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A WAY TO ESTIMATE THE FREQUENCY OF RAINFALL-INDUCED MASS MOVEMENTS (NOTE)

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ABSTRACT

Frequency of mass movement is hard to estimate from meteorological data, soil physical data, or historical records, because insufficient data are available except at research sites. An analysis of sites with documented past events suggests that there is a relationship between event frequency and mean annual rainfall. A provisional equation, tested against independently collected data, provides approximate estimates of long-term average mass movement frequency, for catchments 10 to 1000 km^2 in area, with mean annual rainfalls between 500 and 2500 mm.

INTRODUCTION

Mass-movement erosion is triggered by a bewildering range of rainfall magnitudes, durations and intensities. Crozier (1986) offers perhaps the best recent summary of research on the subject, quoting from extensive earlier work notably Sidle *et al.* (1985) and Caine (1980). Although several predictive models have been developed e.g. Crozier and Eyles (1980), Thomas and Trustrum (1984), these require data rarely available outside well-instrumented research catchments. Hawley (1991) discusses problems in identifying the distribution and frequency of erosion-inducing rainfall from spatially sparse rainfall and flood records. An alternative approach is to ascertain distribution and frequency of the mass movements from historical records, maps and aerial photographs. A number of geomorphologists, both overseas e.g. Shimokawa (1984) and within New Zealand e.g. Trustrum and de Rose (1988), have applied this method to small research areas. Such an approach does not contribute to scientific understanding of how rainfall initiates mass movement, but because it describes how often rainfall induces mass movement over a given area, it is useful in assessing risk. This paper proposes a third approach, which is to correlate mass movement frequencies, derived from historical records at a few sites, with a simple meteorological parameter widely available at others: mean annual rainfall.

ESTABLISHMENT OF A RELATIONSHIP

Hicks (1989), investigating a range of meteorological parameters, concluded that mean annual rainfall held the most promise for correlation with historical records of mass movement, but that event frequencies would need to be derived from thoroughly analysed sources to produce good estimates.

Dated mass movement events from a number of districts within New Zealand are depicted in Figure 1. Sources of information are given in the figure caption. These events are widespread slope failures due to extreme rainfall or protracted wet weather. The failures encompass rapid shallow landslides and debris avalanches; also contemporaneous but slower-moving, deeper-seated earthflows and slumps. Figure 1 excludes earthquake-triggered landslides.

The authors cited have usually collected historical information about dates of mass movement in the course of geomorphological research. It has been possible to update most sources to 1990, using Eyles and Eyles (1982) account of New Zealand-wide storm damage between 1970 and 1981, and from the author's personal knowledge of mass movement events during the period 1976-1990. Where there are two or more sources for a district with some conflict between their chronologies, all dates have been included, on the premise that either source may have uncovered historical information not located by the other. Data for the East Coast have been excluded and are used later to test an empirical relationship derived from Figure 1.

Even small districts can have substantial variations in mean annual rainfall, so average mass movement frequencies derived from Figure 1 have been plotted against median isohyets (Fig. 2). These were obtained by identifying the lower and upper isohyets crossing each district on 1:500,000 mean annual rainfall maps (N.Z. Meteorological Service, unpub), and taking the isohyet halfway between as a median. Lower and upper isohyets are also shown in Figure 2 as horizontal bars.

Figure 2 suggests that frequency of mass movement can be correlated with mean annual rainfalls from 500 to 2500 mm. There are no data for low-rainfall districts. Above 2500 mm the curve appears to approach an asymptote, uncertain in position because the high-rainfall districts are mountainous, and their mass movement frequencies correspond with a wide range of mean annual rainfalls from bottom to top of catchments (indicated by the horizontal bars).

The equation of the provisional curve plotted in Figure 2 is :

$$F = 3009\ R^{-0.8939}$$
$$S = 1.0$$

where F = average frequency of mass movement (years)
and R = mean annual rainfall (millimetres)
and S = standard error in estimate of F (years).

TEST OF THE RELATIONSHIP

Independent data to test the postulated relationship were collected by the author in the East Coast region. Dates of widespread mass movement in eleven East Coast districts (each 100-1000 km^2 in size and contained within catchment boundaries) were ascertained from an East Cape Catchment Board file recording storm damage since 1964, from the Board's annual reports dating back to 1946, and from instances of erosion associated with rainfalls and floods during the period 1920-1953 by Cowie (1957). Over seventy years, the number of mass movement events in different districts ranges from 12 to 27 (Fig. 3). In the Waiapu catchment and its tributaries, mass movement is likely to be underestimated; likewise in the small northern catchments draining to Hicks Bay, because Cowie (1957) contains information about storm damage to roads, bridges and farms only in the catchments' settled lower ends. Anecdotal accounts by local residents indicate widespread mass movement in upper reaches from the 1920s to the 1940s. Events recorded for the Waipaoa

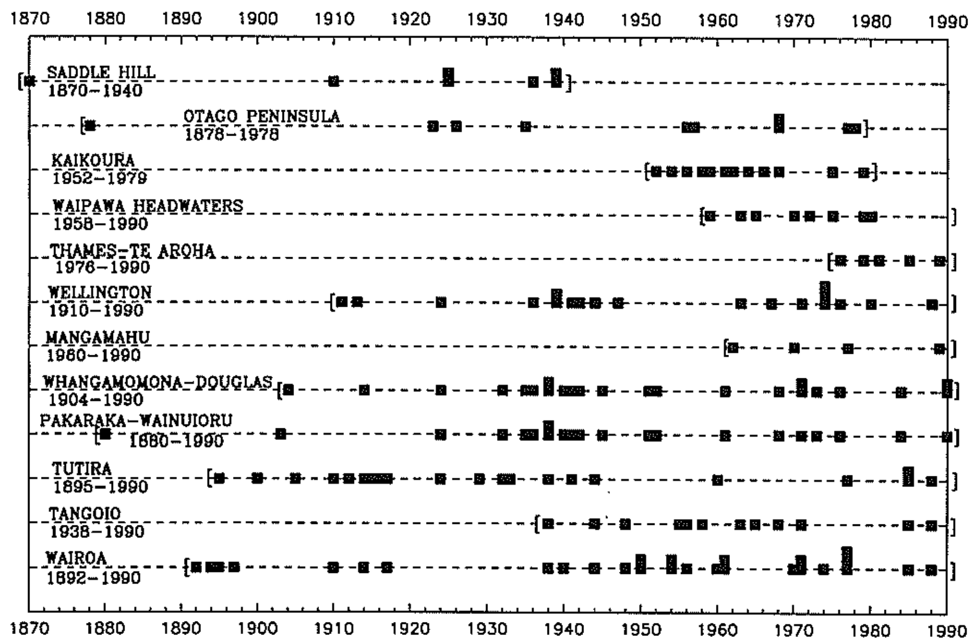

FIG. 1—Dates of widespread mass movement in various districts, New Zealand.

Data sources: Wairoa - Black (1979), Brown (unpub); Tangoio - Campbell and Anaru (1964), Eyles (1971); Tutira - Trustrum, Page, de Rose (unpub; some dates not known to the exact year have been interpolated); Pakaraka - Wainuiioru - Crozier *et al* (1982), Trustrum *et al* (1983); Whangamomona - Douglas - McDonald (1982), Trustrum and de Rose (1988); Mangamahu - Garrett (1980); Wellington - Eyles *et al* (1978), Eyles (1979); Thames - Te Aroha - Vine (1981), Salter *et al* (1983); Waipawa Headwaters - Grant (1982); Kaikoura - Marlborough Catchment Board (1967), Bell (1976); Otago Peninsula - Crozier (1970), Crozier and Eyles (1980); Saddle Hill - Benson (1940; one date not known to the exact year has been interpolated).

catchment and tributaries, and for the small catchments draining to Tolaga and Tokomaru Bays, are probably more accurate. These catchments have a closer network of communications routes, settlements and raingauges. Here, instances of damage recorded by Cowie (1957) and East Cape Catchment Board (unpub) correspond closely with residents' anecdotal recollections.

Lower and upper mean annual rainfall isohyets were identified for each district from the 1:500,000 mean annual rainfall map (NZ Meteorological Service, unpub.), and the mass movement-rainfall relationship (Fig. 2) was applied to estimate ranges in average mass movement frequency. These were compared with average mass movement frequencies derived from the independent East Coast data in Figure 3. The two sets of estimates (Table 1) are close in nine out of eleven districts.

DISCUSSION

Dates in Figure 1 indicate some short-term fluctuation in event frequency. Several of the sources note that the 1920s-1930s appear to have higher frequencies of mass movement than preceding and following decades. This suggests that Figure 2, because it is based on records that span several decades, is probably a poor indicator of short-term fluctuation but a better indicator of long-term average event frequency.

The test data (Fig. 3) illustrate Hawley's (1991) point that erosion frequency changes with the spatial scale of observation :

- Mass movement events have occurred somewhere in the East Coast region 49 times since 1920. On only 6 occasions have events been region-wide.
- Event occurrence somewhere in each East Coast district ranges from 12 to 27 times since 1920. How many events have been district-wide is not known, but the number must equal or exceed the 6 region-wide events.
- Mass movement will have occurred at specific localities (e.g. individual East Coast farms) less than 12 to 27 times since 1920 (because all events in a district do not affect all localities). The number of events at a locality must however equal or exceed the number of district-wide events.

This suggests that Figure 2 should be used to estimate event frequency only for areas similar in size to those from which it was derived. Authors cited in Figure 1 derived their dates and frequencies from historical records, maps and aerial photographs of the districts surrounding specific sites where they carried out geomorphological investigations. These districts range in size from tens to hundreds of square kilometres, but are contained within major catchment boundaries. They are small enough to consist of terrain similar in geology and landforms to the field sites they encompass. Collectively, they constitute a range of terrains (soft-rock hill country, greywacke mountains, dissected volcanics) and vegetation (pasture, tussock, podocarp and beech forest). These factors may affect the frequency of mass movement events, causing a fairly high standard error in the equation for the curve (Fig. 2). Were the number of districts greater, it might be possible to plot separate curves for different terrains and vegetation covers, and calculate more precise equations.

Meanwhile the fit of the curve appears sufficiently good for its equation to provide approximate estimates of mass movement frequency based on rainfall

TABLE 1—Frequency of widespread mass movement, East Coast

District	Estimated from historical records, 1920-1989 Average recurrence interval(years)	Estimated from Figure 1 and NZ Meteorological Service isohyet maps[1] Average recurrence interval(years)
Hicks Bay-Te Araroa	3.2	1.8-4.1
Ruatoria	3.6	2.9-4.1
Waiapu-Mata headwaters	2.6	1.8-3.4
Tokomaru Bay	3.6	3.4-4.6
Tolaga Bay-Tauwhareparae	3.4	3.4-4.6
Gisborne	3.9	4.6-6.3
Waimata	4.4	3.4-4.6
Kanakanaia	5.9	4.1-6.3
Waipaoa headwaters	3.0	2.5-4.6
Wharekopae-Ngatapa	4.4	4.1-6.3
Te Arai-Maraetaha	4.2	3.4-5.3

[1]Because each district is crossed by several mean annual rainfall isohyets, the upper and lower isohyets were used to estimate a range of frequencies.

alone, for catchments which differ or are internally heterogeneous, provided it is not used at regional scale (>1000 km^2) or local scale (<10 km^2), or across major catchment boundaries. This is confirmed by the test against data for East Coast districts (Fig. 3). All are between 100 and 1000 km^2, and are defined by major catchment or sub-catchment boundaries, containing diverse rock types and vegetation covers. Yet the equation has predicted event frequency limits which encompass estimates based on historical data, in nine out of eleven cases (Table 1).

CONCLUSION

Previous researchers e.g. Crozier and Eyles (1980), Thomas and Trustrum (1984) have shown that it is possible to estimate an approximate frequency for rainfall-induced mass movement, either by field studies which match events with data for rainfall magnitude, duration or intensity, or by ascertaining heavy rainfall and associated erosion from historical records. Sparse rainfall and soil physical data, and the vagueness of historical records' references to extent of mass movement, preclude routine use of these methods. An alternative may be to apply a statistical relationship, established between event frequency in a few districts where good historical information is available, and a widely available surrogate meteorological parameter such as mean annual rainfall. Such a relationship has been developed and tested. It appears capable of supplying reasonably good estimates of average frequency over several decades, for heterogeneous catchments 10-1000 km^2 in size, with mean annual rainfalls between 500 and 2500 mm. It would be a quick and inexpensive alternative to using computer models based on meteorological and soil physical data, which to produce reliable answers require data at spatial densities that are simply unavailable. The method, therefore, would appear to hold considerable promise for quick estimation of mass movement risk by government agencies and local authorities.

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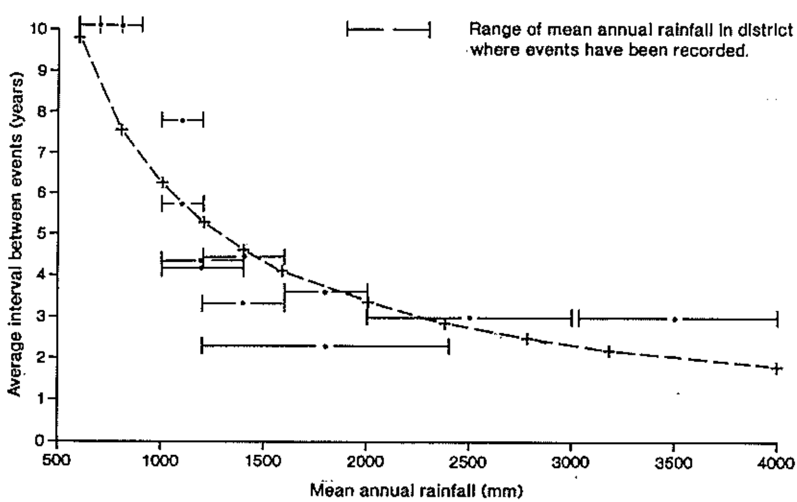

FIG. 2—Mean recurrence intervals of widespread mass movement.

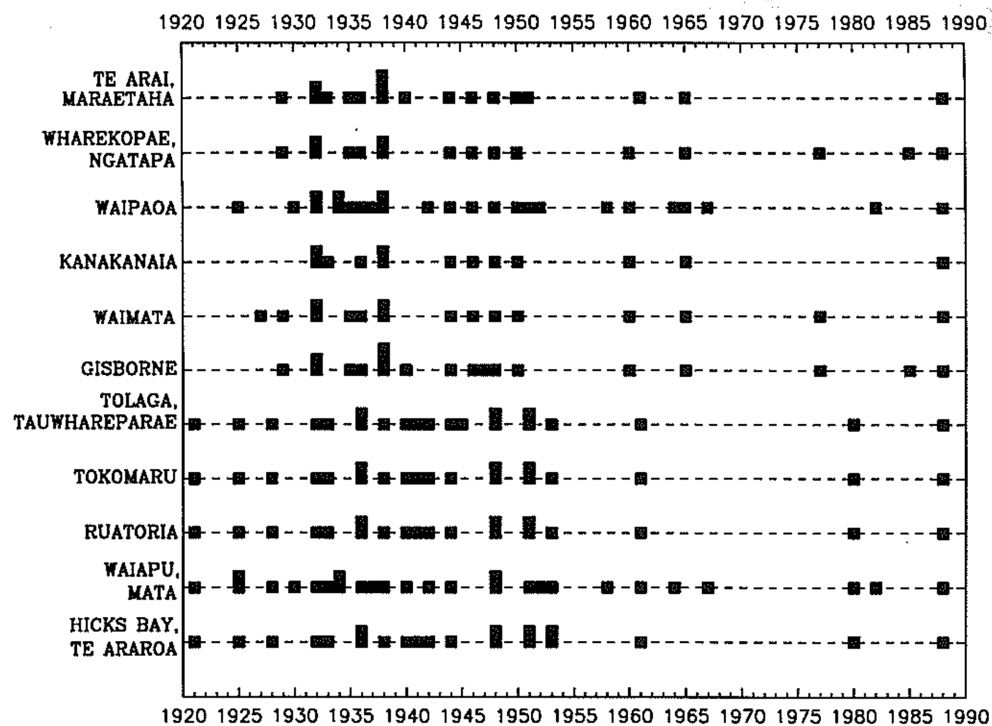

FIG. 3— Dates of widespread mass movement in various districts, East Coast.
Data sources: Cowie (1957); East Cape Catchment Board (unpub.)

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