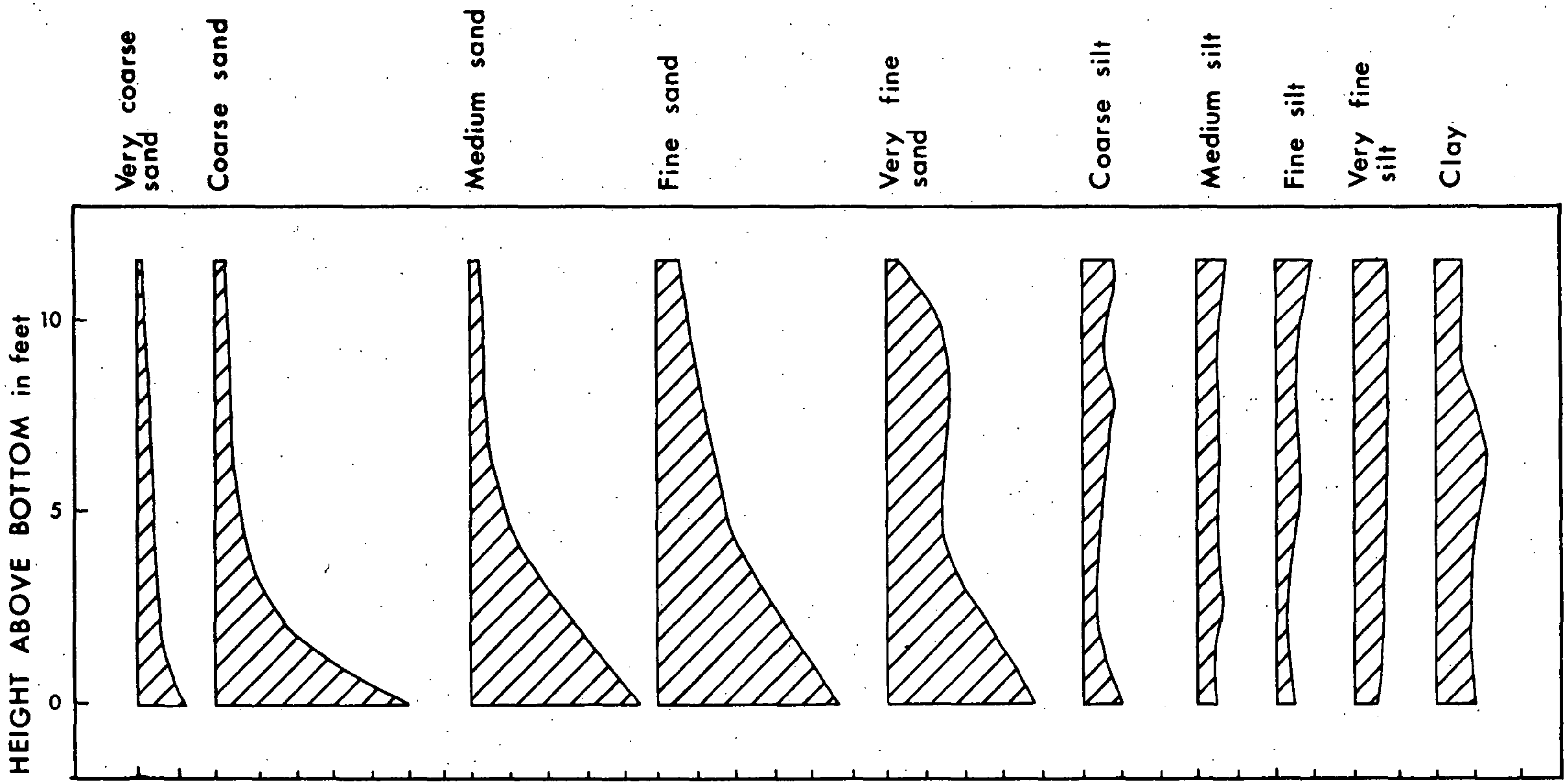
1. Sub-committee on Sedimentation Report No. 14 "Determination of Fluvial Sediment Discharge" St. Anthony Falls Hydraulic Laboratory, Minneapolis, 1963, p. 433.

Figure 1

VERTICAL DISTRIBUTION OF SEDIMENT IN THE MISSOURI RIVER

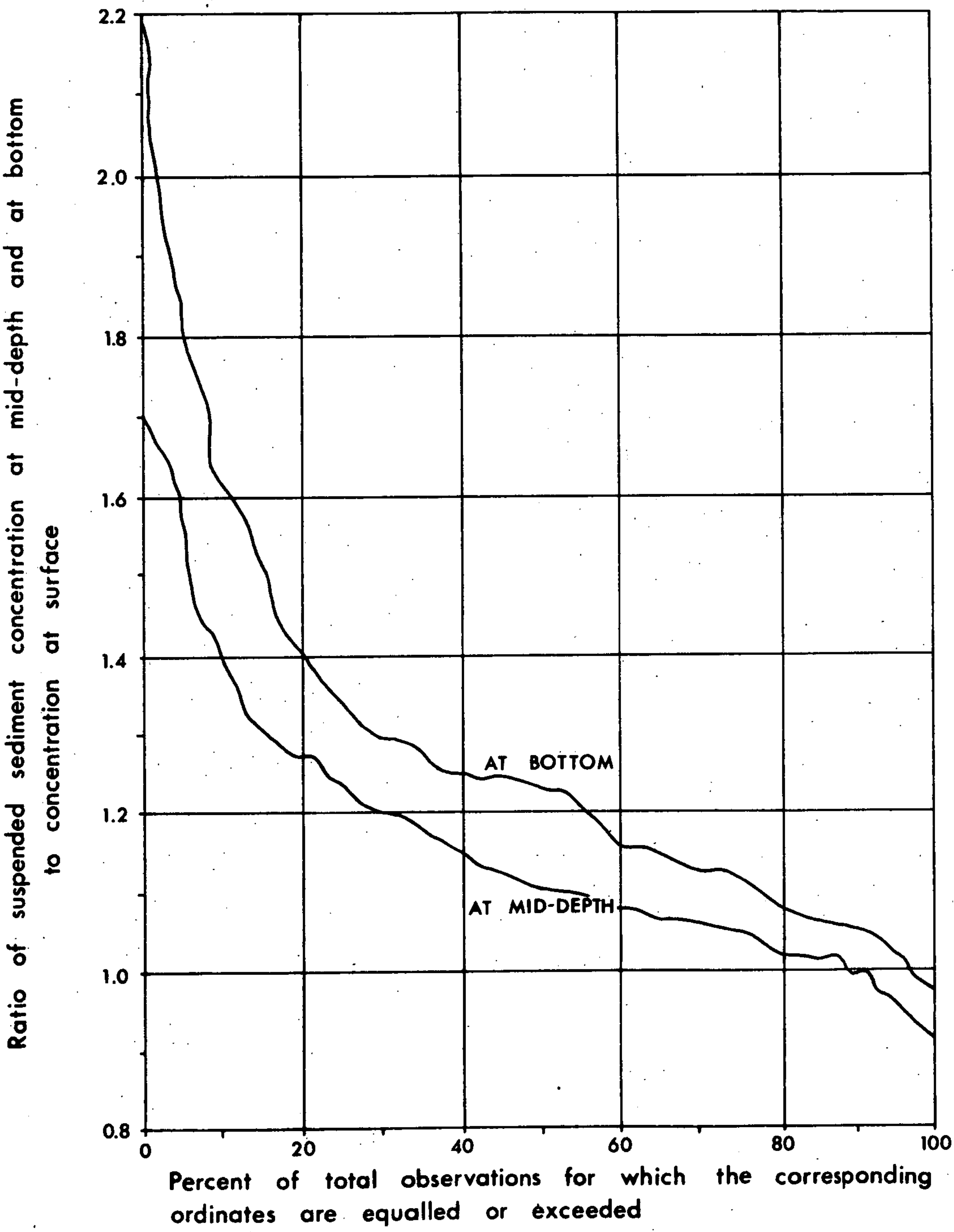


CONCENTRATION 1 Space = 100 P.P.M.

(after Sub-Committee on Sedimentation 1963)

Figure 2

OBSERVED VERTICAL DISTRIBUTION OF SUSPENDED SEDIMENT



(after Sub-Committee on Sedimentation 1963)

Irregularities in cross-section will also produce variations in horizontal concentrations due to varying stream velocities. Using the available information on the transverse distribution of sediment, the Sub-committee on Sedimentation has plotted the frequency of deviations from the mean concentration (Figure 3). Comparison with the variation of vertical concentration (Figure 2) reveals that the transverse distribution is much less variable.

While the distribution of sediment in the cross-section may be relatively constant, variations in bed form may result in radical variations in the sediment concentration. Morisawa[1] has given a number of examples of this influence. Where discharge and velocity are held constant, there was an increase in sediment concentration with a change in bed configuration from dune to plane to antidune form (Figure 4). This could result in variations in the cross-section.

The suspended sediment load is closely related to many of the stream characteristics. Past observations have shown that a strong correlation exists between suspended sediment load and stream discharge, permitting the establishment of a sediment discharge rating curve for a particular stream. The relationship is usually linear when plotted on logarithmic scales and can be expressed in the form

$$L = kQ^n$$

where L is the sediment load, Q the discharge, and k and n are empirical constants which differ from river to river.

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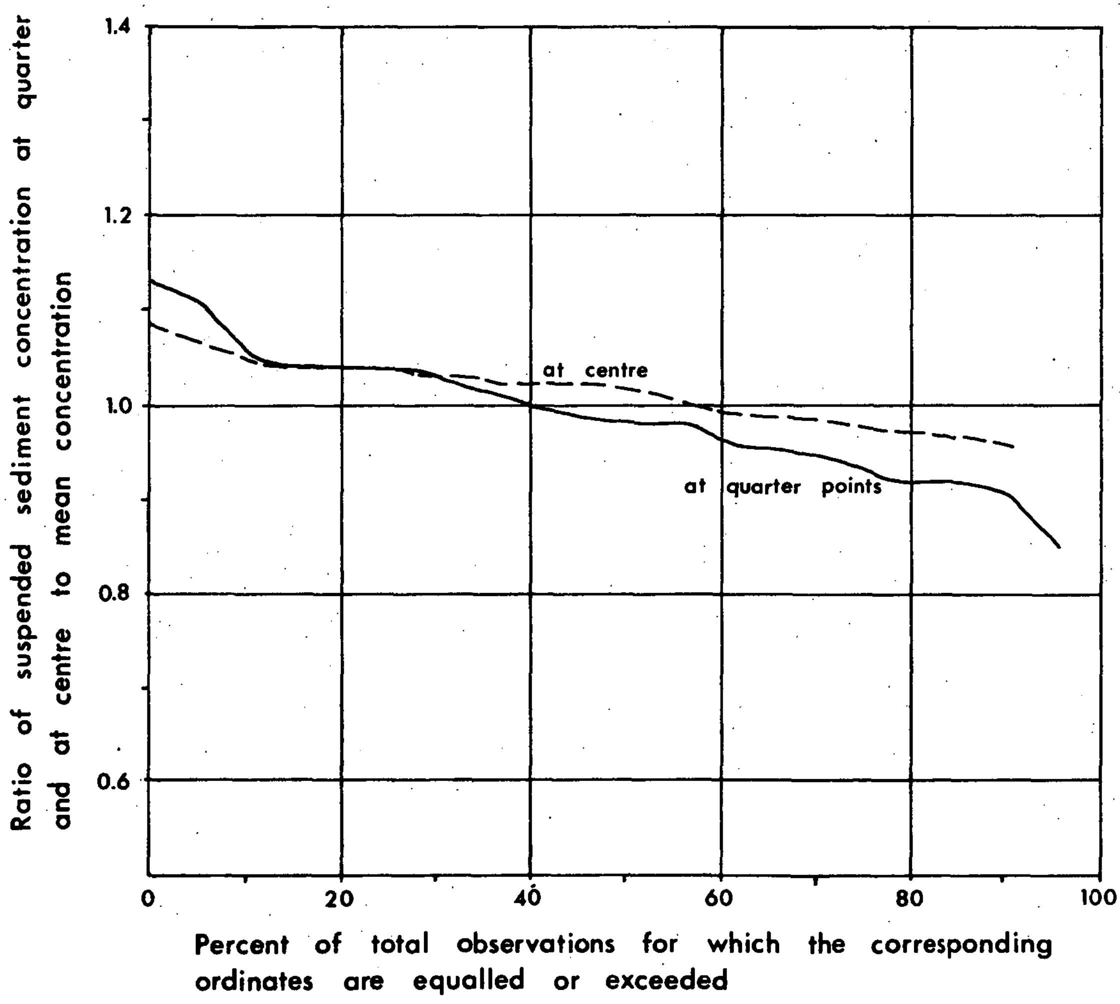
1. Morisawa, M. op. cit. p. 60.

Figure 3

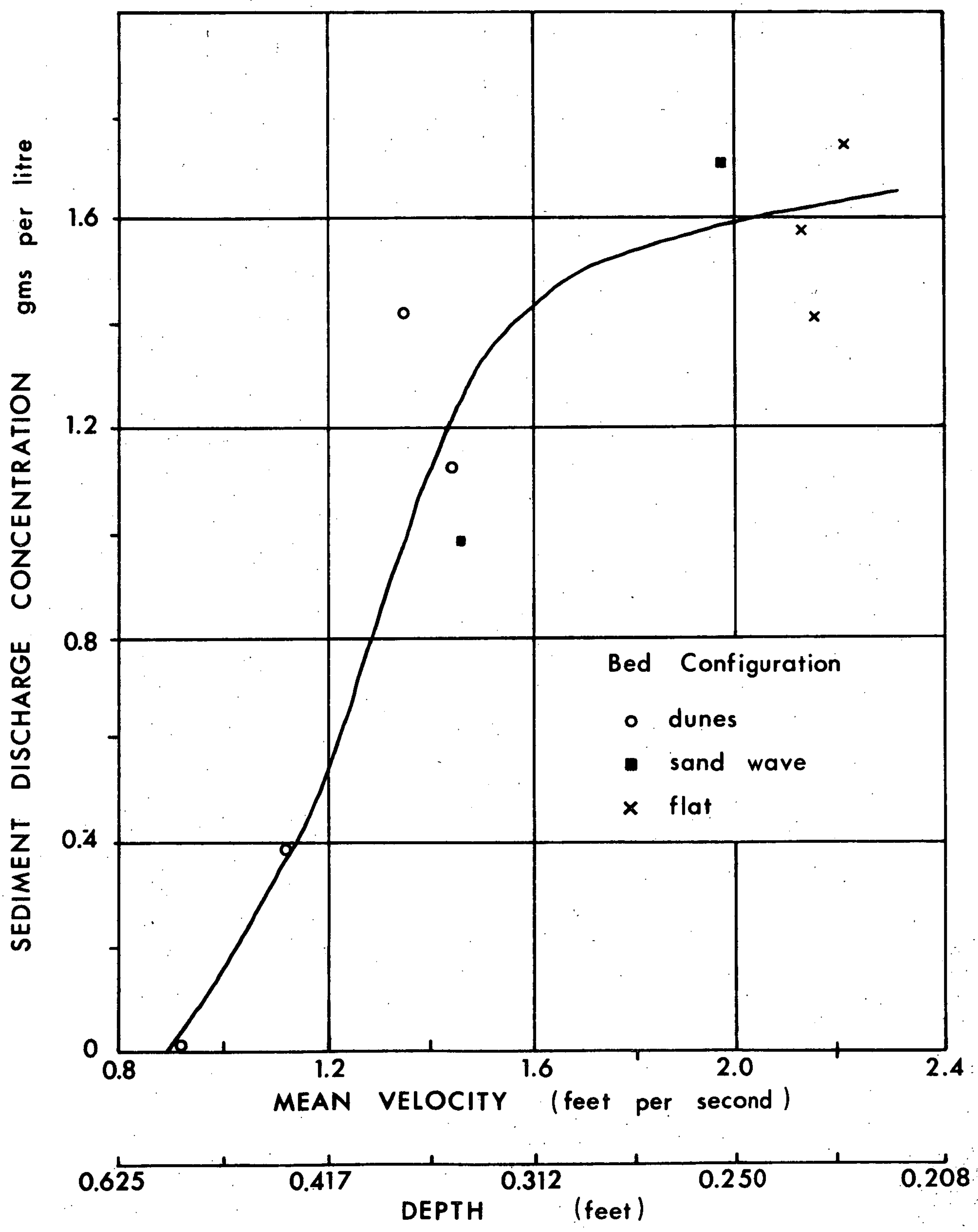
OBSERVED TRANSVERSE DISTRIBUTION OF SUSPENDED SEDIMENT



(after Sub-Committee on Sedimentation 1963)

Figure 4

VARIATION OF SEDIMENT CONCENTRATION WITH MEAN VELOCITY AND DEPTH



(after Morisawa 1968)

While this relationship exists between suspended sediment discharge and stream characteristics, catchment variables also play a role in determining the suspended load. During periods of run-off into the stream most sediment is already in suspension by the time it reaches the stream and tends to remain in suspension in the stream. The run-off suspension is a result of soil erosion and is related to the many catchment variables, the most important of which are set out in Figure 5. As suspended sediment concentration is greatest during periods of high flow and these correspond to periods of run-off it is likely that a significant part of the suspended load is derived from the catchment rather than the stream bed and banks.

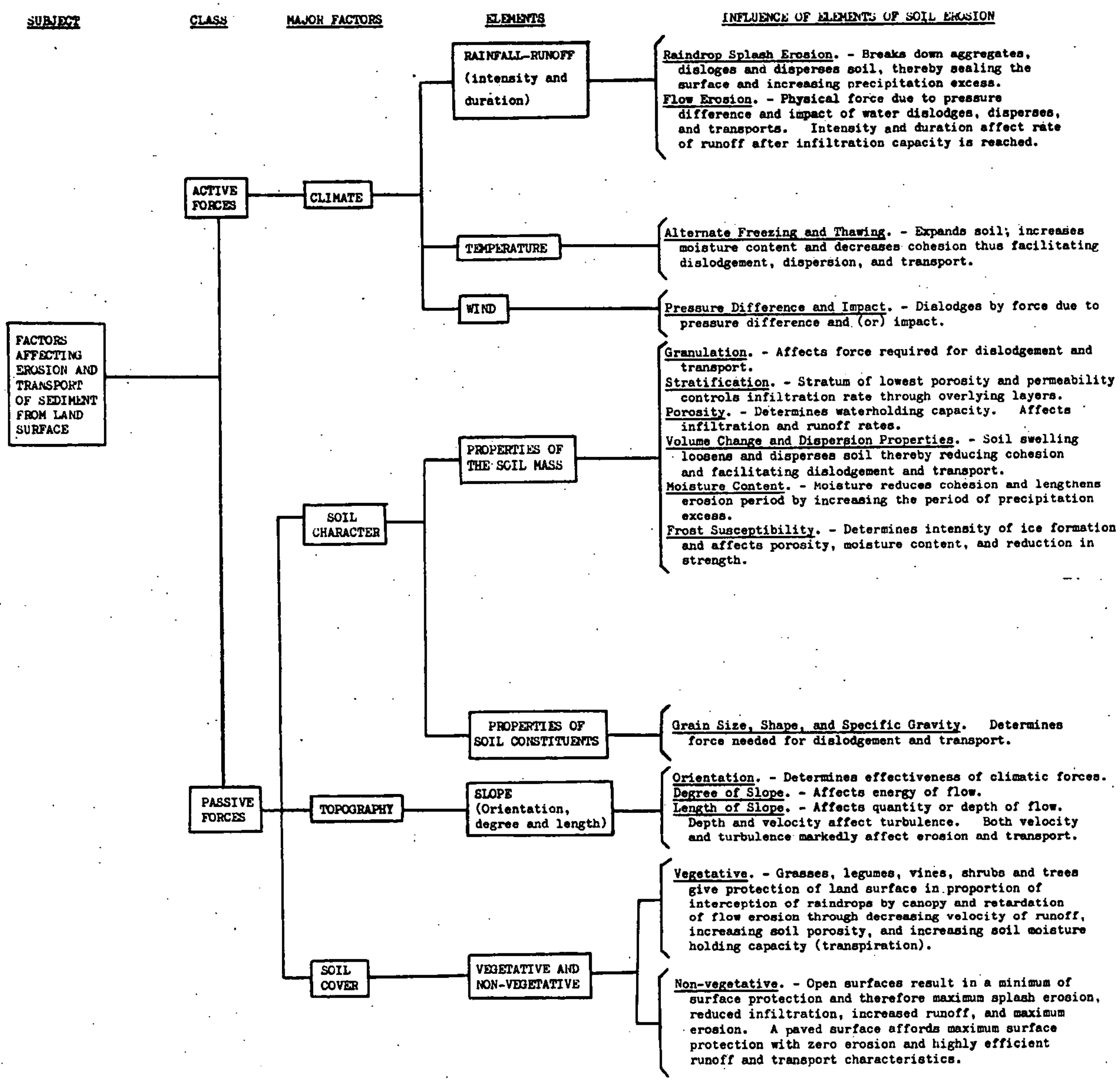
The suspended load of a stream, like the bed load, is closely related to the stream variables, particularly the discharge. Unlike the bed load however it is also related to the catchment variables as a significant part of it is derived from the catchment.

SOLUTION LOAD

The solution load is that part of the sediment load which is dissolved in the stream water and carried in solution. This part of the sediment load is generally not visible and has often been ignored or treated briefly in many sediment studies. It may however constitute a sizeable proportion of the total sediment load. The concentration of the solution load is related to a number of variables, many of which are unique to the solution load.

FIGURE 5

CATCHMENT VARIABLES AFFECTING SEDIMENT LOADS



Solution load is dominantly removed from the catchment by ground water. During the passage of ground water through the soil, salts pass into solution and are removed from the catchment. Concentration of the load depends most heavily on the relative contributions of ground water and surface run-off to stream flow. The greater the importance of ground water then generally the greater the amount of solution load. As the most common stream flows are low flows when there is no surface run-off and the stream is fed solely by ground water, solution load is high for much of the time. Surface run-off moves relatively directly to streams and is little affected by the conditions of the soil surface. When surface run-off occurs after precipitation then the solution load is diluted and tends to decrease with increasing discharge. However the exact relationship between dissolved material concentration and discharge is not known. The amount of material transported by the stream in solution tends to be evened out and this form of transport is very regular.

The concentration of the solution load in the ground water is related to a series of variables. Gorham[1] states that the five principal environmental factors are climate, geology, topography, biota and time. All five interact to determine the ionic concentration and composition of precipitation, soil and stream waters. Waters which are acidic are capable of increased corrosion. Water passing through areas with decaying vegetation such as swamps obtain a large supply of organic acids which aid

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1. Gorham, E., 1961 "Factors influencing the supply of major ions to inland waters, with special reference to the atmosphere", Bull. Geog. Soc. Am. 72, p. 795-840.

in the removal of material in solution. Organisms both in the stream and the catchment alter the nature of the solution load by removing certain ions during their life cycle and releasing them, often in a different form.

A factor which has a complex relationship with the solution load is precipitation. It has already been stated that periods of precipitation result in surface run-off and thus a dilution of the solution load occurs. The chemical composition of precipitation is also of major importance but is generally much more difficult to assess and analyse. Livingstone[1] listed the variation in the chemistry of rainwater falling on the catchment as one of the two most important determinants of the solution load. The role of precipitation in the chemical composition of rivers has been discussed in several recent articles, notably by Douglas[2] and Carroll[3], and several studies have made allowances for the solutes contributed by precipitation. As some of the solution material being removed by the stream was originally brought into the catchment by precipitation it does not constitute denudation of the catchment so must be subtracted from the solution load. Such allowances have been made by Hembree and Rainwater[4] in their study in the United States.

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1. Livingston, D.A.,"Chemical composition of Rivers and Lakes", US Geol, Surv. Prof. Paper 440G, 1963.
2. Douglas, I.,"Intensity and periodicity in denudation processes with special reference to the removal of material in solution by rivers", Zeits. fur Geom. 8, 1964, pp. 453-73.
3. Carroll, D.,"Rainwater as a chemical agent of geologic processes" - A review, US Geol. Surv. Water Supply Paper, 1535G.
4. Hembree, J.H., and Rainwater, F.H.,"Chemical degradation, Wind River Range", Wyoming. US Geol. Surv. Water Supply Paper, 1535E, 1961.

Further studies question whether the total solution contribution of precipitation should be deducted from the stream solution load. Gorham[1] points out that while much of the airbourne salt falling on coastal catchments is derived from the ocean this decreases rapidly inland. Inland areas derive their airbourne salts largely from dust which has been made available by weathering so when added to the rivers this dust forms part of the denudation process. A complete understanding of the resources of supply of ions is required before the importance of ions derived from precipitation can be assessed meaningfully.

As well as adding salts to the catchment, the ions in the precipitation also affect the corrosive action on rocks. Acid aerosols result in rain becoming a dilute acid solution which increases corrosion. It has been found however that precipitation acquires the chemical characteristics of the catchment environment and the acidity of precipitation is more commonly related to the catchment environment than outside factors.

Earlier studies have shown that the concentration and composition of the solution loads of small catchments is variable due to varying catchment environments. Variability in most of the factors however tends to decrease with increasing basin size so that the chemical content of large rivers is often similar. The common anions are bicarbonate, sulphate and chloride while calcium and sodium are the important cations with these five ions making up 90 per cent or more of the chemical content of most rivers.

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1. Gorham, E., op. cit.

Despite the relative neglect in many sediment studies, it has been shown that the removal of material in solution by rivers is important in the degradation of the land surface. Livingstone[1] has estimated that 3,905 million metric tons of soluble material is carried from the earths surface annually by running water, with many streams carrying more dissolved matter than solid particles.

WASH LOAD

Because of the difficulty of making the physical distinction between suspension and bed loads, Einstein[2] proposed the term wash load. The wash load is the material which can be carried most easily in large quantities by the stream, that is the finer part of the load. It includes the solution load and the major part of the suspension load excluding the larger particles which fluctuate between the suspension load and bed load. The techniques used to measure the wash load are the same as those for suspension load, and the wash load can be further analysed for solution and suspension loads.

As the wash load can be transported by the stream through almost the full range of discharges, potential for removal is often greater than the supply of sediment, and the wash load is usually poorly represented in the stream bed. If upstream sources are depleted, a full supply of

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1. Livingstone. D.A., op. cit.
2. Einstein, H.A., op. cit.

sediment is not available to maintain absolute capacity. Therefore the movement of wash load through a reach is not affected by the transport capacity of the reach and without taking direct readings it is not possible to predict the rate of wash load transport.

Clearly the rate of wash load movement is related to the supply of material to the stream rather than the stream variables. The rate of supply is a function of the catchment variables as set out in Figure 5. Also the supply of sediment to a particular stream is generally very variable, depending on the conditions prevailing. Changes in any of the catchment variables are likely to result in changes in sediment supply. Usually wash load concentrations are higher on the rising stage of the hydrograph than on the falling stage[1]. Seasonal variations in catchment conditions can also affect the supply of sediment to the stream.

It is the wash load which is considered in this study and it has been further analysed to find solution and suspension loads. Wash load, according to Einstein[2], constitutes the predominant bulk of the sediment load with between 80 and 90 per cent of the total load. Wash load, being closely related to the catchment variables, bears a close relationship to catchment erodibility, the assessment of which is the aim of this study. Bed load however is almost completely independent of the catchment and is more closely related to the stream variables so can be disregarded in analysing catchment erodibility. The methods used to determine the wash load and the solution and suspension load components are set out in Chapter 3.

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1. Leopold, L.B., and Maddock, T.,"The hydraulic geometry of stream channels and some physiographic implications",US Geol. Surv. Prof. Paper 252, Washington, 1953.

2. Einstein H.A., op. cit.

CHAPTER 2

THE STUDY AREAS

PREVIOUS STUDIES

1. The World

A large number of sediment studies have been carried out in the United States, mainly under the auspices of the United States Geological Survey. This body has a widespread network of sediment sampling stations for which relatively long periods of record are available. The majority of the studies examine specific catchments and only analyse the variables which are of importance in those catchments so they have only limited application outside the area studied. Two studies which have examined the majority of catchment parameters for specific catchments are those by Maner[1] and Lustig[2]. A number of papers has examined the importance of land use in determining sediment yields for specific catchments. Some of the

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1. Maner, S.B., "Factors affecting sediment delivery rates in the Red Hills Physiographic area." Am. Geophys. Union Trans., 39, 1968, pp. 669-75.

2. Lustig, L.K., "Sediment yield of Castaic watershed western Los Angeles County, Calif." US Geol. Surv. Prof. Paper 422F. 1965, 23p.

most important of these are those by Jones[1], Striffler[2] and Ursic[3] all of which gave consideration to mans role in altering sediment yields.

Other studies have covered a much wider area and the relationships derived have much wider application. Schumm examined the relationship of sediment yield to the relief of the catchment area[4] and in a later and more widely known study with Langbein related sediment yield to mean annual precipitation[5]. An analysis of storm-period variables affecting stream sediment transport was carried out by Guy[6]. Probably the greatest contribution to fluvial denudation studies has been made by Anderson who carried out many of the early studies. His 1949 paper[7] outlines a simple equation for determining sediment yields for catchments where no sediment samples have been

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1. Jones, B.L., "Sedimentation and land use in Corey Creek and Elk Basins, Penn., 1954-60." US Geol. Surv. open file report 1964, 112p.
2. Striffler, W.D., "Sediment, streamflow and land use relationship in northern Lower Michigan." US Forest Service research paper LS16, 1964, 12p.
3. Ursic, S.J., "Sediment yields from small watersheds under various land uses and forest covers." US Dept. Ag. Misc. Pub. 970, pp. 47-52.
4. Schumm, S.A., "The relation of drainage basin relief to sediment loss." Pub. No. 36 de l'Assoc. Internal d'Hydrologic, Vol. 1, 1954, pp. 216-9.
5. Langbein, W.B. and Schumm, S.A., "Yield of sediment in relation to mean annual precipitation." Am. Geophys. Union Trans. Vol. 39, 1958, pp. 1076-84.
6. Guy, H.P., "An analysis of some storm-period variables affecting stream sediment transport." US Geol. Surv. Prof. Paper, 462E, 1964.
7. Anderson, H.W., "Flood frequencies and sedimentation from forest watersheds." Trans. Am. Geophys. Union, Vol. 30, 1949, pp. 567-86.

taken. Aided by the large amount of sediment data available, Anderson carried out several studies examining the influence of streamflow, topography, soil and land use on sediment yield using multiple regression[1]. In a later study[2] a similar analysis is made but a wider range of catchment parameters is included such as soil, slope and catchment area. In this paper he suggests that such a study should include as many different catchments as possible and, by carrying out an analysis of co-variance, catchments can be grouped so giving a good method of estimating sediment loss for unmeasured catchments. A similar analysis was carried out with Andre in Northern California[3] and in a recent paper Anderson reviews the research carried out between 1963 and 1967 on sediment yields[4].

Similar work to that done in the United States has been carried out in Sweden by a number of workers notably by Hjulstrom[5], and Sundborg[6]

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1. Anderson, H.W., "Suspended sediment discharge as related to stream-flow, topography, soil and land use." Trans. Am. Geophys. Union, Vol. 35, No. 2, 1954, pp. 268-81.
2. Anderson, H.W., "Relating sediment yield to watershed variables." Trans. Am. Geophys. Union, Vol. 38, No. 6, 1957, pp. 921-24.
3. Andre, J.R. and Anderson, H.W., "Variation of soil erodibility with geology, geographic zones, evaluation and vegetation type in the Northern Californian Wildlands." J. Geophys. Res., Vol. 66, No. 10, 1961, pp. 3351-8.
4. Anderson, H.W., "Erosion and Sedimentation." Trans. Am. Geophys. Union, Vol. 48, No. 2, 1967, pp. 697-700.
5. Hjulstrom, F., "Studies of the morphological activity of rivers as illustrated by the River Fyris." Bull. Geol. Inst. of Univ. Upsala Sweden, XXV, 1935, pp. 221-525.
6. Sundborg, A., "The River Klaralven, a study of fluvial processes." Geografiska Annaler, 38, 1956, pp. 127-316.

who has developed a simple and accurate method of measuring steam sediment, and Axelsson[1]. Studies of the rest of the world are limited with only a few localised studies such as those carried out by Douglas in Singapore and Malaysia[2] and his analysis of the solution load of the River Thames[3].

Several studies have been carried out of denudation rates on a world or continental scale. These have generally been made by using the available sediment load data and estimating losses from those areas where no samples have been taken. Calculations of denudation in the United States have been made by Judson and Ritter[4]. Durum, Heidel and Tison[5] have made an estimation of world solution loads. The major studies of world denudation have been reveiwed

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1. Axelsson, V., "The Laitaure Delta." Geografiska Annaler, 49A, 1, 1967, pp. 1-127.

2. Douglas, I., "Natural and man made erosion in the humid tropics of Australia, Malaysia and Singapore." Internat. Assoc. Scientific Hydrol., Pub. 75, 1967, pp. 17-30. "Erosion of granite terrains under tropical rainforest in Australia, Malaysia and Singapore." Internat. Assoc. Scientif. Hydrol. Pub., 75, 1967, pp. 31-40.

3. Douglas, I., "Intensity and periodicity in denudation processes with special reference to the removal of material in solution by rivers." Zeits. fur. Geomorph., 8, 1964, pp.453-73.

4. Judson, S. and Ritter, D.F., "Rates of regional denudation in the United States." J. Geophys. Res., 69, (16), 1964, pp. 3395-3401.

5. Durum, W.H., Heidel, S.G. and Tison, L.J., "World-wide run-off of dissolved solids." Internat. Assoc. Scientif. Hydrol. Gen. Assembly of Helsinki, Pub. No. 51, 1960, pp. 618-28.

by Stoddart[1] who notes that estimates vary considerably because of the multivariate controls of the rate of erosion. Among the studies quoted by Stoddart is that by Corbel[2] who studied total erosion for different temperature zones in terms of three humidity and two relief categories. Different results were obtained by Fournier[3] who derived an equation for predicting sediment yield when climate and relief are known. His results are supported by a study by Strakhov[4] whose results are slightly lower. Both Stoddart and Douglas[5] feel that Strakhov's rates may be geologically more "normal".

Obviously, outside the United States, sediment studies are isolated and a great deal remains to be examined. Until the rest of the world develops a network of sediment sampling stations as exists in the United States, insufficient data will be available to carry out any large scale studies.

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1. Stoddart, D.R., "World erosion and sedimentation," in "Water, Earth and Man." ed. R.J. Chorley, Methuen, London, 1969, pp. 43-64.
2. Corbel, J., "L'erosion terreste, etude quantitative, (Methods - techniques - resultats)", Annales de Geographie, 37, 1964, pp. 44-59.
3. Fourier, F., "Climat et erosion: la relation entre l'erosion du sol par l'eau et les precipitations atmospheriques (Paris) 1960, 20p.
4. Strakhov, N.M., "Principles of Lithogenesis: Vol. 1," London, 245p.
5. Douglas, I., "Man, vegetation and the sediment yields of rivers," Nature, 215, 1967, pp. 927.

2. Australia

Few studies of sediment sampling and associated denudation rates have been carried out in Australia and much of the work carried out has not been published. Published work is limited to four workers.

The Snowy Mountains Authority initiated the first sediment sampling programme in 1953 to determine the sediment loads of some of the representative streams in the scheme. From the work carried out only one publication has emerged; that by Stephens[1] on the sampling techniques employed. Following the example of the Snowy Mountains Authority, extensive studies have been carried out in the Hunter River Basin by the Hunter River Valley Research Foundation. Again little of this work has been published or released.

Douglas[2] presented a doctoral thesis at the Australian National University on denudation rates and water chemistry of selected catchments in eastern Australia and from this study several papers have been published. In his 1967 paper[3], Douglas examines the influence of man on sediment yields through modification of some of the catchment variables, the most important being vegetation.

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1. Stephens, S.K., "Sediment sampling in the Snowy Mountains Area." Snowy Mtns. Hydro-electric Authority, Cooma, NSW, 1961.
2. Douglas, I., "Denudation Rates and Water Chemistry of selected catchments in Eastern Australia and their significance for tropical Geomorphology." Unpublished Ph.D. thesis ANU, Canberra, 1966.
3. Douglas, I., <u>op. cit.</u>, 1967, pp. 925-28.

A later paper[1] deals with the solution load of catchments in tropical north-east Queensland and the Central and Southern Tablelands of New South Wales. The influence of precipitation chemistry and lithology on solution load is examined for the two areas.

Loughran has carried out a number of studies in the New England area of New South Wales and two studies have been published. In his 1968[2] and 1969[3] publications he records the results of a study of five small catchments in the New England area and examines the influence of catchment lithology on the wash loads. A further study[4] examined the influence of an urban area on the wash load of a small stream. Loughran is currently carrying out research on the sediment yield of the Chandler River, a much larger catchment in the New England area.

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1. Douglas, I., "The effects of precipitation chemistry and catchment area lithology on the quality of rivers water in selected catchments in Eastern Australia." Earth Science J. 2 (2), 1968, pp. 126-44.

2. Loughran, R.J., "The susceptibility to fluvial erosion of three rock types on the New England Tableland NSW." Inst. Aust. Geographers Conference, Monash Univ., Melbourne, 1968.

3. Loughran, R.J., "Fluvial Erosion in five small catchments near Armidale NSW." Research Series in Physical Geography No. 1, Univ. New England, Armidale, NSW, 1969.

4. Burkhardt, J., Loughran, R.J., and Warner, R.F., "Some preliminary observations on streamflow and wash load discharge in Dumaresq Creek at Armidale NSW." Research Series in Applied Geography No. 18, Univ. New England Armidale NSW, 1967.

Abrahams[1] has analysed drainage densities and sediment yields in eastern Australia. Using the sediment data collected by Douglas and Loughran and the available reservoir siltation rates, he has analysed the influence of annual precipitation and vegetation on sediment yields.

Sediment studies in Australia have been largely neglected and only a small number of studies have been carried out. As well as those outlined above, a small number of studies have been carried out by engineers but these are concerned more with stream mechanics than catchment denudation. To the author's knowledge no sediment studies have previously been carried out in Tasmania. The programme of representative catchments being instituted over the next few years by the Australian Water Resources Council will do much to provide basic information and a closer understanding of fluvial denudation in Australia.

THE STUDY AREA

This study is an examination of the sediment yields of three small catchments in south-east Tasmania. Rates of fluvial erosion are influenced by the various parameters of the catchment such as geology, vegetation, slope, rainfall and run-off and an attempt is

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1. Abrahams, A.D., "Drainage densities and sediment yields in Eastern Australia." Aust. Geogr. Studies, Vol. 10, No. 1, 1972, pp. 19-42.

made to assess the importance of these. Erosion rates of the area are also calculated and comparison is made to other Australian studies in different environments. At the time of the study no work of this type had been carried out in Tasmania and, therefore, it is hoped that it will provide a basis for more detailed analyses of fluvial erosion in the area.

In considering fluvial erosion only that part of the sediment load referred to by Einstein[1] as the "wash load" has been considered. As indicated in Chapter 1, wash load is that part of the load which can be carried independent of stream velocity and is made up of the solution load and the greater part of the suspension load. Bed load has been ignored as it is relatively independent of the catchment variables and no adequate method has been derived for its determination. As well as total wash load measurements, the solution and suspension load components were analysed. These loads were found by carrying out a sampling programme over a twelve month period from July 1969 to June 1970.

Two of the streams studied, Browns River and Snug Rivulet flow into the D'Entrecasteaux Channel, while the Mountain River, the third catchment studied, is a part of the Huon system. The location of these three catchments, and their position in the drainage pattern of the area is shown in Figure 6. All are in relatively close proximity to Hobart and are easily accessible even during periods of high flow.

1. Einstein, H.A., op. cit.

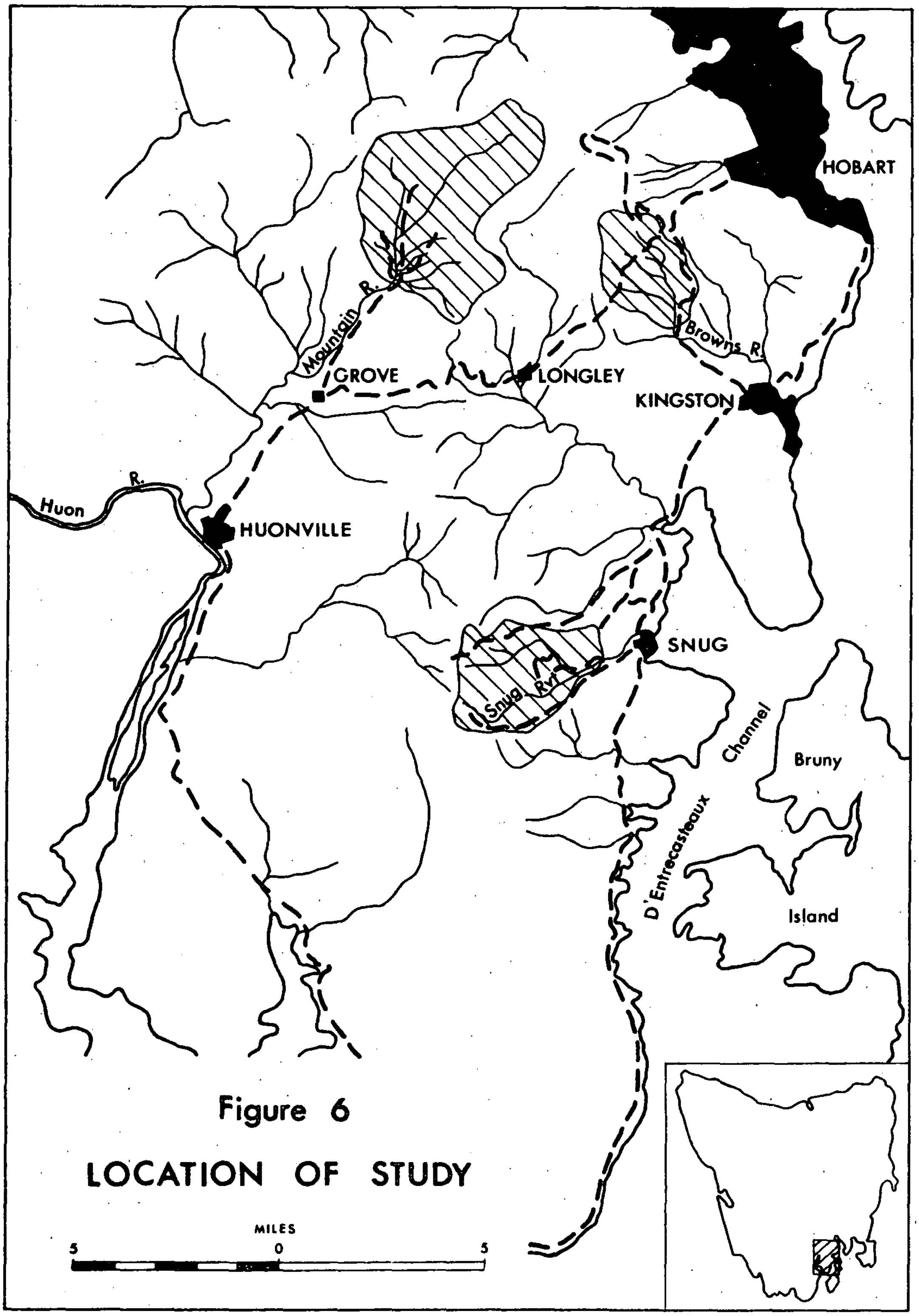

Figure 6

LOCATION OF STUDY

The catchments vary in size from 7 to 28 square miles. Sampling points for all catchments were at the sites of the Rivers and Water Supply Commission's stream gauging sites, which provide a continuous record of discharges.

A tributary joined the Mountain River slightly upstream of the gauging point and, as its catchment varied from that of the rest of the Mountain River, sediment readings were taken of the tributary and the river upstream of it as well as at the gauging site downstream.

THE PHYSICAL ENVIRONMENT

Geology

The geology of all three catchments falls into the same system of Permian and Triassic sediment which have been intruded by Jurassic dolerite in the form of sills and dykes. At present no geological map of the area has been produced, but localised studies have been carried out. A study by Rodger[1] includes the Snug Rivulet area while the Mountain River is considered in a paper by Mather[2]. The surface geology of Browns River has been mapped on a relatively small scale in the Geological Map of Hobart prepared by the Department of Mines (1965). Geological maps of the three catchments are shown in Figures 14, 21 and 30.

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1. Rodger, T.H., "The Geology of the Sandfly - Oyster Cove Areas, Tasmania." Paper and Proc. Roy. Soc. Tasmania, Vol. 91, 1965, pp. 109-114.

2. Mather, R.P., "Geology of the Huon District." Papers and Proc. Roy. Soc. Tasmania, Vol. 80, 1955, pp. 191-202.

The dolerite intrusions have complicated the stratigraphy of the area as the sills and dykes have fractured the sediment and only one unit remains whole. The accompanying heat at the contacts has also considerably altered the character of the sediments.

Four sedimentary groups have been recognised. The oldest unit in the area is the Malbina Siltstone and Sandstone of Permian age which outcrops in limited areas at the base of the sediments in Browns River. The Risdon Sandstone is a 20 feet thick marker bed with an average grain size of 0.07mm to 0.12mm[1]. A more important Permian unit is the Ferntree Mudstone which outcrops through much of the three catchments. It is made up of three facies which remain constant through the area. At the base is a grey mudstone composed of a fine crystalline matrix and quartz grains up to 1mm. This is relatively resistant and outcrop is often in cliff faces such as the falls on the Snug Rivulet. Above this layer is a yellow sandy mudstone with only a small percentage of crystalline matrix. It is friable and relatively susceptible to weathering. The upper horizon is up to 150 feet thick and the sediment is very similar to the lower band. At the igneous contacts only minor alteration has occurred.

Kocklofty Sandstone and Shale is the only Triassic group outcropping in the area. It is a major group of possibly greater than 900 feet thickness and outcrops extensively in the catchments. The base of this formation consists of variable conglomerates with sub-

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1. Rodger, T.H., <u>op. cit.</u> p. 111

angular and sub-rounded quartz particles up to 1cm in diameter with a sand size quartz matrix[1]. Above this is 200 to 300 feet of massive sandstone which is commonly cross-bedded and has slump structures. The sediment is well rounded quartz with an average diameter of 0.25mm. Moving up the formation it changes from sandstone to shale and the increasing amount of shale is associated with an increase in feldspar. Colour ranges from brown to grey but on weathering only quartz remains, leaving a very clean sand. The thickness of the upper member of sandstone and shale is approximately 200 feet.

The key to the structure of the area lies in the Jurassic Dolerite which occurs as a complex series of dykes and sills. It is fine-grained within 50 feet of the margin. The rock consists of a ground mass of feldspar laths in which there are occasional crystals of quartz. Faulting accompanied the intrusion of the dolerite, which left the area composed dominantly of dolerite with varying sized blocks of sediment floating in it. In some areas faulting was complex as shown in the map of the Browns River area.

The only other outcrop is that of Quaternary fluvial material in the Mountain River valley. These deposits consist of ill-sorted semi-consolidated sedimentary material showing little evidence of bedding. They are composed mainly of rounded dolerite pebbles and cobbles ranging up to 40cm in diameter set in a matrix of sand and silt.

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1. Mather, R.P., op. cit., p. 196.

Climate

The area lies within the westerly wind regime and this is reflected in the annual averages of temperature, pressure, rainfall and cloud cover. However, the influence of this system is never uniform or steady, Climate is temperate marine and falls in Köppen's Cfd climate. The marine influence, due to heat absorption, results in milder winters and cooler summers than would normally be expected at this latitude.

Annual average rainfall lies between 20 and 40 inches as shown in Figure 7 and is distributed throughout the year although there are distinct wet and dry periods. Maxima occur in late autumn and late spring with minima in late summer and late winter[1]. The maxima are related to small cyclonic pressure centres which affect the eastern half of the state. Rainfall increases with elevation due to the orographic influence, rising from 25 inches at Hobart to 36 inches on Mount Wellington. There is also a general trend for rainfall to increase westward due to the increasing influence of the westerlies. Rainfall is generally light, but local pressure disturbances can result in heavy storms and localised flooding. Relative reliability of annual rainfall ranges from 14% to 18% with again an increase in reliability to the west (Figure 7). Snow can fall over all the area but is generally restricted to the higher sections where it can occur at any time. Heaviest falls occur in June and July when cold

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1. Langford, J., "Weather and Climate", in Atlas of Tasmania, ed. J.L. Davies, Lands and Survey Dept., Hobart, 1965, p. 9.

Antarctic air passes over the State and Mount Wellington is snow covered for much of this time down to 3,000 feet.

Mean temperatures in the coastal areas range from 45°F to 62°F with 8 or 9 months above 50°. Short hot periods can occur in summer with temperatures over 100°F due to the inflow of hot dry air masses from the Australian continent, and frosts are not uncommon in winter. On the elevated areas temperatures are up to 12° to 15°F below those in coastal locations and mean monthly temperatures approach freezing point in July. Over 100 frost cycles per annum have been recorded in these locations.

Evaporation measured from a water surface in a sunken tank in low lying areas varies from 31 to 34 inches per annum[1]. Evaporation is greatest in coastal locations, where winds are stronger and there is ample sunshine, and decrease with elevation and also to the west. Evaporation is relatively high in summer, while in winter values are very low. This combined with the seasonality of rainfall, has a marked effect on stream discharge, which is at a maximum in winter and often there is no flow in late summer.

Topography

Elevation of the area ranges from slightly above sea-level to over 4,000 feet. The catchments are typical mountain catchments with no flood plain development and only limited flat areas which are found mainly on

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1. Langford, J., op. cit.

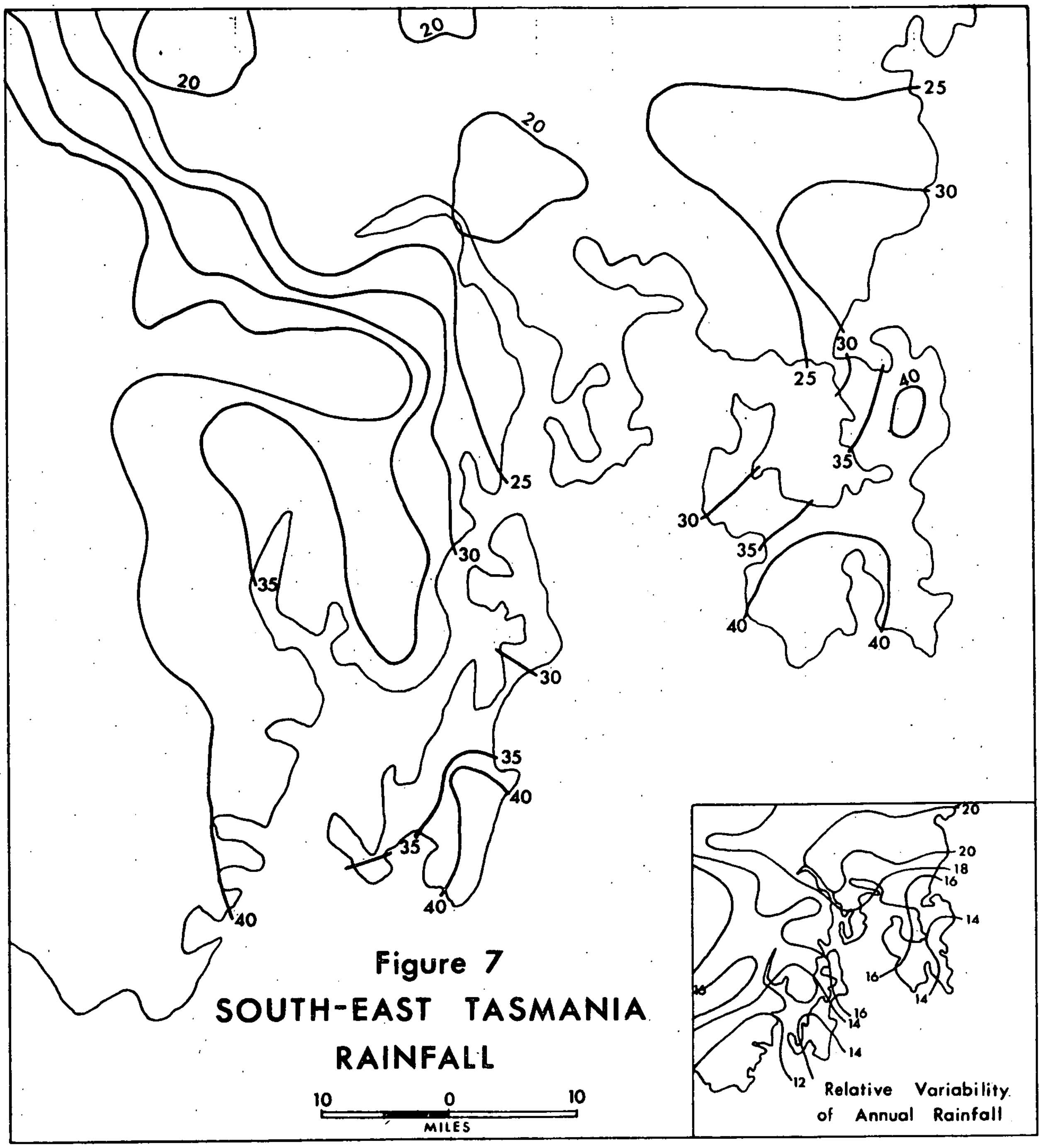

Figure 7
SOUTH-EAST TASMANIA RAINFALL

the upper sections of the streams where there are poorly drained plateau-like surfaces. Valley sides are steep and rise from the stream channels.

The area falls into two of Davies's process provinces[1]; the humid province, and the periglacial province. Most of the area falls into the humid province where fluvial erosion is dominant and periglacial and aeolian processes are relatively minor. Terraces are generally well developed but are absent in the study area where no deposition has occurred.

The periglacial province is restricted to the highest sections and occurs in the Mountain River and Browns River catchments. In this province significant modification of the landforms has occurred as a result of freeze-thaw processes during the Pleistocene. Both frost shattering of rock and movement of weathered material down-slope have occurred. Where dolerite has been involved large amounts of boulders and clay have resulted, with the boulders filling the valleys in some instances. These boulders are currently being reworked by stream action and are transported as bed load and now extend well below the lower limit of Pleistocene periglacial action. The clay material supplies an abundant source of material for stream transport.

Soils

At present no detailed soils maps of the area have been compiled, and published material on this area is limited to a generalised description

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1. Davies, J.L., "Landforms" in Atlas of Tasmania, ed. J.L. Davies, Hobart, 1965, p. 20.

by Nicholls and Dimmock[1]. They have recognised four great soil groups based on the Great Soil Group Classification of Stephens. Podzolic soils are dominant with two groups related to the parent material. The lower areas where siliceous sandstones occur have yellow podzolic soils which have greyish A horizons and yellow mottled B horizons and are strongly acid throughout. An A2 horison is usually present which may be strongly leached. Depth of the profile is usually shallow, varying from one to several feet. Duplex profiles are dominant with a marked change of texture from a sandy or silty A to a clay B horizon.

Grey-Brown Podzolic soils are associated with dolerite parent materials and are found in the higher sections of the area. Profiles are duplex with a grey fine sandy loam A horizon and a dark yellowish brown clay B horizon which passes gradually into weathered dolerite at depths of 2 to 3 feet. While being moderately acid at the surface, the profile becomes neutral or alkaline in the C horizon. Dolerite boulders are common throughout the profile.

The remaining soil types are Alpine Humus soils. In Tasmania these soils are associated with periglacial solifluction deposits and so are found in areas above 2,000 feet. The deposits are usually composed of dolerite fragments in a fine brown matrix and the profile changes little with depth. All deposits are moderately to strongly acid. A variation occurs on the plateau top of Mount Wellington where the Alpine Humus Soils are interspersed with moor peats in marshy locations. These are commonly 15 to 20 inches deep and serve as water catchments and temporary storages.

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1. Nicholls, K.D. & Dimmock, G.M., "Soils" in Atlas of Tasmania, ed. J.L. Davies, Lands & Surveys Dept., Hobart, 1965, pp. 26-29.

Vegetation

The vegetation of Tasmania has been mapped by Davies[1] and described by Jackson[2]. Distribution of the various types is related to rainfall, soils and fire frequency. Sclerophyll Forest is the dominant vegetation while there is a limited area of moorland vegetation and sections of the coastal lowlands have been cleared for agricultural purposes.

Eucalypts dominate the sclerophyll forest with most forests consisting of a mixture of two species. The dominant species usually belongs to the Ash Peppermint group of the Renantherae, with a Macrantherous subordinate species. In this area the Ash group is represented by obliqua while the Peppermint Group is represented by tasmanica, linearis, amygdalina and coccifera. Most of the sclerophyll forest is of the dry type, while the wetter margins may be in the transition to wet sclerophyll forest. Structure is the basis of distinction between the two types. In dry eucalypt forest, shrub layers are low and often sparse with members of the Compositae, Leguminosae, Myrtaceae, and Epacridaceae predominating. As rainfall increases, the tall shrub layer of acacias and tall composites increases in density until the 40" isohyet where a transition to wet sclerophyll occurs with dense tall shrub layers of Pomaderris, Bedfordia and Phebalium. Gully corridors of rain forest extend into the sclerophyll forests at altitudes of 1500 to 2000 feet.

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1. Davies, J.L., "A Vegetation map of Tasmania." Geog. Rev. 54, 1964, p. 249.

2. Jackson, W.D., "Vegetation", in Atlas of Tasmania, ed. J.L. Davies, Lands and Surveys Dept., Hobart, 1965, pp. 30-35.

These corridors extend to low altitudes as fern gully communities with Atherosperma and Olearia dominant, overlying a tree fern stratum of Dicksonia and Gyathea[1].

The plateau surfaces at elevations above 2,000 feet have moorland vegetation. This comprises the non-forest austral-montane vegetation of Epacridaceous - Proteaceous shrubbery, coniferous shrubbery, micro shrubbery, fell field, sedgeland, swamp and bog[2].

An important factor in the vegetation of the area is the occurrence of periodic fires. In many cases these have led to the development of disclimaxes. The distribution of rain forest is limited by this factor. A great deal of the area was subjected to the bushfires of February 1967 when much of the former forest was destroyed. The affected areas are currently undergoing regrowth with a dominence of saplings and shrubs. The importance of the fires will be treated in detail at a later stage.

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1. Curtis, W.M., and Sommerville, J., "The Vegetation." ANZAAS Handbook. Hobart, 1949, pp. 51-7, sec. 8 & 9.

2. Jackson, W.D., op. cit., p. 32.

CHAPTER 3

METHODS AND TECHNIQUES

The study involved field measurements of stream water discharge and the associated wash load concentration. Laboratory analysis was carried out to find the wash load, solution load and suspension load concentrations for the particular discharges sampled.

STREAMFLOW MEASUREMENT

All three catchments have permanent, continuous recording stream gauges installed in association with weir controls, which are operated by the Rivers and Waters Supply Commission of Tasmania, and these were used as the basis for the study. The use of weir controls results in greater accuracy due to the constant nature of the stream cross-section. These sites were also advantageous as they were wadable at all but the highest discharges and adjacent bridges allowed sampling to be carried out when the stage was too high to permit wading. The three gauges were fitted with Leopold and Stevens A35 Recorders, with the Browns River gauge having a recording range of 9 feet, Snug Rivulet 12 feet and the Mountain River 9 feet. As the recording sites had not been rated above the top of the weir, valid recordings could only be obtained up to this level (4.75 feet in the case of Browns River and Snug Rivulet and 1.5 feet in the Mountain River).

Both Browns River and Snug Rivulet have standard V notch weirs and have been rated by the weir formulae:

i) for stages from 0 to 1.75 feet (i.e. to the top of the V notch)

$$Q = 2.52 H^{2.47}$$

ii) for stages from 1.75 to 4.75 feet (from the top of the V notch to top of the weir)

$$Q = 2.52 H^{2.47} + 3.33 (23.25 - H_2) (H_2 - 1.75)^{3/2}$$

Where Q is the discharge in cubic feet per second (cusecs). H is the stage in the V notch and H_2 is the height of the stage above the V notch.

The rating curve based on these formulae is shown in figure 8. At no time during the study did the stage exceed the top of the weir so all discharges could be calculated using this rating curve.

The Mountain River was fitted with a rectangular weir with two rectangular notches 7 and 10 feet wide. This gauge has been rated by the standard formula for rectangular weirs:

$$Q = 3.33 (L - 0.2 H) H^{3/2}$$

Where Q is the discharge, H the stage and L the width of the rectangular notch.

Calculations are made substituting both 7 and 10 for L and the two resulting values are summed to give the total discharge. The rating curve for the Mountain River is given in Figure 9. On several occasions

Figure 8
RATING CURVE OF V-NOTCH WEIR

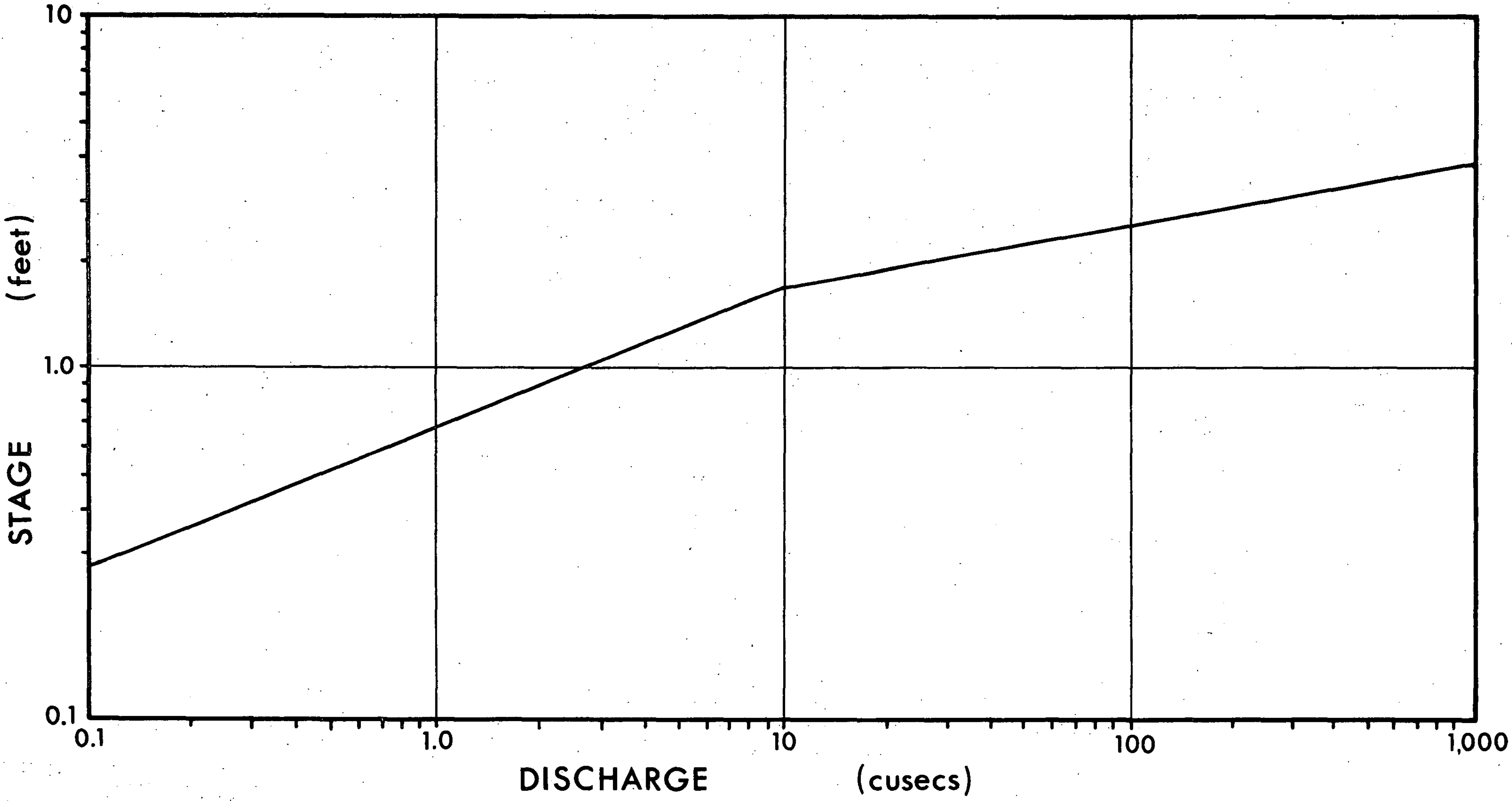
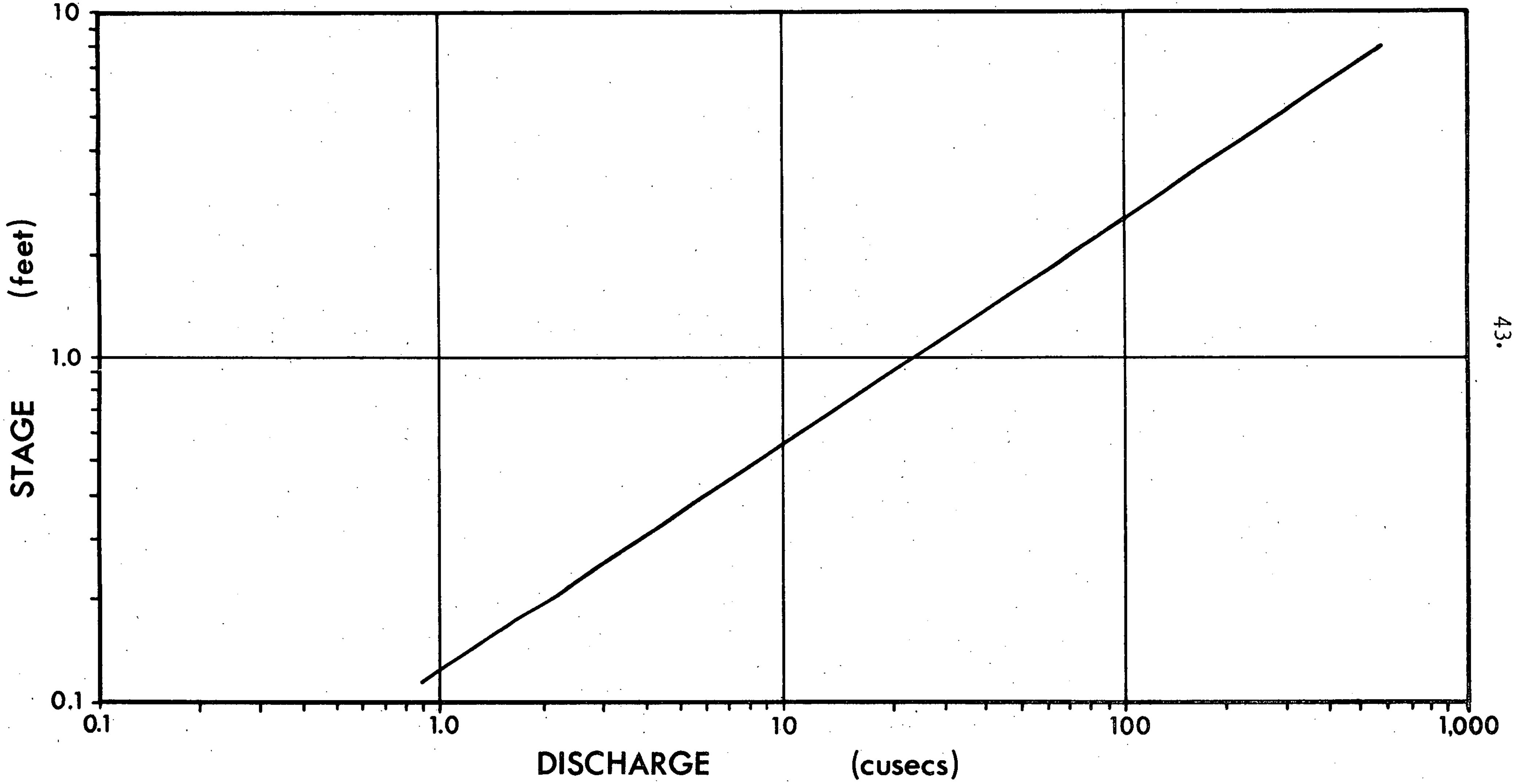


Figure 9

MOUNTAIN RIVER RATING CURVE



the stage of the Mountain River exceeded the top of the weir and the discharge was calculated by mechanical methods which will be described later.

As none of these gauging stations has been checked by current meter measurement, the accuracy of the rating curves cannot be determined. Changes in approach velocity and sedimentation of the weir are the major causes of error. All are located on relatively straight sections of the streams so the approach velocity should not be altered. Sedimentation had occurred in the Browns River gauge and this may result in some error, while behind the Mountain River gauge deposition of large rounded boulders occurred after periods of extreme high flow. Also a number of times after high flow, damage from flood debris had occurred to the weirs and the streams had to be gauged by current meter. Gaps occur in the discharge record due to the malfunction of the recording apparatus and as checks were made only quarterly by the Rivers and Water Supply Commission, up to three months of record could be lost. As the Commission was dominantly concerned with low flows it tended to neglect high flows and, when discharge exceeded the capacity of the weir, discharge was estimated. In the author's experience these estimates were usually low and so errors are introduced in periods of high flow with the estimates up to 50% below actual discharge. This results in an underestimation of total discharge.

In the case of the Mountain River further discharge figures were required where stream gauges were not available. A tributary entered the Mountain River slightly above the gauging weir, and in order to assess the relative contribution of the main stream and the tributary it was necessary to determine the discharge of each. This was done by determining the cross-sectional area of the stream at the point to be gauged and the velocity of the water flowing past the given point. Using this data the discharge can be calculated. The sites for these gaugings were chosen to allow wading or gauging from overhead bridges depending on the discharge. The controls chosen were quite stable as the stream bed consisted of bedrock and the banks were cemented bridge supports. Stream depths were determined at one foot intervals across the section. Using similar intervals the current meter was placed at 0.6 of the stream depth from the surface to obtain the mean velocity[1]. The more accurate measurement of the average of .2 and .8 of the depth could not be used in most cases because of the shallowness of the water. Total discharge was calculated by summing the discharge of each of the 1 foot sections.

The current meters used were the Ott Meter No. C1 and the Hilger and Watts Water Current Meter SK 70. The latter was limited to a minimum depth of 6 inches and could not record low velocities whereas the Ott could operate down to 3.2 inches and is sensitive to low velocities.

As stated, several times during the study the Mountain River overflowed the gauging weir and mechanical gauging was required to calculate the amount of over weir flow. If the weir was wadable this excess was calculated with a current meter using the above method. When overweir

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1. Boyer, M.C., "Streamflow Measurement", Section 15, in Handbook of Applied Hydrology, V.T. Chow (ed.), McGraw-Hill, New York, 1964.

flow became too great, the surface velocity was calculated by using floats over a measured distance of from 30 to 50 feet. By timing the floats over the distance and repeating at a number of positions in the cross-section the average surface velocity can be calculated. Mean velocity of the cross-section can then be found by multiplying the surface velocity by 0.8 (i.e. Mean Velocity = Surface Velocity x 0.8)[1]. Discharge can then be calculated by using cross-sectional area.

These discharge figures are vital to the consideration of water and sediment yields of the catchments.

WASH-LOAD SAMPLING

Two main types of wash-load samplers have been developed which are either depth or point integrating. Point integrating samplers collect samples at a specific point in the cross-section over a period of time and are used mainly to determine the distribution of sediment within the cross-section. Depth integrating samples collect an average sample of a particular vertical within the cross-section. This is done by lowering the sampler to the bottom of the stream and then raising it to the surface at a uniform speed so that the sample is collected on both the downward and upward journeys. All samples collected in this study were depth integrated.

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1. Ibid.

The sampler used in this study was based on a sampler designed by Loughran[1] who called it the UNE Sampler, and was built in the workshop at the University of Tasmania. The design is shown in Figure 10. The sampler is made up of a one pint milk bottle fitted with a rubber stopper. A quarter inch water intake of glass tubing was fitted into the stopper ensuring that the intake nozzle protrudes well forward of the sampler (4 inches) to minimise errors due to turbulence around the bottle. A similar size air outlet was fitted into the stopper allowing the air in the bottle to escape above the water surface. The bottle was fitted into a wading rod which had an attached stabilising fin to ensure that the sampler was kept pointing upstream. The sample was taken by lowering and raising the bottle at a constant rate until the water level in the bottle had almost reached the level of the air outlet.

The requirements for an ideal sampler have been stated by Nelson and Benedict[2] and the UNE sampler meets many of these requirements. It is inexpensive, rugged and simply constructed and the sample container is easily removable and can be transported without spillage of the sample. Sampling can be carried out to within 2 inches of the stream bed which is closer than the commonly used American samplers. Streamlining is sufficient to reduce drag and flume observations showed that the intake protruded forward of any turbulence caused by the sampler and the sampler filled smoothly without any inrush or gulping.

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1. Loughran, R.J., op. cit., 1969, p. 28.

2. Nelson, M.E. and Benedict, P.B., "Measurement and Analysis of suspended loads in streams". Am. Soc. Civ. Eng. Trans., 116, 1951, pp. 891-918.

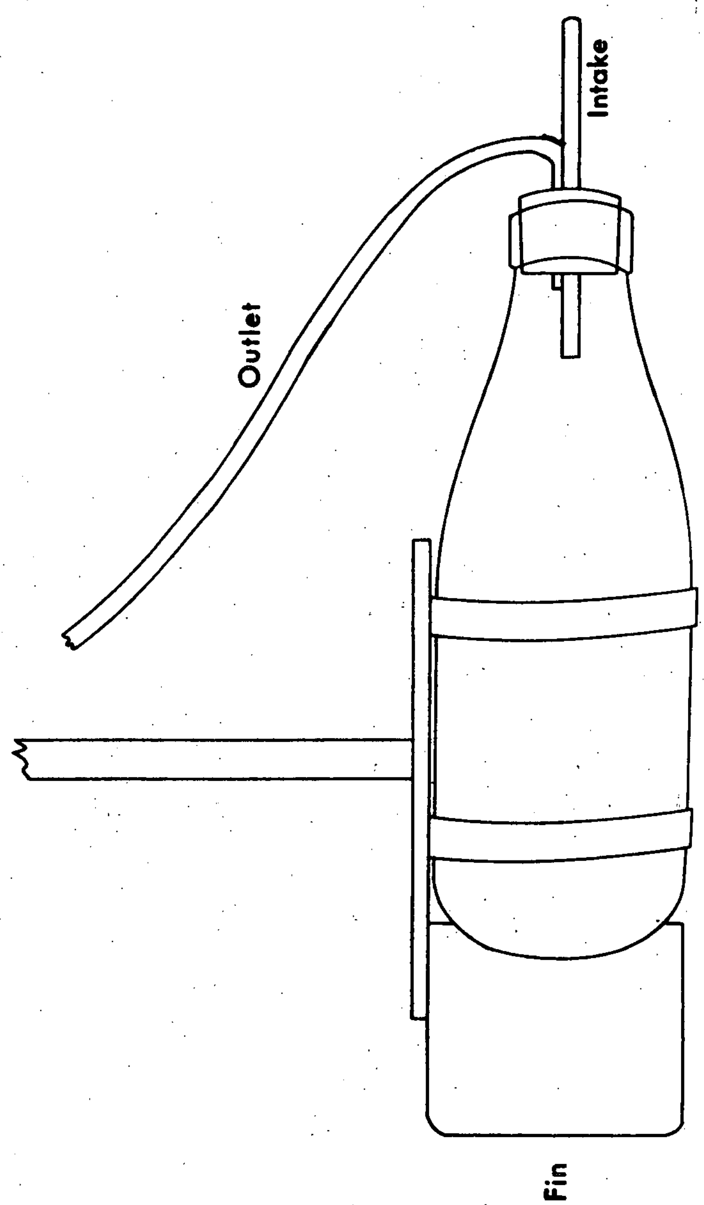

Figure 10
U.N.E. SEDIMENT SAMPLER

The most important requirement of a sampler is that the intake velocity of the sampler should be the same as the stream velocity. If the stream velocity is greater then the stream lines diverge as they approach the intake, but the sediment particles, because of their greater density and inertia, change direction less readily and so enter the sampler producing an excess. Where the converse occurs and the intake velocity is greater than the stream velocity, sediment particles converge less than the water and the observed sediment concentration is too low. The Sub-committee on Sedimentation[1] found that sampling rates below the stream velocity produced much larger errors than those resulting from sampling rates above normal. Also, as sediment size increases above 0.06mm diameter, errors increase markedly and with an intake velocity of one quarter stream velocity, sediment of 0.06mm diameter gave an 8% error while sediment of 0.45mm diameter gave 100% error. Sundborg[2] found that sediment of 0.05mm diameter resulted in an error of minus 20% with an intake velocity three times the stream velocity and an error of plus 100% where intake velocity was only a quarter of the velocity of the stream. With sediment of 0.05mm however the error was reduced to less than 1% in both cases. The coarsest sediment encountered during the study was of fine silt size and was less than 0.05mm, so errors due to anomalies in the intake velocity will be insignificant.

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1. Sub-committee on Sedimentation, "Laboratory investigation of suspended sediment samplers", Report No. 5, 1941.

2. Sundborg, A., "The River Klaralven, a study of fluvial processes" Geografiska Annaler 38, No. 2, 1956, p. 235.

Field testing of the UNE sampler was carried out by Loughran by using it simultaneously with a US DH-48 Depth Integrating hand sampler[1]. Twenty samples were collected at varying stages and the UNE sampler gave an average concentration 2% higher than that of the US DH-48 sampler. Loughran felt that this higher concentration was a result of the UNE sampler being able to sample closer to the bottom.

In this study, laboratory tests of the sampler were carried out in the Geography-Geology flume at the University of Tasmania to examine the relationship between stream and intake velocities. These were done using clean water as no facilities were available for the flume testing of actual sediment sampling. Three tests were carried out. The first tested the sampler at a constant depth but with varying water velocities; the second, the influence of varying depths with a constant water velocity; and finally the influence of turbulence upstream from the sampler.

All the tests were carried out in the centre of the cross-section of the flume to reduce any effects from the sides and bottom and observation of the testing section showed that the flow was relatively even and uninterrupted. In all cases the flume was filled to a depth of 32 centimetres. The water velocity was measured with an Ott Meter No. C1. Three velocity readings were taken at the testing point before the water sample was taken and three after and the average velocity was calculated. It was found that fluctuations in velocity

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1. Loughran, <u>op. cit.</u> , 1969, p. 30.

were insignificant. The water sample taken was a point-integrated sample. It was taken by sealing the air outlet and inserting the sampler to the testing point. The outlet was then opened and a sample of 150 to 200ccs taken before sealing the air outlet and stopping the flow. A stopwatch was used to record the time taken to obtain the sample. The volume of the sample obtained was measured in a measuring cylinder. A small amount of water entered the sample bottle before the outlet was unsealed due to compression of the air in the bottle by water pressure, but this amount was measured and taken into account in measuring the water sample obtained. Three water samples were taken for each reading and then averaged to minimise errors. The average velocity of the intake can then be calculated using the formula

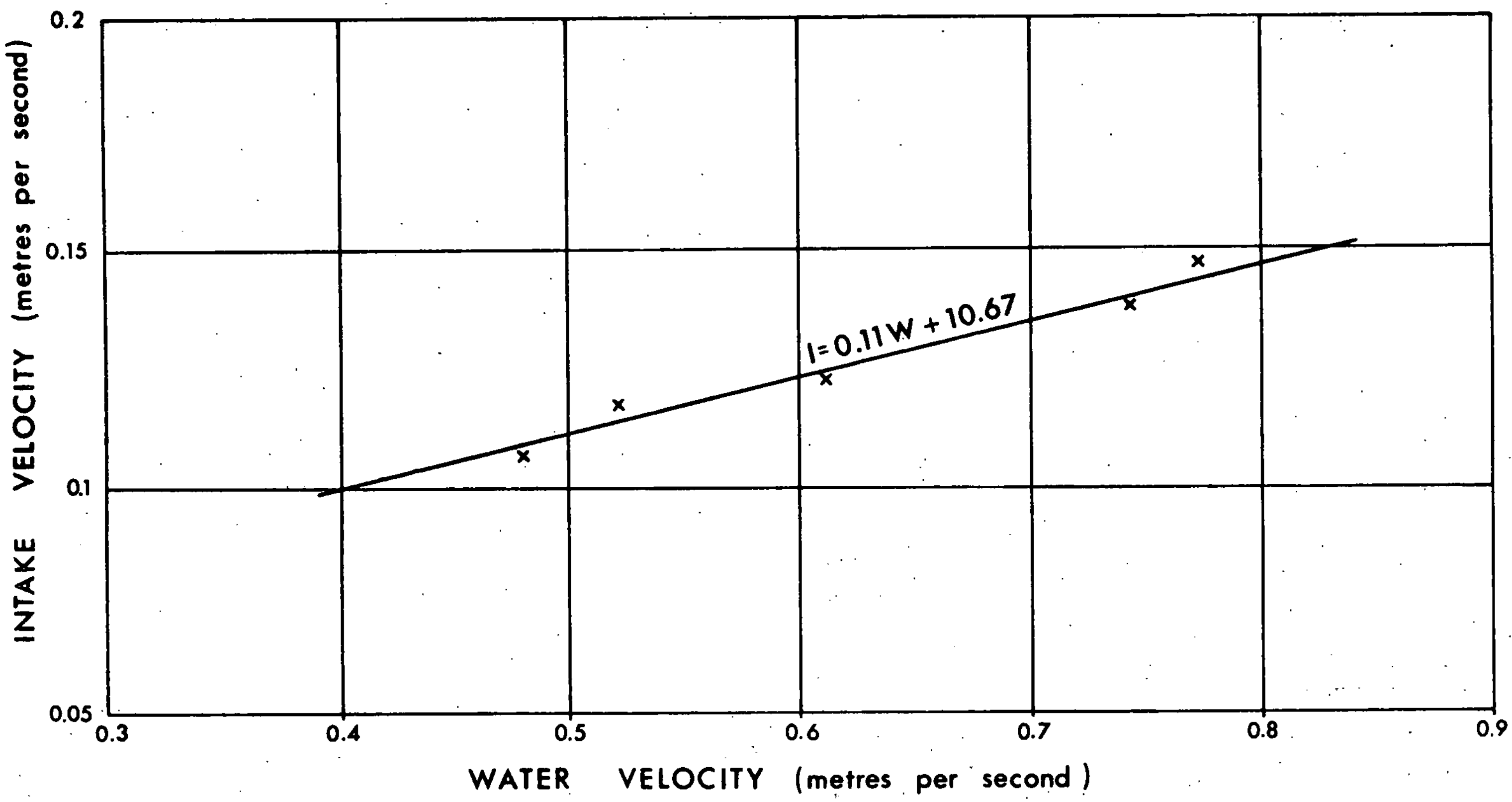
$$V = \frac{Q}{A}$$

Where V is the average velocity, Q the discharge and A the cross-section area of the intake.

In the first experiment the sampler was set at a depth of 16cm and five readings were taken with the water velocity varying from 48 to 77cms/second. It was found that while a strong linear relationship exists between the water velocity and intake velocity (Figure 11) only at low velocities was there any equality between the two. As velocity increases so does the discrepancy between water velocity and intake velocity. No apparent reason could be found for this discrepancy. The differences would introduce sampling errors especially at higher

Figure 11

RELATIONSHIP BETWEEN SAMPLER INTAKE VELOCITY AND WATER VELOCITY WITH CONSTANT DEPTH

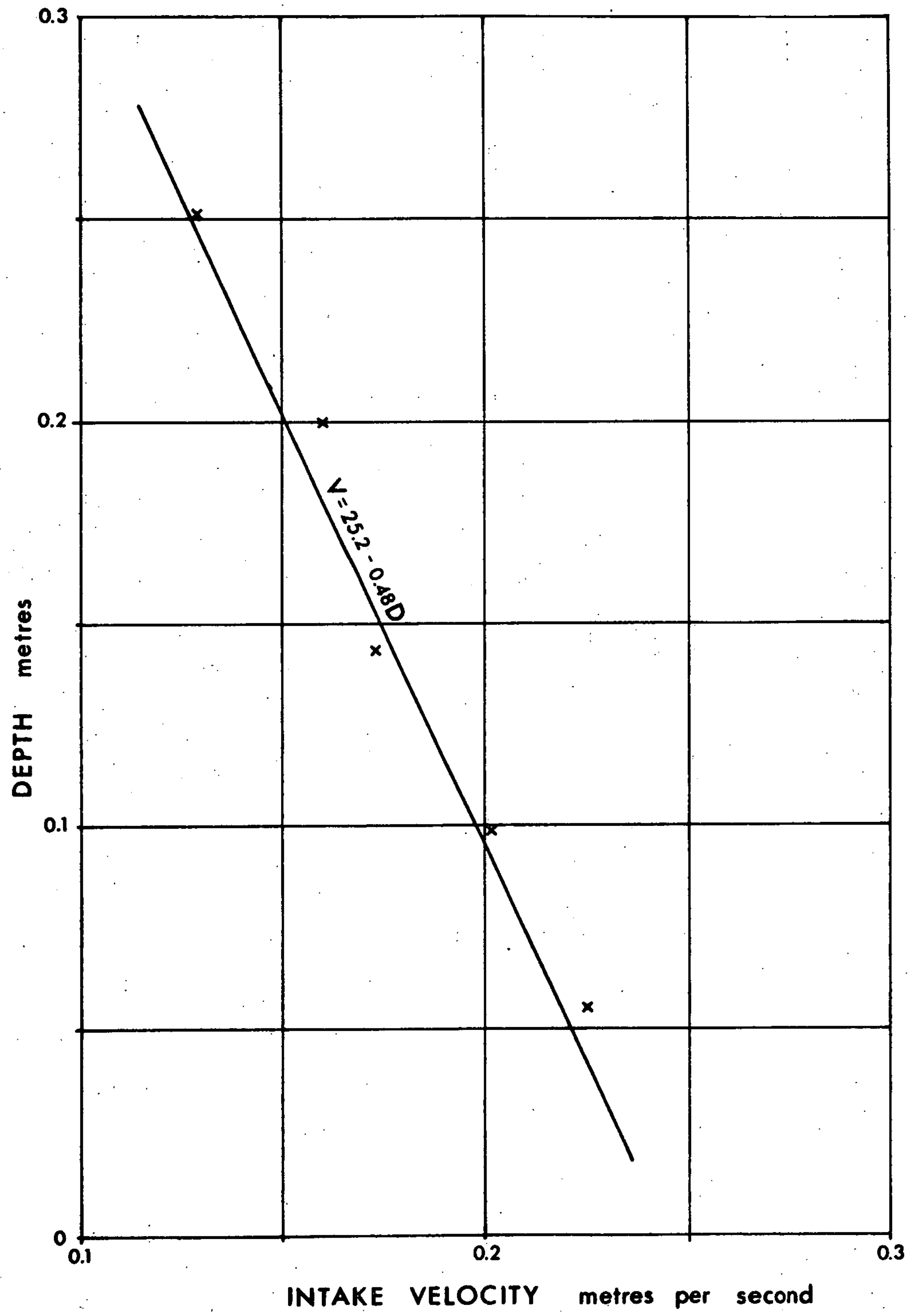


velocities when coarse sediment is evident. However, velocities in the study streams were generally low, reaching a maximum of approximately 60cms/sec and as stated the sediment was very fine, so errors should not be significant.

The second experiment involved a constant water velocity but varying depth of the sampler. Again five readings were taken and it was found the water velocity in the central vertical of the flume was constant with only slightly reduced velocities within a few centimetres of the bottom, but these low velocities were below the minimum depth of the sampler. The water velocity in the experiment was 55cms/second. An analysis of the intake velocities showed that velocity increased significantly with depth giving a strong linear relationship (Figure 12). The reason for the increase with depth is related to the relative positions of the sampler intake and outlet. As the outlet is above the water surface the pressure acting on it will be atmospheric pressure. The intake however as well as having pressure exerted on it by the moving water will also have a composite force of air pressure plus water pressure due to the depth of immersion, thus setting up a pressure differential other than that due to the stream velocity. Water pressure increases with depth giving an increasing velocity discrepancy. This results in a biased sample if the sampler is lowered and raised at a constant speed as the lower sections of the stream will have a proportionately higher percentage of the sample. As sediment concentration is greatest near the stream bed this could produce results significantly higher than the actual average sediment concentration. In the final experiment analysing the effects of turbulence no significant results were obtained.

Figure 12

RELATIONSHIP BETWEEN SAMPLER INTAKE VELOCITY AND DEPTH



It is apparent from the flume test carried out that the UNE sampler has a number of inherent faults. Because of the fine nature of the sediment in this study these faults should not lead to any significant errors in sample collection. This is supported by laboratory studies by Sundborg and by Loughran's field testing with sediment conditions similar to those in this study. A great deal of further testing is required to find the reason for these faults and many improvements need to be made to the sampler itself. The problem of pressure differential due to the depth of immersion could probably be overcome by placing the outlet in the stream facing downstream at the same level as the intake rather than above the water surface. In its present state it would be inadvisable to use the UNE sampler where there are unusually high stream velocities or where sediment size exceeds 0.05mm diameter.

When taking samples in the field, two samples were taken at each sample point to minimise the chance of error. Samples were taken from points at a quarter, a half and three quarters the width of the stream. Half of each sample was taken at the mid-point and the remainder at either a quarter or three quarters width. The water temperature and pH were also taken at the time of each sample.

LABORATORY ANALYSIS OF SEDIMENT

Despite the large literature on stream sediment determination very little is written on the laboratory techniques used to analyse the samples obtained. Most of the literature is concerned with the way in which the sample is obtained and only gives brief mention to the actual analysis.

WASH LOAD

Several methods were examined for the calculation of the wash load and most of them proved unsuitable for this study. Decanting after allowing the sample to settle and then evaporating the concentrate was unsuitable because of the extremely fine nature of the sediment which involved either extremely long settling periods or considerable loss of sediment in the decanting process. Processes involving asbestos filter mats or fritted glass filters have been shown to be inadequate as they either let a significant amount of the sediment through the filter or quickly become blocked with sediment if finer filters are used. Douglas in his study in Australia[1] used Whatman 452 filter papers to separate out the suspended load. Before filtering the papers were washed and dried in an oven and weighed. After filtering the papers were once again washed and dried, dessicated and then weighed and the concentration calculated by comparing with the weight of the original sample. In using this method some anomalous results have been obtained as in some cases the filter papers have been found to be lighter after filtering, probably due to loss of fragments of filter paper during

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1. Douglas, I., op. cit., 1966.

filtering. This error is not always constant, and when dealing with low sediment concentrations the method is unsatisfactory. All the above methods find only the suspension load and further processing is required to determine the solution load and total wash load.

The method finally decided upon was based on one developed by Loughran[1] which enables an accurate and relatively fast method of calculating total wash-load. A 150ml Phillips Beaker was washed, dried and dessicated for at least 20 minutes and then weighed on a Mettler H6T Analytical balance (accurate to 0.1mg). A few drops of weak soap solution were added to the sediment sample to help disperse the clay particles. The sample was shaken well to ensure a homogeneous mixture and approximately 50cc were drawn off and the beaker was once again weighed. The bulk of the water was then boiled off and then the remainder was evaporated in an oven. After allowing the dry sample to cool in a dessicator for at least 20 minutes the beaker was again weighed and the weight of the dry sediment could be determined. Total wash-load in parts per million (ppm) can then be calculated. As two samples were taken at each station, by averaging the results obtained from these any error can be reduced. This method has the advantages of being relatively simple and fast as a number of samples can be processed at the same time. Accuracy of the method is relatively good as a number of analyses carried out on the same sample gave similar results with variations of no greater than 5% with low sediment concentrations and the error decreases with increasing sediment concentration.

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1. Loughran, R.J., op. cit., 1969.

Significant sources of error are introduced by changes in temperature and humidity in the laboratory between the initial weighing of the beaker and the weighing of the dry sediment. Because of the low sediment concentration and therefore the low weight of the sediment, changes in weight of the beaker due to temperature changes can be significant and in a number of cases errors of up to 25% were experienced. These errors were overcome by attempting to carry out the analysis when temperature and humidity were relatively constant and by checking the weight of the beaker after the dry sediment had been weighed. This was done by thoroughly washing and drying the beaker, dessicating it for a short period and re-weighing. By averaging the two weights for the beaker this error can be reduced significantly. Generally the analysis provides a simple but accurate method of determining total wash-load.

SUSPENSION AND SOLUTION LOAD

As well as determining total wash-load an attempt was made to find the suspension load and solution load which made up the wash load. Several methods were examined and most proved too costly for the present study. The method used is essentially that used by Sundborg[1] and slightly modified by Loughran[2], both of whom were faced with a similar problem of low sediment concentration. Most of the methods used in the

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1. Sundborg, A., op. cit., 38 (2), 1956, p. 296.

2. Loughran, R.J., "Some observations on the determination of fluvial sediment discharge." Aust. Geog. Studies, Vol. 9, No. 1, 1971, pp. 54-60.

United States are designed for greater concentrations and are not adequate in dealing with low concentrations. The method involves the use of the total sample collected after the amount for the wash-load determination has been removed. As the equipment required became available only half way through the study, suspension and solution load analysis was only done for the last six months.

A clean dry porcelain crucible with lid was taken and placed in a furnace at 800°C for 20 minutes. It was removed and dessicated for 20 minutes after allowing it to cool and then was weighed on the Mettler Balance (correct to 0.1mg). The total sample was then weighed on a Mettler P2000 Balance (correct to 0.1gm) and filtered through Whatman 542 ashless filters using a vacuum pump. If sediment concentration was high the sample was filtered through a coarser ashless filter before using the finer 542 papers as these soon became clogged. After filtering, the empty sample bottle was weighed to determine the weight of the original sample. A portion of the filtrate (approximately 50cc) was then removed and processed in the same manner as the wash-load sample to enable the determination of the solution load. The filter paper containing the suspension load was placed in the weighted crucible which was placed in the furnace and the paper burnt off slowly with no flame. It remained in the furnace for 20 minutes at 800°C. After allowing to cool, the crucible and residue were dessicated for 20 minutes and weighed correct to 0.1mg. The filter papers are claimed to be ashless leaving a residue of less than 0.1mg which is not significant. Concentration of the suspension load can then be calculated in ppm. As with the determination of the wash-load, significant errors could be introduced by temperature changes but these were overcome in a similar way by re-weighing the crucible and lid after the analysis and averaging the two weights. It was found in most cases that the value for the wash-load obtained by summing the solution and suspension loads was slightly higher than the value obtained by the direct method with approximately a 5% discrepancy in low concentration samples but decreasing with increasing sediment concentration. No reason can be found for this discrepancy.

Once values had been obtained for the three components of the sediment load the various loads could be expressed in tons per day. This enabled the plotting of a log-log graph of wash-load in tons per day, against instantaneous discharge, to give a sediment rating curve. The conversion of concentration to sediment load was done by assuming the density of water to be 62.321 lb/cu ft. Then one cusec flowing for one day would yield 2404 tons of water per day. The wash-load in tons per day can then be calculated by using the formula[1]:

$$L = 2404 \times Q \times C \times 10^{-6}$$

Where L is the wash load, Q the discharge and C the concentration in ppm.

Towards the end of the study several analyses were made of the mineralogical composition of the wash-load. This was done by collecting a sample of approximately 2 litres, evaporating the water off and drying the sediment in the oven. This was then subjected to X-Ray Diffraction analysis in the Geology Department, University of Tasmania.

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1. Loughran, R.J., <u>op. cit</u>., 1969, p. 33.

CHAPTER 4

BROWNS RIVER

The Browns River catchment is located approximately 10 miles southwest of Hobart with the stream extending from the Mount Wellington area to its mouth at Kingston. The gauging point is located adjacent to Summerleas Road where the road crosses the river and is approximately 3 miles upstream from the mouth. The catchment area studied had an area of 5 square miles and is shown in Figure 13. Map coverage is available on the Hobart 1:31,680 sheet and aerial photograph coverage is also available.

Relief in the area is high as the stream rises in the vicinity of the summit of Mount Wellington and quickly falls to sea-level over a distance of 8.5 miles. Stream gradient varies from 1020 feet per mile in the upper sections to 130 feet per mile around the gauging station and the relief ratio[1] is 0.12. In the upper sections, where bedrock outcrop is common, valleys are ill-defined but in the lower sections the stream has heavily dissected the area to produce deep valleys with extremely steep slopes. Deposition has occurred in a limited area adjacent to the gauging site. The stream bed and banks are composed of dolerite bedrock in the upper sections while further down the stream they change to dolerite boulders and brown clay material. Below the dolerite contact there are occasional bedrock bars of mudstone while the bed often contains shaley material up to 5cm in diameter.

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1. Relief ratio as defined by Schumm (1954) is the total basin relief divided by the horizontal distance along the longest catchment dimension parallel to the principal drainage line.

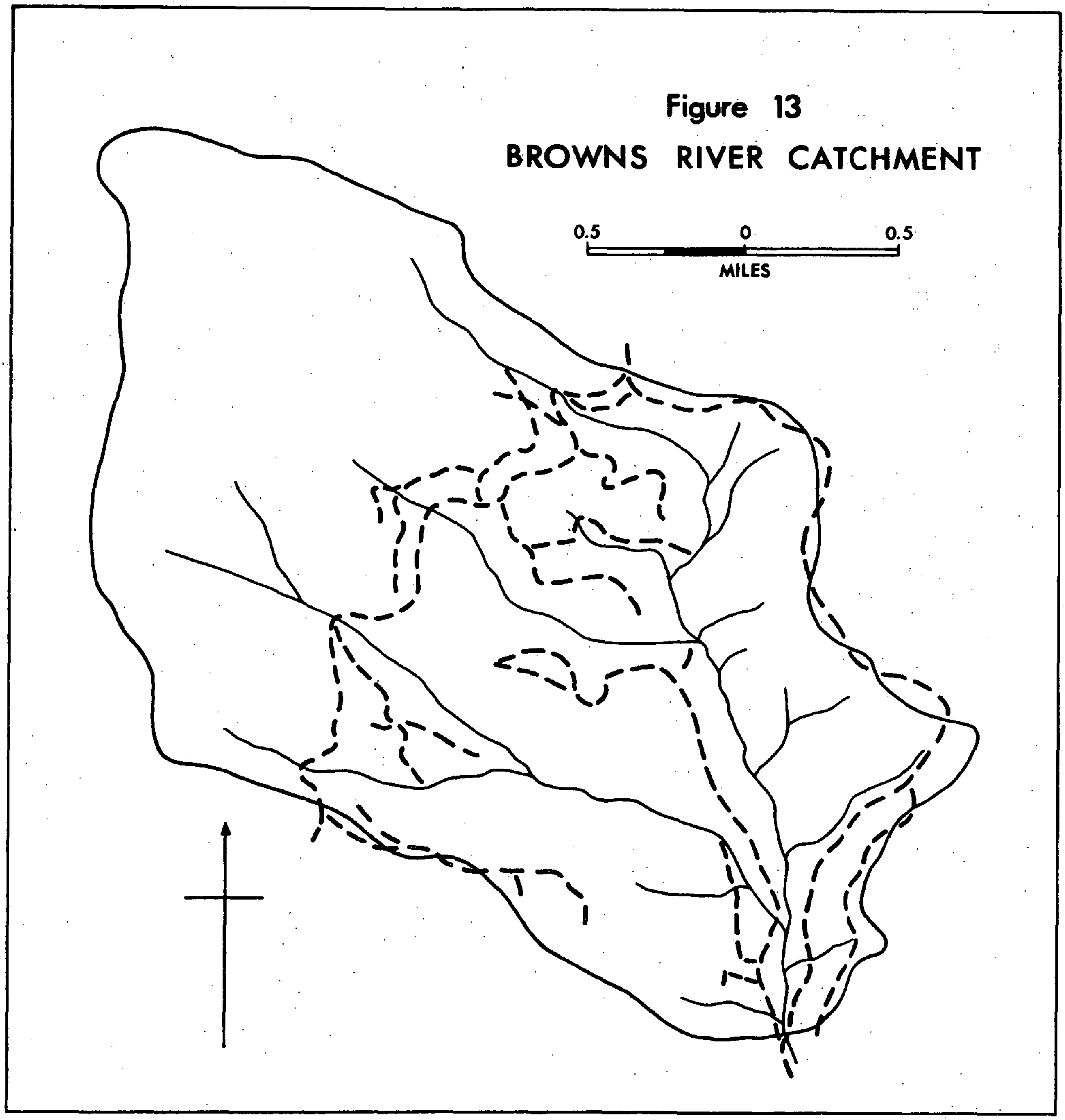


Figure 13
BROWNS RIVER CATCHMENT
0.5
0
0.5
MILES

The geology of this catchment is rather complex with five geological formations outcropping in the catchment all of which have been disturbed by extensive faulting. The area has been mapped on the Geological Map of Hobart which has been reproduced in Figure 14. No detailed information on the Geology has been published. The oldest unit is the Malbina Sandstone which outcrops in three limited areas at the base of the other sediments and outcrops over only 3 per cent of the catchment area. It is a light coloured felspathic sandstone with medium grain size. Above this formation is the Risdon Sandstone which is a 20 feet thick marker bed occupying only 1 per cent of the catchment area. This consists of at least 90 per cent well rounded quartz while the remainder is feldspar. It is a coarse rock with grain size ranging from 0.5mm to 1mm.

Outcropping over 24 per cent of the catchment is the Ferntree Mudstone. Most of this formation is composed of a grey and white mottled mudstone with some small glacial erractics of less than 3cms diameter which are more common towards the base. Grain size is relatively constant around 0.08mm, while the rock is composed of up to 60 per cent of a fine siliceous matrix with grains of quartz and felspathic material.

The Knocklofty Formations and Springs Sandstone, forming the upper members of the sedimentary sequence in the catchment, occupy 26 per cent of the total area. Lithology of the Knocklofty Formation varies from conglomerate to sandstone and siltstone with the sandstone being dominant. The conglomerate consists of sub-angular quartz grains up to 1cm in diameter set in a matrix of sand sized quartz with limited amounts of feldspar. Above the conglomerate, the coarse sandstone

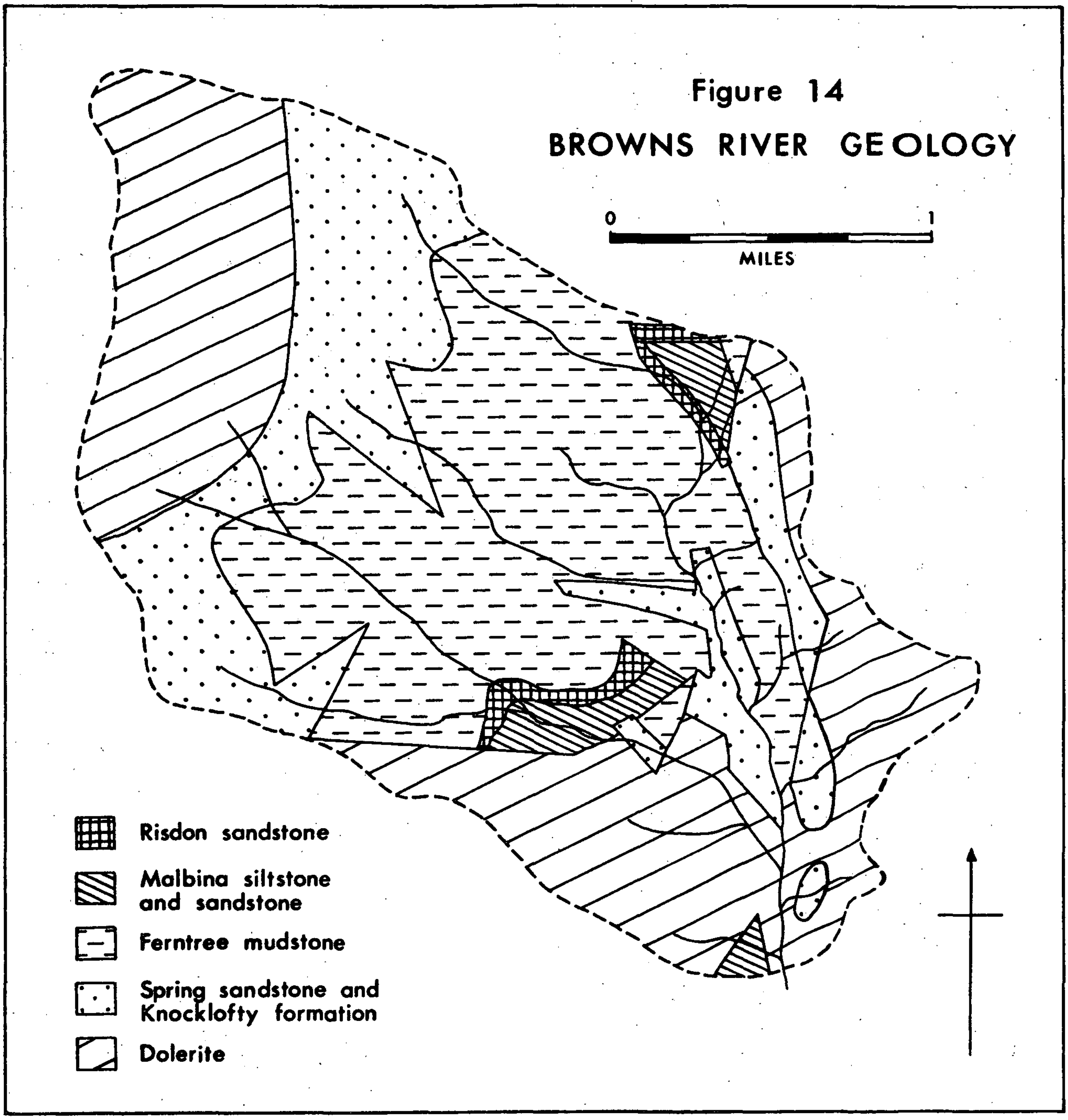


Figure 14
BROWNS RIVER GEOLOGY
0
1
MILES
Risdon sandstone
Malbina siltstone and sandstone
Ferntree mudstone
Spring sandstone and Knocklofty formation
Dolerite

passes into finer sandstones interbedded with siltstones which are easily weathered. The standstone is of a light colour, consisting of sub-angular quartz grains with feldspar being almost absent in the upper phases. Overlying the Knocklofty Formation, the Springs Sandstone consists of even grained quartz and feldspar grains with grain size varying from 0.1 to 0.3mm.

Intruded into the sediments is the Jurassic Dolerite which is the most common rock type extending over 46 per cent of the catchment. This is usually relatively fine grained with labradorite laths up to 1mm and augite crystals up to 2mm.

No detailed studies of the vegetation of the catchment have been carried out and so it was necessary to compile a vegetation map (Figure 15). This was done on the basis of the amount of ground cover provided, as it is this aspect which is most important in relation to fluvial erosion. The map was prepared from the Lands Department aerial photographs (Derwent-D'Entrecasteaux 1965 Pun 6 Photos 88 and 89, Run 7 Photos 27 and 28) and The 1967 Fire Assessment photo (Run 9 Photos 58-62 and Run 10 Photos 88-91).

Four vegetation types were recognised; sclerophyll forest occupying 74 per cent of the catchment area, partially cleared forest and pasture 12 per cent, cultivated areas 3 per cent, and moorland 11 per cent. The sclerophyll forest has a tree cover of greater than 50 per cent but has large areas with a greater than 80 per cent cover. Below the tree cover is a discontinuous layer of saplings and shrubs with some grasses at ground level. Bare ground often occurs below the trees particularly on steep slopes. The forest becomes very thick in the gullies in the higher rainfall area around the Huon Highway. In some areas the forest has

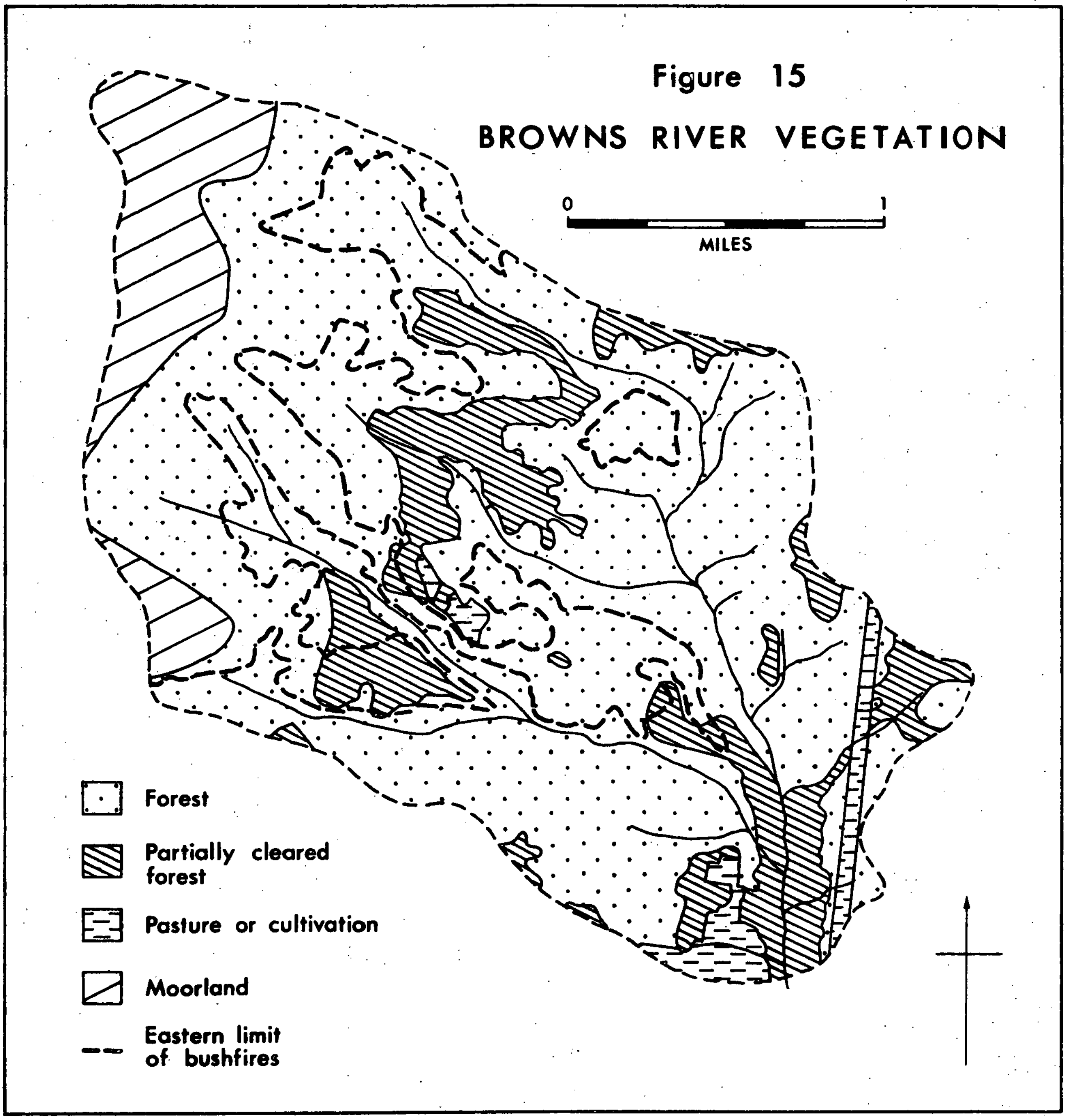


Figure 15
BROWNS RIVER VEGETATION

been partially cleared and pasture has been sown. These areas are restricted to the lower sections of the stream and to a ribbon along the Huon Highway. Vegetation cover here consists of a tree cover of less than 50 per cent with a complete ground cover of grasses.

Moorland vegetation occurs in the highest sections of the catchment above the treeline. It consists of a cover of shrubs and grasses which are broken by rock outcrop and dolerite boulders. The cultivated areas are extremely limited in extent. Cover here is variable depending on the season and also the amount of fallowing varying from no vegetation to approximately 50 per cent cover.

The bushfires of February 1967 have had an effect on the vegetation which was still evident during the study period. Approximately 38 per cent of the catchment was affected mainly in the upper sections and extending down along the ridges as shown in Figure 15. All of the moorland vegetation was destroyed, but by the time of the study this had almost recovered. In the sclerophyll forest the influence was greater although only 34 per cent of the forest was effected. Recovery is still occurring and during the study the tree cover was less than half the pre-fire cover. There is however a denser cover of shrubs and saplings than occurs in the areas not affected by the fires.

RAINFALL AND RUN-OFF

No rainfall recording stations occur in the catchment itself but there are two stations in the adjacent area. The first of these is at Ferntree approximately half a mile east of the catchment boundary on the Huon Highway, while the other is at Kingston near the mouth of Brown's

River and approximately 3 miles downstream from the gauging point. A great deal of difference occurs between the recording of the two stations as is shown in the monthly and annual figures in Table 1. The Kingston station has an annual average of 26.92 inches while the Ferntree average of 48.10 is almost double this. The main reason for this variation is the different elevations of the two stations. The Kingston station is almost at sea-level while the Ferntree station is at an elevation of 1120 feet is subject to a considerable orographic influence. The upper part of the catchment experiences several snowfalls each winter.

Both stations receive a relatively equal distribution of rain throughout the year with a slight maximum in the spring months and a minimum in late summer. The monthly means of the two stations vary with Kingston having a maximum in December and a minimum in January while Ferntree has an August maximum and June minimum. While the monthly means are relatively constant the nature of the rain varies significantly. Winter rain is associated with depressions and tends to be of relatively low intensity, while in summer rain is associated with convectional storms and is of much greater intensity. For example, at Kingston where the monthly mean rainfall for February and September are approximately equal, February has an average of 3 days when rainfall is greater than 10 points while September has 8.

Rainfall for the 12 months during the study period was 51.32 inches at Ferntree and 31.07 inches at Kingston. Both of these figures were considerably above average. The distribution of the rainfall over the 12 month period also differed significantly from the means as indicated in Table 1. Despite the above average 12 month total, monthly figures

Table 1

Ferntree & Kingston Rainfall Data

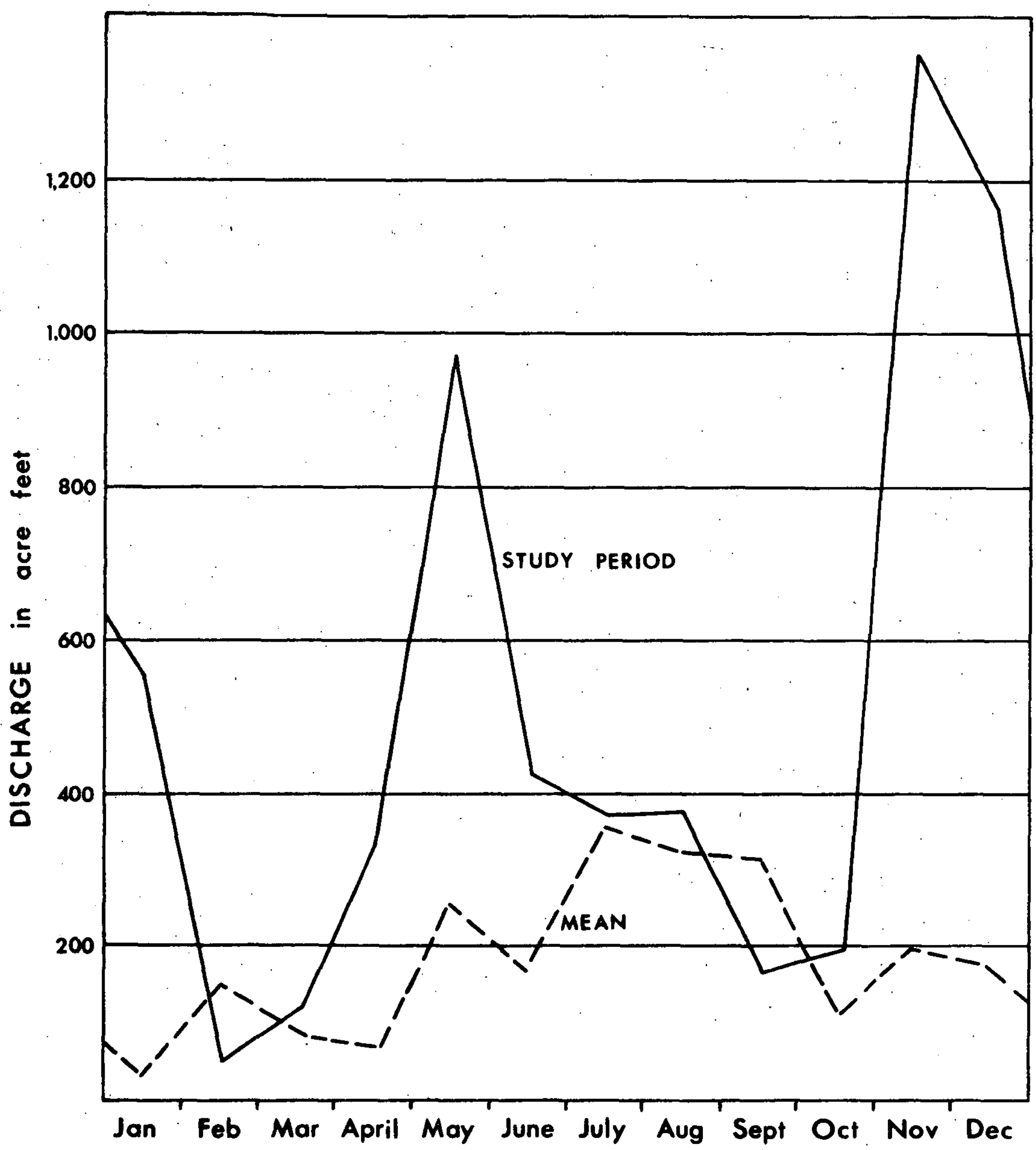
	Ferntree		Kingston	
	Mean	Study Period	Mean	Study Period
January	310	827	174	491
February	424	206	193	153
March	368	738	212	203
April	375	197	239	80
May	398	183	214	145
June	299	321	248	136
July	432	179	223	110
August	489	262	214	202
September	364	85	203	91
October	406	276	264	173
November	467	1,066	240	715
December	478	792	268	608
Total	4,810	5,132	2,692	3,107

were below average for 8 months at Ferntree and 9 months at Kingston with some months less than a quarter of the mean for that month. Rain was concentrated in November and December 1969 and January 1970 when rainfall was at least double the monthly mean. The rainfall was further concentrated into three rainfall episodes of three to four days duration when rainfall intensity was very high. The Ferntree station had above average precipitation in June which was associated with abnormally heavy snowfalls.

Stream run-off is directly related to the rainfall of the catchment. The Rivers and Water Supply Commission's gauging weir was established in May 1963 and discharge records are available from this time. Average annual discharge over this period was 3,080 acre feet but has varied from a minimum of 1,670 acre feet in 1965 to a maximum of 6,150 feet in 1969. Because of the short period of record, monthly means are strongly influenced by values for particular years and if there has been a month with abnormally heavy rainfall then the mean for that month may be doubled. For this reason the means obtained for this short period are of doubtful accuracy and value. Despite this however the monthly means for discharge correspond relatively closely to the longer term, and more accurate, rainfall records. The hydrograph shown in Figure 16 shows distinct seasonality of discharge with a maximum in late winter and spring and a minimum in late summer and early autumn. While this corresponds with the rainfall pattern, the variations are much more marked as the period of maximum rainfall corresponds with the period of minimum potential evaporation and a relatively large proportion of

Figure 16

BROWNS RIVER HYDROGRAPHS



rainfall is removed from the catchment as run-off. In summer when rainfall is at a minimum, potential evaporation is greatest and so proportionately less water is removed from the catchment as run-off. It is quite common for the river to cease flowing in summer. Annual discharge during the study period was 3,990 acre feet which is 30 per cent above the annual mean. The hydrograph for the study period varies significantly from the average hydrograph as shown in Figure 16 with major variations occurring in November and December 1969 and January 1970 when three floods occurred. Daily discharge figures are shown in Appendix 1 and they range from 1.1 cusecs in October to 180 cusecs in December which is the highest discharge ever recorded.

As stated, a strong relationship exists between rainfall and run-off. This has been examined by a number of past workers who have used several methods of analysis. One of the best known of these is the use of "double-mass curves" as developed by Searcy and Hardison.[1] These involve the plotting of cumulative annual totals of rainfall against discharge. The resulting graph should be linear if the catchment has remained constant. Any changes in slope can be a result of changes in catchment parameters such as vegetation, or changes in recording methods or sites or can indicate errors in the recordings of either rainfall or discharge. Two double-mass curves

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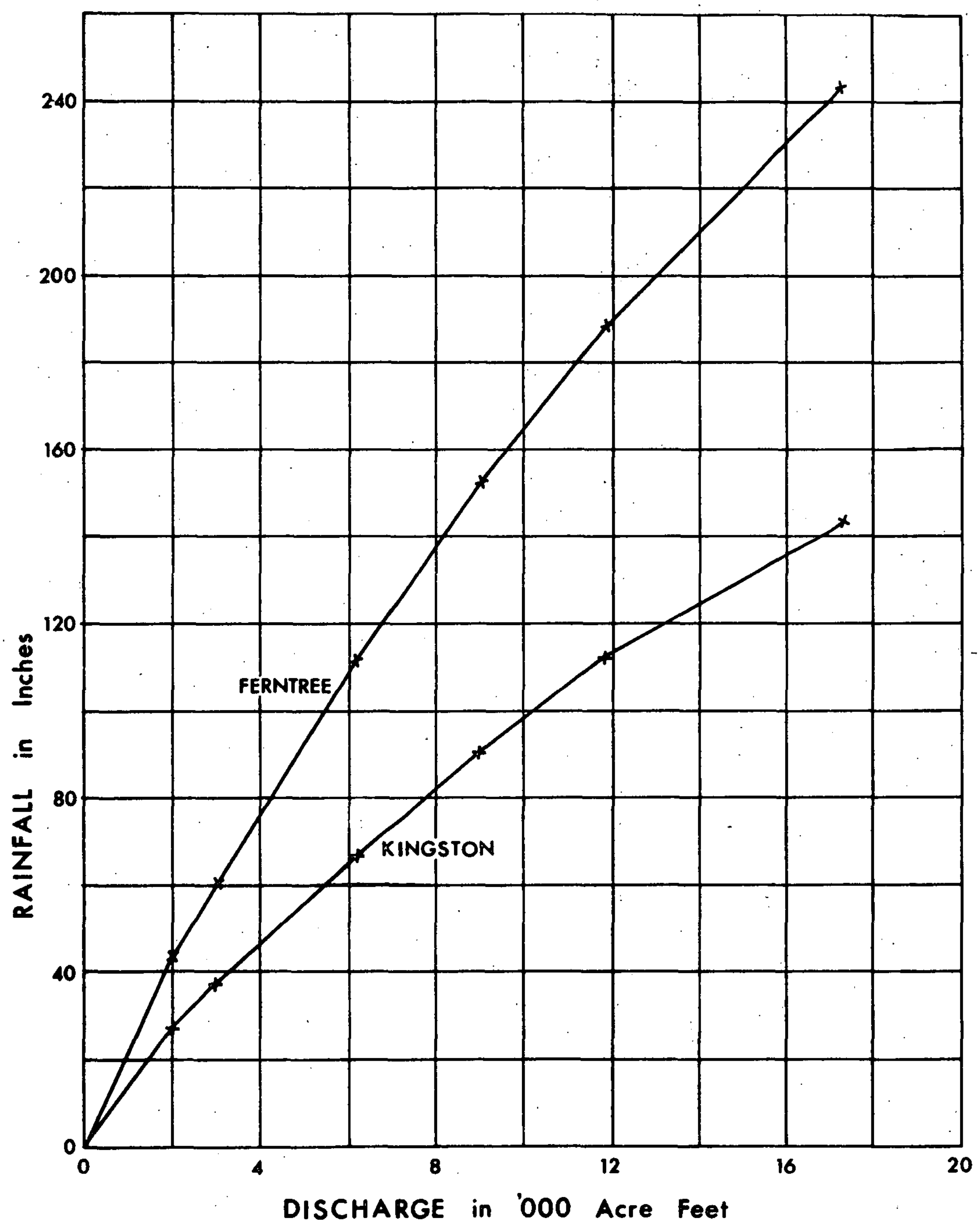
1. Searcy J.K. and Hardison C.H., "Double-Mass Curves", U.S. Geol. Survey Water Supply Paper 1541B, 1960.

have been plotted for the Brown's River catchment (Figure 17) one based on the rainfall recordings from Kingston and the other on those from Ferntree. In both cases the plot is approximately linear. This is a good indication that the rainfall run-off recordings for these stations are accurate. Through the period of record the amount of run-off has become proportionately greater but only to a small degree. This is to be expected as the original vegetation is cleared and vegetation cover reduced resulting in a decrease in interception and transpiration. Many studies throughout the world have noted marked changes in double-mass curves if the vegetation is significantly changed, especially by fire. Although 35 per cent of this catchment was burnt out in February 1967 no distinguishable change has occurred in the double-mass curves and in fact this is the section of the curve showing the least change. An explanation for this lack of influence can be found in the nature of the fire damage. Generally the fire was restricted to the forest canopy and often the ground cover was left virtually unaffected. It is the ground cover which has the greatest influence on run-off and so any impact of the fires is limited. Also, where the ground cover was destroyed it recovered quickly and so the influence on the annual total for 1967 was reduced. The fires however do not appear to have had any lasting effect on the hydrology of the catchment.

SEDIMENT DATA

Sediment sampling at Brown's River was carried out upstream from the gauging weir pond except at extremely high flows, when sampling could only be carried out at the weir itself. Thirty five samples of the wash

Figure 17
BROWNS RIVER DOUBLE MASS CURVES



load and 12 samples of solution and suspension loads were taken during the period of the study, and these are shown in Tables 2 and 3.

WASH LOAD

The wash load samples cover discharges ranging from 0.95 to 363 cusecs, with the majority of readings in the lower end of the range, generally below 5 cusecs. There is a clear break in the range of discharges, with readings at low flows, and extremely high flows, but very few at intermediate flows. This is a result of the nature of the catchment which is relatively small with high relief and so during a rainfall episode the discharge rises and falls relatively rapidly. Those readings falling in the intermediate range are all taken on the falling stage as discharge falls less rapidly than it rises.

Concentration of the wash load ranged from 54 parts per million (ppm) to 403 ppm. Generally however, it was within the range of 50 to 100 ppm, with only 4 readings greater than this range. A regression analysis was made to examine if any relationship existed, between wash load concentration and instantaneous discharge. Regression was done both numerically and on a logarithmic basis but no significant relationship was found to exist. A further analysis was carried out by examining a particular run-off episode from the 15th to the 25th of March 1970. A hydrograph and a sediment concentration curve were plotted (Figure 18) from which it can be seen that sediment concentration reaches a peak on the rising stage before maximum discharge is reached. From the results of these two analysis it is apparent that discharge is not a dominant variable in determining sediment concentration.

By using the concentration and instanteneous discharge figures, wash load in tons per day can be calculated as shown on page 60. This value is the most commonly used one in the examination of wash load relationships. Using these values, the wash load rating curve for Brown's River was plotted. The rating curve is a logarithmic regression analysis of instantaneous discharge and wash load in tons per day. It has been found in most fluvial studies that a strong relationship exists between these two variables and this is supported by this study. The relationship for Brown's River is shown in Figure 19 where the regression equation is:

$$L = 0.157\ Q^{1.184}$$

where L is the wash load in tons per day and Q is the instantaneous discharge. The correlation co-efficient was 0.97 which is significant at the 0.1 per cent level. The value of 1.184 indicates that wash load rises at an increasing rate relative to discharge.

Using the rating curve and the daily flow figures it is possible to calculate daily wash load discharges for the study period (Appendix 11). From these figures it is clear that wash load discharge is low for much of the time, with several isolated episodes contributing a large amount of sediment to the annual total, which is in keeping with the discharge pattern. Of the annual total of 695 tons of sediment, approximately half is contributed by four individual episodes covering a total of 15 days.

Table 2

BROWNS RIVER - WASH LOAD DATA

Date	Instantaneous discharge (cusecs)	Concentration (ppm)	Wash load (tons/day)
4. 7.69	7.45	80	1.43
8. 7.69	9.18	82	1.81
8. 8.69	10.07	106	2.58
14. 8.69	7.55	86	1.56
25. 8.69	4.62	92	1.02
2. 9.69	3.48	74	0.62
7. 9.69	2.96	83	0.59
17. 9.69	2.70	77	0.50
26. 9.69	2.78	65	0.44
3.10.69	2.50	81	0.49
10.10.69	2.91	54	0.38
26.10.69	0.95	77	0.18
3.11.69	44.0	93	9.84
10.11.69	3.63	66	0.58
17.11.69	363.0	403	352.12
18.11.69	338.0	170	138.14
27.11.69	7.20	66	1.14
3.12.69	12.50	93	2.79
16.12.69	8.00	72	1.38
21.12.69	4.60	50	0.55
11. 1.70	5.70	73	1.00
23. 1.70	6.75	84	1.36
3. 2.70	2.54	80	0.51
9. 2.70	1.62	92	0.36
23. 2.70	1.79	88	0.38
2. 3.70	1.43	76	0.26
10. 3.70	1.43	87	0.30
15. 3.70	1.25	100	0.30
20. 3.70	56.00	304	40.93
21. 3.70	92.00	94	20.79
25. 3.70	12.50	69	2.07
2. 4.70	3.70	91	0.81
19. 4.70	2.08	79	0.40
26. 4.70	1.62	86	0.34
3. 5.70	3.23	85	0.66

Table 3

BROWNS RIVER - SUSPENSION AND SOLUTION LOAD DATA

Date	Instantaneous discharge (cusecs)	Suspension Concentration (ppm)	(tons/day)	Solution Concentration (ppm)	Load (tons/day)
9.2.70	1.62	5	0.018	76	0.30
23.2.70	1.79	5	0.020	74	0.32
2.3.70	1.43	8	0.026	79	0.28
10.3.70	1.43	7	0.023	84	0.28
15.3.70	1.25	9	0.028	105	0.32
20.3.70	56.00	130	17.44	100	13.47
21.3.70	92.00	18	3.98	70	15.48
25.3.70	12.50	13	0.376	38	1.13
2.4.70	3.70	8	0.071	92	0.82
19.4.70	2.08	11	0.055	79	0.40
26.4.70	1.62	11	0.043	80	0.31
3.5.70	3.23	11	0.082	76	0.59

Figure 18

BROWNS RIVER RUN-OFF EPISODE 15th-30th MAY 1969

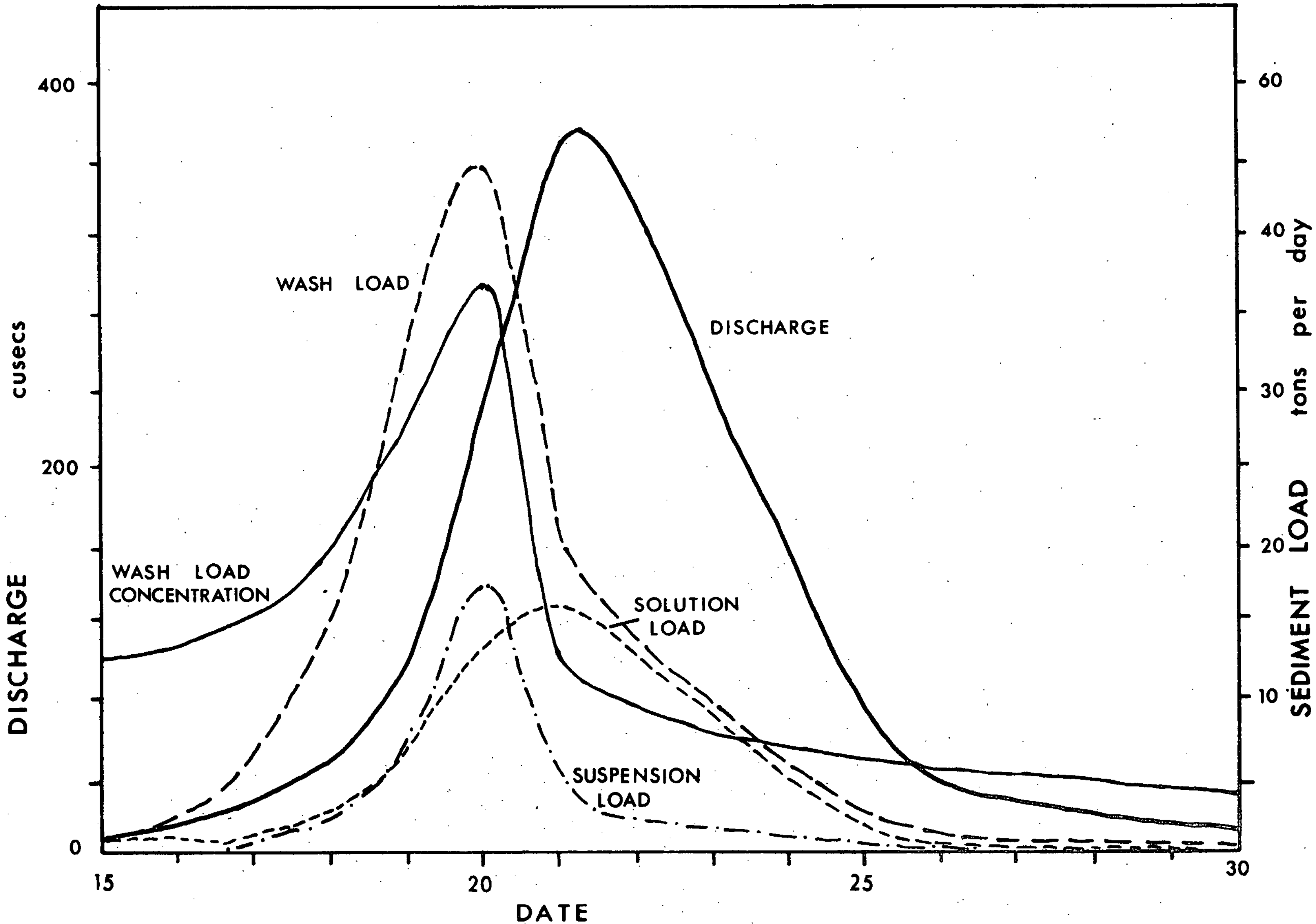
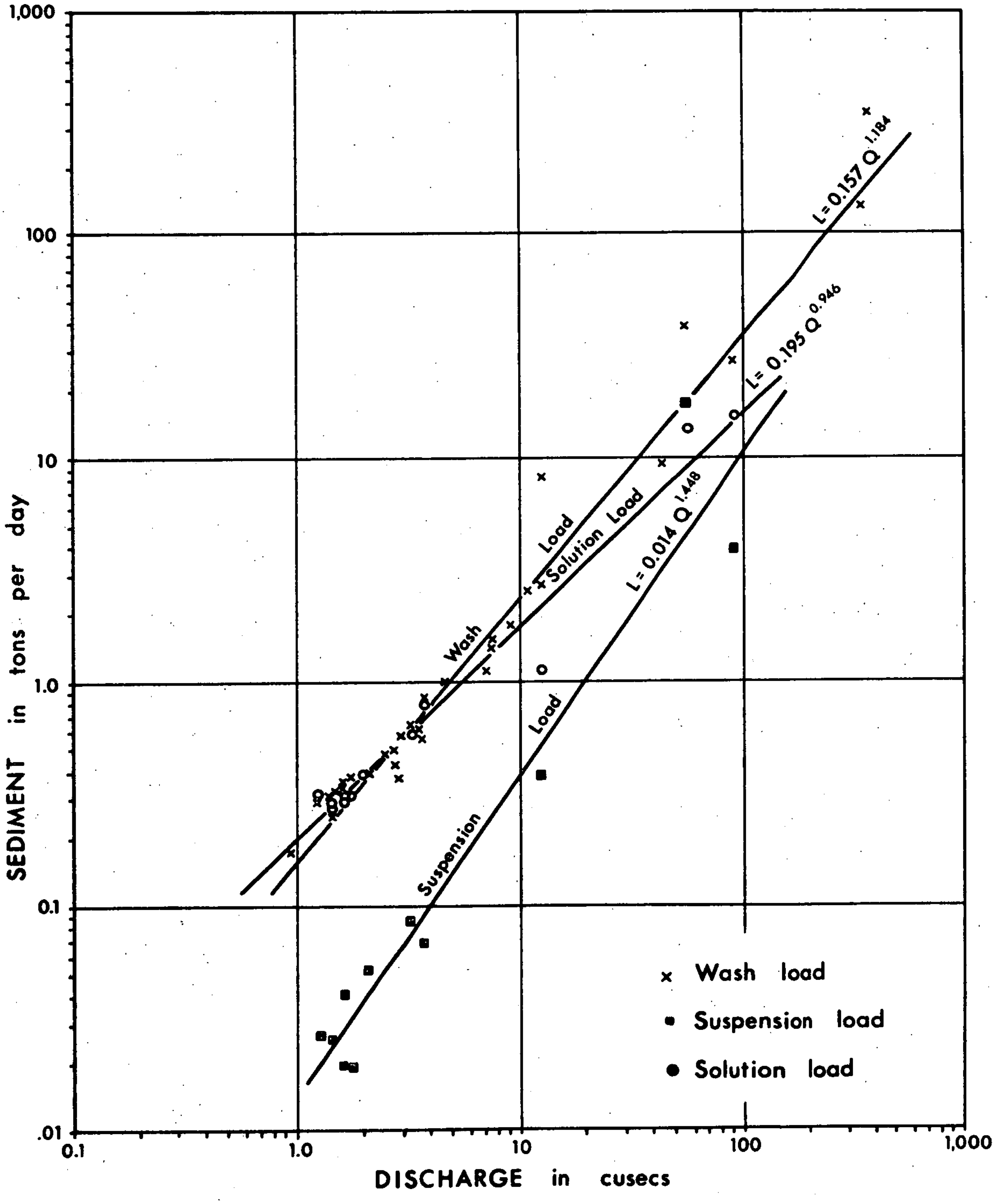


Figure 19

BROWNS RIVER SEDIMENT RATING CURVES



A graph was plotted of wash load and the hydrograph for the same run-off episode as that for wash load concentration (Figure 18). A stronger relationship exists than with the concentration graph although peak sediment discharge is still reached before peak stream discharge.

X-Ray diffraction analyses were carried out on two wash load samples to determine their composition. One sample was taken during basal flow and the other at a discharge of 56 cusecs. In both cases much of the material was too fine for the composition to be determined and was probably composed of clay colloids. Of the material that was identified, both samples were found to contain quartz, montmorillonite and sodium chloride.

SUSPENSION LOAD

Suspension load samples were taken for discharges ranging from 1.25 to 92 cusecs (Table 3). These samples were taken only over a 6 month period towards the end of the study period and as a result the range of discharges covered is limited. During this period there was only one rainfall episode and most readings are of basal flow with only several higher readings. Because of this limitation the suspension data may not be representative of the longer term characteristics of the catchment.

The concentration of suspended sediment varied from 5 to 130ppm. As with the wash load concentration, a regression analysis with instantaneous discharge revealed no significant relationship.

The suspension load rating curve (Figure 19) has the equation:

$$L = 0.014Q^{1.448}$$

and with a correlation co-efficient of 0.97 which is significant at the 0.1 per cent level. The curve lies below the wash load curve as would be expected while the gradient is greater than that of the wash load curve. This indicates that the suspension load makes up an increasing proportion of the total wash load with increasing discharge. At basal flows the suspension load is almost negligible while at extremely high flows it is the most important component of the wash load.

A projection of suspension load for the study period has been made (Appendix 1), although the accuracy of this is questionable due to the limited range of discharges sampled and the short period of record. Daily suspended sediment discharge is rarely above 0.5 tons/day and the dominance of individual run-off episodes is even more marked than in the case of total wash load. Of the annual total of 145 tons, 73 tons were discharged in 3 run-off episodes over a total of 12 days, while there were three months when the discharge was less than 2 tons for the month.

The pattern of suspended sediment discharge plotted for the wash load over one episode is shown in Figure 18.

SOLUTION LOAD

Solution load samples were taken with those for suspension load and cover a similar range of discharges with the same limitations on the reliability of the results.

The concentration of solution load ranged from 38 to 105 ppm and showed a much smaller variation than either wash load or suspension load. Even during basal flow solution concentration remains relatively high, with a tendency to increase with discharge although a regression analysis revealed no significant relationship. The readings for solution concentration may be artificially high in higher discharges due to the inability of the filters used to collect fine clay colloids (as has already been outlined in the discussion of the methods used).

The solution rating curve shown in Figure 19 has the equation:

$$L = 0.195Q^{0.962}$$

and a correlation co-efficient of 0.98 which is significant at the 0.1 per cent level. For discharges below 2.5 cusecs the theoretical solution load is greater than total wash load. This is probably due to the use of linear analysis. The gradient of the solution load curve is less than that for wash load, and solution load increases at a decreasing rate with increasing discharge (unlike both wash and suspension loads).

The predicted values for daily solution load discharge are shown in Appendix 1. The lower variability of concentration is reflected in daily load. While individual run-off episodes contribute significant amounts to the annual total of 463 tons, their dominance is not as marked as in the case of wash and suspension loads. The pattern of solution discharge for the episode already considered may be seen in Figure 18. In this episode, solution load increased and decreased more slowly than suspension load, while its variation corresponds more closely to the variations in discharge.

DENUDATION RATES

Total wash load for the period July 1969 to June 1970 was 695 tons. With an area of 5 square miles this is a rate of 148 tons/square mile.

Suspended sediment discharge for the study period was 145 tons which is a rate of 31 tons/square mile. Discharge of solution material was 463 tons or a rate of 99 tons/square mile.

SUMMARY OF RESULTS

During the period of the study, rainfall was significantly above the mean. The distribution of this rainfall was also atypical, with a concentration during the months when minimum rainfall usually occurs. This has been reflected in the run-off figures which also show an above average run-off and concentration in the summer months. It is to be expected that these hydrologic conditions will have an influence over the sediment load which was removed during the period. The double-mass curve indicated a relatively constant linear relationship between rainfall and run-off, indicating that the recordings are accurate and there has been no change in the relationship between rainfall and run-off over the past 6 years. It appears that the bushfires of 1967 have had little long term impact on the hydrology of the catchment as no break is evident in the curve at this time. This is in contrast to results obtained elsewhere in the world which have shown significant changes after fires of similar severity. This is a result of the limited effect on the ground cover.

The wash load results cover a wide range of discharges and are representative of the discharges which occur. Although there is a lack of middle range discharges sampled, this is characteristic of streams which rise and fall rapidly. The concentration of wash load does not appear to vary as widely as discharge and no significant relationship could be found between discharge and wash load concentration. There was a strong relationship between discharge and wash load however, with a wash load rating curve of

$$L = 0.157Q^{1.184}$$

The lack of middle range stream discharges accentuates the importance of isolated episodes of high flow to total wash load discharge, when a relatively high proportion of the total wash load is discharged.

The suspended sediment rating curve for the study period was

$$L = 0.014Q^{1.448}$$

The equation however was derived from a limited range of samples as was the solution load rating curve of:

$$L = 0.195Q^{0.962}$$

The examination of the behaviour of the various loads during one run-off episode revealed a number of different patterns. Wash load concentration and wash load both rise rapidly reaching a maximum well before the occurrence of discharge peaks. They also fall rapidly as discharge declines. A similar pattern exists with the suspension load. The solution load curve varies significantly, as it rises much more slowly and its peak occurs about the same time as peak discharge. It also falls more slowly.

The erosion rate of the catchment for the period was found to be 148 tons/square mile of which suspended sediment accounted for approximately 20 per cent, and solution load the remainder.

CHAPTER 5

SNUG RIVULET

The Snug Rivulet catchment is located approximately 15 miles south of Hobart with the sampling point and gauging weir located on the Snug Falls road 1 mile from the river mouth. The catchment covers an area of 7.5 square miles as shown in Figure 20. Map coverage is provided on the provisional 1:31,680 Huonville sheet and aerial photograph coverage is available.

Elevation ranges from 100 feet to 2300 feet above sea-level with an average stream gradient of 440 feet per mile and a relief ratio of 0.11. Stream gradient is not constant, varying from 320 feet per mile in the upper sections to 1200 feet per mile in the central section. At Snug Falls there is a vertical drop of approximately 40 feet. The rivulet has heavily dissected the Snug Plains with only remnants of this former flat area being found in the upper parts of the basin above Snug Falls. On these remnants the drainage pattern is ill-defined and swampy sections occur. Below Snug Falls, where dissection is greatest, the stream has cut V shaped valleys with steep valley sides which have a slope of up to 1 in 4. No depositional landforms occur in the valleys. The bed of the stream is composed of sandstone and dolerite outcrops and more commonly of rounded dolerite boulders up to 18 inches in diameter while the banks are composed of dark clay material and interspersed dolerite boulders.

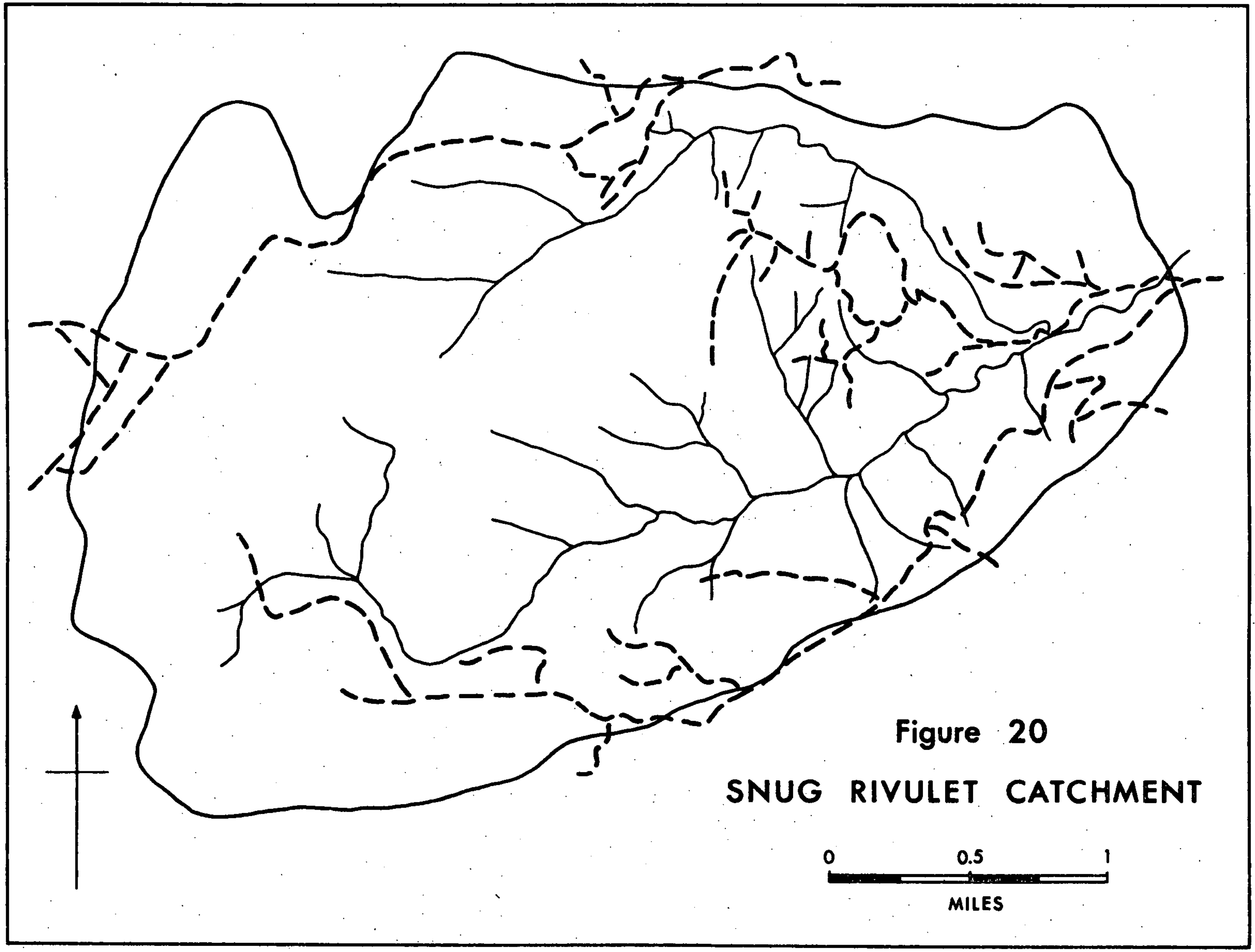


Figure 20

SNUG RIVULET CATCHMENT

The geology of the area has been examined in detail by Rodger[1] and has been mapped on the University of Tasmania, Geology Department one inch series, Oyster Cove sheet. This map was checked during the study and a slightly revised version of the catchment is shown in Figure 21. From this it can be seen that there are three formations making up the catchment. The Knocklofty Sandstone and Shale extends over 42 per cent of the catchment area, the Ferntree Mudstones over 33 per cent and Dolerite 25 per cent.

In the catchment, the Knocklofty Sandstone and Shale is composed dominantly of an even grained brown to cream sandstone with grains ranging from 0.1mm to 0.5mm with an average grain size of 0.25mm,[2] all grains being well rounded. Shale bands make up a minor part of the formation and usually occur as resistant bands in the soil. On weathering the sandstone and shale breakdown to clay compounds with some fine quartz crystals.

The Ferntree mudstone is made up of two distinct facies. The lower one consists of a grey mudstone composed of quartz grains up to 1mm in diameter set in a fine crystalline matrix which makes up 60 per cent of the rock. This rock changes little on weathering and is commonly associated with the steepest slopes and scarps such as those at Snug Falls. Above this facies is a horizon of yellow sandy mudstone which has a grain size similar to the lower unit but with a much smaller proportion of crystalline matrix. As a result, it is much more friable, weathers more easily and is usually associated with gentler slopes.

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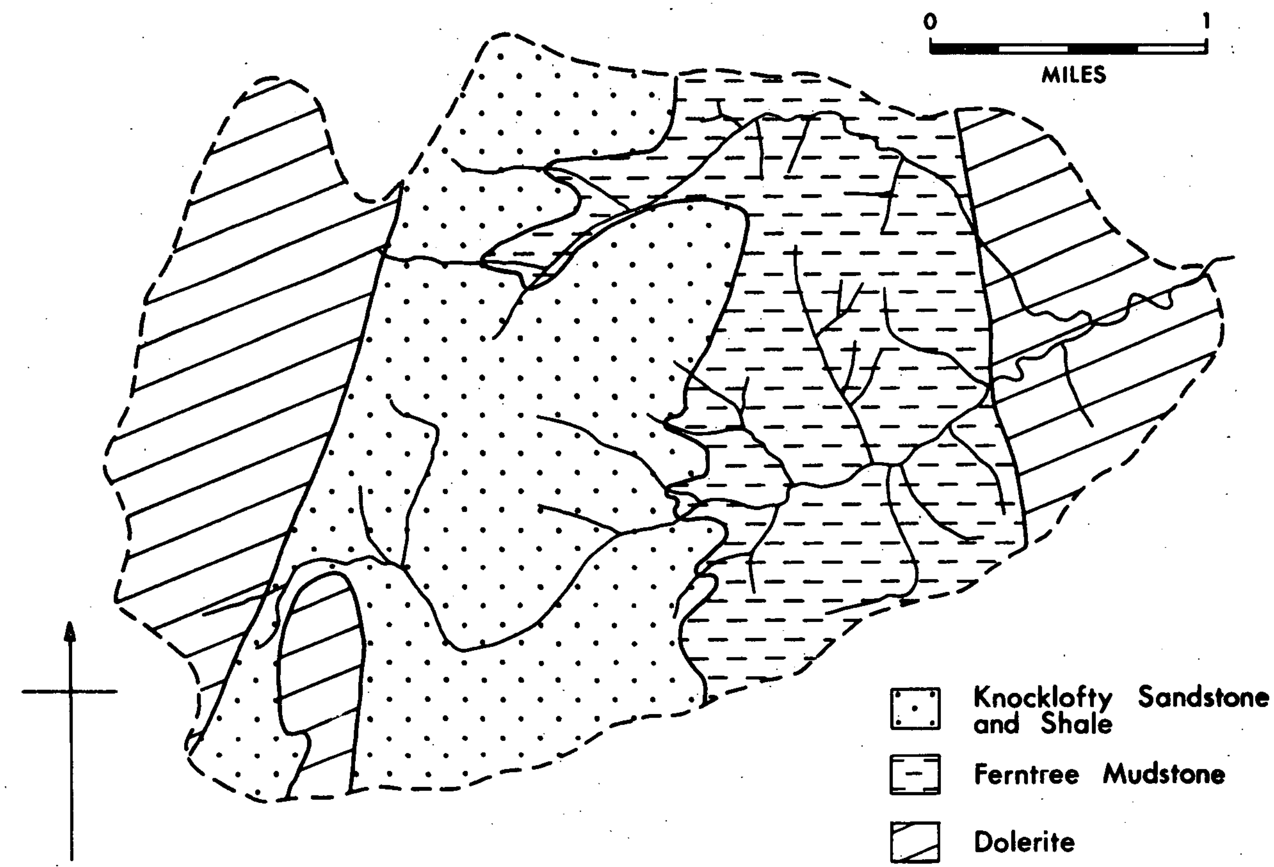
1. Rodger, T.H., <u>op. cit.</u>
2. <u>Ibid</u>, p. 111.

Figure 21

SNUG RIVULET GEOLOGY



The dolerite ranges from fine grained near the contacts to medium grained away from the contacts. It is composed of a ground mass of feldspar laths (usually labradorite) with occasional quartz grains. Around Red Hill the dolerite is composed of a different mass to the main body. It is a coarse granophyre consisting dominantly of quartz and orthoclase with some plagioclase.

Soils are closely related to lithology in the catchment as in most cases they consist of poorly developed soils often the direct weathering products of the underlying rock type.

A vegetation map (Figure 22) was compiled using the Lands Department aerial photographs (Derwent-D'Entrecasteaux 1965 Run 6 Photo 81, and Run 7 Photo 168) and the 1967 Forestry Fire Area photos (Area 5, Run 1 Photos 181-185, Run 2 Photos 120-126 and Run 3 Photos 115-119). Vegetation is dominated by sclerophyll forest which covers 75 per cent of the total catchment area. The dominant species of this forest have already been discussed (page 38). Tree cover within the forest varies from 50 per cent to 100 per cent but is commonly greater than 80 per cent. Associated with the forest are lower layers of herbaceous plants and saplings with some grasses. However on the steeper slopes much of the ground below the tree cover is bare. The forest occurs mainly on the sloping areas and is thickest in gully corridors along the stream course.

In sections of the catchment the forest has been partially or totally cleared resulting in two vegetation types. The first is where partial clearing has been carried out associated with the timber industry. Here there is a tree cover of less than 50 per cent (more commonly less than 10 per cent) with a complete grass cover. In other sections the forest has been completely cleared and the present vegetation cover is of grasses of cultivated crops. Clearing has however been restricted in area with only 7 per cent of the catchment area partially cleared and 7 per cent completely cleared.

The final vegetation type is the moorland which occurs in the flat areas in the upper part of the catchment and occupies 11 per cent of the total area. Here trees are absent and the vegetation consists of a 100 per cent cover of low shrubbery and grasses.

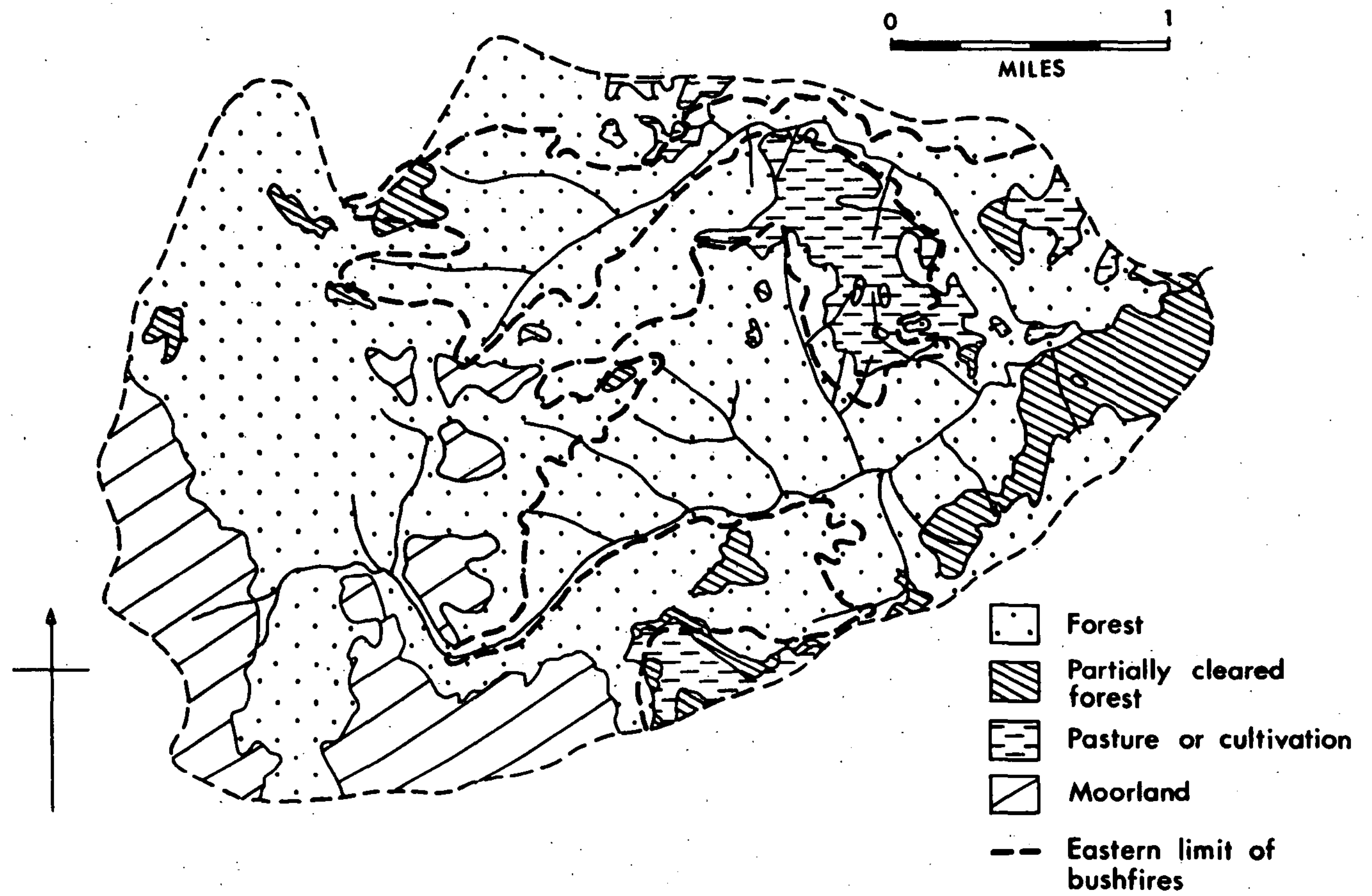
An important factor in the vegetation is the influence of the bushfires of February 1967 which affected 65 per cent of the catchment mainly in the higher sections (Figure 22). In these fires all of the moorland and 65 per cent of the forest was affected. The moorland was re-established quickly and had recovered by the time the study had commenced. The influence was much greater in the forest canopy which is still in the process of re-establishment and during the study the vegetation cover was less than the pre-fire vegetation cover. However the ground cover under the forest had completely recovered and in most cases was more dense than that in the unburnt areas. As a result any effect on the hydrology of the catchment will be minimal.

RAINFALL AND RUN-OFF

A rainfall recording station is located in the centre of the catchment at Snug Plains (see on Figure 20). A further station occurs just outside the catchment at Snug. The rainfall records of these two

Figure 22

SNUG RIVULET VEGETATION



stations have a similar distribution pattern but with the Snug station having a much lower total due mainly to the difference in altitude. For the purpose of the study the Snug Plains station has been taken as representative of the catchment. The mean monthly and annual rainfall for the Snug Plains station are shown in Table 4. Mean annual rainfall is 44.92 inches with a marked concentration in late winter (July average 5.75 inches) and minimum in late summer (January average 2.34 inches). Rainfall intensity also shows seasonality with intense summer rainfall associated with thunderstorms, while winter rain is frontal and much less intense.

During the twelve months study period rainfall was 47.37 inches which is significantly above the average figure. The distribution of this total also varied significantly from the mean with the pattern reversed and the maximum occurring in December and minimum in July (see Table 4). Despite the above average total, 9 months had rainfall less than their mean figure and so rainfall is extremely concentrated in the three months November, December and January when over 31 inches of rain fell. Rainfall was further concentrated in these months in three rainfall episodes of around four days duration with 12 days receiving 24 per cent of the total rainfall for the twelve months.

Closely related to the rainfall pattern is the pattern of stream discharge. Run-off records are available for the catchment dating from 1964 when the Rivers and Water Supply Commission installed a gauging weir. The average annual discharge for this period was 3,190 acre feet with major variations from the mean ranging from a minimum of 1,174 feet to a maximum

TABLE 4

SNUG RIVULET RAINFALL DATA

	Mean	Study Period
J	234	536
F	348	176
M	302	621
A	332	195
M	394	204
J	325	346
J	575	262
A	434	224
S	457	112
O	374	273
N	393	1024
D	324	764
Total	4492	4737

of 6,650 acre feet. Monthly means are shown in the hydrograph in Figure 23. Because of the short period of record and the large variations in discharge which are experienced, the value of a mean is doubtful and in most years the monthly figures have varied significantly from the mean. But the means do show a similar pattern to those of rainfall, with peak flow during late autumn and spring and minimum flows during late summer. The variations of the hydrograph are increased by coincidence of the period of maximum rainfall with minimum evaporation and vice versa. This also results in a greater proportion of the total rainfall being removed as run-off rather than being lost by evapotranspiration.

Total annual discharge for the study period was 5,079 acre feet which is well above the mean. As with rainfall, run-off was concentrated in the three months of November, December and January. As a result the study period hydrograph contrasts with the mean hydrograph as shown in Figure 23. Daily discharges ranged from 0.35 cusecs to 192 cusecs which is the highest discharge on record. Appendix 2 shows the daily discharges for the twelve month period. Again a marked concentration occurs with several isolated episodes accounting for a relatively high proportion of the annual discharge.

The relationship between rainfall and run-off was examined and a double mass curve was plotted for discharge and rainfall data from the Snug Plains recording station (Figure 24). The method involved has already been outlined in the discussion of the Brown's River discharge.

Figure 23

SNUG RIVULET HYDROGRAPHS

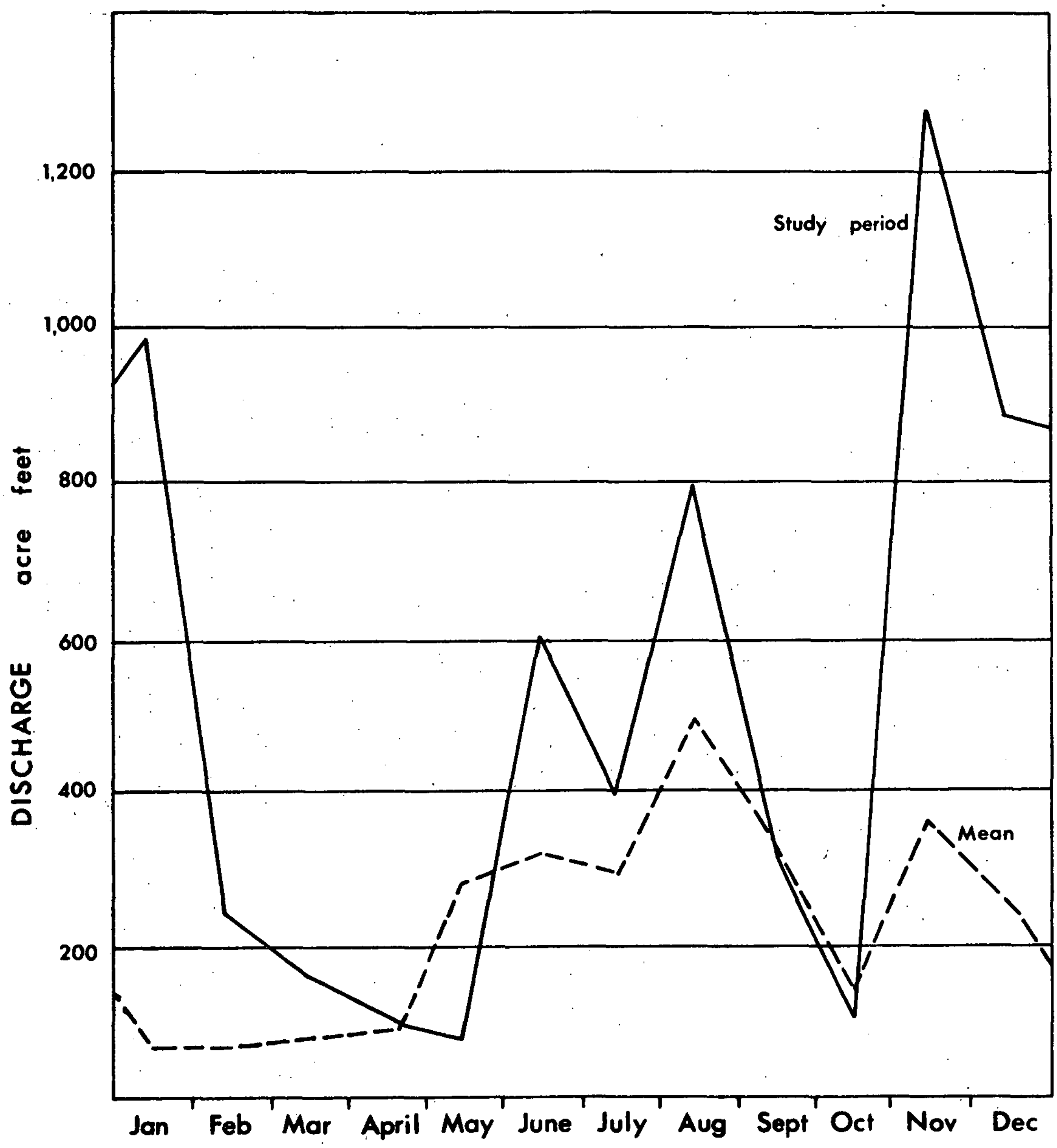
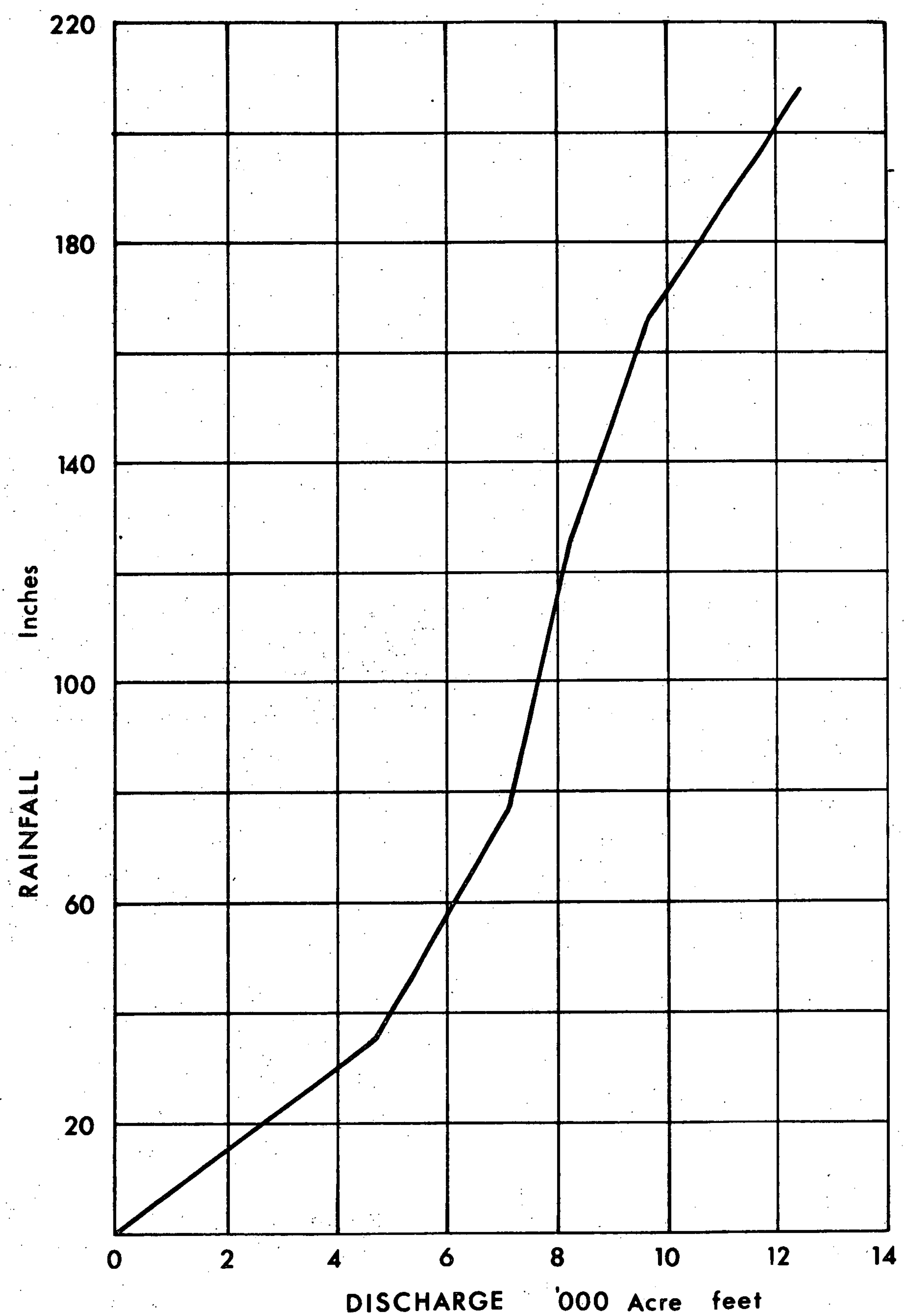


Figure 24

SNUG RIVULET DOUBLE MASS CURVE 1964-8



This curve shows a number of changes of gradient in what should be a linear relationship. The only change in the catchment which was of significant magnitude to influence the rainfall/run-off relationship was the destruction of 65 per cent of the vegetation in the February 1967 bushfires. The section of the curve which corresponds to this period is the only section which shows any linearity. Research from other parts of the world would suggest that such a marked change should be reflected in the double-mass curve. It may be that secondary growth, especially grasses, quickly re-established so reducing the influence of the fires.

It still remains to explain the variation in the double-mass curve. Searcy and Hardison[1] state that apart from variations in catchment parameters, breaks in the double-mass curves can be due to either changes in gauging sites or errors in measurement of either rainfall or discharge. The gauging sites have remained constant and so it could be possible that the rainfall or discharge records are inconsistent. An examination can be made to determine any errors by comparing both records with those of an adjacent catchment with similar characteristics. This was done by comparing rainfall and run-off with Browns River, once again by plotting double-mass curves (Figures 25 and 26). These show that a good linear relationship exists between the rainfall of both catchments and suggests that the rainfall recordings for Snug Plains are accurate. The mass-curve for discharge deviates from a linear pattern while an earlier curve (Figure 17) showed a linear relationship between Browns River rainfall and run-off. Therefore it is possible to conclude that inaccuracies exist in

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1. Searcy and Hardison, op. cit., 1960.

Figure 25

SNUG RIVULET – BROWNS RIVER RAINFALL

DOUBLE MASS CURVE 1964–8

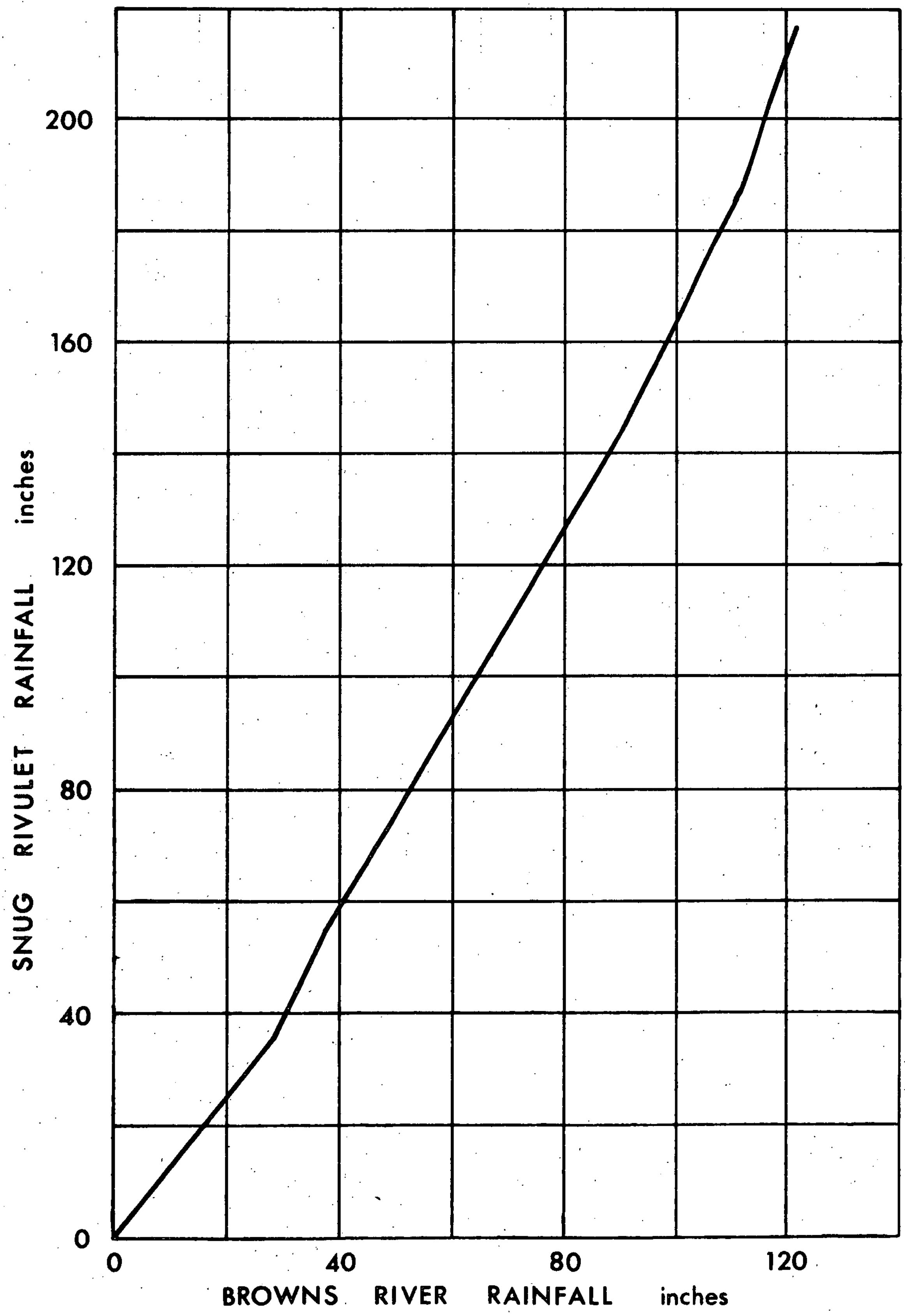
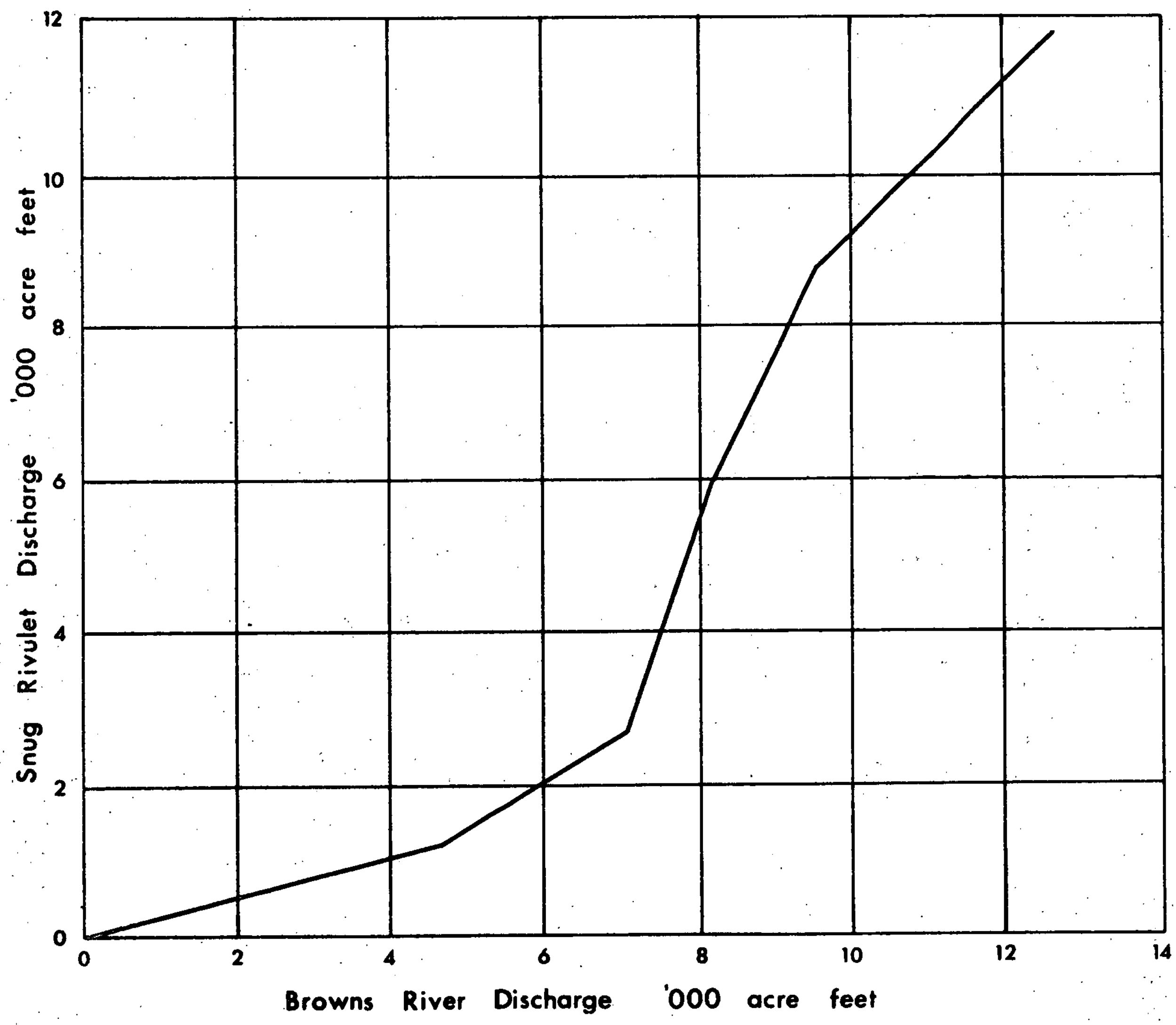


Figure 26

SNUG RIVULET - BROWNS RIVER DISCHARGE

DOUBLE MASS CURVE 1964-8



the recordings for Snug discharge, probably due to flood damage to the weir which was often not repaired for several months. An attempt was made to overcome these errors by manually determining discharge for the sediment samples. Where the Rivers and Water Supply Commission records have been used it must be kept in mind that errors could exist.

SEDIMENT DATA

Sediment sampling was carried out above the influence of the gauging weir except during high flows when samples were taken at the weir itself. Wash load was sampled on 36 occasions while 12 samples were taken of suspension and solution loads. The results of the analysis of these samples are shown in Tables 5 and 6.

WASH LOAD

Discharge samples ranged from 0.30 to 442 cusecs with the most extensive cover in the lower range below 5 cusecs. There is a distinct break in the coverage with reasonable coverage up to 12 cusecs and then a large gap to the upper readings of 310,414 and 442 cusecs. This is a result of the nature of the catchment where run-off occurs quickly and the stage raises and falls rapidly, often within a period of several hours, and so middle range discharges are limited in extent through time.

Wash load concentration ranged from 69 to 301 ppm although again there is a distinct gap with the majority of readings below 120 ppm with two readings above this at 204 and 302 ppm. Visually, there appears to

TABLE 5

SNUG RIVULET - WASH LOAD DATA

Date	Instantaneous Discharge (cusecs)	Concentration (ppm)	Wash Load (tons/day)
4. 7.69	8.20	78	1.55
8. 7.69	6.85	93	1.54
8. 8.69	10.40	132	3.28
14. 8.69	10.03	99	2.39
25. 8.69	7.92	102	1.95
2. 9.69	5.88	91	0.96
7. 9.69	4.37	95	1.00
17. 9.69	7.92	91	1.73
26. 9.69	2.72	79	0.52
3.10.69	1.62	90	0.35
10.10.69	1.74	75	0.31
17.10.69	1.06	91	0.23
26.10.69	0.71	94	0.16
2.11.69	12.00	126	3.62
10.11.69	2.72	90	0.59
17.11.69	414.0	302	301.07
18.11.69	442.0	204	214.67
17.11.69	3.79	84	0.77
3.12.69	4.99	104	1.25
16.12.69	4.30	60	0.62
21.12.69	5.42	87	1.13
11. 1.70	4.82	91	1.05
23. 1.70	4.16	96	0.97
3. 2.70	1.25	90	2.70
9. 2.70	1.06	116	0.30
23. 2.70	0.66	89	0.15
2. 3.70	0.70	102	0.18
10.3.70	0.46	115	0.13
15.3.70	0.30	121	0.09
20.3.70	4.4	104	1.11
21.3.70	310.0	125	93.58
25. 3.70	12.00	69	2.01
2. 4.70	3.50	87	0.73
19. 4.70	0.95	99	0.23
26. 4.70	1.10	93	0.25
3. 5.70	4.80	106	1.22

TABLE 6

SNUG RIVULET - SUSPENSION AND SOLUTION LOAD DATA

Date	Instantaneous Discharge (cusecs)	Concentration (ppm)	Load (tons/day)	Concentration (ppm)	Load (tons/day)
9.2.70	1.06	6	0.015	107	0.27
23.2.70	0.66	5	0.009	91	0.14
2.3.70	0.70	6	0.011	107	0.18
10.3.70	0.46	3	0.003	108	0.12
15.3.70	0.30	8	0.006	133	0.10
20.3.70	4.40	11	0.111	88	0.94
21.3.70	310.0	42	30.93	93	68.64
25.3.70	12.00	9	0.256	58	1.69
2.4.70	3.50	16	0.122	83	0.69
19.4.70	0.95	8	0.019	101	0.23
26.4.70	1.10	7	0.018	97	0.25
3.5.70	4.80	11	0.127	109	1.26

be some relationship between instantaneous discharge and wash load concentration with a general rise in concentration with increasing discharge. In the lower range of discharges however concentration appears to reach a minimum and with lower discharges concentration increases. A regression analysis, both numerical and logarithmic, was carried out and no significant linear relationship was found to exist.

An examination was made of the variation of concentration over a particular run-off episode by plotting curves for discharge and concentration (Figure 27). The period used was the 15th to 25th March 1970. With an increase in discharge, concentration first decreases but as discharge continues to increase concentration reaches a peak and then falls rapidly. The reasons for this pattern will be discussed in a later section.

Using the instantaneous discharge and concentration figures, the wash load can be computed in tons per day and using these values the rating curve for wash load can be drawn (Figure 28). The regression analysis revealed a strong relationship, with a correlation co-efficient of 0.99 which is significant at the 0.1 per cent level. The resulting regression equation was:

$$L = 0.217Q^{1.093}$$

The exponential value of 1.093 indicates that wash load increases at a slightly increasing rate as discharge increases.

Using the equation for the rating curve it is possible to compute daily wash load for the period of study and these are shown in Appendix 2.

Figure 27

SNUG RIVULET RUN-OFF EPISODE 15th-30th MAY 1969

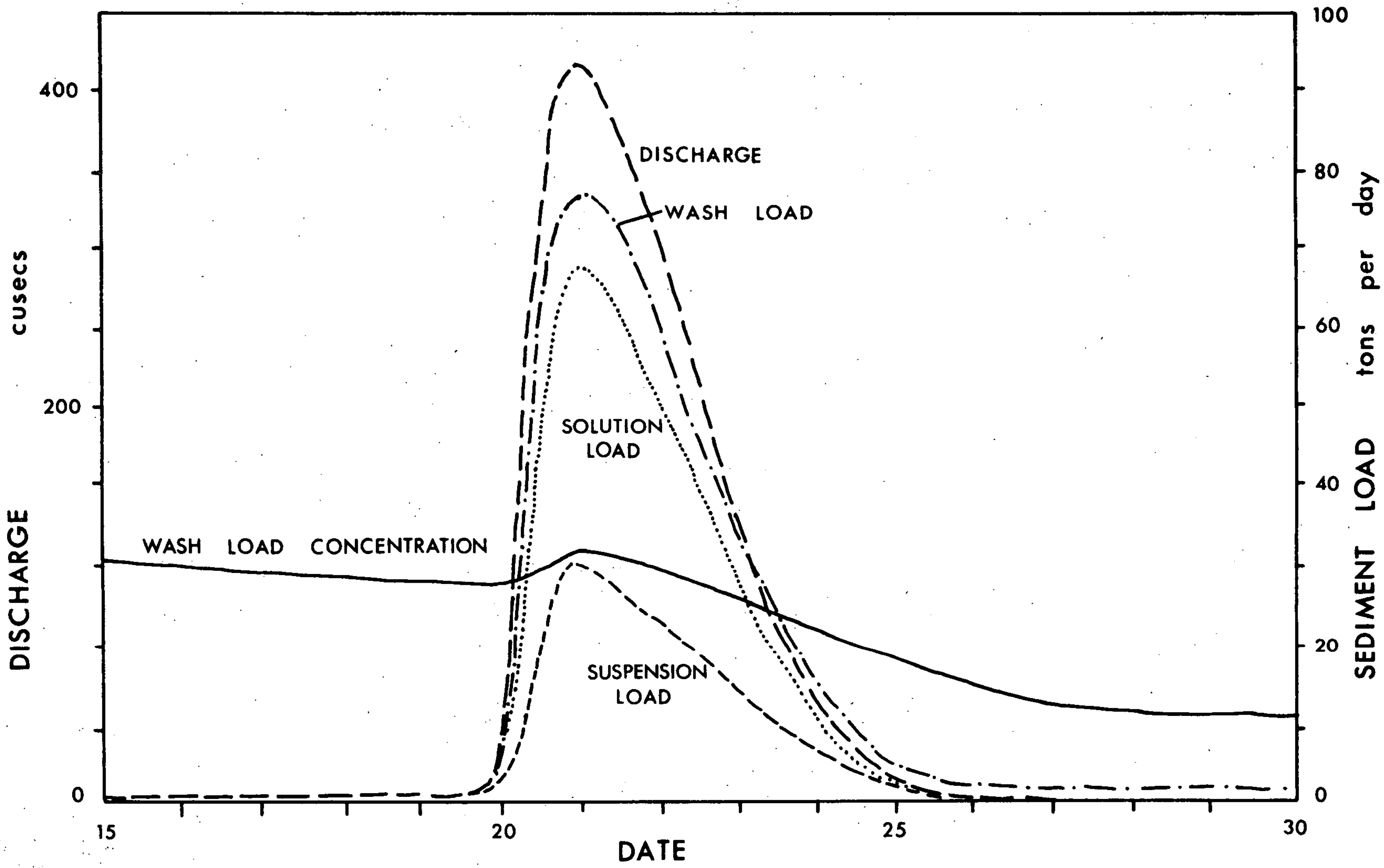
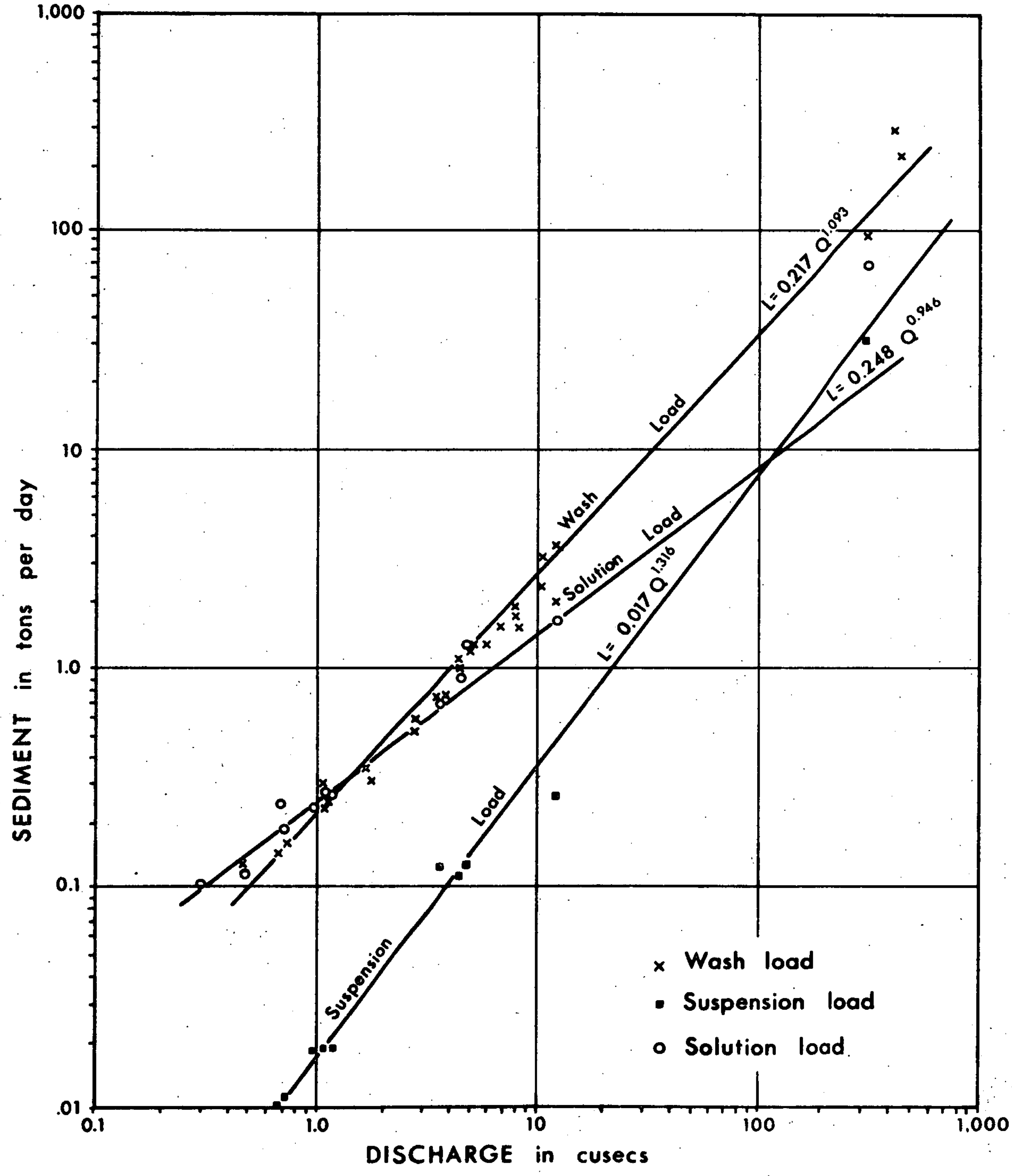


Figure 28

SNUG RIVULET SEDIMENT RATING CURVES



From this table it is clear that for the majority of the time daily wash load discharge is below 5 tons/day and that a number of isolated run-off episodes contribute a major proportion of the total sediment discharge. In the annual total of 1171 tons, 553 tons were discharged in three episodes extending over a total period of 17 days and on one day 127 tons or 11 per cent of the annual total was discharged.

The pattern of wash load discharge was plotted for the same episode used for wash load concentration (Figure 27) and it can be seen that it bears a much closer relationship to discharge than does the concentration pattern.

An analysis was made of the composition of two wash load samples by X-Ray diffraction analysis. One sample was of basal flow while the other was taken at a discharge of 310 cusecs. While much of the material was too fine to be identified the larger particles were found to be composed of quartz, montmorillonite and sodium chloride.

SUSPENSION LOAD

Samples of suspension load were taken for discharges ranging from 0.3 to 310 cusecs. Because of the limited period of sampling only discharges below 1 cusec are well covered with a scattered cover of higher discharges mainly from one run-off episode. Because of this limited coverage the accuracy of these values in relation to long term characteristics is doubtful.

Values for concentration of the suspension load range from 3 to 42 ppm. However, the values are probably artificially depressed because of the inability to filter out fine clay particles in the laboratory analysis, this influence will be more marked in the higher concentration. While there appears to be a general relationship between concentration and discharge, a linear regression revealed no significant relationship.

The rating curve for suspension load (Figure 28) was highly significant with a correlation co-efficient of 0.99 which is significant at the 0.1 per cent level. The regression equation for the suspension load was:

$$L = 0.067Q^{1.316}$$

As with the Wash load rating curve, the suspension load increases at an increasing rate with increasing discharge. The gradient of the suspension load rating curve is greater than that of the wash load curve and so the suspension load increases its proportion of the wash load as discharge increases.

While a projection of daily suspension load has limited value due to the limitations of the original data, this has been done for the study period to obtain some evaluation of its importance (Appendix 2). Again there is a marked concentration of suspension load discharge into a limited number of run-off episodes, with concentration more marked than in the case of wash load. The maximum daily suspension load was 127 tons which is 15 per cent of the annual total discharge of 856 tons and in four run-off episodes over 17 days 546 tons were discharged which is 64 per cent of the total suspension load for the twelve month period.

As with wash load the pattern of suspension load discharge was plotted for the period from the 15th to the 25th of March 1970 (Figure 27).

SOLUTION LOAD

Samples for solution load were taken with those for suspension load and cover a similar range of discharges. The results are also subject to the same limitations as those outlined for the suspension load data.

Concentrations range from 58 to 133 ppm with a relatively good coverage throughout the whole range. As with wash load there appears to be a relationship with discharge, with solution concentration increasing with discharge except in the lower ranges where a decrease in discharge results in an increase in solution concentration. The readings for higher discharges may be inflated due to the presence of clay particles.

The rating curve for the solution load (Figure 28) has the regression equation:

$$L = 0.248Q^{0.946}$$

with a correlation co-efficient of 0.995 which is significant at the 0.1 per cent level. With an exponential of 0.946 solution load increases at a decreasing rate, as opposed to wash and suspension loads which increase at an increasing rate. As a result, while solution load makes up the major proportion of the wash load at lower discharges, its dominance decreases with increasing discharge.

Daily discharge figures for solution load during the study period have been computed and are shown in Appendix 2. In the annual total of 803 tons, individual run-off episodes contribute significant amounts but their dominance is not as great as with suspension which is a reflection of the smaller variation of concentrations. The sum of the annual suspension and solution loads (1659 tons) is significantly higher than the wash load total of 1171 tons and is probably due to errors introduced by projecting suspension and solution loads based on limited data.

The pattern of solution discharge for the individual episode already considered as shown in Figure 27. Significant differences exist between suspension and solution loads. The suspension load follows discharge relatively closely while the solution concentration initially falls with rising discharge before rising, and towards the end of the episode with falling discharge. This pattern will be discussed in a later section.

Denudation Rates

Total wash load for the study period was 1171 tons and as the catchment has an area of 7.5 square miles this represents an erosion rate of 156 tons per square mile. Suspended sediment discharge for the period considered was 856 tons giving a rate of 29 tons/year. Total solution discharge was 803 tons at a rate of 107 tons/square mile.

SUMMARY OF RESULTS

As with Browns River, rainfall for the study period was considerably above the mean and was concentrated in summer rather than winter. The discharge distribution showed a similar pattern with variance from the mean.

The double-mass curve revealed no linear relationship except over the period around the time of the 1967 bushfires. By comparison with the relationships in the adjacent Browns River catchment it is possible to conclude that the discharge figures for Snug Rivulet are subject to error. In 1967 bushfires have had no significant impact on the hydrology of the catchment as is indicated by the linear nature of the double-mass curve for this time.

A representative range of discharges has been covered by the wash load sampling programme again with a minimum number of middle discharge readings because of the nature of the stream. Wash load concentration is relatively steady with only a limited range of values and there was no significant relationship between stream discharge and wash load concentration The wash load rating curve showed a strong relationship with the resulting equation

$$L = 0.217Q^{1.093}$$

The characteristic feature of the projected daily wash load figures is the marked dominance of isolated discharge episodes which contribute a relatively large proportion of the total wash load.

In both suspension and solution concentrations no relationship could be found with stream discharge. The rating curves however, both showed strong relationships with a suspension load curve of

$$L = 0.248Q^{0.946}$$

and a solution curve of

$$L = 0.248Q^{0.946}$$

These relationships are subject to limitations as only a limited number of samples were taken.

The examination of one run-off episode illustrates the rapid rise and fall of the stream and the difficulty of sampling middle range discharges. In this case all three loads peak at a similar time as discharge. An interesting pattern occurs with wash load concentration where it initially falls probably due to a diluting of sediment and as additional sediment is supplied to the stream by surface run-off it rises.

The erosion rate for the wash load during the twelve month period was 156 tons/acre. Suspension and solution loads made up approximately equal proportions of this load although their combined total is greater than the wash load figure due to errors in the laboratory method.

CHAPTER 6

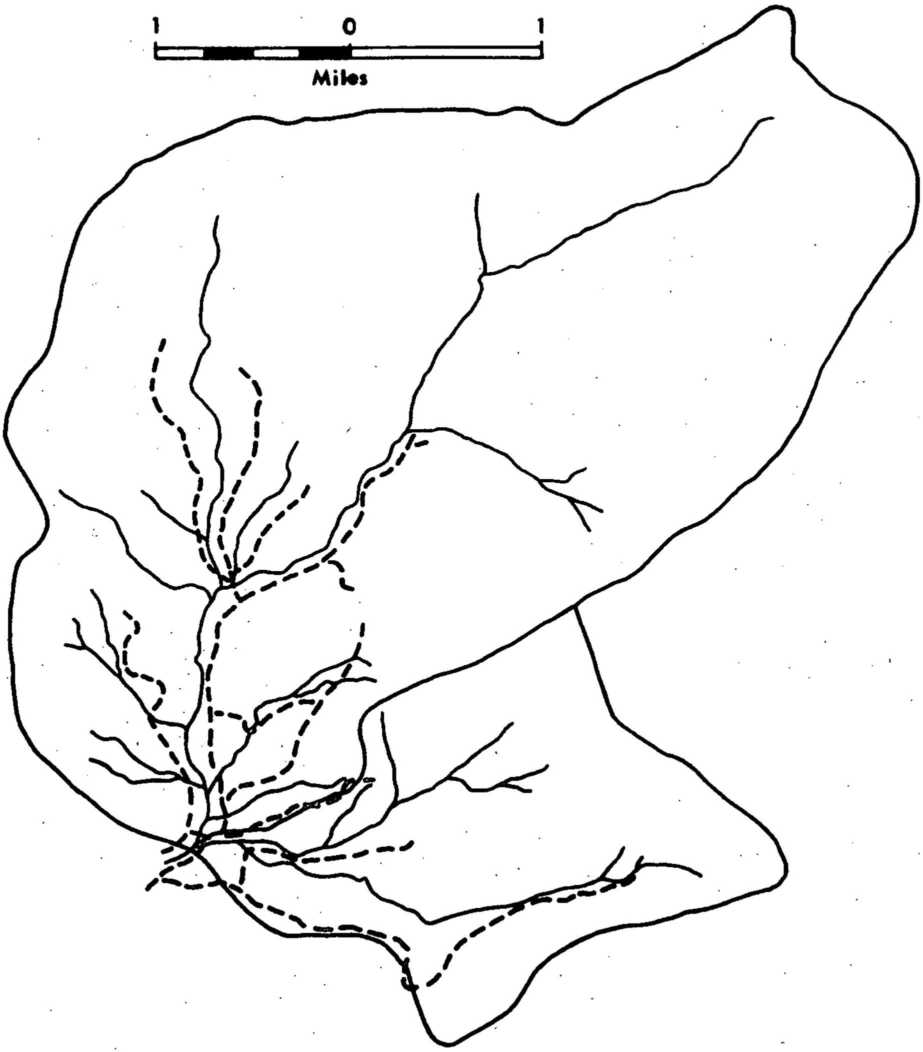
MOUNTAIN RIVER

The Mountain River catchment is located approximately 15 miles south-west of Hobart and is a part of the Huon River system. The gauging weir is located at Grove, adjacent to the Mountain River Road and is approximately 8 miles above the confluence with the Huon River. The catchment extends into the south western section of the Mount Wellington block and covers an area of 15.5 square miles as shown in Figure 29. Just above the gauging weir a tributary enters the river which has a catchment of slightly less than 3 square miles. The area has been mapped in the Longley 1:31,680 sheet and air photo coverage is available.

The relief of the catchment is high, falling 3,000 feet over a distance of approximately 2 miles and the relief ratio is 0.10. Stream gradient varies markedly from 130 to 676 feet per mile. The upper sections of the catchment consist of relatively gently sloping periglacial block fields with steeper sections associated with rock outcrop. In this area drainage is often ill-defined. The stream then falls rapidly in deep V shaped valleys to the lower section where a well defined flood plain has developed which is up to 0.5 miles wide in the vicinity of the gauging weir. The tributary drains an area of much more subdued relief in the order of 200 to 300 feet where slopes are gentler and valleys are broader than in the upper section of the main river. The bed of the river is composed mainly of rounded dolerite boulders with some rock bars, while the banks consist of dolerite boulders set in a matrix of fine clay. In the tributary the dolerite boulders are virtually absent.

Figure 29

MOUNTAIN RIVER CATCHMENT



The geology of the area has been described by Mather[1] but no detailed geological map has been compiled. A map of the area was drawn (Figure 30) using information gained from field measurement and the interpretation of aerial photographs. The map was based on relatively scant information and its accuracy is doubtful, but as the geology of the catchment is relatively simple, it gives a reasonable representation of the extent of the individual units. The catchment is made up of three units; Knocklofty Sandstone and Shale, Jurassic Dolerite and Quaternary Alluvium. Dolerite is the dominant rock type occupying 85 per cent of the catchment area while the sandstone extends over 11 per cent and alluvium 4 per cent. The tributary catchment has a greater proportion of sandstone which extends over 18 per cent of the area while the remaining 82 per cent consists of dolerite.

The Knocklofty Sandstone consists dominantly of a light coloured, even grained sandstone of sub-angular to sub-rounded quartz fragments with the diameter ranging from 0.1 to 0.3 mm.[2] Shaley bands occur within the sandstone which have primary muscovite and graphite. The shale is much less resistant to weathering and as a result is often obscured. Isolated bands of conglomerate also occur with sub-angular quartz fragments up to 1cm in diameter set in a matrix of sand sized quartz.

The dolerite occurs as intrusive masses in the Triassic sediments and in this area overlies the Triassic sediments. Its lithology is similar to that already described containing labradorite laths up to 1mm and augite crystals up to 2 mm[3].

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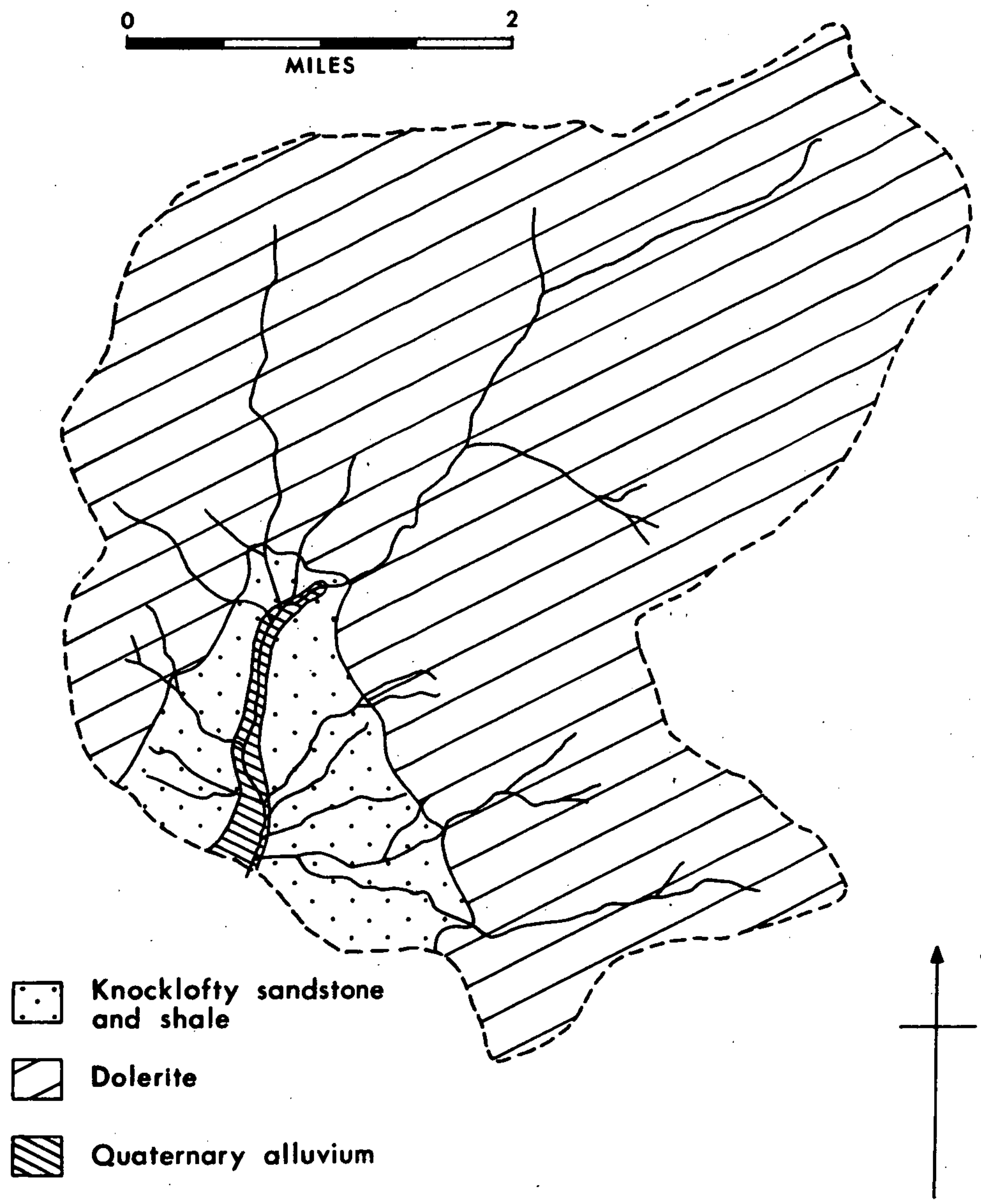
1. Mather, R.P., <u>op. cit</u>.
2. Ibid., p. 196.
3. Ibid., p. 199.

Figure 30

MOUNTAIN RIVER GEOLOGY



A relatively well developed flood plain occurs in the lower part of the Mountain River catchment which is composed of Quaternary alluvial material. These deposits are semi-consolidated consisting of ill-sorted quartz and dolerite pebbles and cobbles set in a matrix of sand, silt and clay. The dolerite cobbles range up to 40cm in diameter while the quartz pebbles are much smaller.

As the vegetation had not been mapped in detail it was necessary to compile a vegetation map. This was done based on the amount of cover afforded and is shown in Figure 31. The map was compiled from the Lands Department aerial photographs (Hobart 1969 Run 6 Photos 187-189, Run 7 Photos 106-108 and Run 8 Photos 28-32). Four vegetation types were recognised; sclerophyll forest occupying 52 per cent of the catchment area, moorland 35 per cent, partially cleared forest 5 per cent, and cultivated areas 8 per cent.

The sclerophyll forest consists of a tree cover providing from 80 per cent to 100 per cent canopy cover. Associated with it are lower layers of herbaceous plants and saplings with scattered grasses. Bare ground is found beneath the forest in steeper areas. The forest is restricted mainly to the middle section of the catchment in the dissected area where the stream falls from the higher block and is densest along the steep valleys.

In some areas the vegetation has been partially cleared for grazing purposes resulting in a tree cover of less than 50 per cent associated with a complete grass cover. This has taken place on the slopes of the lower section of the catchment. On the flood plain the former vegetation

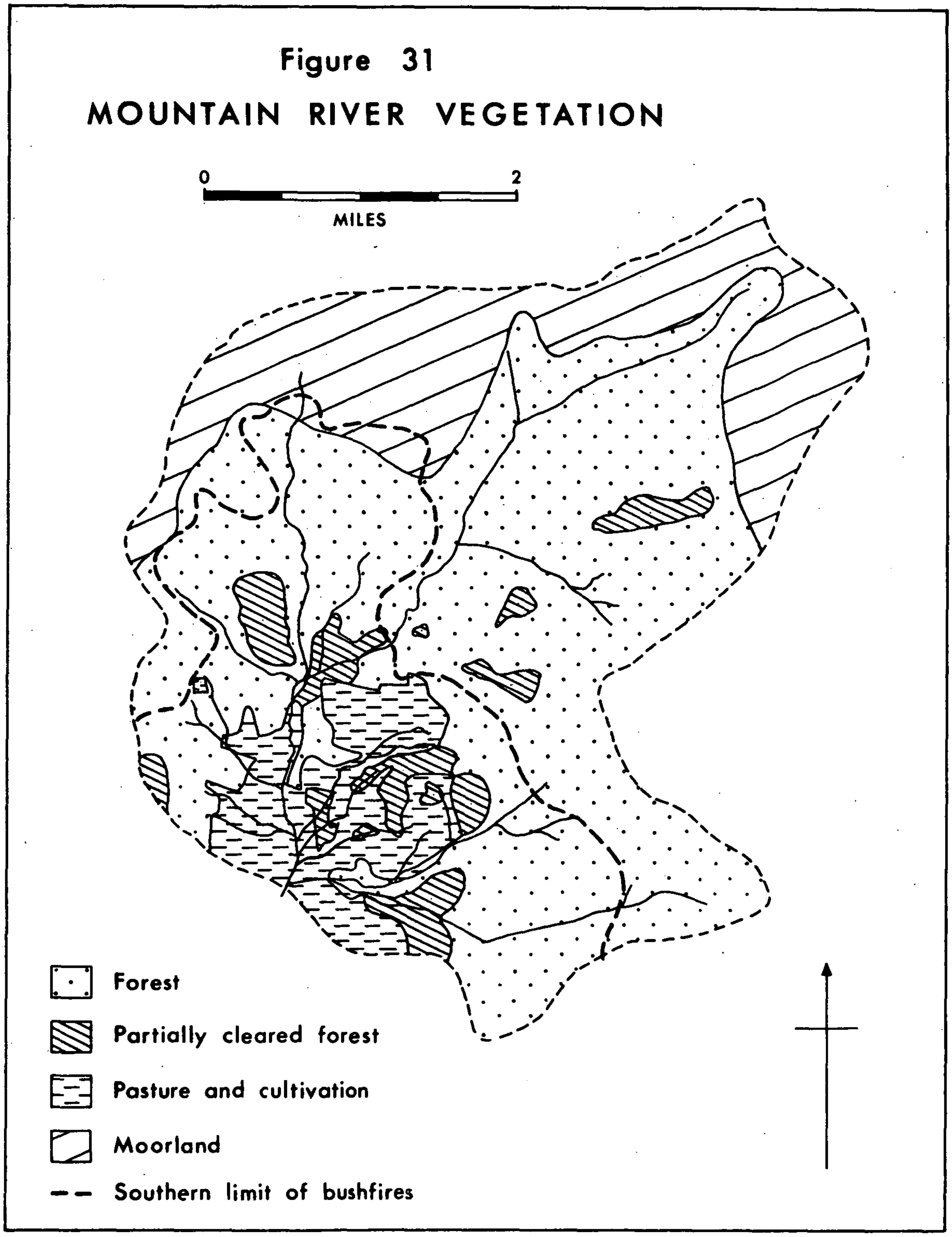


Figure 31
MOUNTAIN RIVER VEGETATION
0
2
MILES
Forest
Partially cleared forest
Pasture and cultivation
Moorland
Southern limit of bushfires

has been completely removed to be replaced by either improved pasture or fruit trees. Ground cover here varies from 0 to 100 per cent ranging from bare fallow to a complete pasture cover.

The moorland vegetation consists of shrubs and grasses which provide up to 50 per cent ground cover. This cover is broken by rock outcrop and the dolerite boulders of the blockfields. Moorland is restricted to the higher areas in the upper sections of the catchment.

The Mountain River catchment was affected by the 1967 bushfires and approximately 70 per cent of the catchment was burnt. All the moorland vegetation was destroyed but the majority of this had recovered by the time of the study. Approximately 60 per cent of the sclerophyll forest was also involved and the vegetation had still not completely recovered, although the lower layers were denser than in the unaffected areas.

RAINFALL AND RUN-OFF

There are no rainfall recording stations in the catchment and the nearest station is at Grove, several miles downstream from the gauging weir. This station is several thousand feet below the highest part of the catchment and so its rainfall is probably lower than that of much of the catchment as it is not subject to any strong orographic influence. The mean annual and monthly rainfall figures are shown in Table 7. The annual average is 30.67 inches which is spread throughout the year. Seasonality is not great, but there is a drier period from January to March with a minimum of 1.53 inches

TABLE 7

GROVE RAINFALL DATA

	Mean	Study Period
January	292	141
April	311	214
September	265	143
October	276	130
November	269	562
December	262	425
January	153	578
February	200	130
March	156	28
April	314	142
May	311	118
June	258	247
Total	3,067	2,858

in January. For the remainder of the year rainfall is fairly evenly distributed, ranging from a minimum of 2.58 inches to the maximum of 3.14 inches in April.

During the twelve months of the study rainfall was 28.58 inches, which is approximately 2 inches below the annual mean. The distribution of the rainfall as shown in Table 7 was very atypical with marked concentrations in November and December 1969 and January 1970 when over 15 inches fell, constituting 55 per cent of the twelve month total. The wettest month was January yet this month has the lowest mean rainfall. Rainfall for the remaining 9 months was below average with a minimum of 0.28 inches in March 1970 which is only 20 per cent of the mean figure for this month. In the three wet months, rainfall was further concentrated into four main episodes covering a total of 13 days. These 13 days account for over 40 per cent of the rainfall for the 12 month period.

Run-off records for the Mountain River are only available from May 1968 when the Rivers and Water Supply Commissions gauge was installed and so only two complete years of record are available. Discharge for these two years was 21,750 acre feet in 1969 and 30,646 acre feet in 1970. Obviously no mean figure will be significant until a much longer record has been obtained. During the period of the record, monthly discharges have varied markedly, ranging from 489 to 7,729 acre feet. For the twelve months before the study was undertaken, when rainfall followed a similar pattern to that of the mean figure, the discharge pattern is one of minimum flows in late summer with higher flows during the remainder of the year.

Discharge during the study period was 23,438 acre feet. This was concentrated during summer, following the pattern of rainfall. Although no mean figures are available this is probably an atypical distribution. The hydrographs for the study period and the preceding 12 months have been plotted in Figure 32.

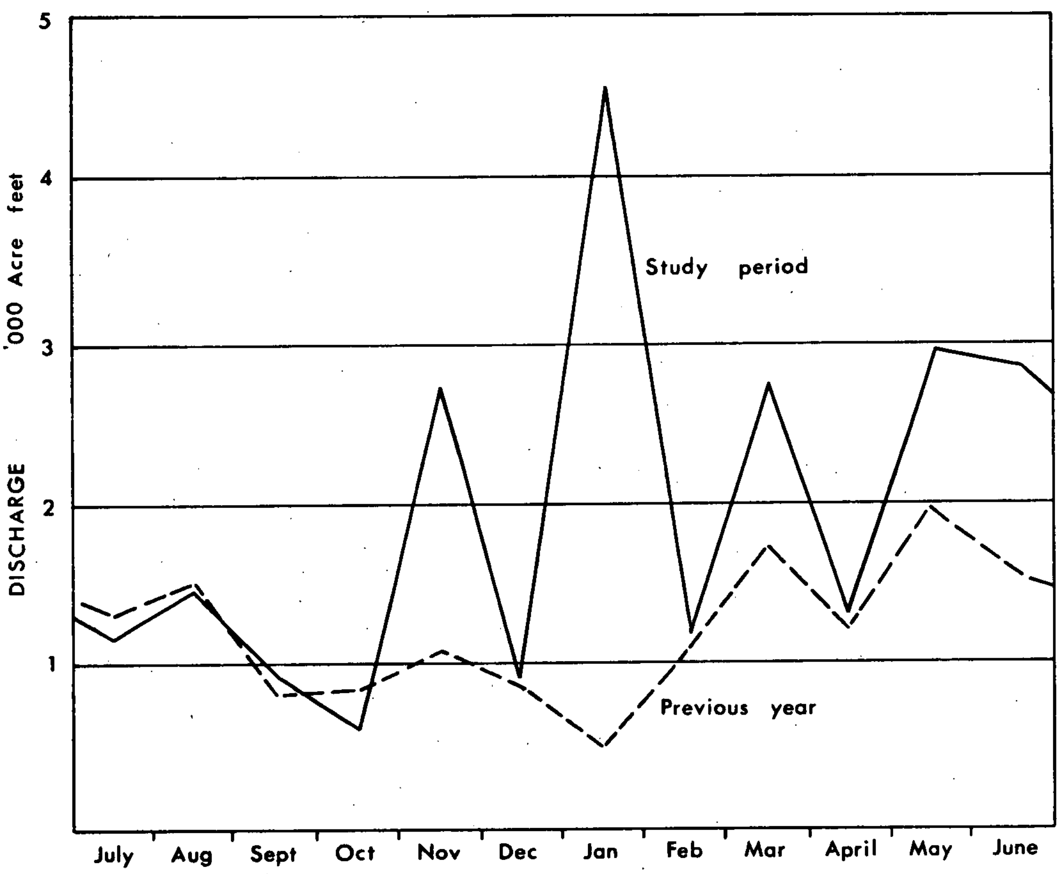
Daily discharges for the period are shown in Appendix 3 and range from 7.6 to 143 cusecs which was the highest discharge recorded from the commencement of gauging. From the figures for daily discharge it can be seen that marked concentrations of discharge occur with isolated run-off episodes contributing a relatively large proportion of discharge, although the concentrations are not so marked as those in the other two streams.

The contribution of the tributary to the total stream discharge could not be determined because of the lack of discharge readings. Similarly a discharge rating curve could not be plotted.

Because of the short period of discharge record, normal double-mass curves could not be plotted to analyse the relationship between rainfall and run-off. In an attempt to overcome this problem double-mass curves were plotted based on monthly rather than annual figures. No linear relationship could be found however. This is probably due to changes in the rainfall-run-off relationship due to seasonal changes in vegetation cover and evapo-transpiration. There could also be some errors in the discharge recordings as during the study period the gauging weir suffered severe flood damage which resulted in errors in recording. It was therefore impossible to examine the hydrologic impact, if any, of the 1967 bushfires.

Figure 32

MOUNTAIN RIVER HYDROGRAPHS



SEDIMENT DATA

Sampling was carried out above the influence of the gauging weir and just below the entry point of the tributary into the major river. Several samples were also taken of the tributary and the river above the tributary at the bridges adjacent to the gauging weir. Thirty three samples of the wash load and 12 samples of the suspension and solution loads were taken from the river (Tables 8 and 9). Six wash load samples and 3 solution and suspension samples were taken from the tributary, and from the river above the tributary 4 and 3 samples were taken respectively (Table 10).

MOUNTAIN RIVER BELOW THE TRIBUTARY

(i) Wash Load

Sampling was carried out at discharges ranging from 6.2 to approximately 1500 cusecs with good coverage up to 30 cusecs and scattered samples above this.

Wash load concentration ranged from 55 to 826 ppm with the majority of the samples having a concentration of less than 100 ppm. While there appears to be some relationship between concentration and discharge a linear regression analysis revealed no significant correlation. Consideration was given to the pattern of wash load concentration over a particular run-off episode from the 15th to the 25th of March 1970 (the results are shown in Figure 33). Concentration rises rapidly and peaks before discharge then falls rapidly while discharge continues to rise, quickly returning to a "normal" level while discharge decreases relatively slowly.

TABLE 8

MOUNTAIN RIVER - WASH LOAD DATA

Date	Instantaneous discharge (cusecs)	Concentration (ppm)	Wash Load (tons/day)
8. 8.69	36.5	86	7.55
14. 8.69	32.2	61	4.68
25. 8.69	16.4	66	2.59
7. 9.69	14.2	59	2.02
17. 9.69	16.4	61	2.41
26. 9.69	15.2	68	2.49
3.10.69	11.8	60	1.70
10.10.69	11.8	75	2.13
17.10.69	9.6	71	1.63
26.10.69	8.2	75	1.47
3.11.69	32.2	92	7.07
10.11.69	12.4	61	1.82
14.11.69	10.7	74	1.89
17.11.69	84.0	321	64.82
18.11.69	128.0	131	0.31
27.11.69	24.5	61	3.59
3.12.69	28.0	61	4.11
16.12.69	81.0	61	11.88
21.12.69	30.3	55	4.01
11. 1.70	031.4	68	5.13
23. 1.70	21.3	73	3.74
9. 2.70	8.9	91	1.94
23. 2.70	10.8	63	1.64
2. 3.70	9.4	68	1.54
10. 3.70	7.2	67	1.16
15. 3.70	6.2	69	1.02
20. 3.70	147.0	826	291.9
21. 3.70	1,500	180	647
25. 3.70	66.0	83	13.11
2. 4.70	24.5	84	4.95
19. 4.70	8.2	83	1.68
26. 4.70	7.2	68	1.17
3. 5.70	42.0	58	5.85

TABLE 9

MOUNTAIN RIVER - SUSPENSION & SOLUTION LOAD DATA

Date	Instantaneous discharge (cusecs)	Suspension Concentration (ppm)	Suspension Load (tons/day)	Solution Concentration (ppm)	Solution Load (tons/day)
9.2.70	8.9	8	0.16	72	1.53
23.2.70	10.8	5	0.13	61	1.58
2.3.70	9.4	6	0.12	69	1.55
10.3.70	7.2	6	0.10	65	1.12
15.3.70	6.2	7	0.10	68	1.01
20.3.70	147.0	563	197.8	125	44.0
21.3.70	1,500	99	356	67	242.5
25.3.70	66.0	30	4.78	52	8.17
2.4.70	24.5	12	0.71	82	4.80
19.4.70	8.2	9	0.71	79	1.58
26.4.70	7.2	7	0.12	77	1.38
3.5.70	42	9	0.86	78	6.86

TABLE 10

MOUNTAIN RIVER TRIBUTARY - WASH LOAD DATA

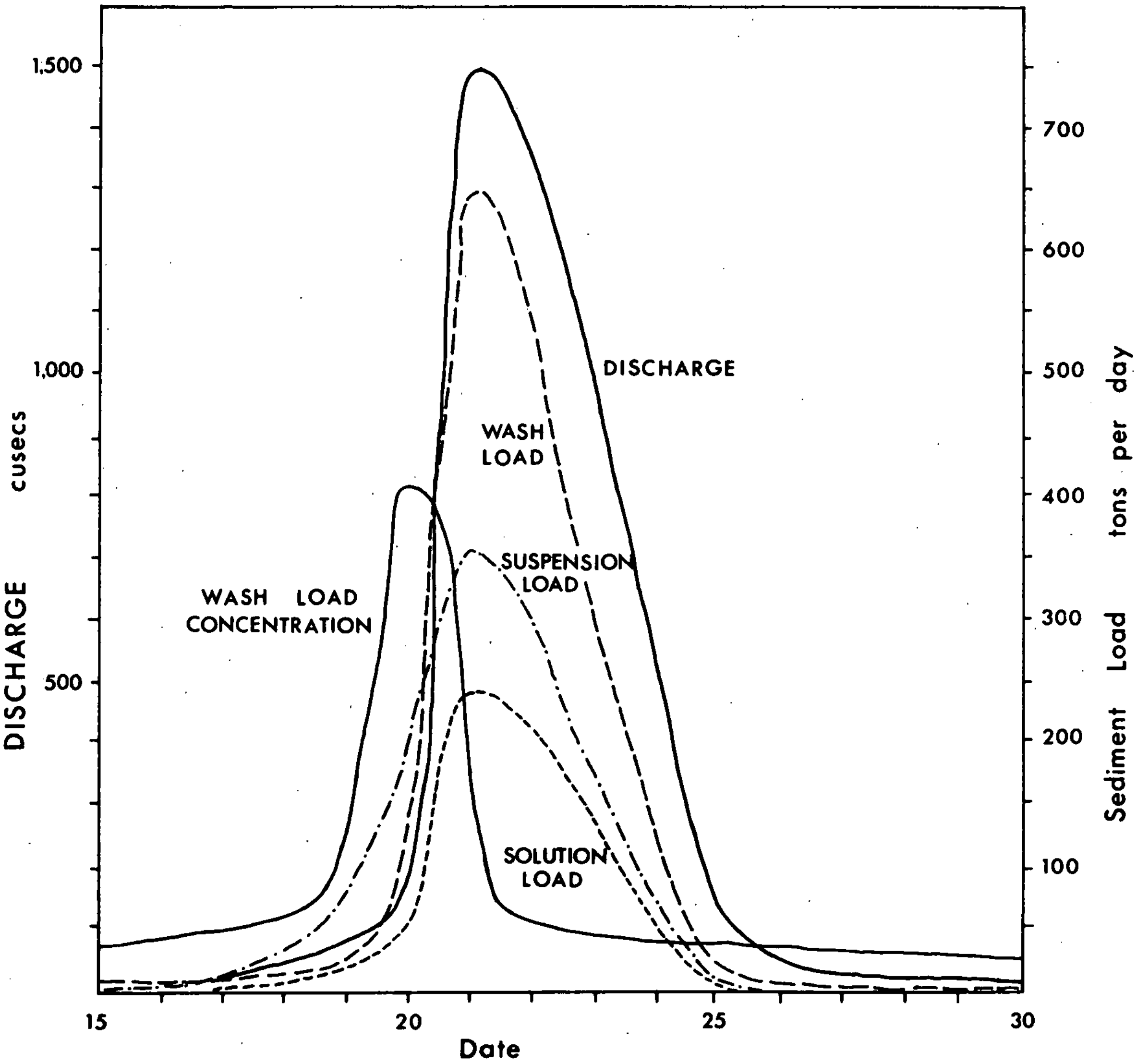
Date	Q	Wash Load Conc	Wash Load (tons/day)
14.11.69	3.45	58	0.48
21. 3.70	126	229	69.36
2. 4.70	3.2	107	0.82
3. 5.70	8	71	1.38

MOUNTAIN RIVER ABOVE TRIBUTARY - WASH LOAD DATA

Date	Q	Wash Load Conc	Wash Load (tons/day)
14.11.69	7.88	62	1.16
21. 3.70	1375	308	1020
2. 4.70	20	87	4.19
3. 5.70	36	58	5.04

Figure 33

MOUNTAIN RIVER RUN-OFF EPISODE 15th-30th MAY 1969



Wash load in tons/day was computed from the concentration figures and a rating curve determined (Figure 34). The regression equation of the rating curve was

$$L = 0.085Q^{1.270}$$

and the correlation coefficient of the relationship was 0.89 which is significant at the 1 per cent level. With an exponential of 1.27, wash load increases at anincreasing rate with a rise in discharge.

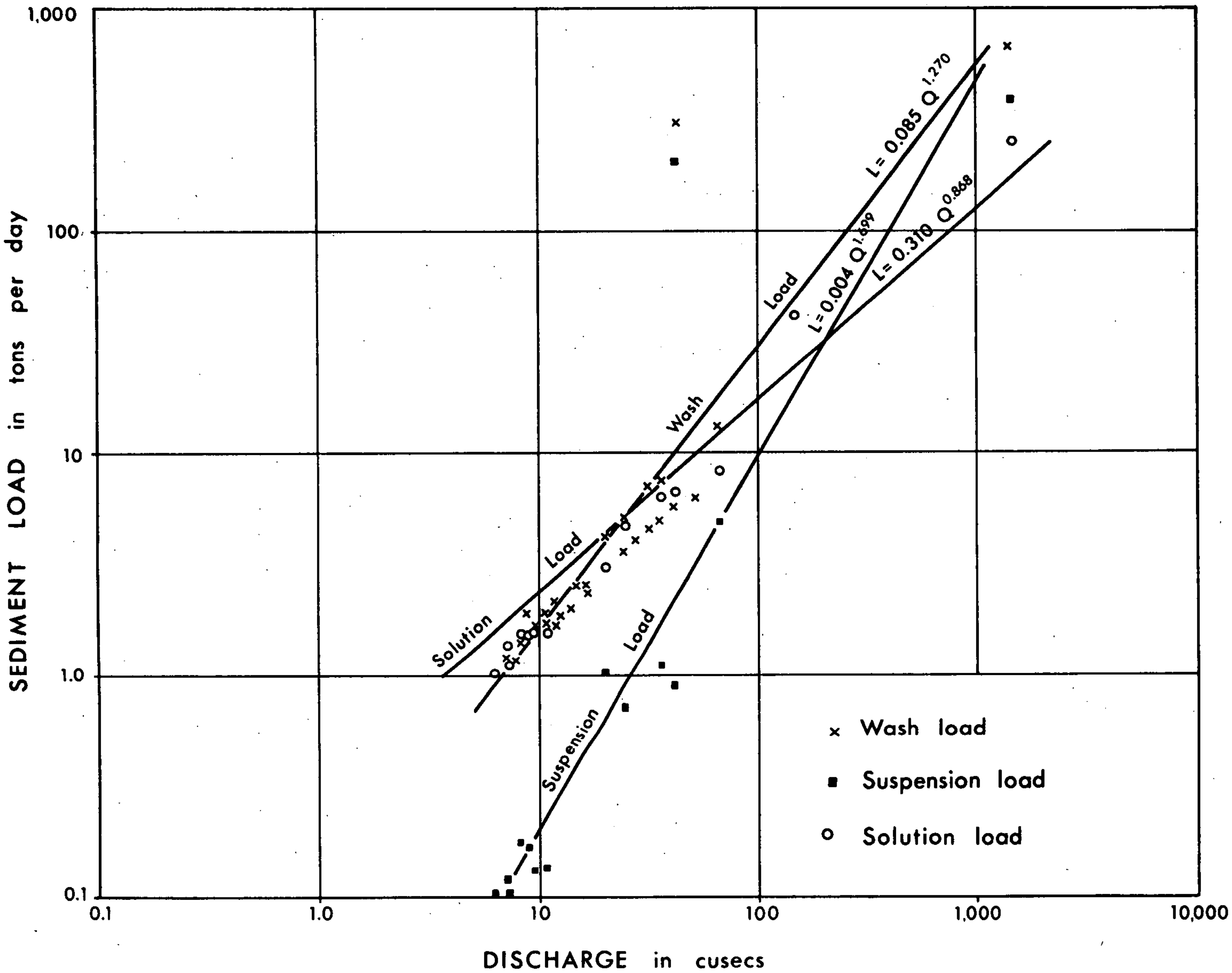
The rating curve equation was then used to compute the daily wash load discharge for the twelve month period of the study and the results are shown in Appendix 3. Daily wash load is spread relatively evenly throughout the twelve months with no marked dominance of individual episodes and values generally lie between 1 and 10 tons/day. Several episodes occur which have discharges above this range however, and these contribute significantly to the annual total. The maximum daily discharge is 46 tons which is 2.7 per cent of the annual total, but several days occur when wash load is near this maximum.

As with the wash load concentration a plot was made for the period 15th to the 25th March 1970 (Figure 33). Wash load discharge shows a much closer correlation to stream discharge than does the concentration with a less rapid rise and fall than with concentration.

An X-Ray diffraction analysis was made to determine the composition of two wash load samples, one of basal flow and the second at a discharge of 147 cusecs. While much of the material consisted of clay colloid particles too fine to be analysed, both samples were found to contain quartz, montmorillonite and sodium chloride.

Figure 34

MOUNTAIN RIVER SEDIMENT RATING CURVES



(ii) Suspension Load

Suspension load samples were taken for discharges ranging from 6.2 to approximately 1500 cusecs with the majority of samples from discharges of less than 10 cusecs and only scattered coverage of discharges above this figure (Table 9). As with the other two catchments, the length of record is only three months and so the accuracy of the values is doubtful.

Suspension load concentration ranged from 5 to 563 ppm. Regression analysis revealed no significant relationship between concentration and instantaneous discharge.

The suspension load rating curve (Figure 34) showed a highly significant relationship with a correlation co-efficient of 0.96 which is significant to the 0.1 per cent level. The resulting equation for the rating curve was

$$L = 0.004Q^{1.699}$$

The gradient of the suspension load rating curve is significantly greater than that of wash load so while suspension load is insignificant at low discharges it rapidly becomes dominant with increasing discharge.

Projected daily suspension load discharges are shown in Appendix 3 however it must be remembered that they are based on relatively scant information. Daily suspension discharge is below 1 ton/day for the majority of the period while the maximum daily discharge is 16.98 tons. It is likely that the suspension load during higher discharges is artificially low because of the inability to separate clay colloids from the solution load, and the limitations of using mean daily discharges for computing sediment load while during a particular day discharge could be much higher for limited periods.

Again the pattern of suspension load was plotted over the period 15th to 25th of March 1970 (Figure 33).

(iii) Solution Load

The same range of discharges as those for suspension load were sampled for solution load and the results are subject to the same limitations.

Concentrations range from 52 to 125 ppm with all values but one below 82 ppm. There appears to be some relationship with instantaneous discharge. Solution concentration rises as discharge increases except in low flow where there is a tendency for solution load to increase with a decrease in discharge. A regression analysis revealed that there was no significant linear relationship.

The solution rating curve is shown in Figure 34 and was found to have the equation

$$L = 0.310Q^{0.868}$$

The associated correlation co-efficient was 0.992 which was significant at the 0.1 per cent level. The gradient of the curve is much less than that of either wash or suspension loads and so while solution load is dominant at low flows its relative importance decreases with increasing discharge. Again at low flows, theoretical solution load is greater than total wash load, probably due to laboratory errors already outlined.

Daily solution discharge figures were computed and are shown in Appendix 3. Daily solution load is below 5 tons/day for the majority of the time while several episodes have loads up to 23 tons/day. The dominance of individual episodes is not marked, the maximum value only constituting 1.4 per cent of the annual total.

The pattern of solution load was plotted for the individual episode already plotted for the other two loads (Figure 33). The pattern resulting appears close to that for suspension load.

(iv) Denudation Rates

Total wash load for the period of the study was 2,170 tons and as the catchment has an area of 15.5 square miles this results in an erosion rate of 140 tons/square mile.

With a suspended sediment discharge of 473 tons for the period the resulting erosion rate was 31 tons/square mile while solution discharge was 1,905 tons giving an erosion rate of 129 tons square mile.

MOUNTAIN RIVER TRIBUTARY

Four readings were taken of wash load for the tributary with three suspension and solution load samples covering discharges ranging from 3.2 to 126 cusecs. The results are shown in Table 10. The small number of samples severely restricts the value of the results but they were obtained to gain some idea of the relative contribution of the tributary to the main stream.

Wash load concentrations vary from 62 to 229 ppm. The wash load rating curve (Figure 34) has the equation:

$$L = 0.214Q^{1.29}$$

with a correlation co-efficient of 0.97. The gradient of this curve is very similar to that of the wash load for the river. The constant is greater however and therefore the sediment load of the tributary for a given discharge is greater than that of the main river for the same discharge.

Discharge of the tributary makes up only a small proportion of total stream discharge and so while its relative contribution is greater, its absolute contribution is only small.

While there are insufficient readings of solution and suspension loads to enable a significant analysis, a general impression can be obtained. Solution load of the tributary appears similar to that of the main stream while suspension load is significantly greater especially in higher discharges.

X-Ray Diffraction analysis of one of the samples indicated that the sediment was composed of quartz, montmorillonite and sodium chloride. The proportion of quartz was less than the main stream while there was approximately the same amounts of clay and salt.

MOUNTAIN RIVER ABOVE THE TRIBUTARY

Four samples were taken of wash load and three samples of solution and suspension load covering discharges ranging from 7.9 to 1,375 cusecs.

Wash load concentrations vary from 58 to 308 ppm. and the resulting rating curve has the equation:

$$L = 0.085Q^{1.27}$$

which was found to be significant at the 1 per cent level with a correlation co-efficient of 0.99. This curve is very similar to that of the stream below the tributary as would be expected because of the small absolute contribution of the tributary. While no rating curve was calculated for suspension and solution loads because of the limited number of readings, it appears that they are similar to those of the stream below the tributary.

SUMMARY OF RESULTS

The rainfall during the study period was slightly below average but again distribution varied significantly from the mean, with strong concentrations during summer when the minimum usually occurs. A similar pattern exists with discharge but no mean values are available for comparison because of the short period of record. Also, no double-mass curves could be plotted so the accuracy of the records and the effect of the 1967 fires cannot be examined.

A wide range of discharges was sampled for wash load with again a lack of middle range discharges. No correlation was found between wash load concentration and stream discharge but a strong correlation exists in the wash load rating curve with the equation

$$L = 0.085Q^{1.270}$$

The suspended sediment rating curve for the period was

$$L = 0.004Q^{1.699}$$

while the solution rating curve was

$$L = 0.195Q^{0.962}$$

In the lower range of discharges theoretical solution load exceeds total wash load due to errors involved in the laboratory analysis.

In the analysis of a run-off episode all the loads peak at a similar time as discharge. Wash load concentrations reach a maximum earlier however and then fall with increasing discharge. This was also the case with the concentration of solution and suspension loads which are not shown in the graph.

The wash load erosion rate over the twelve months was 140 tons/square mile of which slightly over 20 per cent was made up of suspended load and the remainder of solution load.

The Mountain River tributary was sampled on several occasions covering a very limited range of discharges. The wash load rating curve showed significant relationship however with the following equation

$$L = 0.214Q^{1.29}$$

Insufficient readings were taken to calculate suspension and solution rating curves but it appears that while solution is similar to that of the main stream, suspension load is significantly greater.

A similar number and range of samples were taken of the main stream above the confluence with the tributary. The wash load rating curve had the equation

$$L = .085Q^{1.27}$$

which is exactly the same as that for the stream below the confluence. It appears that the tributary supplies a relatively greater proportion of the wash load due mainly to a greater suspended sediment discharge. Because of the small size of the tributary its absolute impact is not great and its greater sediment discharge is not large enough to affect the rating curve of the stream below its confluence.

CHAPTER 7

DISCUSSION OF RESULTS

The environment of the three catchments is in many ways similar. The lithological and vegetation units in all catchments are similar, varying only in the proportions of the various units in each catchment. The relief of the catchments are significantly different with relief in the Mountain River catchment being approximately three times that of Snug Rivulet. Because of the varying size of the catchments however the stream gradients are comparable, as are the slopes, so the energy potential per unit area is similar in all cases.

RAINFALL AND RUN-OFF

The rainfall received during the twelve months of the study differed from the mean in all catchments. Both the Browns River and Snug Rivulet catchments had totals which were well above average, while that of the Mountain River catchment was slightly below average. The mean distribution for the rainfall of all catchments shows a maximum in late winter and early spring and a minimum in late summer and early autumn. Rainfall during the study was very atypical with a marked concentration in November, December and January, the period when minima usually occur.

This pattern of rainfall is reflected in the stream discharge. Total discharge is above the mean of Snug Rivulet and Browns River. In the case of the Mountain River, insufficient record is available to calculate a meaningful mean but the discharge for the period is the highest recorded. Discharge in all the streams was concentrated in the summer months, the period when minimum flows usually occur. This atypical rainfall pattern and hydrograph will probably have some effect on the sediment which is supplied to the streams and transported by them. This will be due to differences in evapo-transpiration and vegetation cover from that which normally occurs during the period of maximum rainfall.

The daily discharge figures revealed a similar run-off pattern in all cases. The characteristic features are the long periods of low or basal flow with the dominance of individual episodes of run-off, which cover only a short time span, but account for a relatively large proportion of the total run-off. As the catchments studied are relatively small and relief is high, run-off occurs rapidly after rainfall with the stage rising steeply. The decrease in run-off also occurs rapidly after rainfall has ceased with the falling stage often falling as rapidly as it rose, which is characteristic of small mountain streams. In many cases the stream can rise and fall in a matter of hours. These features can be seen in the hydrographs of a particular run-off episode for each of the streams shown in Figure 18, 27 and 33.

Double-mass curves could only be plotted for Brown's River and Snug Rivulet. The Brown's River curve showed a strong linear relationship which illustrates that the rainfall and stream discharge figures are relatively accurate and that the water budget of the stream has not changed significantly. No linear relationship occurred in the Snug Rivulet curve and by comparison with Browns River it appears that this is due to errors in the discharge readings for Snug Rivulet. Insufficient record was available to allow the plotting of a double-mass curve for the Mountain River.

The bushfires of 1967 have apparently had little impact on the hydrology of the catchments. If any hydrologic change had occurred a break in slope would be evident in the mass curves at this time but no such breakes have occurred. This could be related to the extent of the fires and the vegetation types involved. Not all of the catchments were burnt with the Snug catchment which was the most seriously affected having 65% of the total area burnt. Much of the area which was burnt had a cover of moorland vegetation which recovered relatively quickly so any change would only be short term and would not be reflected in the annual figures used in the mass curves.

In the forest areas fire damage was restricted mainly to the tree canopy and the ground cover was less affected. On the destruction of the canopy, rapid growth of the ground layers occurred resulting in a denser ground cover than that which existed before the fires. As the ground cover is the dominant vegetational control of run-off the increase in density would tend to reduce run-off. Therefore despite a major change in vegetation the hydrologic impact is very minor.

SEDIMENT LOADS

WASH LOAD

In all catchments wash load samples were taken over a wide range of discharges. There was a dominance of samples in the lower discharge range because of the limited occurrence of high flows, and the inherent problems of obtaining samples before the stream has fallen again. This could lead to a degree of inaccuracy in the projection of sediment loads because of the reliance on a limited number of samples, which may be atypical and so may not be representative of the longer term characteristics of the catchment. This problem could not be overcome because of the limited time available for the study.

The wash load concentration covered a limited range of values with several exceptions. Concentration tends to be relatively constant rising appreciably only during periods of extremely high flow when a rapid increase in concentration occurs. In all cases no linear relationship existed between wash load concentration and instantaneous discharge. This suggests that the concentration of wash load is independent of discharge, and by implication, stream velocity. This is in keeping with Einstein's definition of wash load as that part of the load which will be transported by the stream independent of velocity and discharge. Wash load is solely dependent on the catchment parameters which have been outlined in Figure 7 and is completely independent of the channel. The stream can only transport the amount of wash load which is supplied to it by the catchment. This is made particularly clear in the catchments in this study where the bed and banks of the streams are made up of bedrock, dolerite boulders, or gravel and no wash load material is evident. Obviously all the wash load material in transport must be derived from the catchment rather than the channel.

In the examination of actual wash load rather than wash load concentration, a strong relationship exists in all catchments between wash load and instantaneous discharge. This is the sediment rating curve which has been used in almost all sediment studies to examine sediment loads. It has already been stated however, that wash load concentration is independent of stream discharge and dependent on catchment parameters outside the channel. It appears anomalous that such a strong relationship can exist when wash load is independent of discharge.

It is possible that the apparent relationship illustrated by the wash load rating curve is an artificial one. Wash load is determined by the two variables, instantaneous discharge and wash load concentration, using the equation

$$L = 2404 \times Q \times C \times 10^{-6}$$

in which each of the variables is of equal importance in the equation.

The non-relationship between concentration and discharge is counteracted in the conversion to wash load by multiplying by discharge. It is quite possible that the resulting relationship is one between discharge and discharge rather than discharge and wash load. For example, if wash load concentration remained constant over a range of discharges, then wash load would increase with discharge and a perfect correlation would exist despite the fact that the relative amount of sediment had remained constant. In this case although an apparent relationship occurs the real relationship is between discharge and discharge and not sediment and discharge.

As the dependent variable is derived from the independent one, then obviously a strong relationship must result which is however an artificial one. This could explain the consistently high correlation co-efficients which usually result from sediment rating curves. It could also explain the exponentials of the curve which usually are close to unity. Any variation from unity is related to concentration, and so the exponential is a crude index of relative erodibility. As the correlation has been so strong it has only rarely been questioned and has been used as the major method of examining sediment loads.

A further factor is the relationship between stream discharge and rainfall. It has already been outlined that rainfall is the dominant factor controlling stream discharge. Rainfall is also an important catchment parameter which must be important in determining the supply of wash load to the stream. The suspension load component of the wash load is derived from soil erosion and is transported through the catchment to the channel by surface run-off which occurs only during, and immediately after rainfall. It is possible then that the relationship in the rating curve is an indirect one between rainfall and wash load through the medium of the dependent discharge.

As wash load concentration has been shown to be independent of discharge, the wash load rating curve is not really a valid tool for comparing the relative erodibility of catchments except by use of the exponential value and the slope of the curve. It appears to be a rather artificial simplification of what is a complex relationship involving a large number of variables with no dominant variable, as is suggested by the rating curve. A more satisfactory method needs to be derived to enable a more realistic appraisal of the role of the variations of catchment parameters in determining wash load.

The wash load rating curve does remain however, as a valuable tool in determining absolute sediment values. The strong correlation allows a high degree of accuracy in the prediction of absolute sediment amounts for a given period. In this case the absolute amount of sediment is related to discharge as well as concentration, as shown in the equation for determining daily wash load. In many studies it is these absolute values which are important and the relative sediment amounts are of no interest. It is on the basis of these that erosion rates can be calculated.

The wash load rating curves show a strong relationship which is significant at the 0.1% level in all cases. The resulting regression equations are:

Brown's River	L =	$0.157\ Q^{1.184}$
Snug Rivulet	L =	$0.217\ Q^{1.093}$
Mountain River	L =	$0.085\ Q^{1.270}$

In all cases wash load increases at an increasing rate with increasing discharge, as all have exponential values of greater than one. Significant differences occur between the curves as is indicated in Figure 35. The Snug Rivulet curve has the lowest exponential value and so increases at a slower rate than the other two. It has however the highest constant value and so wash load at low discharges is greater than that of the other two. Brown's River with the middle value for both the exponential and the constant lies between the other two curves except in the range 40 to 100 cusecs when it is greater. The rating curve for the Mountain River is lower in the lower range of discharges but because of its larger exponential it becomes dominant when discharge is greater than 100 cusecs. The wash load rating curve of the Mountain River Tributary with the equation

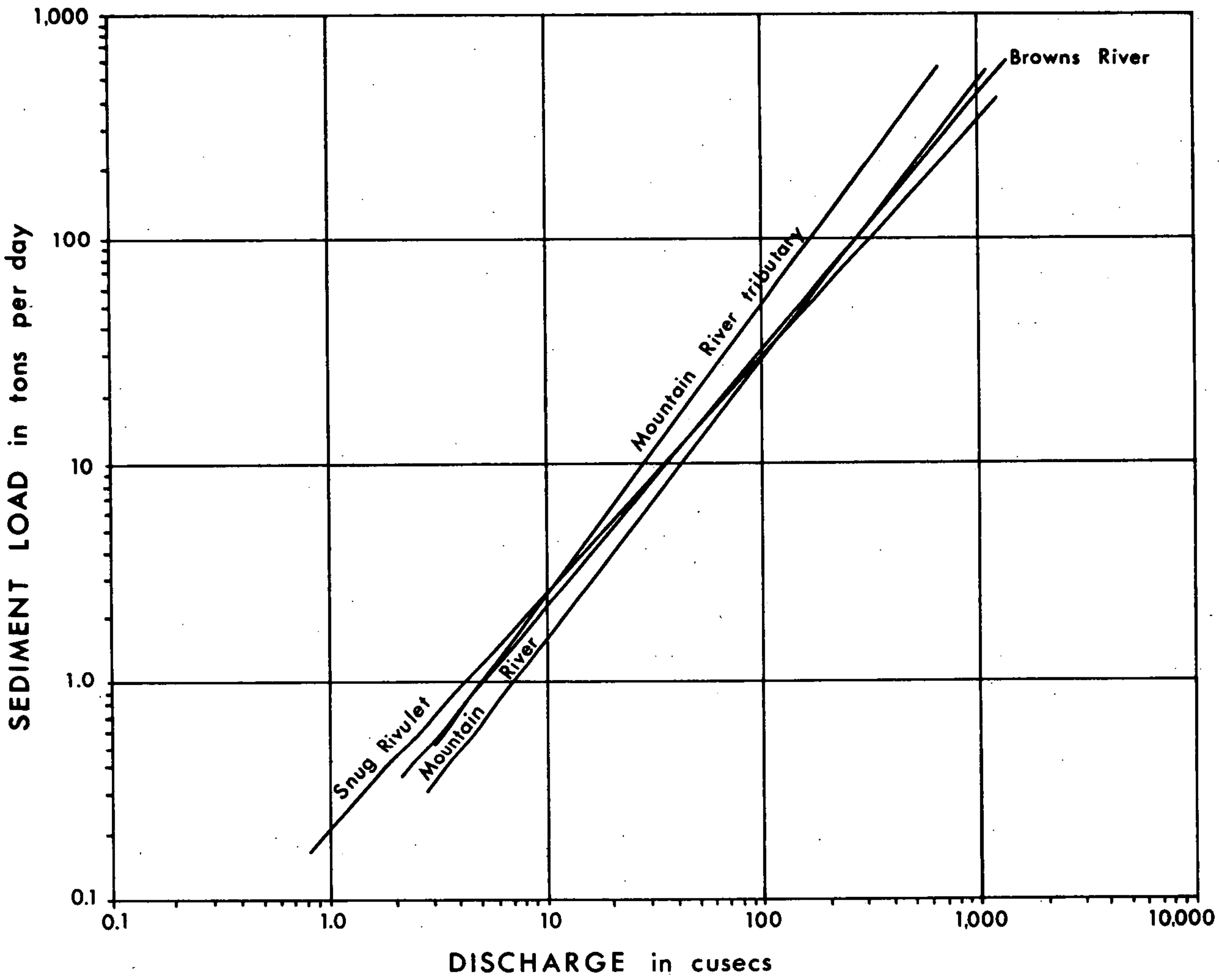
$$L = 0.214\ Q^{1.29}$$

has also been drawn in Figure 35. With a high constant and exponential wash load in the tributary is greater than that of the other three streams for all but the lowest discharges.

While the wash load rating curve has been shown to be a poor indicator of the influence of catchment parameters it can provide a rough index of the relative erodibility of catchments. This is indicated by the varying gradients and positions of the individual curves. As no other more satisfactory method could be found, this technique was used to

Figure 35

WASH LOAD RATING CURVES OF THE THREE STREAMS



gain some insight into the importance of the various catchment parameters. Because of the limited nature of the study with only three catchments, it is impossible to carry out any detailed analysis such as that carried by Anderson, where data was available for a large number of catchments and multiple regression was possible. The analysis is further limited by the fact that no homogeneous catchments could be found and the environments of all three catchments are similar, varying only in the proportions of the particular units.

Variations between catchments were found for four main variables; rainfall, lithology, vegetation and catchment size. The rainfall of the three catchments ranged from 28.58 inches for the Mountain River, to 51.32 inches for Browns River with the rainfall for Snug Rivulet being 47.37 inches. This pattern does not appear to be reflected in wash load rating curves except in that the Mountain River curve is generally below that of the other two wetter catchments. The Mountain River Tributary however, with a similar rainfall pattern as the Mountain River has a wash load which is greater than that of either Brown's River or Snug Rivulet which tends to rule out rainfall. This pattern is reflected in the denudation rates of the three catchments which are similar despite rainfall differences. From this very superficial and qualitative examination it appears that rainfall is not important in explaining the differences in the rating curves.

The geology of the catchments is made up of the same three rock types with variations in the proportion of the area which is occupied by each unit. The only exception is the Mountain River catchment which has some Quaternary alluvium. The Brown's River catchment consists of sandstone, which extends over 30% of the area, mudstone 24% and dolerite 46%. In the Snug Rivulet catchment, sandstone covers 42% of the area, mudstone 33% and dolerite 25%, while in the Mountain River catchments the proportions are sandstone 11%, dolerite 85% and alluvium 4%.

A broad relationship can be found with an apparent correlation between the proportion of sandstone and mudstone and the wash load. The Mountain River with a low proportion of these two lithologies (11% of the total area of the catchment) has a wash load rating curve below that of Browns River the catchment of which consists of 54% sandstone and mudstone. The Browns River curve lies below the Snug Rivulet curve and the Snug Rivulet catchment is 75% sandstone and mudstone. As the sandstone is relatively resistant to erosion while the mudstone is much more susceptible, it is likely that this increase in wash load is more closely related to the proportion of mudstone and this is suggested by the actual figures for the three catchments given above. This pattern is also reflected in the erosion rates with the Snug Catchment having the highest erosion rate of 156 tons/ square mile ranging through Brown's River with 148 tons/square mile to a minimum in the Mountain River of 140 tons/square mile. While a relationship does appear to exist, the lack of information, particularly due to the limited number of catchments, does not allow detailed analysis and if further information was available it might be found that the apparent relationship is not valid.

As with geology, the vegetation of the three catchments is made up of the same basic units varying only in the proportion of each. The Brown's River catchment has 74% of its area covered by sclerophyll forest, 14% is cleared forest and 12% moorland vegetation. In the Snug Rivulet catchment the proportions are 75%, 14% and 11% respectively and in the Mountain River 52%, 13% and 35%. The Browns River and Snug Catchments have almost the same proportion of each type while in the Mountain River there is less forest and more moorland. The tributary to the Mountain River has no moorland vegetation and consists solely of forest and cultivated areas.

This general pattern is refelcted in the wash load rating curves where the wash load increases with increasing proportion of forest. In the forest areas much of the ground has no vegetation cover although there is an overhead tree cover. Therefore the forest areas are much more susceptible to erosion by surface run-off resulting in a greater wash load. There is no apparent relationship between vegetation cover and the denudation rates.

The final variable which differed between the catchments is catchment area with Browns River have an area 4.7 square miles, Snug Rivulet 7.5 square miles, the Mountain River 15.5 square miles and its tributary approximately 3 square miles. No consistent relationship is apparent although the size of the catchment could explain the low values for the Mountain River wash load. Also it could explain the difference between the wash loads of the Mountain River and its tributary which is much smaller and has a higher wash load.

As stated any examination of the importance of the catchment parameters and their influence on wash load can only be made on a qualitative level due to the limited amount of information and is of necessity superficial. While a relationship was apparent between wash load and geology and vegetation the importance of these cannot be appraised. The relationship is a complex one and it is impossible to separate out any particular variable with confidence. It does appear however that in this study geology and vegetation are major determinants of the relative erodibility of the catchments studied.

Suspension Load

As the laboratory equipment required to separate suspension and solution loads became available towards the end of the study, only a limited number of samples could be taken. Also only one rainfall episode occurred, and so the range of discharges sampled is limited to low flows with only one or two higher readings. Because of these limitations it is possible that the resulting rating curves are not an accurate representation of the long term characteristics of the catchments. A further limitation results from the inability of the laboratory equipment to separate the fine clay colloids of the suspension load from the solution load. This results in an over-estimation of the solution load at the expense of the suspension load. This error becomes more marked with increasing discharge as a greater proportion of clay colloids are supplied to the stream. Allowing for these errors however, a general impression of the behaviour of the suspension load can be gained.

Suspension load concentration covered a limited range of values because of the dominance of low flows during the sampling period with several higher values associated with the rainfall episode. As with wash load no significant relationship was found between discharge and suspension load concentration. It did appear however that concentration remained relatively constant while there was no surface run-off and rose rapidly when any surface run-off occurred.

Strong linear relationships were found in the suspension load rating curves which were all significant at the 0.1% level. The resulting equations were:

Brown's River $L = 0.014\ Q^{1.4481}$

Snug Rivulet $L = 0.017\ Q^{1.3163}$

Mountain River $L = 0.004\ Q^{1.6989}$

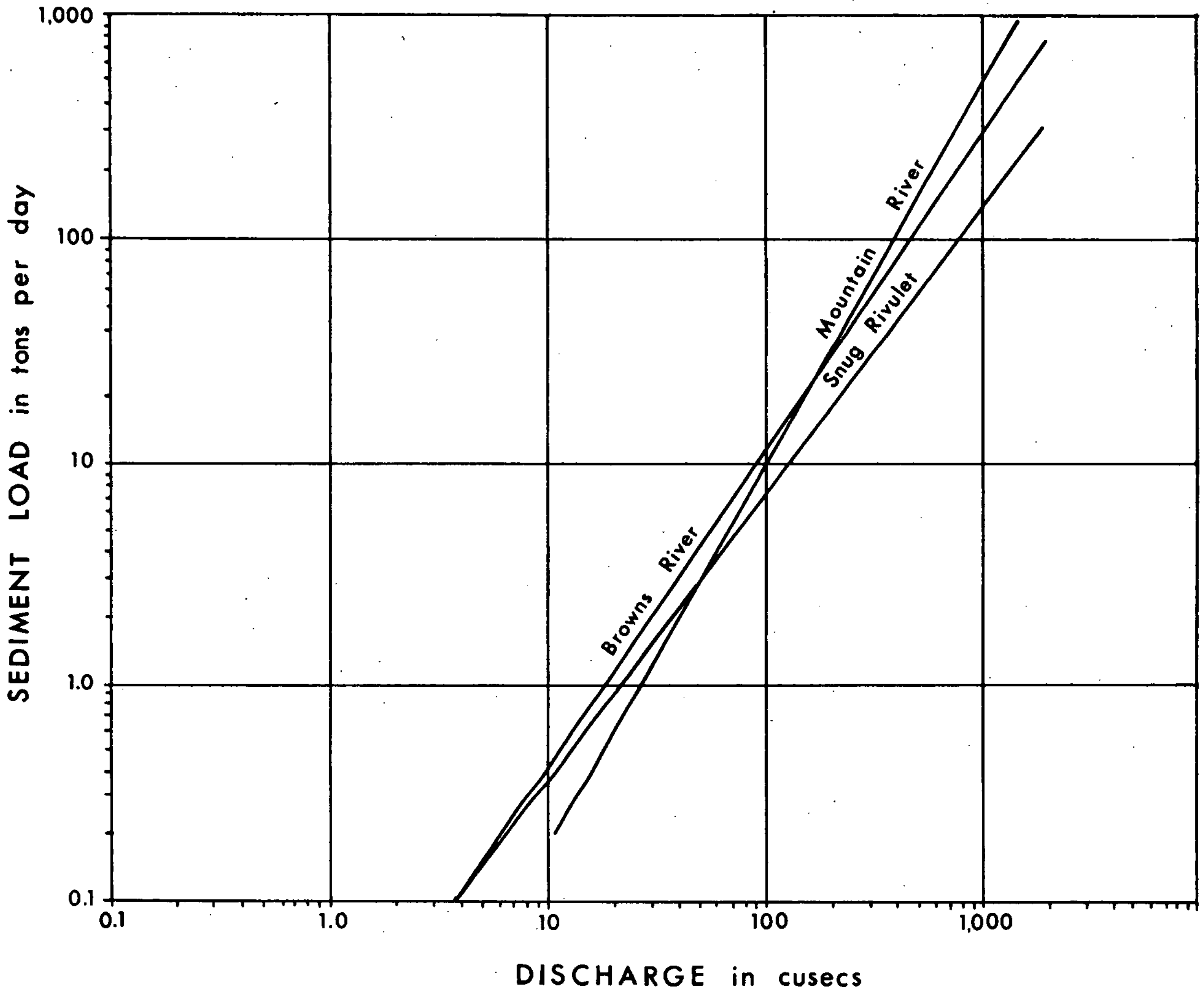
In all cases the constant is less than that for the wash load and suspension load makes up only a minor part of the total wash load during low flows. The value of the exponentials are greater than those of the wash load and so the importance of the suspension load increases with discharge. This increase is probably more marked than is evident in these curves because of the clay colloids which could not be separated from the solution load. The resulting pattern of suspension load discharge is one of long periods of extremely low sediment discharge with isolated periods of high discharge associated with rainfall and run-off episodes. The dominance of these individual episodes is even more marked than is the case with total wash load.

Differences occur between the suspension load rating curves of the three catchments as is shown in Figure 36. The general pattern is that the curves are somewhat similar with the suspension load of Brown's River slightly greater than that of Snug Rivulet. The Mountain River Curve is below the other two in the low discharge range but has a greater gradient and as a result in the higher discharges, suspension load is greater. The relationship between the three is similar to that of the wash load rating curves.

In the lower stream discharges, suspension load is greatest where there is a greater proportion of mudstone. During the low flows, suspension load is derived from the channel and this tends to suggest that a greater amount of mudstone is available in the banks and bed. This was evident in the field, where although all three streams had only a small amount of wash load material in the bed and banks, a greater proportion was evident

Figure 36

SUSPENSION LOAD RATING CURVES OF THE THREE STREAMS



in Brown's River and Snug Rivulet the two catchments with mudstone present. At higher discharges suspension load is greater in the catchments with a high dolerite content. During high flows surface run-off is important and suspension load is derived mainly from the catchment rather than the channel. Therefore it appears that in the catchment a greater proportion of dolerite is available for removal as suspension load. In this study the dolerite is in the form of periglacial solifluction material with an abundance of fine clay particles which are easily transported in suspension. The mudstone and sandstone however are not as readily available and so in the higher range of discharges where surface run-off is important suspension load is greater from dolerite areas.

While these differences exist between the suspension load rating curves, they tend to be balanced out in the erosion rates where no significant differences occur. The suspended sediment erosion rates for the three catchments are: Brown's River 30 tons/square mile, Snug Rivulet 29 tons/square mile, and Mountain River 31 tons/square mile. It must be remembered that these erosion rates are artificially depressed due to the loss of clay particles to the solution load in the laboratory analysis.

In summary, while it is recognised that the suspension load determined is somewhat artificial, it does give some insight into the pattern of this load. Any errors produced will be constant for the three catchments and so a valid comparison between catchments is possible. This revealed that during low flows suspended load is greater for mudstone areas while during high flows when surface run-off is occurring suspended load is greater from dolerite areas.

SOLUTION LOAD

The solution load results were taken over the same period as those for suspended load and are subject to the same limitations. The errors introduced by the inability to separate out the fine clay colloids which have already been outlined lead to an over estimation of solution load. This error increases with increasing discharge when a greater amount of colloids is carried.

Concentration of solution load is relatively constant with a general tendency to rise with discharge. At low flows however the trend is reversed and concentration rises with decreasing discharge. This is to be expected as the solution load is derived mainly from ground-water discharge and the importance of this type of discharge increases with decreasing stream discharge. The rise in solution load with increasing stream discharge in the higher ranges is thought to be due in large degree to the increasing proportion of clay colloids which are really part of the suspension load. While these general patterns were evident, no statistically significant relationship could be found between solution load concentration and stream discharge.

As with total wash load and suspension load, the solution rating curve showed a strong linear relationship between solution load and discharge. All the regression equations were significant at the 0.1% level. The rating curves for the three streams were:

Brown's River	L	=	$0.195\ Q^{0.9615}$
Snug Rivulet	L	=	$0.248\ Q^{0.9458}$
Mountain River	L	=	$0.310\ Q^{0.8683}$

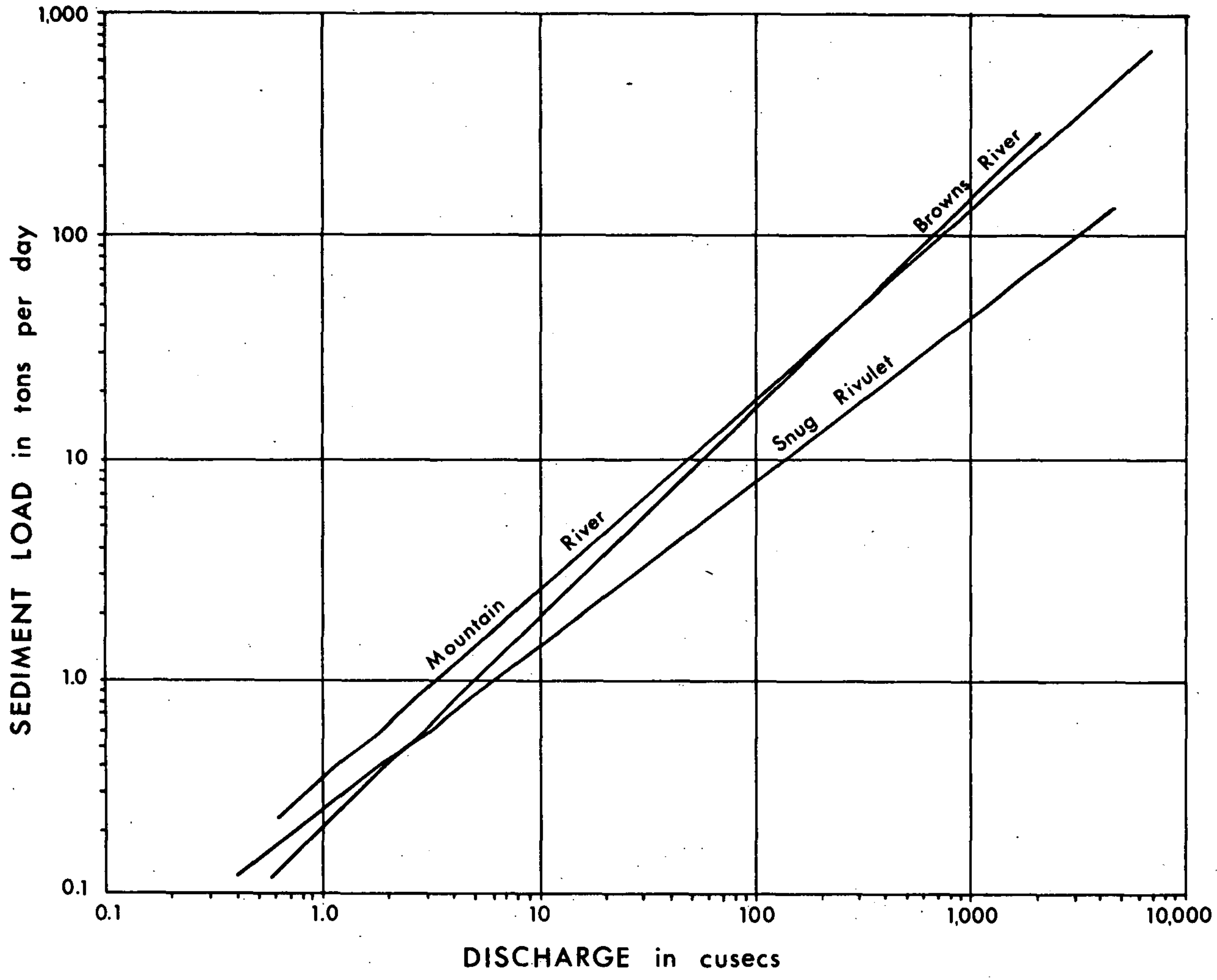
The constants of all three curves are high but the exponential values are all less than one. So, while the solution load makes up a significant proportion of the total wash load at low discharges, its importance decreases with increasing discharge. The decrease is probably more marked than is shown due to the increasing proportion of clay colloids which remain in the solution load. The resulting pattern of daily solution load discharge is much more regular than the pattern for wash load and suspensión load. The periods of high flow do not dominate the pattern as is the case with the other two loads.

The solution load rating curves of the three streams show significant differences (Figure 37). The pattern is the reverse of that which was evident for the suspension load. The solution load of the Mountain River is greater than that of the other two streams in all but the highest discharges where the Brown's River load is greater. In the case of Snug Rivulet its solution load is less than the other two streams in all but the lowest discharges when it exceeds that of Brown's River.

As with suspension load these variations appear to be related to the geology of the catchments. The Mountain River has a high proportion of dolerite which appears to be removed in solution to a greater extent than the other lithologies. Snug Rivulet has a low proportion of dolerite but a high proportion of sandstone and mudstone, which do not appear to be as susceptible to solution as dolerite, and so the solution load is lower. These differences are not necessarily wholly related to solution load; it is possible that differences in the colloid content could explain the differences. This is probably true to a certain extent as the dolerite yields a relatively high proportion of fine clay material, while the grain size of the sandstone and mudstone precludes the production of large amounts of colloids.

Figure 37

SOLUTION LOAD RATING CURVES OF THE THREE STREAMS



It is evident from the study that solution load is relatively constant with changing discharges and is relatively more important at low flows than it is at higher flows. Solution load is apparently greater from dolerite areas than sandstone or mudstone areas although this can be explained to some extent by the greater proportion of colloids yielded from dolerite areas.

COMPARISON WITH OTHER STUDIES

Any comparison with studies carried out elsewhere is difficult because of the problems of varying sediment sample collection methods and methods of laboratory analysis. It has already been seen that the errors resulting from the differing laboratory methods are not fully known, but it is clear that these errors do vary significantly. In much of the published work the methods used for sampling and laboratory analysis are not outlined, which further limits any valid comparison. Where varying methods are used, any comparison is of limited value as differences which occur may be more closely related to differences in methods rather than sediment characteristics. Even in Australia, where the number of studies is extremely limited, there is no uniformity in the methods used in analyzing samples although most use the United States Geological Survey DH-48 sediment sampler to obtain the samples. In any comparison being made then it must be remembered that these variations do exist.

In the large volume of literature on sediment studies very few studies have examined if any relationship exists between sediment concentration and stream discharge. Guy has made such an examination by plotting graphs of daily water and sediment discharge for a particular storm event[1]. This revealed a relationship between the two variables similar to that obtained in this study (Figures 18, 27 and 33). In Guy's study however peak sediment and stream discharge occur simultaneously while in the Tasmanian streams sediment concentration reached a peak before discharge except in Snug Rivulet when the peaks occurred simultaneously. As in each case only one isolated episode is considered, it is difficult to draw any significant conclusions from the differences.

The wash load concentration figures can be directly compared with studies carried out by Loughran[2] and Burkhardt[3] in the New England area of New South Wales as the same collection and laboratory techniques have been used. In his study of five streams of similar size to those of this study, Loughran found concentrations ranging from 38 to 270 ppm which is a similar range to that in this study. Burkhardt's figures tended to be higher with an average concentration of 405 ppm which is probably due to increased erosion associated with the urban development of Armidale. This conflicts with the results obtained by Langbein and Schumm[4], in the United States, who found that concentration decreased with increasing precipitation (Figure 38). In the Australian results annual rainfall ranged from 30 to 140 inches while sediment concentration remained relatively constant. Although little information about the catchments is given in Langbein and Schumm's study,

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1. Guy H.P. An Analysis of some storm-period variables affecting stream sediment transport. USGS Prof. Paper 462E, 1964, p. E14.

2. Loughran R.J. op. cit.

3. Burchardt J. op. cit.

4. Langbein W.B. and Schumm S.A. "Yield of Sediment in Relation to Mean Annual Precipitation". Am. Geogphys Union Trans. Vol. 39, 1958, pp. 1076-84.

they do outline changes in vegetation density with marked increases in density with increasing precipitation. In the Australian studies no similar quantitative analysis of vegetation has been made, but the vegetation in all cases is sclerophyll forest with little change in vegetation density as rainfall increases. This factor is probably the main cause of the differing patterns. In Langbein and Schumm's study the increasing vegetation density provides greater protection from erosion and outweighs the influence of increasing precipitation. In the Australian studies where vegetation density remains relatively constant no extra protection is provided and sediment concentration remains relatively constant.

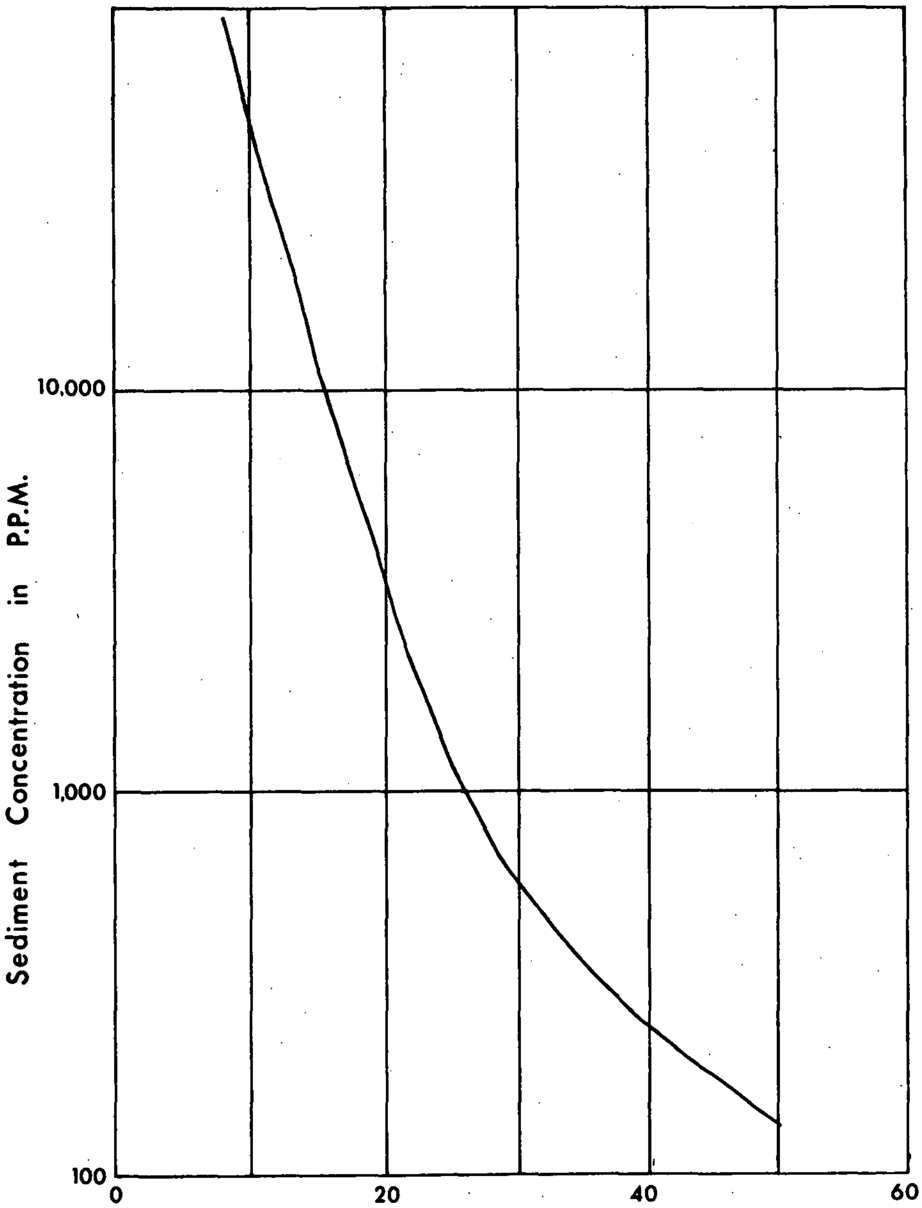
A large number of studies has been done to find wash load, normally using the sediment rating curve as the tool for analysis. The results obtained in these studies are similar to those of the present study with a very strong linear relationship on a logarithmic scale with associated high correlations. The slope of the curves is usually approaching unity as occurs in the Tasmanian streams.

Probably the most useful method of comparing wash loads from different areas is by comparing the denudation rates. The results obtained in Australia are shown in Table 11. Abrahams[1], in a recent study of Eastern Australia, has collected results of siltation rates in a number of reservoirs which are shown in Table 12. The denudation rates found in this study lie between those of Loughran and those of Douglas and Burkhardt. They also fall in the range of results listed by Abrahams.

1. Abrahams A.D. op. cit., p.37.

Figure 38

VARIATION OF SEDIMENT CONCENTRATION WITH ANNUAL PRECIPITATION



(after Langbein & Schumm 1958)

TABLE 11

Australian Denudation Rates

	Catchment	Area	Wash Load (tons/mile^2/year)
Loughran	(Little Styx	3.7	455
	(Serpentine	7.9	419
	(Bullock Creek	2.9	353
Douglas	(Bramina Creek	26.6	76
	(Sherlock	22.7	56
	(Queanbeyan	22.3	49
	(Queanbeyan	110.8	26
	(Queanbeyan	67.1	21
	(Strike-a-Light Creek	84.1	20
	(Brindabella Creek	10.2	15
Burkhardt	(Dumaresq Creek	21.5	26
Olive	(Brown's	4.7	148
	(Snug Rivulet	7.5	156
	(Mountain	15.5	140

TABLE 12

SILTATION DATA FOR SOME SOUTH-EAST AUSTRALIAN RESERVOIRS

Reservoir	Catchment Area km^2	Rate of siltation $m^3/km^2/year$
NSW		
Wyangala (Lachlan R)	8300	79.47
Burrenjuck (Murrumbidgee R)	12950	40.75
Hume (Murray R)	15300	41.93
Cunningham Ck (near Yass)	818	66.22
Guthega (Snowy R)	93	19.87
Stephens Ck (near Broken Hill)	513	132.44
Umbesumberka Ck (near Broken Hill)	422	269.99
A.C.T.		
Cotter (Cotter R)	482	32.60
Lake Burley Griffin	1865	14.26
Victoria		
Eildon (Goulburn R)	3885	54.51
Glenmaggie (Macalister R)	1890	37.18
Cairn Curran (Loddon R)	1593	22.92
Melton (Werribee R)	953	17.16
Pykes Ck (Werribee R)	124	48.81

The major differences between the streams considered is that of rainfall and run-off, with Douglas' and Burkhardt's studies being done in areas with average annual rainfalls of around 20 to 40 inches, while in Loughran's study the annual rainfall was 90 to 140 inches. Rainfall in this study ranged from 30 to 50 inches. An analysis was done to examine if a relationship exists between the denudation rates of these studies and their respective annual rainfalls. A regression analysis was done on both an arithmetic and logarithmic scale, and while both analyses were significant, the most significant results were obtained from the arithmetic analysis. The resulting distribution pattern is shown in Figure 39. The correlation co-efficient was 0.96 which is significant at the 1% level. Similar results were obtained by Abrahams.

These results differ significantly from those of Langbein and Schumm[1] who carried out a similar analysis in the United States of America. The results of their study are shown in Figure 40. Denudation rates increase to a maximum at 12 inches of rainfall per annum and then decrease with increasing precipitation. In the case of the Australian studies, denudation rates increase with increasing precipitation throughout the range giving a linear pattern. This difference is similar to that of sediment concentration where variations in vegetation cover result in marked differences in erodibility. The Australian vegetation, which is relatively constant, provides less protection in the higher rainfall areas than is the case in the United States. As a result denudation rates increase with rainfall in the Australian studies, while they decrease in the American study.

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1. Langbein & Schumm, op cit.

Figure 39

RELATIONSHIP BETWEEN SEDIMENT YIELD AND PRECIPITATION IN AUSTRALIA

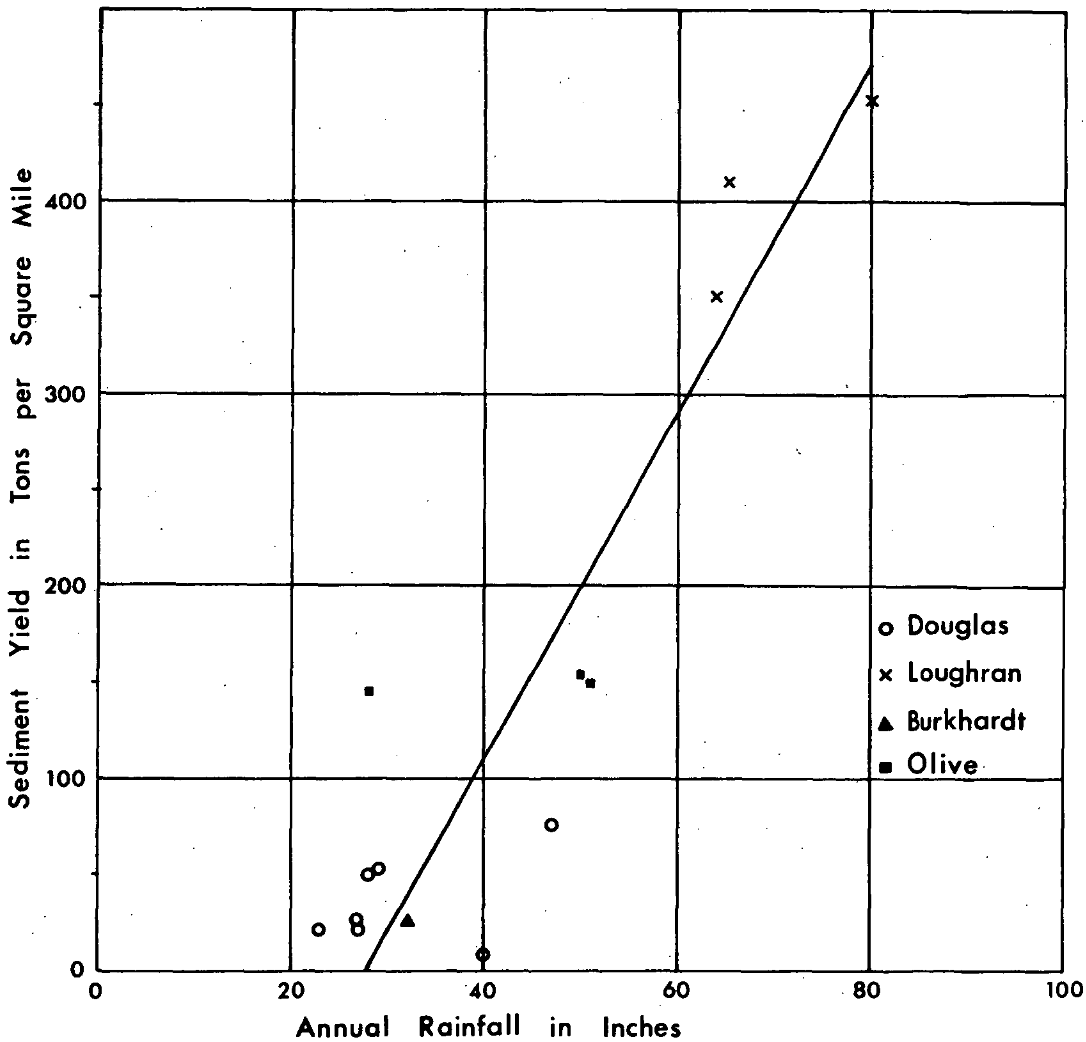
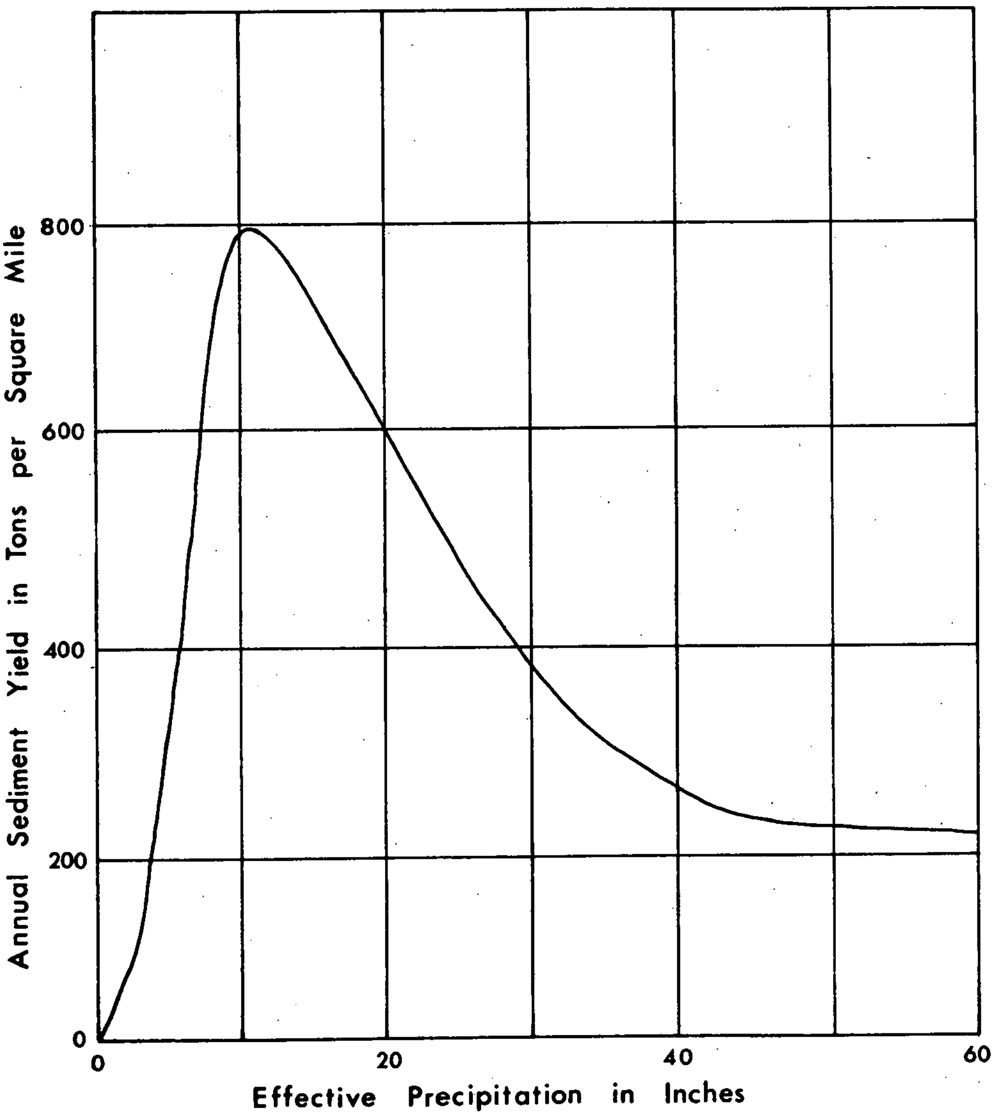


Figure 40

RELATIONSHIP BETWEEN SEDIMENT YIELD AND PRECIPITATION



after, Langbein & Schumm 1958

Apart from the three Australian studies considered above, little work has been done on the denudation carried out by Australian streams. The only additional figures which have been published are on a continental basis based not only on stream measurements but more heavily on basin sedimentation. Notable among these studies is that of Strakhov[1] who estimated average Australian denudation as 111 tons/square mile which is the lowest of any of the continents of the earth.

Comparison of the results obtained with those from overseas, notably the United States, is difficult as most of these studies have concentrated on suspended sediment load rather than wash load. The results of the wash load studies are shown in Table 13. Most of the values are well above those of this study although some cover a similar range. The catchments are all much larger than those of this study so any worthwhile comparison cannot be made.

A large amount of literature has been published on the suspension loads carried by streams, the majority of which relates to streams in the United States. As yet however, no information has been published on Australian streams. Douglas was concerned with total load and solution load and gave little attention to suspension load. Both Loughran and Burkhardt concentrated solely on wash load and made no attempt to separate the suspension and solution load components. In a current study, Loughran has separated the two loads using a similar method to that in this study, but as yet the results have not been published.

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1. Strakhov, op cit.

TABLE 13

American Denudation Rates

Catchment	Area	Wash Load (tons/mile^2/yr.)
Little Colorado	8,100	199
Canadian R	19,445	336
Colorado	30,600	105
Bighorn	15,900	114
Green	40,600	530
Colarado	24,100	808
Iowa	3,721	510
Mississippi	1,140 x 10^6	337
Sacremento	27,000	190
Flint	2,900	183
Juniata	3,354	265
Delaware	6,780	270

A comparison can be made with the results obtained in the United States although again the problem of lack of information on the catchment characteristics limits the value of such an analysis. Any comparison is further hindered by the under-estimation of suspension load in this study due to the inadequacies of the laboratory analysis which have already been outlined.

The concentrations of suspension load are similar to those obtained by Anderson[1] which ranged from 5 to 200 ppm in two streams. These streams were significantly larger than those of this study with the smallest having a catchment area of 98 square miles. The majority of studies have shown suspension load concentrations of between 200 and 400 ppm. This is probably due to the higher erosion rates which exist in America.

A comparison of erosion rates shows that the suspension load of the streams in this study is much lower than those of streams of similar size in the United States (Table 14). Also the suspension load comprises a much lower proportion of the total load. In this study the suspension load comprises only approximately 20% of the total load while in the American streams listed it is never less than 36% and is commonly greater than 60%. However, Dole and Stabler[2] in an early regional study of North America claimed that in the North Atlantic region suspended load made up only 23% of total load.

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1. Anderson H.W., op cit, 1954.

2. Dole R.B. & Stabler. Denudation. US Geol Surv Water Supply Paper 234, 1909.

TABLE 14

Suspended Sediment-Denudation Rates

	Catchment	Area	Susp. Load (tons/mile^2/yr.)
Anderson	Wilson	56	372
	Elk Creek	133	15
	Elk Creek	85	140
	Calopooya	98	233
	Marys	155	122
	Coast Fork	69	71
	Coyote	100	79
	Long Tom	100	79
Collier	Black Earth Creek	46	71
	Mount Vernon Creek	16	96
	Yellowstone	29	236
	Dell Creek	45	15
Olive	Brownes	4.7	31
	Snug	7.5	29
	Mountain	15.5	31

While it is possible that the suspension loads of the Tasmanian streams could be low, they have been artificially lowered by the inability of the filter papers to trap clay colloids. In the dolerite areas clay minerals are the dominant weathering product removed by the streams and these could make up a significant proportion of the suspension load but have been measured as solution load. The amount of clay colloids could not be determined as they were too fine to be detected even by X-Ray diffraction analysis. Therefore the real suspension load of the Tasmanian streams cannot be calculated.

Comparisons of solution loads are also of limited value because of the artificial exaggeration of their importance. Douglas[1] in his study of Eastern Australian rivers found solution load concentrations ranging from 19 to 101 ppm in streams with varying catchment characteristics. The majority of his streams have concentrations of 50 to 60 ppm which correspond to Livingstone's[2] estimate for Australia of 59 ppm, again the lowest of any of the continents. These results are lower than those of this study which are generally above 80 ppm. While this is partly due to the laboratory errors it is possible that solution concentration is greater in the Tasmanian streams particularly in the dolerite catchments.

Little information has been published on the erosion rates associated with solution loads as most studies are concerned with water quality and so are reliant on concentration. Langbein and Dawdy[3] related

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1. Douglas I., op cit., 1968.

2. Livingstone D.A. Chemical composition of rivers and lakes. US Geol. Surv. Prof. Papers 4406, 1964.

3. Langbein W.B. & Dawdy D.R. Occurrence of dissolved solids in surface waters in the United States. US Geol. Surv. Prof. Papers 501-D, 1965, p. D115-117.

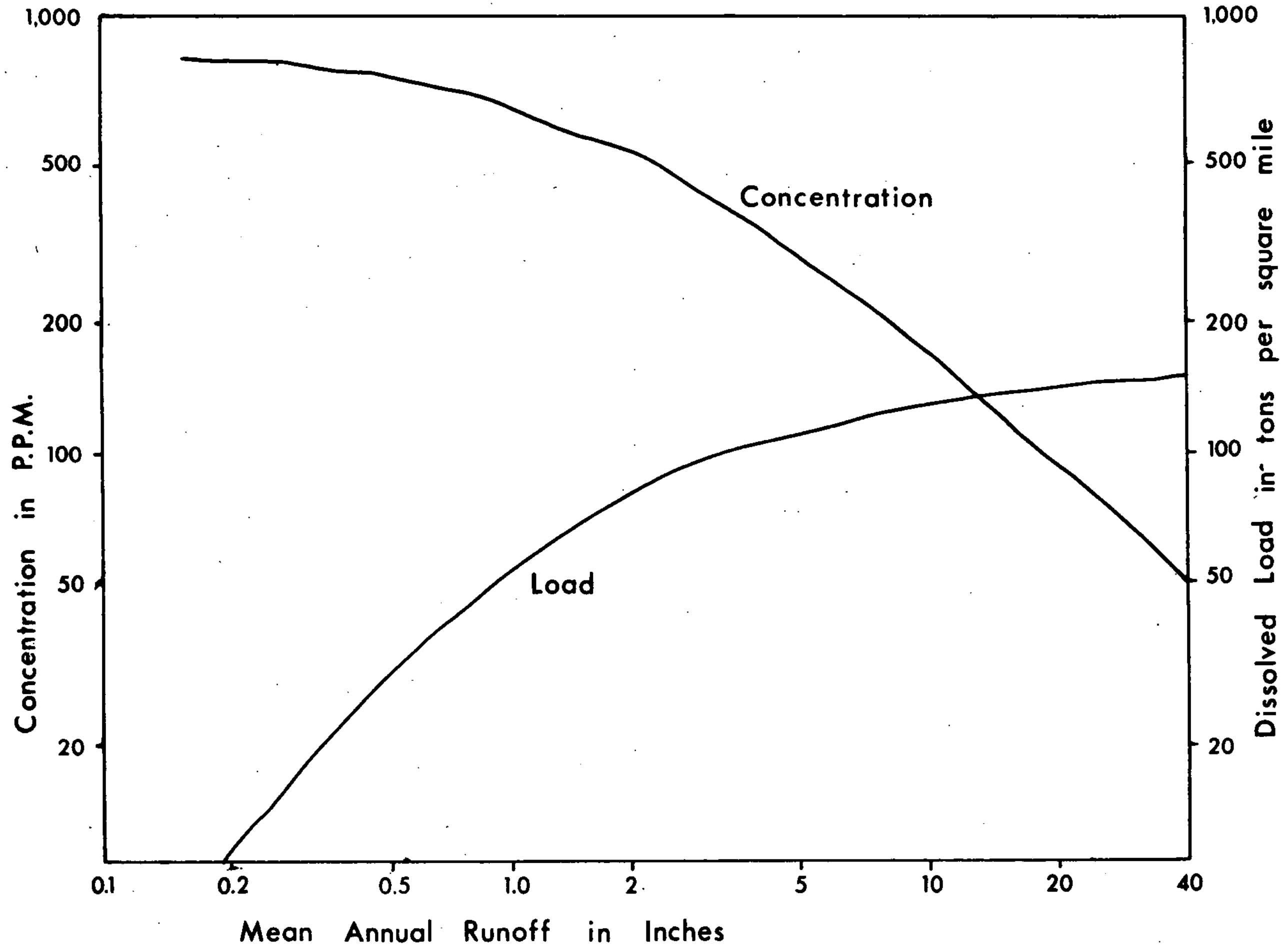
solution load to mean annual rainfall in a study of American streams. The results of their study are shown in Table 15. They found that with increasing annual rainfall, solution concentration decreased and the solution load erosion rate increased (Figure 41). Insufficient information is available to find if this relationship is valid in Australia. The solution load erosion rates of this study correspond to those of Langbein and Dawdy for a similar rainfall, however the solution concentration is significantly higher.

TABLE 15

Dissolved Solids in Surface Water of the U.S.

Range in mean annual run-off	Median Conc (ppm)	Median Load (tons/mile^2)
0 - 0.25	720	10
0.26 - 0.50	950	25
0.51 - 1.00	630	33
1.01 - 1.80	460	50
1.81 - 3.00	460	77
3.01 - 6.00	360	123
6.01 - 8.00	235	115
8.01 - 11.0	140	99
11.1 - 15.0	90	88
15.1 - 18.0	110	132
18.1 - 22.0	100	140
22.1 - 25.0	108	180
25.1 - 80.8	57	136

Figure 41
RELATIONSHIP BETWEEN SOLUTION LOAD AND RUNOFF IN THE UNITED STATES



after Langbein & Dawdy 1965

CHAPTER 8

CONCLUSIONS

The limited scope of the study with only three streams and a tributary studied for a period of twelve months restricts the conclusions which can be drawn. Further limitations are imposed by the short period of analysis of suspension and solution loads. Also, rainfall and run-off varied significantly from the average pattern and as a result the sediment loads calculated may not be indicative of longer term trends in the streams. Despite this limitation however, a number of conclusions can be drawn.

A study of the literature and an appraisal of this study indicates a number of major problems still exist in the collection and analysis of sediment samples. While most studies are based on the sampling methods outlined by the United States Inter-Agency on Water Resources[1] there is no standardisation of the laboratory techniques used in analysing the sediment samples. In the majority of publications of the results of sediment studies the techniques of laboratory analysis are not outlined. In a pilot study at the commencement of this project a variety of techniques were examined yielding a wide range of results. Therefore no valid comparison of results can be carried out unless a standardised method is used or at least some allowance made for the varying results of different methods.

The method used in this study was one developed by Sundborg[2] and refined by Loughran[3] which proved satisfactory in both their studies as

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1. Inter-Agency Committee on Water Resources, 1963, op cit.
2. Sundborg, A. 1956. op cit.
3. Loughran, R.J. 1971. op cit.

the suspension load was coarser than the filter pore size. A problem arose in this study in the separation of suspension and solution loads. The filter papers retain all the suspension load except for material of colloidal size. The results obtained suggest that significant amounts of colloidal material are carried by the streams considered, resulting in artificial results for suspension and solution loads. A possible solution to this problem lies in a technique which was not known to the author at the time this study was carried out. This method has been outlined by Douglas[1] and involves the use of polymer filters which have a finer grain size and therefore trap some of the colloids. Their pore size is controlled however, so the sediment size which will pass through is known.

Rainfall and Run-off were considerably above average for Brown's and Snug Rivulet during the study, while the Mountain River had slightly below average rainfall. In all the catchments the rainfall was atypically distributed with marked concentrations in summer, the period when minimums usually occur. These two factors would have an influence on sediment loads and the results obtained are probably not representative of the long term characteristics of the streams. Any prediction of erosion rates outside the period studied then are of limited value and are subject to error.

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1. Douglas, I. Comments on the determination of fluvial sediment discharge. <u>Aust. Geog. Studies</u>. Vol. 9, No. 2, 1971, pp. 172-6.

The wash load concentrations of the study were similar to those obtained in other Australian studies. This contrasts with the results of Langbein and Schumm[1] who found in the United States that concentration decreased with increasing rainfall. The consistency of the Australian concentration results through changing rainfall regimes is thought to be related to the uniformity of the Australian vegetation. In the United States study, vegetation density increases with rainfall and this reduces the concentration of sediment.

An examination of the relationship between wash load concentration and stream discharge revealed that concentration is independent as no significant relationship could be found in any of the streams studied. This is to be expected as Einstein defines wash load as that part of the load which is independent of stream discharge and velocity. An examination of the pattern of sediment concentration through one storm episode also showed the concentration is independent of discharge as it peaks earlier than the discharge reaches a maximum and then falls rapidly while stream discharge continues to rise.

The daily wash load discharge figures show the marked importance of individual storm episodes where up to 20% of the annual sediment load was carried in a single episode of three to four days duration. On the other hand, there are long periods when wash load discharge is minimal. This is characteristic of most streams but is more marked in this study because of the nature of the catchments where streams rise and fall rapidly.

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1. Langbein and Schumm, 1958. op cit.

A number of general relationships can be recognised between sediment yield and the various catchment parameters. The wash load tends to be greater from sandstone and shale areas than from corresponding dolerite areas. This is reflected in both the rating curves and erosion rates. A similar relationship exists with vegetation where the wash load increases with increasing proportion of forest. The forest areas, while having a relatively thick tree cover, have a high proportion of bare ground which is susceptible to erosion accounting for the higher wash load. No further relationships could be found with any of the other variables.

The wash load erosion rates are consistent with those obtained elsewhere in Australia, falling in the middle of the range of the Australian erosion rates calculated. As with other Australian studies the erosion rates are significantly lower than those obtained in the United States. An analysis of the Australian results related to annual rainfall yielded a strong relationship with erosion rates increasing with rainfall. This contrasts with the results of Langbein and Schumm[1] which showed erosion rates reached a maximum at approximately 12 inches and then decreased with increasing rainfall. These differences are associated with the uniformity of the Australian vegetation where no extra protection is afforded with increasing rainfall and as a result erosion increases. In Langbein and Schumm's study however there is a marked increase in vegetation density with increasing rainfall and this more than compensates for the increased potential erosion.

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1. Langbein and Schumm, 1958.

The suspension load results are significantly lower than those obtained in other studies. This is due mainly to the inability of the laboratory analysis to separate colloidal material from the solution load. Similarly the solution load results are much higher than those obtained elsewhere. It is possible however that these differences are not solely due to laboratory errors and the streams have a higher proportion of their load transported in solution. The most significant fact is the high proportion of the total load which is transported either in solution or colloidal suspension. From 65 to 80 per cent of the total load of the streams is transported in this way. Even during periods of extremely high flow, solution load and colloids make up the major part of the total load with the suspension load never being coarser than silt size. The suspension load was insignificant during periods of low flow, but increased in importance as discharge increased, while solution load was dominant during low flows and its proportion decreased with increasing discharge. As a result, the daily discharge figures for suspension load show a marked dominance of individual storm episodes with negligible suspension load transport during low flows. This trend is more marked than in the case of wash load. With solution load however, these individual episodes are less dominant and sediment discharge is more evenly spread throughout the year.

Of the catchment variables which influence sediment yields a relationship could only be found with geology. Suspension load was much greater from sandstone and shale areas while "solution load" was more important from the delerite areas. The sandstone and shale consisting of quartz fragments set in a matrix are relatively stable chemically and so yield a greater proportion of suspension material. The weathering products of the dolerite however are dolerite boulders, which are transported as bed load, or fine clay minerals and salts which are transported either in solution or colloidal suspension and so were measured as solution load. Very little suspension material is supplied from the dolerite areas.

This study is extremely limited in scope and so its conclusions are of limited value. It is however, the first study of sediment yields which has been carried out in Tasmania despite the large amount of dam construction which has been carried out. The conditions which apply in the three catchments studies are representative of much of south-eastern Tasmania and in fact for much of the eastern section of the state. Therefore it does give some indication of sediment yields and erosion rates for a larger area. It is hoped that this study will provide a basis for more detailed and widespread studies. Certainly with the establishment of the representative basin network, more information will become available for future studies.

SUPPLEMENT

Some additional explanations and minor corrections are included in this supplement following the suggestions received from the two examiners for which the author acknowledges his gratitude.

Throughout the thesis the term "solution load concentration" is used to refer to the concentration of dissolved material per unit volume of water. This could be confusing and probably a better term is "solute concentration".

In this study, rainfall of the catchment is taken from single recording stations and this can lead to a false impression as all three catchments have considerable relief and precipitation varies due to the orographic influence. This is most marked in the case of the Mountain River where the weather station is outside the catchment. This problem could be overcome by projecting isohyets, but this is made difficult in this area because of the limited number of rainfall recording stations. Also, the stations are all located in the populated areas at low elevations so there are no reliable figures for the higher sections of the catchments. Because of this lack of data no attempt was made to project more detailed isohyets.

Page 5

The term "stream variables" refers to those variables which operate solely within the channel, for example, discharge and stream velocity. "Catchment variables" are those that operate outside the channel but within the catchment.

The bed load of the three streams is of Pleistocene peri-glacial origin and is therefore derived from a former geomorphic system. Although it was derived from the rocks of the catchment, the catchment variables are no longer active in its transport which is dependent on the stream variables.

<u>Page 13, line 10</u>

While it is difficult to quantify the source of suspension load it was apparent in this study that the majority of the suspension load was derived from the catchment rather than the channel. The banks and beds of all the streams were composed of either bedrock or large dolerite blocks which made up the bed load and therefore the finer material must have been eroded from outside the channel.

<u>Page 15, line 5 & 11</u>

The term "solution load" here is misleading as it is the solution concentration which decreases. As stated by Douglas (1964) concentration decreases arithmetically while discharge increases logarithmically which means that the solution load (the product of discharge and concentration) increases, but at a slower rate as shown on the sediment rating curves for the three streams (pages 80, 106 and 130).

Pages 162 and 163

It must be noted that the scale of the graphs in Figures 39 and 40 differ and the Australian curve does not include the bottom half of the precipitation range shown in the American results. While the Australian curve within the studied range is linear, this does not exclude the possibility of a polynomial curve with peaks outside the range.

It should be noted that the wash load rating curves on Figure 35 (Page 144) are all close together and there is considerable overlap between the three point patterns. Testing the difference between regression co-efficients and the distance between regression lines (Chakravarti I.M., et. al., Handbook of Methods of Applied Statistics, Wiley, 1967, p. 365) failed to identify significant differences between the rating curves. Testing of the the suspension load curves (Figure 36, Page 150) and solution load curves (Figure 36, Page 154) also revealed no statistically significant differences. Therefore, any discussion of the influence of the various catchment parameters is of limited value.

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APPENDIX I

BROWNS RIVER

DISCHARGE IN CUSECS

JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MARCH	APRIL	MAY	JUNE
21.400	3.000	3.800	2.500	17.600	10.000	3.300	2.500	1.700	4.000	2.900	2.200
11.800	3.100	3.400	2.500	40.000	11.800	4.400	2.100	1.500	3.500	2.800	2.000
9.500	8.800	3.200	2.300	30.000	12.700	12.000	2.200	1.500	3.400	2.800	2.900
7.800	12.700	2.900	2.400	17.600	9.300	75.000	2.000	1.500	3.400	3.000	5.100
13.900	8.700	2.800	2.500	10.000	8.000	40.000	1.900	1.500	3.200	3.000	4.900
11.800	7.000	3.000	2.700	7.600	8.000	35.400	1.900	1.500	3.000	3.000	4.000
8.800	6.500	2.800	3.600	6.400	7.300	25.500	1.800	1.500	2.900	2.900	3.500
8.300	8.500	2.600	3.100	5.300	6.300	17.600	1.800	1.400	2.800	2.500	3.000
6.400	8.800	2.300	3.100	4.700	5.400	11.700	1.700	1.400	2.800	2.400	2.800
5.900	8.800	2.300	3.000	3.800	4.800	9.300	1.700	1.400	2.800	2.300	3.500
5.100	8.500	2.200	2.800	3.400	4.800	7.400	1.700	1.400	2.600	2.200	3.000
4.900	6.600	2.300	2.800	3.000	86.000	10.800	1.700	1.400	2.500	2.000	2.800
4.900	6.200	2.700	2.200	2.900	180.000	26.900	1.700	1.400	2.500	2.000	3.500
4.800	7.200	2.800	1.700	2.700	75.000	18.200	1.700	1.500	2.300	2.200	7.300
4.600	6.600	2.700	1.700	2.900	33.000	16.000	1.500	1.500	2.100	1.900	29.000
4.000	5.800	2.800	1.700	3.300	19.600	21.400	5.800	4.400	2.100	2.200	32.000
3.800	5.600	2.700	1.700	10.600	14.900	11.500	5.800	72.000	2.200	2.900	18.200
3.900	5.300	2.900	1.700	1.500	10.800	5.600	5.100	57.000	2.200	2.800	11.800
3.800	5.200	3.000	1.500	9.600	10.800	5.200	3.800	44.000	2.200	2.700	14.200
3.800	5.100	3.100	1.500	6.000	8.800	4.600	2.800	22.000	2.200	2.700	18.900
3.600	4.600	3.200	1.500	30.000	7.600	4.000	2.400	13.900	2.200	2.300	15.800
3.600	4.600	3.200	1.300	23.000	6.800	3.800	2.200	10.000	2.100	2.100	10.100
3.400	4.800	3.100	1.400	17.000	5.800	3.600	1.900	6.800	1.900	1.900	8.500
3.300	4.700	3.000	1.300	10.000	5.900	4.000	1.700	6.200	3.200	1.800	6.800
3.100	4.400	2.900	1.300	8.500	5.440	4.000	1.800	5.800	3.300	1.700	5.700
3.100	4.400	2.800	1.300	7.200	4.800	3.500	2.100	5.300	3.000	1.700	5.300
3.200	7.200	2.800	1.200	7.300	4.600	2.800	2.200	4.900	2.800	1.700	4.900
3.300	5.900	2.700	1.200	10.800	4.200	2.200	1.700	4.400	2.600	1.700	4.600
3.400	4.600	2.800	1.100	10.100	3.500	2.900	1.700	4.000	2.700	1.700	4.300
3.100	4.600	2.700	14.900	9.000	3.800	2.500	0.000	4.400	3.500	1.800	3.900
3.100	4.000	0.000	30.000	0.000	3.000	2.500	0.000	4.000	0.000	2.100	3.200

WASH LOAD IN TONS

	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MARCH	APRIL	MAY	JUNE
	5.911	0.577	0.763	0.465	4.689	2.400	0.646	0.465	0.294	0.811	0.554	0.399
	2.920	0.600	0.669	0.465	12.399	2.920	0.908	0.378	0.254	0.692	0.532	0.357
	2.259	2.063	0.623	0.421	8.819	3.186	2.979	0.399	0.254	0.669	0.532	0.554
	1.789	3.186	0.554	0.443	4.689	2.203	26.105	0.357	0.254	0.669	0.577	1.081
	3.546	2.035	0.532	0.465	2.400	1.843	12.399	0.336	0.254	0.623	0.577	1.031
	2.920	1.573	0.577	0.509	1.734	1.843	10.728	0.336	0.254	0.577	0.577	0.811
	2.063	1.441	0.532	0.716	1.415	1.654	7.275	0.315	0.254	0.554	0.554	0.692
	1.925	1.980	0.487	0.600	1.132	1.389	4.689	0.315	0.234	0.532	0.465	0.577
	1.415	2.063	0.421	0.600	0.982	1.157	2.891	0.294	0.234	0.532	0.443	0.532
	1.285	2.063	0.421	0.577	0.763	1.006	2.203	0.294	0.234	0.532	0.421	0.692
	1.081	1.980	0.399	0.532	0.669	1.006	1.680	0.294	0.234	0.487	0.399	0.577
	1.031	1.467	0.421	0.532	0.577	30.699	2.630	0.294	0.234	0.465	0.357	0.532
	1.031	1.363	0.509	0.399	0.554	73.628	7.750	0.294	0.234	0.465	0.357	0.692
	1.006	1.627	0.532	0.294	0.509	26.105	4.879	0.294	0.254	0.421	0.399	1.654
	0.957	1.467	0.509	0.294	0.554	9.872	4.188	0.254	0.254	0.378	0.336	8.472
	0.811	1.259	0.532	0.294	0.646	5.327	5.911	1.259	0.908	0.378	0.399	9.519
	0.763	1.208	0.509	0.294	2.572	3.850	2.833	1.259	24.873	0.399	0.554	4.879
	0.787	1.132	0.554	0.294	0.254	2.630	1.208	1.081	18.861	0.399	0.532	2.920
	0.763	1.106	0.577	0.254	2.287	2.630	1.106	0.763	13.880	0.399	0.509	3.636
	0.763	1.081	0.600	0.254	1.311	2.063	0.957	0.532	6.108	0.399	0.509	5.102
	0.716	0.957	0.623	0.254	8.819	1.734	0.811	0.443	3.546	0.399	0.421	4.127
	0.716	0.957	0.623	0.214	6.438	1.520	0.763	0.399	2.400	0.378	0.378	2.429
	0.669	1.006	0.600	0.234	4.500	1.259	0.716	0.336	1.520	0.336	0.336	1.980
	0.646	0.982	0.577	0.214	2.400	1.285	0.811	0.294	1.363	0.623	0.315	1.520
	0.600	0.908	0.554	0.214	1.980	1.167	0.811	0.315	1.259	0.646	0.294	1.234
	0.600	0.908	0.532	0.214	1.627	1.006	0.692	0.378	1.132	0.577	0.294	1.132
	0.623	1.627	0.532	0.195	1.654	0.957	0.532	0.399	1.031	0.532	0.294	1.031
	0.646	1.285	0.509	0.195	2.630	0.859	0.399	0.294	0.908	0.487	0.294	0.957
	0.669	0.957	0.532	0.176	2.429	0.692	0.554	0.294	0.811	0.509	0.294	0.883
	0.600	0.957	0.509	3.850	2.119	0.763	0.465	0.000	0.908	0.692	0.315	0.787
	0.600	0.811	0.000	8.819	0.000	0.577	0.465	0.000	0.811	0.000	0.378	0.623
TOTAL	42.11	42.63	16.31	23.28	83.55	189.23	110.98	12.97	84.05	15.56	13.20	61.41

ANNUAL TOTAL 695.26

SUSPENSION LOAD IN TONS

	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MARCH	APRIL	MAY	JUNE
	1.182	0.069	0.097	0.053	0.891	0.393	0.079	0.053	0.030	0.104	0.065	0.044
	0.499	0.072	0.082	0.053	2.925	0.499	0.120	0.041	0.025	0.086	0.062	0.038
	0.365	0.326	0.075	0.047	1.928	0.555	0.512	0.044	0.025	0.082	0.062	0.065
	0.274	0.555	0.065	0.050	0.891	0.354	7.268	0.038	0.025	0.082	0.069	0.148
	0.633	0.321	0.062	0.053	0.393	0.284	2.925	0.035	0.025	0.075	0.069	0.140
	0.499	0.234	0.069	0.059	0.264	0.284	2.450	0.035	0.025	0.069	0.069	0.104
	0.326	0.211	0.062	0.089	0.206	0.249	1.524	0.033	0.025	0.065	0.065	0.086
	0.300	0.310	0.056	0.072	0.157	0.201	0.891	0.033	0.023	0.062	0.053	0.069
	0.206	0.326	0.047	0.072	0.132	0.161	0.493	0.030	0.023	0.062	0.050	0.062
	0.183	0.326	0.047	0.069	0.097	0.136	0.354	0.030	0.023	0.062	0.047	0.086
	0.148	0.310	0.044	0.062	0.082	0.136	0.254	0.030	0.023	0.056	0.044	0.069
	0.140	0.215	0.047	0.062	0.069	8.861	0.439	0.030	0.023	0.053	0.038	0.062
	0.140	0.197	0.059	0.044	0.065	25.822	1.646	0.030	0.023	0.053	0.038	0.086
	0.136	0.244	0.062	0.030	0.059	7.268	0.935	0.030	0.025	0.047	0.044	0.249
	0.128	0.215	0.059	0.030	0.065	2.214	0.776	0.025	0.025	0.041	0.035	1.836
	0.104	0.179	0.062	0.030	0.079	1.041	1.182	0.179	0.120	0.041	0.044	2.117
	0.097	0.170	0.059	0.030	0.427	0.700	0.481	0.179	6.851	0.044	0.065	0.935
	0.100	0.157	0.065	0.030	0.025	0.439	0.170	0.148	4.884	0.044	0.062	0.499
	0.097	0.152	0.069	0.025	0.370	0.439	0.152	0.097	3.357	0.044	0.059	0.653
	0.097	0.148	0.072	0.025	0.187	0.326	0.128	0.062	1.231	0.044	0.059	0.988
	0.089	0.128	0.075	0.025	1.928	0.264	0.104	0.050	0.633	0.044	0.047	0.762
	0.089	0.128	0.075	0.020	1.312	0.225	0.097	0.044	0.393	0.041	0.041	0.399
	0.082	0.136	0.072	0.023	0.847	0.179	0.089	0.035	0.225	0.035	0.035	0.310
	0.079	0.132	0.069	0.020	0.393	0.183	0.104	0.030	0.197	0.075	0.033	0.225
	0.072	0.120	0.065	0.020	0.310	0.163	0.104	0.033	0.179	0.079	0.030	0.174
	0.072	0.120	0.062	0.020	0.244	0.136	0.086	0.041	0.157	0.069	0.030	0.157
	0.075	0.244	0.062	0.018	0.249	0.128	0.062	0.044	0.140	0.062	0.030	0.140
	0.079	0.183	0.059	0.018	0.439	0.112	0.044	0.030	0.120	0.056	0.030	0.128
	0.082	0.128	0.062	0.016	0.399	0.086	0.065	0.030	0.104	0.059	0.030	0.116
	0.072	0.128	0.059	0.700	0.337	0.097	0.053	0.000	0.120	0.086	0.033	0.100
	0.072	0.104	0.000	1.928	0.000	0.069	0.053	0.000	0.104	0.000	0.041	0.075
TOTAL	6.52	6.29	1.92	3.80	15.77	52.00	23.64	1.52	19.18	1.82	1.48	10.92

ANNUAL TOTAL 144.86

SOLUTION LOAD IN TONS

	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MARCH	APRIL	MAY	JUNE
	3.537	0.551	0.689	0.464	2.940	1.722	0.603	0.464	0.322	0.724	0.534	0.411
	2.014	0.569	0.621	0.464	6.391	2.014	0.792	0.393	0.286	0.638	0.516	0.376
	1.640	1.526	0.586	0.429	4.868	2.159	2.046	0.411	0.286	0.621	0.516	0.534
	1.361	2.159	0.534	0.446	2.940	1.608	11.584	0.376	0.286	0.621	0.551	0.911
	2.351	1.509	0.516	0.464	1.722	1.394	6.391	0.358	0.286	0.586	0.551	0.877
	2.014	1.229	0.551	0.499	1.328	1.394	5.694	0.358	0.286	0.551	0.551	0.724
	1.526	1.146	0.516	0.655	1.129	1.279	4.175	0.340	0.286	0.534	0.534	0.638
	1.444	1.477	0.482	0.569	0.944	1.112	2.940	0.340	0.268	0.516	0.464	0.551
	1.129	1.526	0.429	0.569	0.843	0.961	1.998	0.322	0.268	0.516	0.446	0.516
	1.045	1.526	0.429	0.551	0.689	0.860	1.608	0.322	0.268	0.516	0.429	0.638
	0.911	1.477	0.411	0.516	0.621	0.860	1.295	0.322	0.268	0.482	0.411	0.551
	0.877	1.162	0.429	0.516	0.551	13.185	1.852	0.322	0.268	0.464	0.376	0.516
	0.877	1.096	0.499	0.411	0.534	26.517	4.391	0.322	0.268	0.464	0.376	0.638
	0.860	1.262	0.516	0.322	0.499	11.584	3.034	0.322	0.286	0.429	0.411	1.279
	0.826	1.162	0.499	0.322	0.534	5.328	2.686	0.286	0.286	0.393	0.358	4.715
	0.724	1.029	0.516	0.322	0.603	3.255	3.537	1.029	0.792	0.393	0.411	5.175
	0.689	0.995	0.499	0.322	1.820	2.511	1.965	1.029	11.145	0.411	0.534	3.034
	0.707	0.944	0.534	0.322	0.286	1.652	0.995	0.911	8.935	0.411	0.516	2.014
	0.689	0.928	0.551	0.286	1.657	1.852	0.928	0.689	6.994	0.411	0.499	2.399
	0.689	0.911	0.569	0.286	1.062	1.526	0.826	0.516	3.630	0.411	0.499	3.145
	0.655	0.826	0.586	0.286	4.868	1.328	0.724	0.446	2.351	0.411	0.429	2.654
	0.655	0.826	0.586	0.250	3.786	1.196	0.689	0.411	1.722	0.393	0.393	1.738
	0.621	0.860	0.569	0.268	2.845	1.029	0.655	0.358	1.196	0.358	0.358	1.477
	0.603	0.843	0.551	0.250	1.722	1.045	0.724	0.322	1.096	0.586	0.340	1.196
	0.569	0.792	0.534	0.250	1.477	0.968	0.724	0.340	1.029	0.603	0.322	1.012
	0.569	0.792	0.516	0.250	1.262	0.860	0.638	0.393	0.944	0.551	0.322	0.944
	0.586	1.262	0.516	0.232	1.279	0.826	0.516	0.411	0.877	0.516	0.322	0.877
	0.603	1.045	0.499	0.232	1.852	0.758	0.411	0.322	0.792	0.482	0.322	0.826
	0.621	0.826	0.516	0.213	1.738	0.638	0.534	0.322	0.724	0.499	0.322	0.775
	0.569	0.826	0.499	2.511	1.559	0.689	0.464	0.000	0.792	0.638	0.340	0.707
	0.569	0.724	0.000	4.868	0.000	0.551	0.464	0.000	0.724	0.000	0.393	0.586
TOTAL	32.53	33.80	15.75	18.35	54.35	92.86	65.88	12.76	47.96	15.13	13.35	42.43

ANNUAL TOTAL 445.16

APPENDIX 2

SNUG RIVULET

DISCHARGE IN CUSECS

JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MARCH	APRIL	MAY	JUNE
17.600	4.500	6.900	1.800	25.100	14.000	7.500	1.400	0.700	3.800	1.700	7.000
12.400	9.400	5.900	1.700	50.000	9.000	7.400	1.400	0.700	3.500	4.600	6.300
9.700	23.800	5.800	1.600	14.800	9.000	7.000	1.300	0.700	3.200	4.800	10.100
10.800	21.500	6.000	2.100	10.500	11.000	7.000	1.250	0.600	3.000	4.500	50.800
17.600	10.500	5.000	2.200	7.800	11.000	6.800	1.200	0.600	2.700	4.200	22.800
10.300	9.100	5.800	3.200	6.530	23.000	6.700	1.140	0.600	2.500	5.000	10.100
8.400	8.600	4.200	4.000	5.000	35.000	6.200	1.100	0.500	2.200	6.200	8.600
7.200	13.800	3.600	2.300	4.000	22.000	5.900	1.080	0.500	1.900	5.500	7.700
6.000	14.800	3.200	2.000	3.500	13.000	5.500	1.060	4.500	1.700	5.000	7.200
5.500	22.800	3.000	1.800	2.800	9.000	5.200	1.000	4.500	1.500	4.800	10.100
4.800	14.800	3.100	1.500	2.500	9.000	5.000	1.000	0.460	1.400	4.500	73.700
4.600	10.800	7.700	1.500	2.300	45.000	4.800	0.980	0.420	1.250	4.200	132.200
4.500	12.800	10.600	1.400	2.100	135.000	4.600	0.980	0.400	1.100	4.000	86.700
3.800	20.800	11.950	1.400	1.900	1.650	4.200	0.900	0.360	1.050	3.700	54.600
3.300	10.300	10.840	1.300	2.600	75.000	3.900	0.880	0.300	1.050	3.500	45.200
3.100	8.300	9.500	1.200	4.000	42.000	3.600	0.840	0.300	1.000	4.600	58.300
5.700	6.900	7.800	1.100	34.200	25.000	3.400	0.800	0.300	1.000	6.500	48.100
8.300	6.000	6.600	1.200	41.000	15.000	3.100	0.750	0.300	0.980	7.000	37.800
5.100	6.500	5.300	1.200	192.000	21.000	2.900	0.710	0.350	0.950	7.200	28.600
4.200	5.500	4.600	1.000	98.000	21.000	2.800	0.690	4.000	0.950	6.800	22.800
3.790	4.400	4.000	1.000	48.000	23.000	2.600	0.670	310.000	0.930	6.500	17.600
5.000	4.000	3.500	0.900	26.000	14.000	2.500	0.660	225.000	0.930	6.300	14.800
5.600	3.800	3.300	0.800	10.000	11.000	2.300	0.650	0.950	0.930	6.200	12.800
5.100	3.300	3.000	0.800	8.000	9.000	2.000	0.650	0.420	0.950	6.050	10.500
3.800	3.200	2.700	0.800	6.000	11.000	2.000	0.650	12.000	0.980	6.000	9.790
3.600	2.900	2.600	0.700	5.000	14.000	1.900	0.660	0.100	1.100	6.000	9.230
3.500	3.100	3.000	0.700	4.000	11.000	1.800	0.680	8.000	1.100	5.900	8.690
3.300	28.000	2.300	0.700	9.000	9.000	1.600	0.700	7.000	1.500	5.800	8.560
2.800	38.750	2.100	3.000	9.000	8.000	1.600	0.000	5.500	1.500	6.800	8.400
2.700	11.500	2.000	4.550	11.000	8.000	1.550	0.000	4.700	1.700	6.900	8.400
2.300	8.700	0.000	9.400	0.000	8.000	1.500	0.000	4.100	0.000	7.000	0.000

WASH LOAD IN TONS

	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MARCH	APRIL	MAY	JUNE
	4.991	1.124	1.793	0.413	7.357	3.886	1.964	0.313	0.147	0.934	0.388	1.821
	3.403	2.514	1.511	0.388	15.629	2.397	1.935	0.313	0.147	0.854	1.151	1.623
	2.602	6.942	1.483	0.363	4.130	2.397	1.821	0.289	0.147	0.774	1.206	2.719
	2.926	6.212	1.539	0.488	2.837	2.985	1.821	0.277	0.124	0.721	1.124	15.903
	4.991	2.837	1.261	0.514	2.050	2.985	1.765	0.265	0.124	0.643	1.042	6.624
	2.778	2.426	1.483	0.774	1.688	6.687	1.736	0.250	0.124	0.591	1.261	2.719
	2.223	2.281	1.042	0.988	1.261	10.582	1.595	0.241	0.102	0.514	1.595	2.281
	1.878	3.825	0.880	0.539	0.988	6.370	1.511	0.236	0.102	0.438	1.399	2.021
	1.539	4.130	0.774	0.463	0.854	3.584	1.399	0.231	1.124	0.388	1.261	1.878
	1.399	6.624	0.721	0.413	0.669	2.397	1.316	0.217	1.124	0.338	1.206	2.719
	1.206	4.130	0.748	0.338	0.591	2.397	1.261	0.217	0.093	0.313	1.124	23.887
	1.151	2.926	2.021	0.338	0.539	13.929	1.206	0.212	0.084	0.277	1.042	45.248
	1.124	3.523	2.867	0.313	0.488	46.297	1.151	0.212	0.080	0.241	0.988	28.529
	0.934	5.991	3.268	0.313	0.438	0.375	1.042	0.193	0.071	0.229	0.907	17.208
	0.800	2.778	2.938	0.289	0.617	24.348	0.961	0.189	0.058	0.229	0.854	13.997
	0.748	2.194	2.543	0.265	0.988	12.917	0.880	0.179	0.058	0.217	1.151	18.487
	1.455	1.793	2.050	0.241	10.318	7.325	0.827	0.170	0.058	0.217	1.680	14.981
	2.194	1.539	1.708	0.265	12.581	4.191	0.748	0.158	0.058	0.212	1.821	11.511
	1.288	1.680	1.344	0.265	68.044	6.054	0.695	0.149	0.069	0.205	1.878	8.486
	1.042	1.399	1.151	0.217	32.619	6.054	0.669	0.145	0.988	0.205	1.765	6.624
	0.931	1.096	0.988	0.217	14.947	6.687	0.617	0.140	114.885	0.200	1.680	4.991
	1.261	0.988	0.854	0.193	7.646	3.886	0.591	0.138	80.928	0.200	1.623	4.130
	1.427	0.934	0.800	0.170	2.690	2.985	0.539	0.135	0.205	0.200	1.595	3.523
	1.288	0.800	0.721	0.170	2.108	2.397	0.463	0.135	0.084	0.205	1.553	2.837
	0.934	0.774	0.643	0.170	1.539	2.985	0.463	0.135	3.283	0.212	1.539	2.628
	0.880	0.695	0.617	0.147	1.261	3.886	0.438	0.138	0.018	0.241	1.539	2.464
	0.854	0.748	0.721	0.147	0.988	2.985	0.413	0.142	2.108	0.241	1.511	2.307
	0.800	8.292	0.539	0.147	2.397	2.397	0.363	0.147	1.821	0.338	1.483	2.270
	0.669	11.828	0.488	0.721	2.397	2.108	0.363	0.000	1.399	0.338	1.765	2.223
	0.643	3.134	0.463	1.137	2.985	2.108	0.350	0.000	1.178	0.388	1.793	2.223
	0.539	2.310	0.000	2.514	0.000	2.108	0.338	0.000	1.015	0.000	1.821	0.000
TOTAL	50.90	98.47	39.96	13.92	203.64	202.69	31.24	5.57	211.81	11.10	42.74	258.87

ANNUAL TOTAL 1170.91

SUSPENSION LOAD IN TONS

	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MARCH	APRIL	MAY	JUNE
	0.741	0.123	0.216	0.037	1.183	0.548	0.241	0.026	0.011	0.099	0.034	0.220
	0.467	0.325	0.176	0.034	2.930	0.307	0.237	0.026	0.011	0.088	0.127	0.192
	0.338	1.103	0.172	0.032	0.590	0.307	0.220	0.024	0.011	0.079	0.134	0.357
	0.390	0.965	0.180	0.045	0.376	0.399	0.220	0.023	0.009	0.072	0.123	2.991
	0.741	0.376	0.141	0.048	0.254	0.399	0.212	0.022	0.009	0.063	0.112	1.042
	0.366	0.311	0.172	0.079	0.201	1.054	0.208	0.020	0.009	0.057	0.141	0.357
	0.280	0.289	0.112	0.105	0.141	1.832	0.188	0.019	0.007	0.048	0.188	0.289
	0.229	0.538	0.092	0.051	0.105	0.994	0.176	0.019	0.007	0.040	0.160	0.250
	0.180	0.590	0.079	0.042	0.068	0.497	0.160	0.016	0.123	0.034	0.141	0.229
	0.160	1.042	0.072	0.037	0.066	0.307	0.149	0.017	0.123	0.029	0.134	0.357
	0.134	0.590	0.075	0.029	0.057	0.307	0.141	0.017	0.006	0.026	0.123	4.882
	0.127	0.390	0.250	0.029	0.051	2.550	0.134	0.017	0.005	0.023	0.112	10.535
	0.123	0.487	0.380	0.026	0.045	10.829	0.127	0.017	0.005	0.019	0.105	6.046
	0.099	0.923	0.445	0.026	0.040	0.033	0.112	0.015	0.004	0.018	0.095	3.289
	0.082	0.366	0.392	0.024	0.060	4.996	0.102	0.014	0.003	0.018	0.088	2.565
	0.075	0.276	0.329	0.022	0.105	2.329	0.092	0.014	0.003	0.017	0.127	3.586
	0.168	0.216	0.254	0.019	1.777	1.176	0.085	0.013	0.003	0.017	0.200	2.784
	0.276	0.180	0.204	0.022	2.256	0.601	0.075	0.012	0.003	0.017	0.220	2.027
	0.145	0.200	0.153	0.022	17.217	0.935	0.069	0.011	0.004	0.016	0.229	1.404
	0.112	0.160	0.127	0.017	7.104	0.935	0.066	0.010	0.105	0.016	0.212	1.042
	0.098	0.120	0.105	0.017	2.776	1.054	0.060	0.010	32.346	0.015	0.200	0.741
	0.141	0.105	0.088	0.015	1.239	0.548	0.057	0.010	21.214	0.015	0.192	0.590
	0.164	0.099	0.082	0.013	0.352	0.399	0.051	0.010	0.016	0.015	0.188	0.487
	0.145	0.082	0.072	0.013	0.263	0.307	0.042	0.010	0.005	0.016	0.182	0.376
	0.099	0.079	0.063	0.013	0.180	0.399	0.042	0.010	0.448	0.017	0.180	0.342
	0.092	0.069	0.060	0.011	0.141	0.548	0.040	0.010	0.001	0.019	0.180	0.317
	0.088	0.075	0.072	0.011	0.105	0.399	0.037	0.010	0.263	0.019	0.176	0.293
	0.082	1.366	0.051	0.011	0.307	0.307	0.032	0.011	0.220	0.029	0.172	0.287
	0.066	2.095	0.045	0.072	0.307	0.263	0.032	0.000	0.160	0.029	0.212	0.280
	0.063	0.423	0.042	0.125	0.399	0.263	0.030	0.000	0.130	0.034	0.216	0.280
	0.051	0.293	0.000	0.325	0.000	0.263	0.029	0.000	0.109	0.000	0.220	0.000
TOTAL	6.32	14.25	4.70	1.37	40.71	36.08	3.47	0.43	55.38	1.00	4.92	48.44

ANNUAL TOTAL 217.08

SOLUTION LOAD IN TONS

	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MARCH	APRIL	MAY	JUNE
	3.736	1.029	1.541	0.432	5.227	3.009	1.668	0.341	0.177	0.877	0.410	1.562
	2.683	2.065	1.329	0.410	10.031	1.981	1.647	0.341	0.177	0.811	1.050	1.414
	2.127	4.971	1.308	0.387	3.172	1.981	1.562	0.318	0.177	0.745	1.093	2.210
	2.354	4.515	1.350	0.500	2.292	2.396	1.562	0.306	0.153	0.701	1.029	10.183
	3.736	2.292	1.136	0.523	1.731	2.396	1.520	0.295	0.153	0.635	0.964	4.773
	2.251	2.002	1.308	0.745	1.463	4.813	1.499	0.281	0.153	0.590	1.136	2.210
	1.856	1.898	0.964	0.920	1.136	7.159	1.393	0.271	0.129	0.523	1.393	1.898
	1.604	2.969	0.833	0.545	0.920	4.614	1.329	0.267	0.129	0.455	1.244	1.710
	1.350	3.172	0.745	0.478	0.811	2.806	1.244	0.262	1.029	0.410	1.136	1.604
	1.244	4.773	0.701	0.432	0.657	1.981	1.179	0.248	1.029	0.364	1.093	2.210
	1.093	3.172	0.723	0.364	0.590	1.981	1.136	0.248	0.119	0.341	1.029	14.478
	1.050	2.354	1.710	0.364	0.545	9.079	1.093	0.243	0.109	0.306	0.964	25.160
	1.029	2.765	2.313	0.341	0.500	25.664	1.050	0.243	0.104	0.271	0.920	16.882
	0.877	4.376	2.591	0.341	0.455	0.398	0.964	0.224	0.094	0.260	0.855	10.902
	0.767	2.251	2.363	0.318	0.612	14.719	0.898	0.220	0.079	0.260	0.811	9.118
	0.723	1.835	2.085	0.295	0.920	8.506	0.833	0.210	0.079	0.248	1.050	11.599
	1.286	1.541	1.731	0.271	7.004	5.207	0.789	0.201	0.079	0.248	1.456	9.670
	1.835	1.350	1.478	0.295	8.314	3.212	0.723	0.189	0.079	0.243	1.562	7.699
	1.158	1.456	1.201	0.295	35.809	4.416	0.679	0.179	0.092	0.236	1.604	5.914
	0.964	1.244	1.050	0.248	18.956	4.416	0.657	0.175	0.920	0.236	1.520	4.773
	0.874	1.007	0.920	0.248	9.651	4.813	0.612	0.170	56.335	0.232	1.456	3.736
	1.136	0.920	0.811	0.224	5.404	3.009	0.590	0.167	41.605	0.232	1.414	3.172
	1.265	0.877	0.767	0.201	2.189	2.396	0.545	0.165	0.236	0.232	1.393	2.765
	1.158	0.767	0.701	0.201	1.773	1.981	0.478	0.165	0.109	0.236	1.361	2.292
	0.877	0.745	0.635	0.201	1.350	2.396	0.478	0.165	2.601	0.243	1.350	2.146
	0.833	0.679	0.612	0.177	1.136	3.009	0.455	0.167	0.028	0.271	1.350	2.029
	0.811	0.723	0.701	0.177	0.920	2.396	0.432	0.172	1.773	0.271	1.329	1.917
	0.767	5.797	0.545	0.177	1.981	1.981	0.387	0.177	1.562	0.364	1.308	1.890
	0.657	7.882	0.500	0.701	1.981	1.773	0.387	0.000	1.244	0.364	1.520	1.856
	0.635	2.498	0.478	1.039	2.396	1.773	0.375	0.000	1.072	0.410	1.541	1.856
	0.545	1.919	0.000	2.065	0.000	1.773	0.364	0.000	0.942	0.000	1.562	0.000
TOTAL	43.28	75.84	35.13	13.91	129.93	138.03	28.53	6.41	112.57	11.61	37.90	169.63

ANNUAL TOTAL 802.78

APPENDIX 3

MOUNTAIN RIVER

DISCHARGE IN CUSECS

JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MARCH	APRIL	MAY	JUNE
44.200	12.500	15.700	12.500	24.300	29.600	15.100	11.700	11.400	34.000	24.700	23.300
31.000	14.700	14.800	12.000	61.300	27.800	21.000	11.400	10.600	32.500	25.000	22.300
25.400	57.600	14.800	12.000	33.300	28.200	110.000	11.700	10.100	31.800	31.400	29.600
28.100	49.300	14.500	12.800	23.000	24.300	89.000	11.200	10.100	29.900	29.200	44.600
28.200	31.800	13.900	12.300	19.400	22.300	87.500	11.200	9.400	39.600	27.400	39.000
29.600	24.700	16.600	14.500	17.800	22.300	78.000	10.900	9.100	28.200	27.800	32.200
26.400	22.000	16.000	14.500	16.600	22.300	62.200	10.400	8.900	27.800	27.800	28.500
24.300	31.800	14.800	12.800	15.400	22.300	47.100	9.900	8.900	27.400	30.700	26.400
22.600	25.400	14.200	12.500	14.500	21.000	39.800	9.600	9.100	26.700	33.300	25.000
20.000	25.000	13.700	12.000	13.100	19.100	33.300	9.600	9.400	25.700	32.500	30.300
19.400	29.600	13.700	11.700	12.300	17.500	31.400	9.900	9.100	25.000	26.700	75.500
18.100	35.200	17.800	11.400	11.700	16.900	72.000	9.900	8.900	24.000	25.400	100.000
17.500	29.600	15.700	11.200	11.200	21.000	86.000	35.200	8.100	23.300	24.000	84.000
16.300	30.300	16.600	10.600	10.600	131.000	76.000	41.000	8.400	22.600	23.000	66.000
15.400	25.400	15.400	10.400	10.900	128.000	51.700	31.800	8.900	22.300	22.300	51.300
14.800	24.300	14.200	9.900	12.000	81.000	41.000	21.000	9.100	22.000	21.600	68.000
17.800	22.000	14.500	9.900	84.000	60.000	35.200	17.500	8.900	21.000	21.300	60.400
14.200	20.000	16.000	9.400	128.000	45.800	30.300	15.400	8.600	21.000	23.300	49.200
14.800	22.000	17.200	9.400	92.000	38.700	27.400	14.500	14.800	21.000	27.400	43.000
14.200	20.000	21.600	9.600	86.000	33.600	26.700	13.400	143.000	21.000	27.400	37.800
14.800	18.400	21.300	9.400	66.000	30.300	25.100	13.100	108.000	20.700	29.600	35.200
14.200	17.500	18.400	8.900	45.200	27.400	23.700	13.400	95.000	21.300	27.800	32.500
13.900	17.200	16.900	8.600	35.500	24.700	21.300	13.400	76.000	21.300	25.400	30.700
13.400	16.300	15.700	8.400	29.600	24.300	19.400	12.300	59.900	20.700	24.000	28.900
13.900	16.300	15.400	8.100	28.500	24.300	18.100	12.000	48.300	20.700	22.300	27.800
13.900	15.700	15.100	7.900	22.600	24.300	17.200	12.000	43.800	21.000	21.600	26.700
15.700	14.800	15.400	7.600	22.600	22.600	16.300	12.000	41.800	39.000	21.300	26.000
15.100	15.400	14.800	8.100	49.200	19.700	15.400	11.600	41.800	35.200	20.700	26.000
14.200	24.300	14.200	12.000	35.200	17.800	14.800	0.000	39.000	29.600	20.000	25.000
13.700	20.000	12.800	16.300	31.400	16.000	15.100	0.000	37.800	27.100	22.000	29.200
13.200	17.200	0.000	18.600	0.000	15.100	13.400	0.000	35.900	0.000	22.700	0.000

WASH LOAD IN TONS

	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MARCH	APRIL	MAY	JUNE
	10.458	2.104	2.810	2.104	4.893	6.286	2.675	1.935	1.872	7.496	4.996	4.639
	6.666	2.585	2.607	1.998	15.842	5.805	4.066	1.872	1.707	7.078	5.073	4.388
	5.176	14.638	2.607	1.998	7.300	5.911	33.280	1.935	1.605	6.885	6.775	6.286
	5.885	12.014	2.540	2.168	4.563	4.893	25.432	1.830	1.605	6.367	6.179	10.579
	5.911	6.885	2.408	2.061	3.676	4.388	24.889	1.830	1.465	9.096	5.699	8.922
	6.286	4.996	3.016	2.540	3.296	4.388	21.510	1.768	1.406	5.911	5.805	6.995
	5.436	4.313	2.879	2.540	3.016	4.388	16.137	1.666	1.367	5.805	5.805	5.991
	4.893	6.885	2.607	2.168	2.742	4.388	11.337	1.565	1.367	5.699	6.584	5.436
	4.463	5.176	2.474	2.104	2.540	4.066	9.155	1.505	1.406	5.515	7.300	5.073
	3.821	5.073	2.364	1.998	2.233	3.604	7.300	1.505	1.465	5.254	7.078	6.476
	3.676	6.286	2.364	1.935	2.061	3.226	6.775	1.565	1.406	5.073	5.515	20.639
	3.367	7.833	3.296	1.872	1.935	3.086	19.432	1.565	1.367	4.817	5.176	29.487
	3.226	6.286	2.810	1.830	1.830	4.066	24.349	7.833	1.213	4.639	4.817	23.632
	2.947	6.476	3.016	1.707	1.707	41.546	20.812	9.507	1.270	4.463	4.563	17.399
	2.742	5.176	2.742	1.666	1.768	40.341	12.761	6.885	1.367	4.388	4.388	12.636
	2.607	4.893	2.474	1.565	1.998	22.566	9.507	4.066	1.406	4.313	4.214	18.071
	3.296	4.313	2.540	1.565	23.632	15.416	7.833	3.226	1.367	4.066	4.140	15.547
	2.474	3.821	2.879	1.465	40.341	10.941	6.476	2.742	1.309	4.066	4.639	11.983
	2.607	4.313	3.155	1.465	26.525	8.835	5.699	2.540	2.607	4.066	5.699	10.099
	2.474	3.821	4.214	1.505	24.349	7.384	5.515	2.298	46.436	4.066	5.699	8.575
	2.607	3.438	4.140	1.465	17.399	6.476	5.099	2.233	32.514	3.992	6.286	7.833
	2.474	3.226	3.438	1.367	10.760	5.699	4.740	2.298	27.628	4.140	5.805	7.078
	2.408	3.155	3.086	1.309	7.918	4.996	4.140	2.298	20.812	4.140	5.176	6.584
	2.298	2.947	2.810	1.270	6.286	4.893	3.676	2.061	15.384	3.992	4.817	6.098
	2.408	2.947	2.742	1.213	5.991	4.893	3.367	1.998	11.705	3.992	4.388	5.805
	2.408	2.810	2.675	1.175	4.463	4.893	3.155	1.998	10.338	4.066	4.214	5.515
	2.810	2.607	2.742	1.119	4.463	4.463	2.947	1.998	9.743	8.922	4.140	5.332
	2.675	2.742	2.607	1.213	11.983	3.749	2.742	1.914	9.743	7.833	3.992	5.332
	2.474	4.893	2.474	1.998	7.833	3.296	2.607	0.000	8.922	6.286	3.821	5.073
	2.364	3.821	2.168	2.947	6.775	2.879	2.675	0.000	8.575	5.620	4.313	6.179
	2.255	3.155	0.000	3.485	0.000	2.675	2.298	0.000	8.031	0.000	4.488	0.000
TOTAL	115.59	153.63	84.69	56.82	260.12	254.43	312.39	76.44	238.41	162.04	161.58	293.68

ANNUAL TOTAL 2169.82

SUSPENSION LOAD IN TONS

	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MARCH	APRIL	MAY	JUNE
	2.310	0.270	0.398	0.270	0.836	1.169	0.373	0.242	0.231	1.479	0.860	0.778
	1.264	0.356	0.360	0.252	4.026	1.051	0.652	0.231	0.204	1.370	0.877	0.722
	0.901	3.622	0.360	0.252	1.428	1.077	10.872	0.242	0.188	1.320	1.292	1.169
	1.070	2.781	0.348	0.281	0.761	0.836	7.586	0.224	0.188	1.189	1.142	2.346
	1.077	1.320	0.324	0.263	0.570	0.722	7.370	0.224	0.167	1.917	1.025	1.867
	1.169	0.860	0.438	0.348	0.493	0.722	6.063	0.214	0.158	1.077	1.051	1.349
	0.962	0.706	0.411	0.348	0.438	0.722	4.127	0.198	0.152	1.051	1.051	1.096
	0.836	1.320	0.360	0.281	0.385	0.722	2.573	0.182	0.152	1.025	1.244	0.962
	0.739	0.901	0.336	0.270	0.348	0.652	1.933	0.173	0.158	0.981	1.428	0.877
	0.601	0.877	0.316	0.252	0.293	0.555	1.428	0.173	0.167	0.919	1.370	1.216
	0.570	1.169	0.316	0.242	0.263	0.479	1.292	0.182	0.158	0.877	0.981	5.736
	0.507	1.569	0.493	0.231	0.242	0.451	5.292	0.182	0.152	0.819	0.901	9.247
	0.479	1.169	0.398	0.224	0.224	0.652	7.157	1.569	0.129	0.778	0.819	6.876
	0.424	1.216	0.438	0.204	0.204	14.630	5.801	2.033	0.138	0.739	0.761	4.565
	0.385	0.901	0.385	0.198	0.214	14.065	3.015	1.320	0.152	0.722	0.722	2.975
	0.360	0.836	0.336	0.182	0.252	6.464	2.033	0.652	0.158	0.706	0.684	4.802
	0.493	0.706	0.348	0.182	6.876	3.882	1.569	0.479	0.152	0.652	0.668	3.926
	0.336	0.601	0.411	0.167	14.065	2.454	1.216	0.385	0.143	0.652	0.778	2.771
	0.360	0.706	0.465	0.167	8.026	1.843	1.025	0.348	0.360	0.652	1.025	2.204
	0.336	0.601	0.684	0.173	7.157	1.450	0.981	0.304	16.978	0.652	1.025	1.771
	0.360	0.521	0.668	0.167	4.565	1.216	0.883	0.293	10.539	0.637	1.169	1.569
	0.336	0.479	0.521	0.152	2.399	1.025	0.801	0.304	8.475	0.668	1.051	1.370
	0.324	0.465	0.451	0.143	1.592	0.860	0.668	0.304	5.801	0.668	0.901	1.244
	0.304	0.424	0.398	0.138	1.169	0.836	0.570	0.263	3.871	0.637	0.819	1.122
	0.324	0.424	0.385	0.129	1.096	0.836	0.507	0.252	2.686	0.637	0.722	1.051
	0.324	0.398	0.373	0.124	0.739	0.836	0.465	0.252	2.275	0.652	0.684	0.981
	0.398	0.360	0.385	0.116	0.739	0.739	0.424	0.252	2.101	1.867	0.668	0.938
	0.373	0.385	0.360	0.129	2.771	0.585	0.385	0.238	2.101	1.569	0.637	0.938
	0.336	0.836	0.336	0.252	1.569	0.493	0.360	0.000	1.867	1.169	0.601	0.877
	0.316	0.601	0.281	0.424	1.292	0.411	0.373	0.000	1.771	1.006	0.706	1.142
	0.296	0.465	0.000	0.531	0.000	0.373	0.304	0.000	1.622	0.000	0.745	0.000
TOTAL	18.87	27.85	12.08	7.09	65.03	62.81	78.10	11.71	63.39	29.09	28.41	68.49

ANNUAL TOTAL 472.92

SOLUTION LOAD IN TONS

	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MARCH	APRIL	MAY	JUNE
	8.319	2.778	3.387	2.778	4.949	5.873	3.274	2.623	2.565	6.624	5.019	4.771
	6.114	3.198	3.217	2.682	11.051	5.562	4.360	2.565	2.408	6.370	5.072	4.593
	5.143	10.470	3.217	2.682	6.506	5.631	18.361	2.623	2.309	6.251	6.182	5.873
	5.614	9.147	3.161	2.836	4.718	4.949	15.276	2.526	2.309	5.925	5.804	8.385
	5.631	6.251	3.047	2.740	4.070	4.593	15.052	2.526	2.169	7.562	5.492	7.462
	5.873	5.019	3.555	3.161	3.777	4.593	13.623	2.467	2.109	5.631	5.562	6.319
	5.318	4.539	3.443	3.161	3.555	4.593	11.192	2.368	2.069	5.562	5.562	5.683
	4.949	6.251	3.217	2.836	3.330	4.593	8.791	2.269	2.069	5.492	6.062	5.318
	4.647	5.143	3.104	2.778	3.161	4.360	7.595	2.209	2.109	5.370	6.506	5.072
	4.179	5.072	3.009	2.682	2.894	4.015	6.506	2.209	2.169	5.195	6.370	5.994
	4.070	5.873	3.009	2.623	2.740	3.721	6.182	2.269	2.109	5.072	5.370	13.243
	3.832	6.827	3.777	2.565	2.623	3.610	12.708	2.269	2.069	4.896	5.143	16.903
	3.721	5.873	3.387	2.526	2.526	4.360	14.828	6.827	1.906	4.771	4.896	14.528
	3.499	5.994	3.555	2.408	2.408	21.369	13.319	7.794	1.967	4.647	4.718	11.783
	3.330	5.143	3.330	2.368	2.467	20.944	9.532	6.251	2.069	4.593	4.593	9.468
	3.217	4.949	3.104	2.269	2.682	14.077	7.794	4.360	2.109	4.539	4.468	12.093
	3.777	4.539	3.161	2.269	14.528	10.847	6.827	3.721	2.069	4.360	4.414	10.910
	3.104	4.179	3.443	2.169	20.944	8.580	5.994	3.330	2.008	4.360	4.771	9.130
	3.217	4.539	3.666	2.169	15.722	7.413	5.492	3.161	3.217	4.360	5.492	8.123
	3.104	4.179	4.468	2.209	14.828	6.557	5.370	2.951	23.059	4.360	5.492	7.263
	3.217	3.887	4.414	2.169	11.783	5.994	5.090	2.894	18.071	4.305	5.873	6.827
	3.104	3.721	3.887	2.069	8.482	5.492	4.842	2.951	16.167	4.414	5.562	6.370
	3.047	3.666	3.610	2.008	6.877	5.019	4.414	2.951	13.319	4.414	5.143	6.062
	2.951	3.499	3.387	1.967	5.873	4.949	4.070	2.740	10.832	4.305	4.896	5.753
	3.047	3.499	3.330	1.906	5.683	4.949	3.832	2.682	8.985	4.305	4.593	5.562
	3.047	3.387	3.274	1.865	4.647	4.949	3.666	2.682	8.254	4.360	4.468	5.370
	3.387	3.217	3.330	1.804	4.647	4.647	3.499	2.682	7.926	7.462	4.414	5.248
	3.274	3.330	3.217	1.906	9.130	4.124	3.330	2.604	7.926	6.827	4.305	5.248
	3.104	4.949	3.104	2.682	6.827	3.777	3.217	0.000	7.462	5.873	4.179	5.072
	3.009	4.179	2.836	3.499	6.182	3.443	3.274	0.000	7.263	5.440	4.539	5.804
	2.913	3.666	0.000	3.924	0.000	3.274	2.951	0.000	6.945	0.000	4.664	0.000
TOTAL	124.76	150.96	101.64	77.71	199.61	200.85	234.26	89.50	178.02	157.64	159.62	230.23

ANNUAL TOTAL 1904.81