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GEOMORPHIC EFFECTS OF TWO STORMS ON THE UPPER WAITAHAIA RIVER CATCHMENT, RAUKUMARA PENINSULA, NEW ZEALAND

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ABSTRACT

Geomorphic response of a drainage basin to two large storms was assessed by river cross-sectional surveys and landslide inventories. Rainfall intensities of 80-150 mm/hour over 3 days in December 1980 caused widespread landsliding and subsequent stream aggradation. Most landslides were small (< 100 m^3) and most occurred on steep slopes (35°). Stream aggradation varied from 2.7 m to 5 m. By 1985, stream downcutting had not restored pre-storm 1980 levels. A shorter duration, less-intense rainstorm in April 1982 caused only minor landsliding. Sediment storage and transfer appear to be related to a cyclic process that moved material from one storage locality to the next. Geomorphic effectiveness of the two storms can be related to crossing of slope thresholds in the first storm but not in the second.

Keywords: Geomorphic response; landslides; stream transport; stream aggradation; storms; channel geometry; Raukumara.

INTRODUCTION

Mass movement and flood damage resulting from high intensity rainstorms have been widely documented (Bell, 1976; Bogucki, 1976; Selby, 1976; Renwick, 1977; Caine, 1980; Crozier, *et al,* 1980; Grant, 1982; O'Loughlin, *et al,* 1982; Pearce and Watson 1983; Harvey, 1984, 1986). Extreme rainfall events can induce a variety of geomorphic effects. Debris from surface erosion, channel scour and mass movement can combine with flood waters, producing flows able to move large amounts of material not carried by ordinary flows.

The magnitude and frequency of the events dominant in the evolution of landforms (geomorphic effectiveness) have received considerable attention within the last few decades. Wolman and Miller (1960) argued that, for fluvial systems, most sediment transport occurred in events of moderate magnitude that recur relatively frequently rather than in rare events of unusual magnitude. However, Selby (1974) and Wolman and Gerson (1978) considered that it is the 'catastrophic' event that is geomorphically effective as a channel and hillslope forming agent. They pointed out that such catastrophes may be common in many environments and that the rate of recovery of landforms after such events may be rapid. Beven (1981) showed that ordering of events and the effects of different thresholds for different processes greatly complicates the interpretation of such effectiveness concepts and of magnitude-frequency-effectiveness relationships in general. He cited two floods (from Newson, 1980), each transporting similar quantities of sediment from the same catchment, but each having a different 'effect'. The first

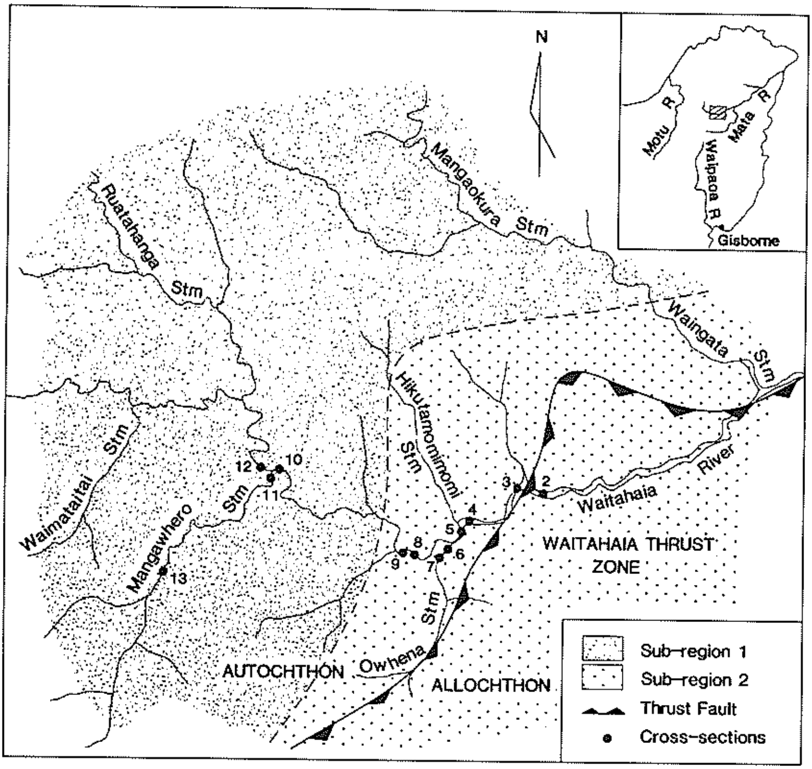


FIG. 1—Location map of the study area showing physiographic sub-regions and river cross-section localities.

event triggered landsliding but caused little apparent change in channel form—a "hillslope-forming event" (*sensu* Wolman and Gerson, 1978). The second event substantially modified the channel by erosion and deposition but triggered no landslides—a "channel-forming event".

The technique of an integrated catchment approach to studying geomorphic effectiveness is not new, either in New Zealand or overseas. This approach (or any other for that matter) has not been widely applied to the Gisborne—East Coast region which periodically receives large cyclonic storms which bring about significant change to the landscape.

The ultimate objective of any integrated geomorphic study is to be able to predict the effects of future events on an area and hence to assist in making recommendations concerning aspects of landuse.

This paper outlines the meteorological conditions of two storms and attempts to evaluate the concept of geomorphic effectiveness by examining the geomorphic change they induced in the drainage basin of the Waitahaia River, Raukumara Pensinsula, New Zealand.

During the period 23-30 December 1980, this area experienced high rainfalls and severe flooding. In April 1982, a similar set of complex meteorological conditions prevailed throughout the region, though the effects were felt over a much larger area of the central North Island.

GEOLOGIC AND GEOMORPHIC SETTING

The study area is located in the upper Waitahaia River valley, a major tributary of the Mata River, 25 km inland from Tokomaru Bay (Fig. 1). The rocks exposed in the study area are mid-Cretaceous to Paleocene sandstones and alternating sandstone/mudstone sequences, with varying degrees of shearing, crushing, and folding (Phillips, 1985). The strong relationship between lithology and physiography in the study area is similar to that described for other parts of the East Coast (Gage and Black, 1979; Phillips and Pearce, 1984).

There are two distinct sub-regions within the study area. Sub-region 1, the uppermost Waitahaia River, Mangawhero and Ruatahunga streams, consists predominantly of steep, dissected forest-covered slopes with dendritic drainage patterns and numerous small gorges and waterfalls, reflecting the influence of the more resistant rock types.

In contrast, sub-region 2, the middle Waitahaia River valley, is less steep and dissected, and the landforms are more typical of those developed on the crushed bedrock lithologies of the Upper Waipaoa River catchment (Gage and Black, 1979). Here, less competent, uppermost Cretaceous and lowermost Tertiary rocks are tectonised within a major SW-NE trending fault zone—the Waitahaia Thrust Zone (Phillips, 1985). This fault zone separates a structurally—simple autochthonous sequence to the west from a structurally-complex allochthonous sequence to the east (Fig. 1). Scree and colluvial debris of late Pleistocene age occur on stable upland areas, and a discontinuous mantle of Holocene airfall tephras extends to lower areas.

METEOROLOGICAL CONDITIONS

December 1980

A depression had moved north-east and reached the west of the North Island by 22 December. Between 23 and 27 December, this depression, with associated north-east and easterly winds, moved over the northern half of the North Island to form a stationary front, the eastern edge of which lay along the axis of the Raukumara Peninsula. Light rain began to fall from 23 December, increasing to a maximum on 26 December throughout the district.

The storm was centred over the study area (Fig. 2). The maximum 24-hour fall recorded by the Mangawhero automatic event recorder was 265 mm, and the maximum fall for a 6-minute period was 15 mm (D. Bragg. Ministry of Works and Development, Gisborne, pers. com.). Over the 8-day duration of the storm, 580 mm of rain was recorded at Mangawhero (Fig. 3).

April 1982

A tropical cyclone, later named 'Bernie' (Revell and Ward, 1982), was centred east of East Cape by 10 April. As the cyclone moved across the North Island, gale force winds caused extensive damage to exotic and indigenous forests in the Central North Island (Littlejohn, 1984).

In the study area, the Mangawhero rain gauge recorded a total of 220 mm rain in the 3 days from 9 to 12 April 1982 (Fig. 3). The maximum 24-hour total was 188 mm and the maximum hourly rainfall was 15 mm.

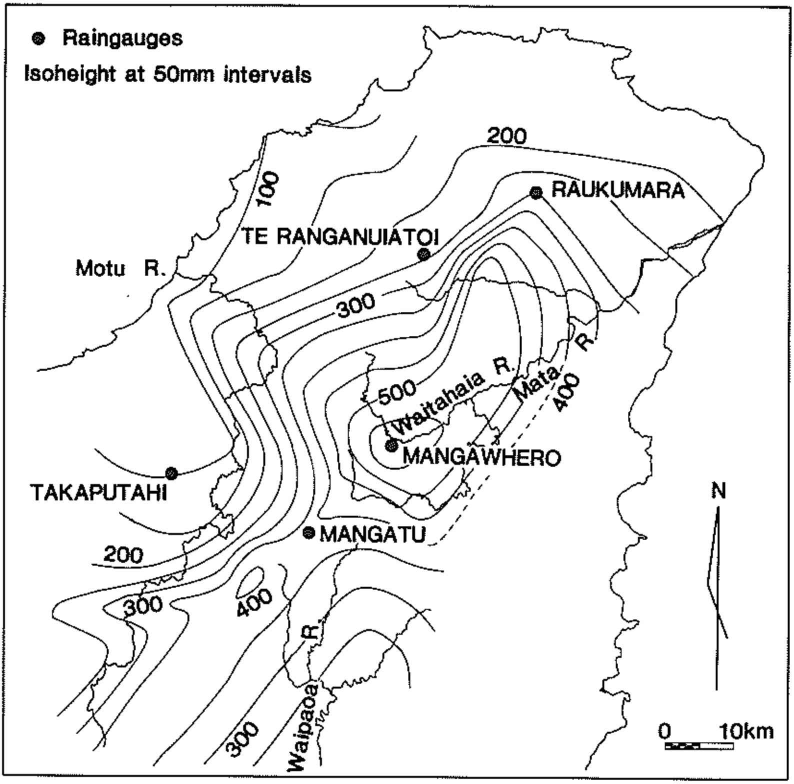


FIG. 2—Isohyetal map (total rainfall) December 1980 storm; 0000hrs 23 December to 2400hrs 30 December. (Reproduced from Ministry of Works and Development (M.W.D.) Gisborne per Mr D. Bragg.)

METHODS

Landslide Inventory

The mid-upper Waitahaia River catchment was surveyed in the 12 months after the December 1980 storm. Landslide dimensions were measured and volumes were calculated, and the landslides assigned to classes based on the type and cause of failure. A total of 116 slides were measured within the study area, most in open pasture and scrub country.

A brief field survey after the April 1982 storm indicated that relatively few fresh landslides had occurred within the middle reaches of the Waitahaia River, though fresh landslides were observed in the uppermost tributaries. Four sample areas were selected for aerial photo study (aerial photos flown November 1982). The sample areas ranged in size from 2 to 7 km^2 and represented four different types of vegetation and steepness. Each area was divided into 'slope units' on the basis of slope aspect and assigned to an aspect octant (N, NE, E, S, SE, SW, W and NW) (Crozier *et al*, 1980). Landslides were also classed on the basis

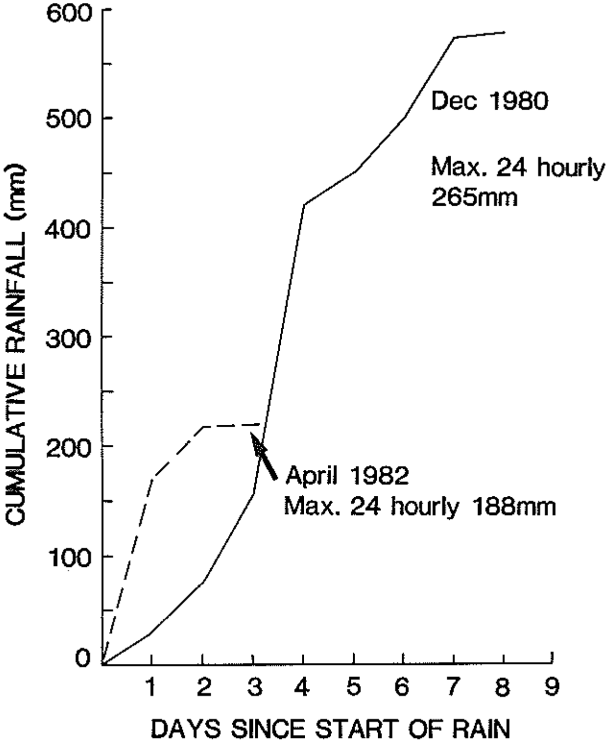


FIG. 3—Cumulative rainfall totals for December 1980 and April 1982 storms (M.W.D. Mangawhero Site 871910).

of position within the slope, i.e., upper, middle, or lower slope. The landslides counted were attributed to the combined influence of both storms.

Stream Aggradation

Twelve cross-sections were established on the Waitahaia River and its tributaries (Fig.1) to record the change in sediment storage with time and to determine how quickly (if at all) the river would regrade to its pre-storm level. Cross-sections were surveyed using a Wild T2 theodolite, and distances and relative heights were calculated from stadia measurements. Measurements were taken quarterly until 1983, then annually.

RESULTS

Mass Movement Effects

The high intensity rainstorm of December 1980 initiated widespread debris-slide avalanche, flow types of mass movement (Varnes, 1978) in the Waitahaia River catchment. Damage caused by mass movement, concentrated runoff, and

FIG. 4—Large debris avalanche which destroyed part of N.Z. Forest Service Road No.5, Owhena.

subsequent aggradation on natural slopes, roads, and riverbeds differed in the two physiographic sub-regions.

The steeper, more stable country of the upper valley, (sub-region 1) experienced debris-slide-avalanches where the shallow regolith failed, presumably in response to saturation of the soil mass. Small, translational landslides became debris-slides and flows as the debris and runoff became concentrated in ephemeral stream channels. Erosion of riparian zones by the moving debris formed a large number of debris slide chutes, especially in the steeper bush-covered areas of the upper catchment. Forest roads were damaged by numerous cut-slope failures, blocked culverts and subsequent erosion of culvert fill, and deposition of debris on the road surfaces. Undermined banks collapsed in stream beds. Stream bed aggradation within the upper reaches of the major streams was generally 2 m.

Sub-region 2 experienced a wide variety of mass-wasting processes. The duration of the storm enabled otherwise inactive earthflows and slumps to be remobilised, and the intensity of rainfall caused gullies to incise and initiated rilling by concentrating runoff in otherwise stable areas. Concentrated runoff undermined streambanks and caused extensive riparian failures. Small translational landslides, where the tephra mantle slid on well defined basal shear planes, were not uncommon. A large debris avalanche above Forest Road No.5, destroyed approximately 300 m of the road. Twenty thousand cubic metres of material failed, and blocks of sandstone larger than 2 m in diameter were deposited on the lower slopes (Fig. 4).

Damage to roads within the rest of the sub-region was similar to that for sub-region 1. Several large slumps were caused by river undercutting on meander bends of the Waiahaia River.

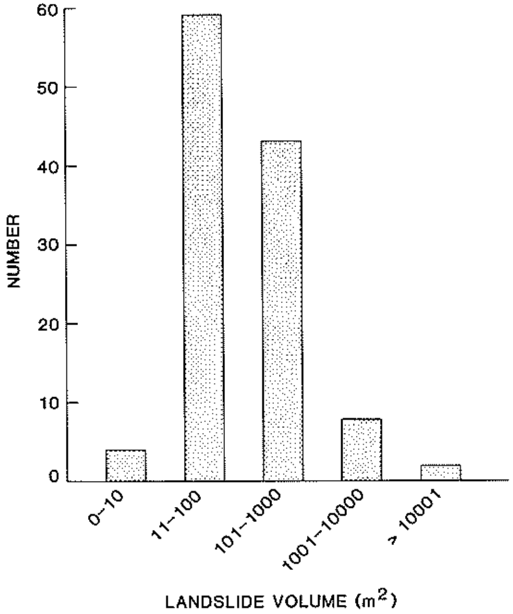


FIG. 5—Landslide size classes versus percent frequency, December 1980.

The April 1982 storm caused less severe mass movement within the study area than did the December 1980 storm. The April 1982 storm track did not pass directly over the study area but further to the west over the Motu River catchment. Extensive windthrow on ridge crests initiated mass wasting in many areas of the Motu Catchment (D. Miller, M.W.D. pers. comm.)

Within the study area mass wasting was generally confined to the forest-covered uppermost tributaries of the Waitahaia River, particularly the Ruatahunga Stream. Here small landslides and debris avalanches were initiated by tree toppling at ridge crests.

Although few fresh landslides were observed within the midreaches of the Waitahaia River catchment, many landslides and erosion features caused by the December 1980 storm were enlarged or reactivated.

Peak Flows

A peak flow discharge of 500 cumecs for the 1980 storm, estimated at the Owhena crossing of Waitahaiha River, was two orders of magnitude greater than the normal summer low flow of 5 cumecs. No peak flow estimates were obtained for the April 1982 event, but water levels were similar to those for the December 1980 event (W. McKee, formerly N.Z. Forest Service, pers. comm.).

Landslide Inventory

The 116 landslides measured after the December 1980 storm ranged in volume from 5 to 20 000 m^3, with a combined volume of 69,800m^3. Most landslides were less than 100 m^3 in size (Fig. 5). Mean depth was 1.04 m (N = 109, S

TABLE 1—Number, type, and cause of failure of measured landslides — December 1980 storm.

Type of slide	Number	%
Planar slides	91	80
Scoop slides	22	20
Riparian slides	65	20
Stream undercutting caused slide	39	39
Debris entered stream	74	64
Road related slides	17	15
Cut-slope failure	5	4
Side-cast failure	10	9
Blocked culverts	8	7
Slide became debris flow	36	34

Number of slides measured = 116
Total volume = 69 846 m^3

= 1.13) and mean slope on which failure occurred was 35° (N = 107, S = 7.07°). Over half the measured slides were in the slopes immediately adjacent to a stream or water course (Table 1). Eighty per cent of the total slides measured were planar, i.e., width and length were greater than 10 times the depth.

An additional five slides were measured downstream of the immediate study area. These slides had a total volume of 262 400 m^3 and were all very large debris-avalanche to block-slump failures.

Air photo analysis indicated that most slips occurred in the north to east-facing octants and on the upper slopes (Table 2). Slip densities were moderate in comparison with other New Zealand studies (Table 3). The prevalence of failures on upper slopes has been reported in a number of New Zealand studies (Crozier et al, 1980; O'Loughlin and Gage, 1975).

Stream Aggradation

The only pre-storm stream bed level available was for cross-section 5 where aggradation in or after the December 1980 storm was 2.7 m. Aggradation in upstream tributaries exceeded this figure, and in several places, e.g., Waimataitai Stream, debris had been caught in trees 5 m above the streambed.

The cross-sections in the upper reaches of the Waitahaia River and in the Mangawhero Stream all showed degradation since 1981 (sections 12, 10, Fig.6.). This was probably related to the narrow width of the river bed at these sections. Storage capacity in these upper reaches is significantly less than further downstream.

Downstream sections showed general lowering of the stream channel, but only minor changes in the aggradational surface; redistribution across the section rather than reduction or elevation of the surface (sections 2, 3, Fig. 6). These larger surfaces are only affected by high flows and will probably become semi-permanent river terraces.

The April 1982 event increased bed elevation in most sections, including those that had been degrading. A maximum of 0.5 m aggradation was attributable to this event, and in upper cross-sections the effect was dissipated within 6 months.

TABLE 2 – Number of landslides assessed from aerial photographs due to December 1980 and April 1982 storms.

Sample Area	Area	Aspect								Slope Segment			Debris Entered Stream	Density Slips/ km²
		N	NE	E	SE	S	SW	W	NW	U	M	L		
1 Ruatahunga — bush covered SF 125	3.8	6	21	28	18	7	10	10	0	50	37	13	77	22
2 Mangawhero Stream — Waimataitai Stream — bush-scrub-pasture	6.8	36	22	31	8	3	0	0	0	38	31	31	66	9
3. Mangaokura Stream — Trig B — scrub-pasture	2.0	35	16	24	0	0	0	1	23	37	33	30	47	25
4. Hikutamomimomi Stream pasture	4.1	11	26	47	7	6	2	0	1	48	23	29	50	27

TABLE 3—Comparison of slip densities from this study and from other New Zealand localities.

1	Waitahaia, East Cape 1980	9–27
2	Pakaraka, Wairarapa 1977	478
3	Wairarapa regional mean 1977	98
4	Tongoio, Hawkes Bay 1971	31
5	West Coast, Sandstone 1973–75	19
6	West Coast, Waimaungan Gravels 1973–75	11
7	West Coast, Oldman Gravels 1973–75	10
8	Wellington City, Winter 1974	19
9	Wellington City, December 1976	16
10	Stokes Valley, December 1976	6

Source	
1	This study
2 & 3	Crozier et al. (1980)
4	Eyles (1971)
5, 6 & 7	O'Loughlin and Pearce (1976)
8 & 9	Eyles et al. (1978)
10	McConchie (1977)

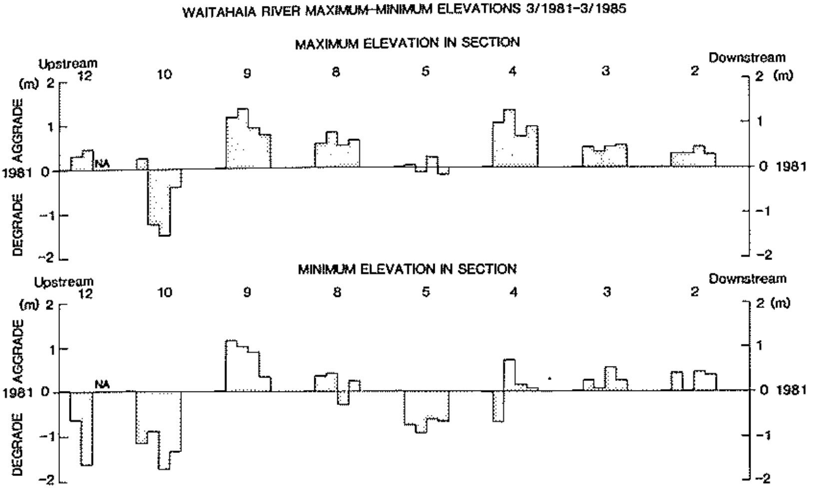
The elevation of the stream channel at cross-section 5 was still approximately 1 m above its pre-December 1980 storm level in March 1985 (Fig. 7). The streambed, though, was returning to the armoured surface of hard round boulders characteristic before the storm. The amount of suspended material appears to have returned to pre-storm levels, and fish and eels have returned.

DISCUSSION

The two landsliding/flooding episodes in the Waitahaia River catchment had major immediate impacts on the stream channels draining the area which are still evident 5 years later. Many landslide scars are still visible, and revegetation of slips has generally been slow. Significant volumes of sediment are retained within the drainage network. A landscape's response to an initial disturbance generally follows the form of an exponential decay curve (Graf, 1977; Mosley, 1978). The change or response after an event is initially rapid, then slows as the new equilibrium state is approached. The response of the landscape to any specific event may be affected by earlier events, and the rate and form of recovery from that event may be affected by both prior and subsequent events (Pearce, 1986).

Recovery of aggraded river sections after major floods has been documented by Lisle (1981) and Nolan *et al* (1987) for an area in north-western California. Here large infrequent events transported a relatively large proportion of the total sediment. Stream bed elevation declined fairly rapidly to levels close to, or higher than pre-food levels (Lisle, 1981, p.209), though this decline was modified by episodes of renewed aggradation attributed to subsequent high-magnitude floods.

A similar pattern of recovery is indicated for the Waitahaia River (Fig. 6). Some sections showed a rapid initial recovery modified by aggradation after the



Note: March 1981 level = 0 elevation each bar represents 1year 1981-1985
NA: not recorded for that year no longitudinal scale implied

FIG. 6—Waitahaia River maximum and minimum elevations 1981-1985.

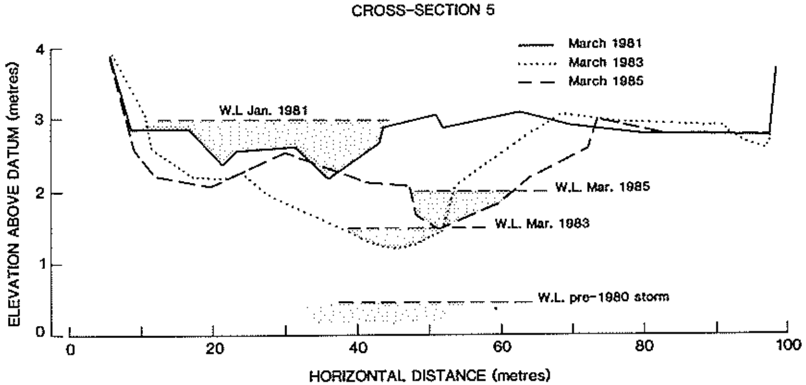


FIG. 7—Cross-section No.5 illustrating profiles for March 1981, March 1983, March 1985 and the pre-1980 storm water level.

April 1982 event. Recovery from this event appears to be slower. Other sections showed no apparent recovery and continued to aggrade. It is not surprising that recovery of downstream sections is slow, given the highly erodible slope materials and the overall active tectonic setting. Fluctuations in aggradational surfaces (Fig. 6) indicate that redistribution of stored material is continuing within the studied reach. The recovery of aggraded sections by flushing of the landslide debris out of the channel and restoration of stream banks to create the former channel width and character is not yet complete, and the sections may never attain pre-flood levels.

A cyclic pattern of sediment storage and removal appears to develop with time. This was especially evident in cross-sections of moderate width (50-100 m). In narrow sections sediment is redistributed within the reach as the channel moves from side to side. It seems likely that material is transferred downstream from one storage locality to the next, though the overall location of storage areas remain fixed each year. This pattern of semi-permanent storage/transfer areas has also been documented by Meade *et al* (1981).

The deposits from landsliding episodes give the adjacent slopes temporary marginal stability. The subsequent erosion of these deposits during moderate flow and the redistribution of material throughout the reach continually alter the form and appearance of the landscape.

The high intensity rainstorm of December 1980 exceeded the threshold intensities indentified by Caine (1980) for the initiation of shallow landslides and debris flows on steep slopes. The lack of renewed mass wasting during the April 1982 storm suggests that all available slope stability thresholds (Palmquist, 1980) had been crossed by the December 1980 event. The April 1982 flow apparently was significant only in redistributing material delivered to the streams by the December 1980 event.

This study shows that it is not easy to assess the geomorphic effectiveness of an individual event in modifying the landscape. The December 1980 storm crossed 'geomorphic thresholds', but the highly variable response of the catchment and its random nature makes it impossible to predict the effects of a similar future event.

An integrated approach to studying geomorphic effectiveness is not new; this study has reached similar conclusions to previous studies giving added confidence to the theory that cyclic trends within an otherwise complex response do commonly occur. The integrated approach, although common, may not be the best method to examine geomorphic effectiveness; it may be easier if single process or specified process complexes are considered rather than the 'total' effects of individual events (Pearce 1986). However, detailed small-scale measurement with high levels of certainty for individual processes will be needed before we are able to link these processes theoretically to the larger time and space scales of significant land form change.

Finally, it is most important when experiments are designed that the design be related to the specific needs of landuse planning.

AUTHOR'S NOTE:

During the final preparation of this paper the Gisborne—East Coast region was severely affected by Cyclone Bola (March 1988). Though the most severe damage was concentrated east of the present study area, 500–800 mm of rain fell in a period of about 2 days within the study area. It is intended that cross-sections will be re-surveyed in addition to a more detailed study of the effects of this event on other parts of the region.

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