GEOMORPHIC EFFECTS OF FLOODS IN THE ORERE RIVER CATCHMENT, EASTERN HUNUA RANGES

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ABSTRACT

The supply of sediment to the channel network and the movement of this material down channel during high-intensity, low-frequency rainstorms is discussed with special reference to the Orere River catchment. Differences in channel form and process in forested and grassed catchments are noted. Under forest, debris flows are important in first-order channels where they remove infill from the channel bed and destroy vegetation beside the channel. Under grass these effects are not so marked. Slope failure under forest contributes vegetation, including large trees, which form debris dams in low-order channels. This rarely occurs under grass. Aggradation behind these obstacles slows down sediment transport, so that under forest the movement of material down channel is intermittent, while under grass it appears to be a relatively steady process.

Evidence is presented to show the importance of low-frequency, high-intensity rainstorms as geomorphic factors. These storms cause marked slope failure and a catastrophic increase in debris supply to the channel network. It is suggested that concepts of magnitude and frequency of geomorphic forces (Wolman and Miller, 1960) need to be modified for areas where slope failure contributes most of the debris to the channel network.

INTRODUCTION

Floods as geomorphic agents have been considered in great detail both overseas (e.g. Benson, 1962; King, 1961; Schumm and Lichty, 1961; Wolman and Eiler, 1958) and in New Zealand (e.g. Pullar, 1963). The objects of this paper are (1) to provide additional information about floods from observations in the Hunua Ranges, (2) to present this information in terms of differences in forms and processes between forested and grassed catchments, and (3) to comment on the magnitude and frequency concepts as presented by Wolman and Miller (1960) in light of this information.

The influence of vegetation as a geomorphic factor has received scant attention in the literature. A study of many papers, mainly from the United States and New Zealand, shows that in most cases

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the effects of cultural destruction of the indigenous vegetation of an area are assumed — often without question — to result in 'accelerated' erosion which removes large amounts of the soil cover and scours out channels. This assumption is not questioned here. Its corollary that 'normal' erosion under the indigenous vegetation is much less damaging to soil cover and channels than 'accelerated' erosion under man-induced vegetation is questioned, however. Cunningham and Arnott, in a study of erosion following heavy rain in the Rimutaka Range, make a significant comment: " . . . one of the most alarming features of this case is the discovery that such rains can cause serious erosion under forest conditions which we at present regard as reasonably satisfactory." (Cunningham and Arnott, 1964: p. 24). Evidence from the Hunua Ranges suggests that serious erosion does occur under forest, and that its results may be different from the results of erosion in grassed catchments.

Wolman and Miller (1960) express the idea that the effectiveness of a geomorphic process is a function of the magnitude of the event and its frequency. After a study of discharge and sediment yield in a number of rivers in the United States, they concluded that at least half of the sediment moved out of a river system is by low or moderate flows, and further, that 90 percent of the sediment is transported out of a system by run-offs or discharges that occur at least once every five years. The overall effectiveness of very large floods for sediment transport is less than that of moderate or low floods because of the extreme rarity of the former. They point out, however, that such a generalization " . . . requires qualification to the extent that catastrophic events produce results that are (1) unique in some respect because of magnitude or (2) different in kind from effects of more ordinary occurrences." (Wolman and Miller, 1960: pp. 71–72). This qualification is important in areas where most of the sediment is derived from slope failure rather than surface wash, because high-intensity, low-frequency rainfalls associated with large floods appear to be more important for slope failure than less intense higher-frequency rainfalls.

THE ORERE RIVER CATCHMENT

The Orere River flows north from the Hunua Ranges and then north-east into the Firth of Thames (Fig. 1). The main stream is eight miles long and the catchment area is approximately 15 square miles. The headwaters rise in finely bedded Jurassic siltstones and sandstones (greywacke) which are unevenly weathered. Because of this unevenness in the weathering, the sediment load of the river varies from fine silts and sands derived from the weathered rock to unweathered gravels and boulders derived from the basement greywacke. About one half of the catchment is covered in indigenous podocarp-hardwood forest with tawa (*Beilschmiedia tawa*) domi-

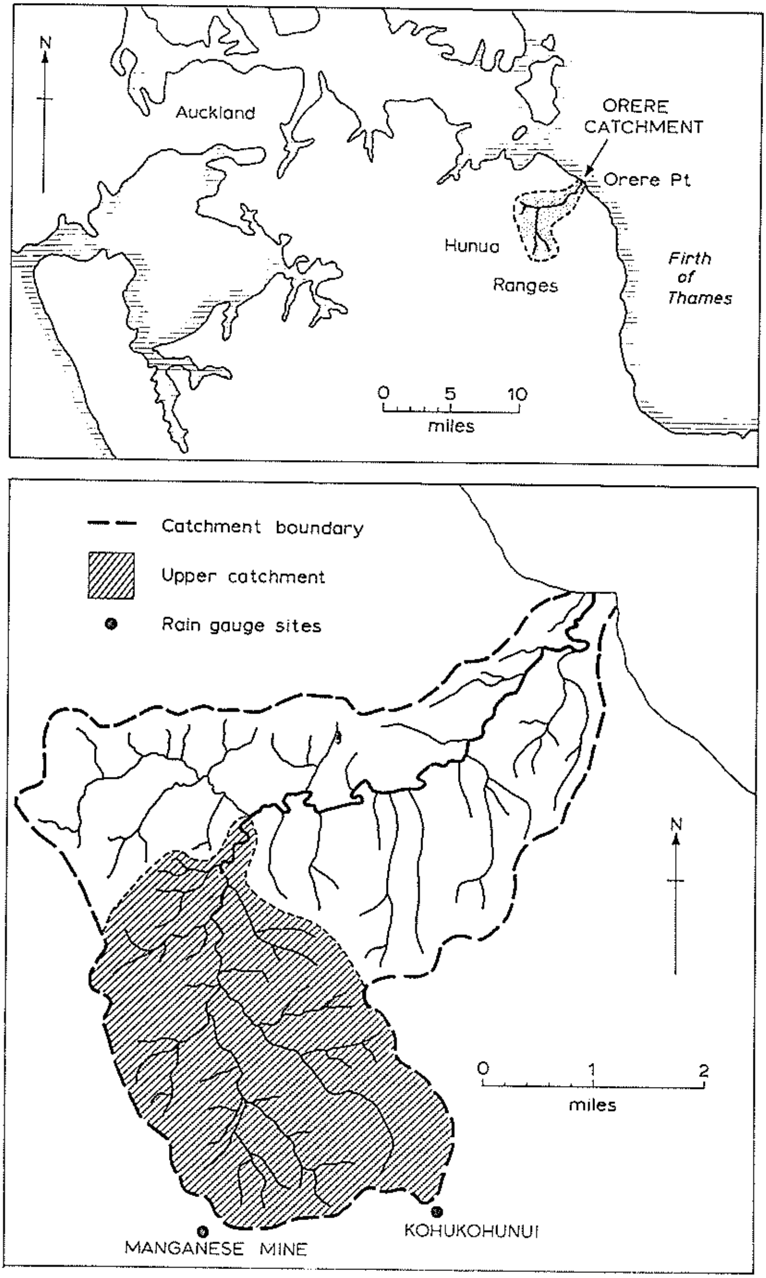

FIG. 1 — Location of the Orere River catchment.

nant. The other half is in pasture and is used for sheep farming. Most of the evidence presented here comes from the seven square miles of the upper catchment (Fig. 1).

RAINFALL DATA

Mean annual rainfall for the period 1949 to 1967 at the manganese mine gauge was 90.8 in. and at the Kohukohunui gauge was 93.8 in. (Fig. 1). An important factor in the rainfall record is indicated in Fig. 2. Here the mean and range for February show the importance of high-intensity cyclonic storms which occur during late summer (Sparrow, 1968). Table 1 gives data from the Konini and manganese mine rain gauges for one such storm which occurred in February, 1966. About one half the total rainfall for February 1966 fell during 18 hours on 28 February. Selby (1967b) has described this storm and some of its consequences in the Lower Waikato Basin, and notes the possibility that rainfalls higher than 10 inches in 24 hours occurred in some parts of the Hunua Ranges.

TABLE 1 — Amount, duration, and intensity of rainfall, 28 February 1966

Amount (*in.*)	*Duration* (*hours*)	*Mean intensity* (*in./hour*)	*Frequency* (*years*)
Konini rain gauge:			
10.69	18.50	0.58	30.0
9.00	8.75	1.03	51.0
4.50	2.68	1.68	15.0
2.25	0.83	2.71	6.0
1.88	0.58	3.24	4.4
Manganese mine rain gauge:			
9.62	19.0	0.29	15.0
9.15	12.0	0.43	28.0
9.12	11.0	0.475	30.0
5.10	4.0	0.73	14.0
2.87	2.0	0.82	4.0
1.61	1.0	0.92	1.5
0.85	0.5	0.97	0.5
0.36	0.17	1.23	0.2

Note: Frequencies are approximate, since no frequency analysis has been carried out for the Hunua Range gauges. All frequencies were obtained by converting rainfall values to Auckland values by the mean annual rainfall factor of 1.75. Moreover, for durations over 6.6 hours the values given are from extrapolated figures.

Source: E. Scanlan, Auckland Regional Authority, Bulk Water Supply Division (pers. comm.).

There has been little work published on precipitation and other climatic factors which precede storms leading to marked flooding and erosion. Two recent storms caused erosion damage in both grassed and forested catchments of the Hunua Ranges — February 1966, and February 1967. Rainfall in 1965 was less than normal, but during December 1965, and January 1966, there was more rain than normal. Thus it appears that even if a dry year had resulted in less soil moisture with dessication and cracking of the soil, the rain during December (7 in.), January (8 in.), and February (9 in. up to the 25th) would have reversed this condition. Moreover, the rainfall records for the Hunua Ranges show that 1965 was not unusual, and that high-intensity rainstorms, although not of the same magnitude as the storm of February 1966, have been relatively common in the Hunua Ranges in recent years. Thus, from the data available no conclusions can be drawn about the significance of climatic conditions before the storms which caused erosion damage.

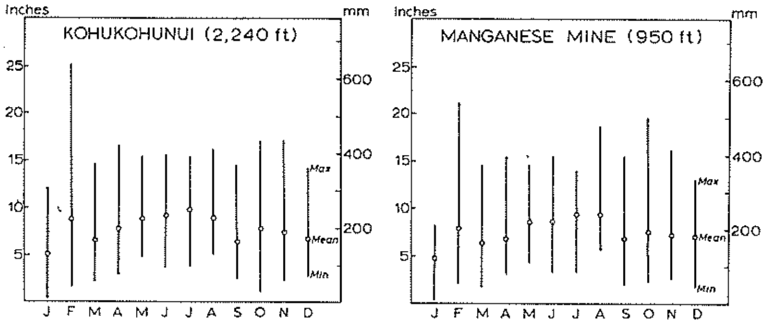

FIG. 2 — Mean and range of monthly rainfall (1949–67).

CHANGES IN LANDSURFACE FORM

Changes in the form of the landsurface resulting from high-intensity rainstorms may be divided into two groups: (1) those which are associated with the initial supply of material to the stream channels, and (2) those which are associated with the movement of this material down the channel. This paper is mainly concerned with the second group of changes, but some points should be noted about the first group (refer Pain, 1968b).

Slope Failure

Selby (1967a, 1967b) has stressed the importance of high-intensity rainfalls for the initiation of mass movement in the South Auckland–Waikato Basin area. He suggested (1967b) that up to 40 percent of the landsurface in some third-order catchments was affected by mass movement that occurred during the February 1966 storm. Nothing comparable to this was seen in the Orere River catchment, but in the lower-order catchments, especially first-order (the smallest channels with no tributaries), up to 30 percent of the landsurface was affected, under both grass and forest. Grant (1965, 1966) also noted the importance of high-intensity rainstorms as factors in the occurrence of slope failure. Jackson (1966) was more explicit in that he noted the occurrence of mass movement on the eastern Hutt hills in April 1966, and then commented on the weather conditions prior to that event. He pointed out that the climatic conditions before slope failure are unlikely to be without precedent in the history of a catchment, and thus some other factor or factors must be involved. Evidence from the Hunua Ranges suggests that high-intensity rainstorms are probably the most important trigger of slope failure, but that other factors must be involved as well, since precipitation conditions before the February 1966 storm were quite different from those before the 1967 storm. Moreover, most of the mass movement which occurred was located on sites where mass movement had occurred previously. These points support Jackson's contention that climatic conditions alone are not the main factor in slope failure.

It is not proposed to discuss the various factors relating to mass movement under forest and grass conditions; these are the subject of work being carried out at the present time. The aim here is to point out the importance of mass movement in the supply of debris to the stream channels during intense rainstorms. Jackson (1966) has suggested that mass-movement debris may be an important source of debris if it reaches the channel, and in the Hunua Ranges 43 from a sample of 50 mass-movement features which occurred in February 1966 contributed debris to the channel network.

Changes in Channel Form

There is a marked difference in the nature of sediment transport through channels in catchments under forest and catchments under grass.

Under podocarp-hardwood forest the collapse of material into the channel, either from mass movement of the slopes or from the channel wall, is nearly always accompanied by the collapse of various amounts of vegetation, including large trees. These logs frequently jam in the narrow, low-order channels so that debris washed into the channel and transported down stream is deposited behind these natural debris dams. Several in the Orere catchment were built and filled during the February 1966 storm. The form assumed by the deposits behind these dams is similar to that described by Lusby and Hadley (1967) for deposition behind man-made dams, although much smaller in size. Typically the surface of the deposits slopes back at an angle of between one and five degrees until the surface of the deposit intersects the bed of the stream.

The nature of the deposits behind these debris dams is quite different from the deposits found on the bed of the streams. Normally the finer fraction of material contributed to the channel network is removed first, leaving mainly large boulders, with gravels and sands in the pools. Deposits behind the debris dams are commonly much finer, containing greater amounts of small gravels and sands. As well as the size difference there is a difference in shape, the deposits found normally on the channel bed being more rounded than those behind the debris dams. The latter may consist primarily of angular gravels, especially if the source slope is adjacent to the debris dam.

Breaching of these dams may occur almost immediately, when the weight of the material becomes too great for the logs, or the form may persist in some cases for many years. No figures relating to the duration of these structures are available; there are, however, numerous small terraces — some only a few inches wide — on the channel sides which indicate the presence of a build-up of material during the storm and a consequent breaching of the dam and incision into the deposits.

Under forest the action of mass movement debris in the first-order channels is an important factor in the development of channel form. Material deposited in first-order channels from mass movement rarely remained within the first-order channel but was moved out either to add to the material in transport in the higher-order channels, or to be deposited as colluvial fans at the debouchure of the first-order channel. Fans are formed where there is sufficient room on a floodplain or low terrace for material to be deposited out of the immediate reach of the stream. This does not usually apply to channels lower than order 3. Reworking of the material in these fans occurs at various intervals after the initial deposition.

The deposits making up the colluvial fans consist predominantly of fines with significant amounts of gravels and boulders up to 12 inches in diameter. Occasionally larger boulders, greater than 24 inches in diameter, have been found. An important feature of these deposits, as with all deposits in forested areas of the Hunua Ranges, is the occurrence of logs and other vegetation.

The passage of the mass-movement debris down the first-order channel is inferred to be in the form of a debris flow (Varnes, 1958), with a high competence for transporting material. Support for this inference comes from the results of debris-flow movements which are firstly the removal of most of the loose material infilling the first-order channel right down to the unweathered greywacke, and secondly the destruction and removal of any vegetation on the channel walls, cutting a swath up to 12 feet wide on either side of the channel (Fig. 3). A thin layer of deposits left on the channel walls is also characteristic of debris-flow phenomena, while small-scale movements observed in progress in the same situation in the

FIG. 3 — The swath cut in a first-order channel by a debris flow.

Orere catchment have been debris flows. The writer has noted these features throughout the Hunua Ranges, and also in forested areas in the Whakatane River catchment.

Under grass the movement of debris from mass-movement features through first-order channels also occurs but is not such an obvious feature of the landscape. However, many of the mass-movement features that occurred in the Orere catchment on 28 February 1966 are now being channelled and are themselves becoming first-order channels (see Selby, 1967b: p. 41). Because mass-movement features are generally smaller under grass than under forest, the total amount of material transported through a given first-order channel is less than through an equivalent channel under forest, provided they both have mass movement at their heads. Thus the two results noted above for channels under forest are not so marked, there being little scouring of material from the channel bed, and little removal of the grass vegetation on either side of the channel.

Deposition in the form of debris dams does not occur in the channels of grassed catchments because of the lack of logs to form barriers. Aggradation does occur behind fences, however — in one place infilling a valley to a depth of more than 10 feet and killing two trees growing near the fence by burial up to the lower branches.

As well as deposition behind fences, aggradation takes place in the channel during storms, and then for a period after the storm incision into the deposits may take place, although the movement of material down channel without downcutting also occurs.

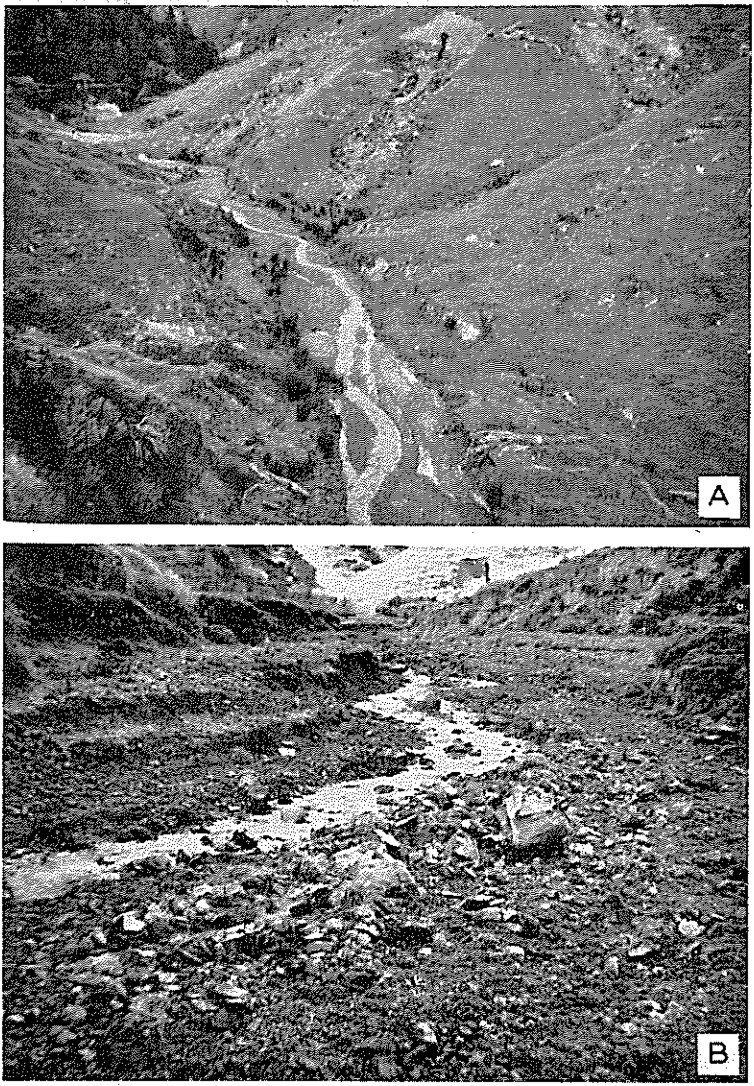

FIG. 4 — (A) Infilled channel under grass with braided stream bed.
(B) Detail of stream under grass — note levels of incision.

Deposition in grass catchments is confined to alluvial deposits along the channels, without the stepped longitudinal profile caused by the debris dams under forest (Fig. 4). Colluvial fans such as those found under forest were not formed in the Orere catchment during the February 1966 storms, and the only examples found in grassed catchments had a moderate development of soil on them, as well as evidence for large root channels indicating the presence of vegetation in the deposits. This suggests that these fans found under grass were perhaps formed at a time when the source catchment was still covered in forest.

The rate of sediment transport down channel would seem to be different under the two vegetation types. Under forest the effect of the debris dams is to slow down the movement of material in a way which occurs only rarely in grassed catchments. Thus, while the movement of material down forested channels appears to be intermittent, debris movement down channels of grassed catchments seems to be a relatively steady process.

DISCUSSION

It is apparent that catastrophic events such as the storm of 28 February 1966 in the Hunua Ranges have a marked effect on the regime of a river. Tricart (1960) and Tricart *et al.* (1961) have noted one such storm which occurred in June 1957 in the French Alps near the Italian border. The regime of the Guil River was modified from a situation where debris transport was relatively unimportant to a situation where large amounts of material supplied to the river by slope failure were transported and deposited in the river channel. Tricart stressed the importance of the forest vegetation present in the catchment and stated (free translation): "Vegetation was very important for the action of the water, large blocks and an unbelievable mass of alluvium being gathered together as a result of the piling up of tree trunks." (Tricart, 1960: p. 73). Tricart *et al.* (1961) showed even more clearly and in great detail the effects of this one storm on the regime of the Guil River.

Grant (1965), in his discussion of the regime of the Tukituki River, Hawke's Bay, stated with reference to the upper catchment: "In the course of a storm, bed load waves have often exceeded channel limits in depth, and overflowed to seriously damage large trees growing on high banks." He went on to say that such extreme events are at present dominant in the overall shaping of channels.

The importance of a single catastrophic event in the regime of a river is emphasized when it is considered that there is ample evidence indicating that some depositional surfaces in river valleys may be the result of a single event. Grant (1965) reported the widespread presence of a depositional surface in the Tukituki River valley, and in the Whirinaki River valley (Grant, 1963), which seems to have been deposited during a single catastrophic event about A.D. 1650. Pullar (1965) reported accumulation of material on the Gisborne Plains which began suddenly, burying an underlying soil. He interpreted this as evidence of a catastrophic event and accepted A.D. 1650 as a possible date for this event. Recent work in the Lower Whakatane River valley (Pullar, Pain and Johns, 1968) and the Galatea Basin (Pain and Pullar, 1968) has found evidence for the rapid and apparently catastrophic accumulation of alluvial material on floodplains and fans during the period between the Kaharoa eruption (*c.* A.D. 1000) and A.D. 1650.

From the evidence presented by these workers, and from independent work in the Orere catchment (Pain, 1968a), it appears that variations in the supply of debris consequent on the rare occurrence of high-intensity rainstorms may be responsible in large part for the presence of distinct depositional surfaces in river valleys. This, and the obvious importance of catastrophic events for the provision of debris to the channel network in the areas discussed, suggest that Wolman and Miller's (1960) statements on magnitude and frequency of geomorphic processes may need to be modified for areas where slope failure plays an important part in the contribution of debris to the channels of the river system. High-intensity, low-frequency climatic events provide an important triggering action to the drainage basin system by adding a large amount of energy in a short time. The system responds with the transport of material across slopes and through the channel network. Initially this movement of material is rapid, but it steadily declines as the system returns to equilibrium conditions. While high- and moderate-frequency events may move most material in a system, the material is not made available for transport by these events. Thus low-frequency events of greater magnitude are very important in that they provide transportable debris both on slopes and in channels.

CONCLUSIONS

Important differences in the nature of channel processes between forested and grassed catchments have been discussed. Under forest the movement of material down channel is intermittent because of the formation of natural debris dams during catastrophic storms. Under grass this movement of material appears to be steady, since there are few trees to build debris dams, the only aggradation that occurs because of barriers taking place behind fences. Thus there is a great need for quantitative research into the rates and processes of sediment transport under the two sets of conditions.

The importance of high-intensity, low-frequency storms as geomorphic factors would also seem to warrant more research. It appears that events of extreme magnitude are significant in areas where the main source of debris is slope failure. This suggests that the frequency and magnitude concepts of Wolman and Miller (1960) need revision and clarification on this point. Also apparent is the conclusion that high-intensity rainfalls are not the only factors involved, and that some other factor or factors such as soil conditions or prior slope movement must play a part in the initiation of the landsurface changes described above.

Finally, it is evident that severe erosion is taking place under forest, and that this erosion is an important source of debris both for the channels in the forested areas, and also for the channels in the grassed areas down stream. The need for research on the stability of forested slopes is thus apparent.

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