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THE WELLINGTON AND HUTT VALLEY FLOOD OF 20 DECEMBER 1976

The following report describes the rainfall pattern associated with this flood and gives particular emphasis to the frequency of similar heavy rainfall. The report was written by Mr A.I. Tomlinson and Mr A.W. Dyke processed the rainfall data and drafted the diagrams.

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NEW ZEALAND METEOROLOGICAL SERVICE

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1. Summary

The flooding in the Wellington and Hutt Valley area on 20 December 1976 resulted from extremely heavy though localized rainfall. This rainfall occurred over a relatively short period with most of the rain being recorded in less than 12 hours.

The damage caused by the flood has been estimated to have cost many millions of dollars. Because of this very large cost, questions of design and insurance to cope with similar events become paramount. This report examines the frequency of such events and concludes as follows.

The rainstorm of 20 December 1976 has a return period in excess of 100 years and possibly in excess of 500 years. The peak rainfalls (return period greater than 50 years) extended over an area of about 300 km^2. This is a characteristic area for the type of atmospheric process that produced the rainfall. There is no reason to expect that any area of similar size in the Wellington Region is more liable to such storms than others. Since there are many such areas in the region, storms of the intensity of that of 20 December 1976 will occur in different parts of the region at much shorter intervals than the return period mentioned above. The last similar one occurred on 26 December 1939 (not to be confused with the Hutt Valley flood of 11 December 1939).

2. Introduction

On 20 December 1976 severe flooding was experienced in the Wellington-Hutt Valley area as a result of a period of extremely heavy rainfall. Major damage was caused by the flood and there was a large amount of ground slope failure and mud flows. The area of heaviest rainfall in the storm extended from Pinehaven and Stokes Valley through to Belmont and Maungaraki and on to Johnsonville, Ngaio and Karori.

The Petone area adjacent to the Western Hills was one of the worst affected. Both the road and railway north out of Wellington were cut at Petone, and the depth of floodwater caused major disruption to industrial plant. Several houses in the Hutt Valley were demolished by the floodwater and the rubble it carried with it. In Wellington's Lambton Quay 30 cm of water covered the road for a short time. Only one person was killed by the flood and this resulted when a land-slip crushed part of a building in the Wellington suburb of Crofton Downs.

The Earthquake and War Damage Commission has estimated the total damage caused by the flood to be approximately 30 million dollars.

Such a major disaster requires an analysis of the rainfall that was the immediate cause of the flood, with a view to assessing the likelihood of the recurrence of a similar event. This report endeavours to do this by looking at the pattern of the rainfall recorded and the nature of the processes which produced it. This, along with a study of rainfall records which extend back over 100 years, allows an assessment of the frequency of such storms to be made.

The New Zealand Meteorological Service maintains a network of raingauges throughout New Zealand. These gauges fall broadly into the two types of manual and recording (or autographic). There are many more manual than recording gauges and the positions of all the gauges, in the greater Wellington area are shown on Fig. 1. On this Figure the automatic gauges are not distinguished from the manual ones. Manual raingauges are read once a day at 0900 hours and the values recorded are the total rainfalls over the previous 24 hours. These values are then allocated to the previous day, so that, for example, if 10.2 mm was recorded at 0900 hours on 20 December the rainfall for 19 December is said to be 10.2 mm. Accordingly, only daily values of rainfall are available from manual raingauges. Recording raingauges furnish a continuous trace of the rate of rainfall. These gauges are generally visited each day at 0900 hours when the daily chart records are changed. The charts are processed to extract whatever information is required. The chart records are calibrated by reference to the manual daily rainfall total recorded at the same station. On a routine basis the data extracted each month from the charts are the maximum rainfalls over durations ranging from 10 minutes to 72 hours and including 6, 12 and 24 hours. The December 1976 charts from stations in the greater Wellington area show very large values for the 6, 12 and 24 hour durations, related to the storm of 20 December. The locations of the recording raingauge sites are shown on the isohyetal maps of Figs 4 and 5.

3. The Pattern of Recorded Rainfall

Most of the rain in this storm fell between midnight on 19 December and 1700 hours on 20 December. At the manual rainfall stations the storm rainfall was therefore divided between 19 and 20 December. Figure 2 shows the pattern of the total rainfall of the storm and represents the recorded rainfall over the 2 days (0900 hours 19 to 0900 hours 21 December 1976). This Figure shows that the heavy rainfall occurred in an elongated curved area, extending from the southern part of Whiteman's Valley to south of Karori. Extremely high rainfalls were recorded over the relatively small area affected. The reason for this area of maximum rain is explained in section 4.

The heaviest rainfall associated with this flood fell in a period of 9 to 15 hours commencing about 0300 hours on 20 December. The heavy rainfall appeared to begin earlier and finish earlier at the northeastern end of the heavy rainfall region of Fig. 2 than it did at the southwestern end (see Fig. 3.).

Figures 4 and 5 show the maximum rainfalls recorded in 24 hour and 12 hour periods respectively. These maps have been drawn from data extracted from autographic rainfall records and a comparison of this data with that used to construct Fig. 2. Figure 4 is included primarily since it shows that practically all the rain fell in 24 hours or less and also because the 24 hour period is a particularly useful one for assessing the return period of this storm (see section 5).

The dashed lines on Figs 4 and 5 help to delineate the area of the storm, since at each point within them the return period of the rainfall was greater than 50 years. It can be seen that the area enclosed by the dashed line on Fig. 5 is slightly greater than that on Fig. 4 indicating that the storm was essentially a 12 hour one and not a 24 hour one.

The position of the centre line of heaviest rainfall in Figs 2, 4 and 5 was determined largely by the rainfall records already described. Further confirmation of the position was gained from several unofficial rainfall measurements made at the time of the storm and also from the pattern and degree of slope failure and mud flows observed by the New Zealand Geological Survey, D.S.I.R. This information about slope failure also assisted in estimating the variation of peak rainfall along the centre line.

4. The Weather Situation

Prior to 19 December 1976 the greater Wellington area had experienced a period of relatively dry though cold weather. For the period 1 October 1976 to 19 December 1976 only 65% of the normal rainfall had been recorded and the temperature had averaged about 1.0°C below the normal. Accordingly the ground in the layer up to 50 cm deep was generally slightly drier than normal but not markedly so since the cooler temperatures and less windy conditions than normal had kept the evaporation relatively low.

The weather situation which produced this very local but extremely heavy rain was not an unusual one in its broadscale features. Figure 6 shows the weather situation at 0600 hours on 20 December 1976. An area of low pressure covered New Zealand with centres of lowest pressure to the west of Northland and to the east of Marlborough. This second centre, to the east of Marlborough, had moved over the Cook Strait area during the previous 18 hours. Its passage was accompanied by a large and active thunderstorm which appeared to move from near Paekakariki to the eastern side of Palliser Bay, between 1600 hours and 1900 hours on the 19th. This thunderstorm indicated that areas of very unstable air existed in the general region of low pressure. It is notable also that the area of low pressure had increased considerably in the 24 hours up to 0600 hours on 20 December. Accordingly at midnight on 19 December 1976 the Wellington Province was in an area of general cyclogenesis and unstable air, and the stage was set for some moderate or heavy rain. This rain subsequently occurred and embedded in it was the small area of extremely heavy rain described earlier.

Figure 7 shows the air-flow at 0900 hours on 20 December. It can be seen that a line of convergence lay northeast-southwest over the area. Southerly winds prevailed to the south of the line and north or northwesterly winds to the north of it. The convergence was very well developed and deep at this time. Although most of the winds near the convergence line were light (calm or Beaufort force 1, i.e. 1 to 3 knots), winds of up to force 4 (11 to 16 knots) blew towards the line from the south and winds of up to force 5 (17 to 21 knots) approached it from the north and northwest. (One report of force 6 is some distance away from the area of heavy rain.) These winds, especially those from the north, carried sufficient moisture to produce the intense rainfall which occurred in the immediate vicinity of the line of convergence shown in Fig. 7. The line of convergent airflows remained close to the position shown in Fig. 7 until about 1700 hours when the southerly winds to the south of it had reached sufficient strength to destroy the vertical structure of the convergence zone. The zone then moved northward probably assuming the normal characteristics of a frontal zone, that is to say, a sloping surface with the colder southerly air progressively undercutting the warmer northerly wind-flow to the north of it.

From 0000 to 1200 hours on 20 December, during the period of the intense rainfall, the winds through a deep layer of the atmosphere (2 km to 10 km) above the line of convergence shown in Fig. 7 appear to have been northeasterly in direction and quite light in strength (less than 10 knots and probably less than 5 knots). The dashed arrow of Fig. 7 indicates the direction of this upper level wind-flow.

Along the line of convergence there were probably pockets of maximum vertical air movement and the ascent was not uniform throughout the line. A thunderstorm was observed at the Kelburn Meteorological Office between 1000 hours and 1100 on the 20th and it appeared to lie to the west or northwest. This indicated the position of one pocket of maximum vertical air-flow. The rainfall patterns in Figs 2 to 5 suggest that other pockets also existed, but their exact locations cannot be deduced from the limited information available. Figure 3, in particular, is of interest since it shows the time sequence of the rainfall during the storm, and suggests a lag with the rainfall beginning and ending first at the northeastern end of the convergence line. This lag is compatible with the northeasterly steering flow moving the main cumuliform rain-producing clouds southwestwards.

The picture which emerges of the intense rainfall producing system is one of a linear zone of very vigorous convergence which remained almost stationary over the area for about 12 hours. Within the zone the convergence was not uniform and centres of maximum ascending motion were continually reforming as they tended to drift southwestwards. This picture accounts for the double peaks of rainfall intensity observed at places north of the Wellington suburb of Newlands, and seen in the Maungaraki and Taita records of Fig. 3.

5. The Recurrence Interval of Comparable Storms

The extremely heavy rain on 20 December 1976 was undoubtedly a rare occurrence over the relatively small area of 200 km^2 to 400 km^2 which it affected. Extreme rainfalls of similar magnitude have been observed during this century in other places in New Zealand. The last similar occurrence in the Wellington Region was on 26 December 1939 and was an event worthy of brief mention here.

Figure 8 shows schematically the isohyetal pattern of the rainfall on 26 December 1939. During the period 0900 hours 26 December to 0900 hours 27 December there was a period of 10 to 12 hours of very intense rainfall. This rain was associated with a stationary frontal zone which lay east-west over the southern tip of the North Island. At Baring Head 387 mm of rain was recorded in 10½ hours and considering the effects of the rain and the general weather situation at the time, there is no reason to doubt that the recorded value was in error by more than a very small amount.

The picture of the atmospheric system that produced the heavy rain recorded at Baring Head is again that of a localised area of convergence and ascending air, which remained almost stationary over Baring Head and adjacent sea areas. In this case it is probable that the vertical air currents were reinforced by the orography. A land area of very approximately 100 km^2 received more than 200 mm of rain in 12 hours. The comparable area for the storm of 20 December 1976 was also 100 km^2 though no sea area was involved in this case.

To assess the return period of the rainfall on 20 December 1976 one can use statistical extreme value theory, and also look at the physical process that produced the rain. There are 3 separate processes capable of producing extreme rainfalls and in any particular storm one or more of them may be responsible. In the two cases described in this report, the dominant process was one of intense convergence and ascending air and the area affected was of the order of 200 km^2 to 400 km^2, over a period of about 12 hours.

The second main process is that of an active depression producing broadscale convergence, and in this case the area affected is likely to be larger and in the range 1000 km^2

to 3000 km^2. The duration of the rainfall may be longer but is unlikely to exceed 2 to 3 days. The third main process is that of orographic lifting of warm moist air. The areas where this can occur are obviously limited by the orography. The West Coast of the South Island would be a most suitable place. This orographic effect may often reinforce the first two processes. It is not possible to put a characteristic area to flood-producing rain from this cause, because of the very high variability which exists. However, the characteristic duration of such rain is likely to be several days but, in areas affected by monsoonal maritime flows such rain may continue for weeks.

Table 1 gives the 50 and 100 year return period values of daily rainfall at a selection of stations in the greater Wellington area. These values may be related to maximum 24 hour rainfalls by the method described by Robertson (1963). Daily series were used for these estimates since much longer series exist of daily values than of maximum 24 hour values. The last column of Table 1 gives the maximum 24 hour rainfall in the storm of 20 December 1976. Daily values are inappropriate for this storm since the heaviest rain straddled the 0900 hour recording time. The values in the last column also appear on Fig. 4.

Table 1. Estimates of the 50 and 100 year return period values for daily rainfall (mm) at a selection of stations with long period records in the Wellington area.

	Length of Record (years)	Maximum 1-day Rainfall Recorded*	Return Period Values of Daily Rainfall		Maximum 24-hr Rainfall in the Dec. 1976 Storm
			50 years	100 years	
Baring Head	40	387**	145	170	-
Beacon Hill	55	156**	150	175	-
Plimmerton	28	112	135	-	-
Brooklyn Reservoir	35	147	150	-	-
Kelburn***	113	161	140	160	153
Karori Reservoir	93	217	170	205	156
Trentham	45	146	150	175	-
Korokoro	28	118	135	-	-
Wallaceville	36	127	135	-	114
Waiwhetu	51	162	170	200	-
Lower Hutt	48	126	145	160	264
Wainuiomata	80	320	285	310	125
Orongorongo	48	265	265	285	-

* includes all data up to the end of 1975.
** on 26 December 1939.
*** at other Wellington sites prior to 1928.

It will be seen that even after allowance is made for the fact that the 24 hour values should be larger than the daily values, the Lower Hutt figure of 264 mm is still considerably greater than the estimated 100 year return period value. A similar conclusion would apply to the value of 288 mm recorded at Taita (see Fig. 4).

Figure 9 details the return period values for 12 and 24 hour rainfalls for sites on the floor of the lower Hutt Valley, and not immediately adjacent to the hills. On the adjacent hills the corresponding rainfall values would be larger. However, the storm of 20 December 1976 did affect quite a large area of the lower Hutt Valley floor and so the value of 264 mm measured at Avalon may be compared with the 24 hour line values of Fig. 9.

Figure 9 was constructed with reference to all available data from the lower Hutt Valley using the return period calculation techniques described by Robertson (1963). The standard error of the 100 year return period value of the 24 hour rainfall on Fig. 9 is 25 mm and this is the standard error of the estimate. Smaller standard errors of estimates apply to return periods of less than 100 years. For return periods of greater than 100 years the standard errors are at least 25 mm.

A comparison of the maximum rainfalls recorded in the storm of 20 December 1976 and the values shown on Fig. 9 leaves little doubt that the return period of this storm is greater than 100 years and possibly greater than 500 years. It is not possible to be confident that the return period is of the order of a much larger value, of say 1000 years or more (which the line would suggest) since the extreme values recorded in this storm may not be members of the family of extremes used to construct Fig. 9. From an experience extending over 100 years of recordings of rainfall in several places in New Zealand, there is no direct evidence that extremely rare events such as the rainfall of 20 December are not adequately dealt with by the extreme value theory used here.

Conclusions

The conclusions from this investigation are presented in the summary which appears at the beginning of this Report.

Acknowledgement

The author is grateful to Mr T. Grant-Taylor of the New Zealand Geological Survey, D.S.I.R. for supplying information about slope failure and mud flows throughout the area of the storm.

Reference

Robertson, N.G., 1963: The Frequency of High Intensity Rainfall in New Zealand. N.Z.Met.S.Misc.Pub. 118.

Fig. 1. The location of rainfall stations in the greater Wellington area. Manual and autographic stations are shown by a black dot. Unofficial manual stations are shown by an open circle.

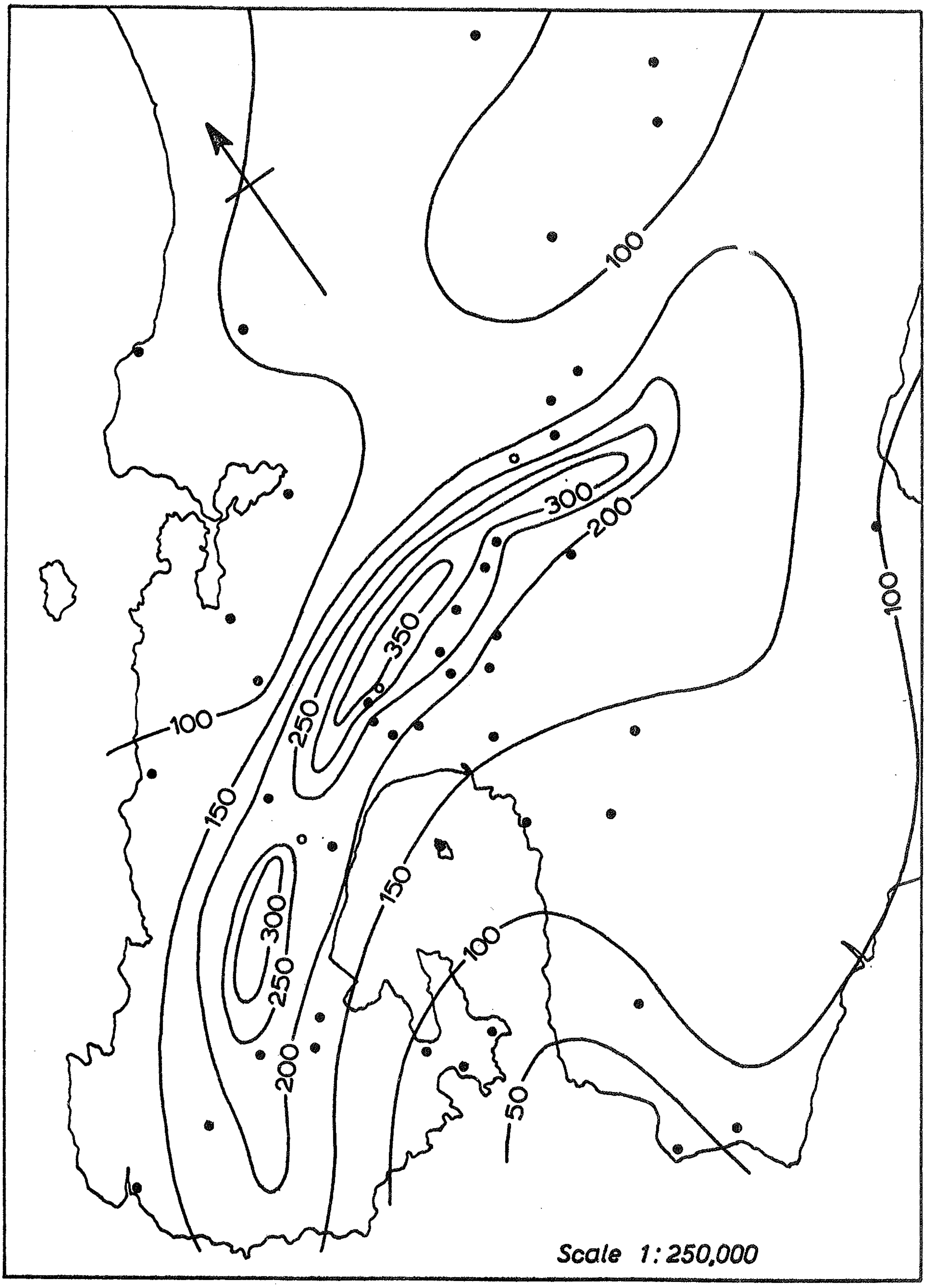


Fig. 2. The total rainfall over the 2 days 0900 hours 19 to 0900 hours 21 December 1976. The isohyets are drawn at 50 mm intervals from 50 mm to 350 mm.

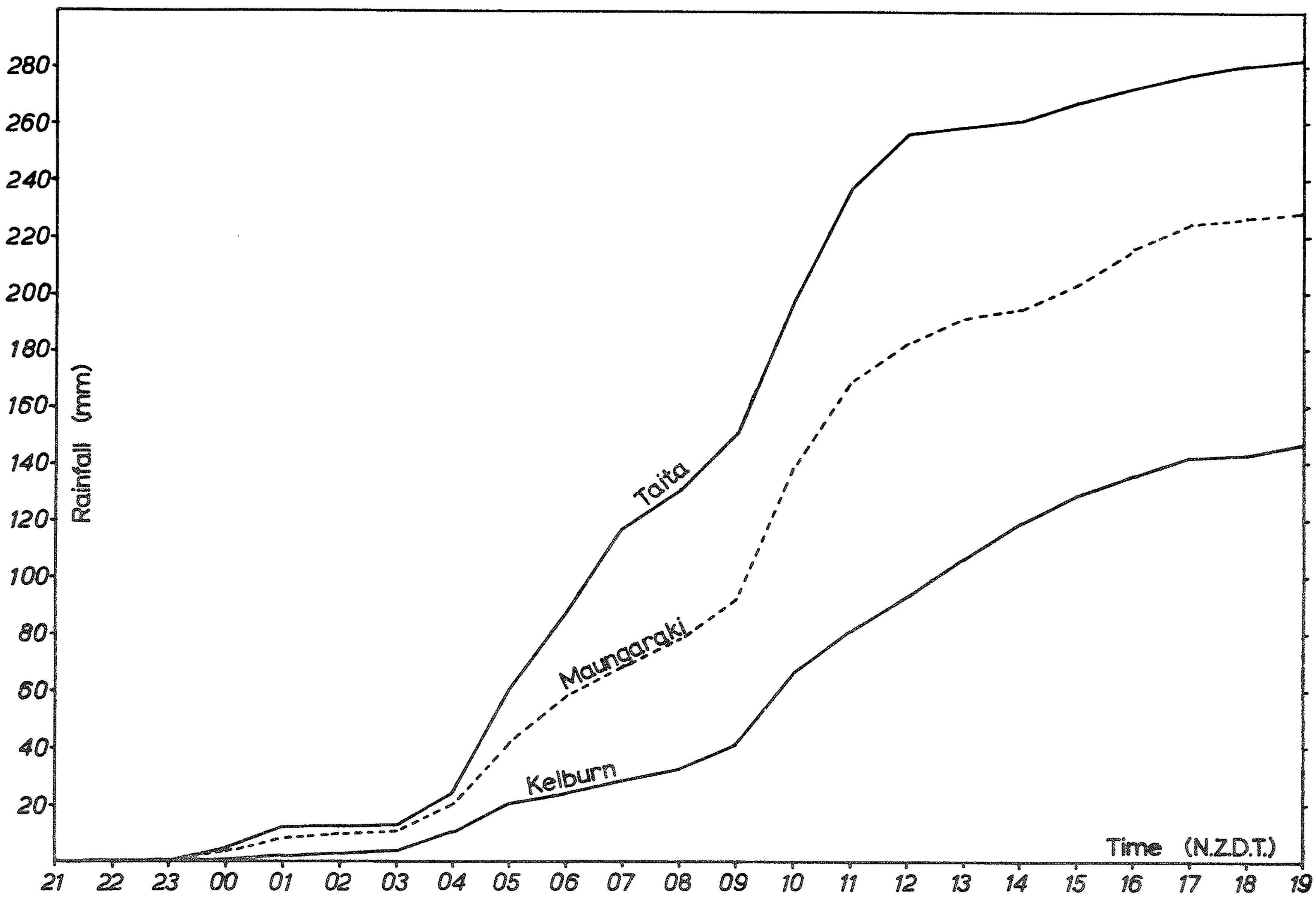


Fig. 3. The accumulation of rainfall from 2100 hours on 19 to 1900 hours on 20 December 1976 at Taita, Maungaraki and Kelburn.

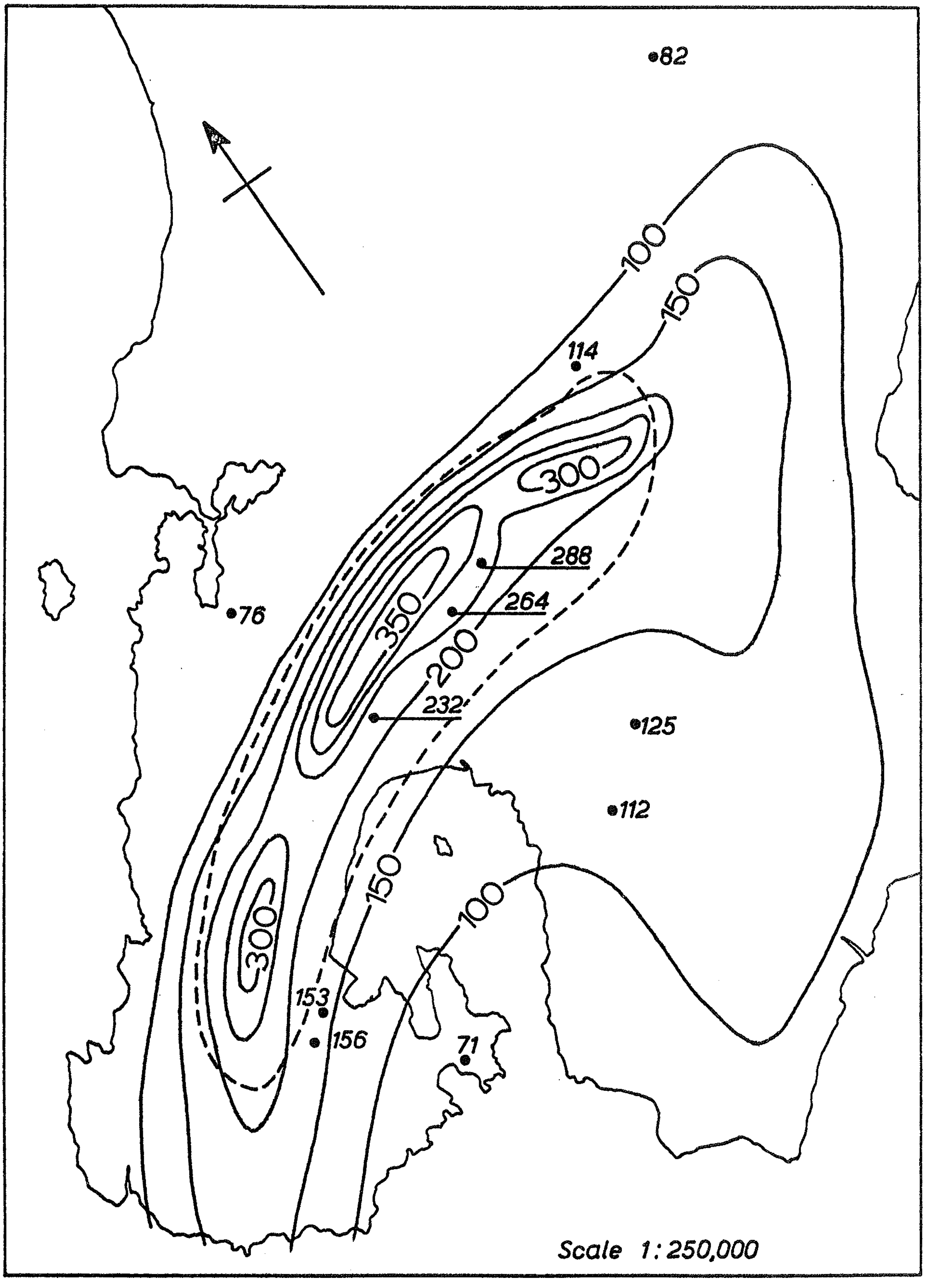
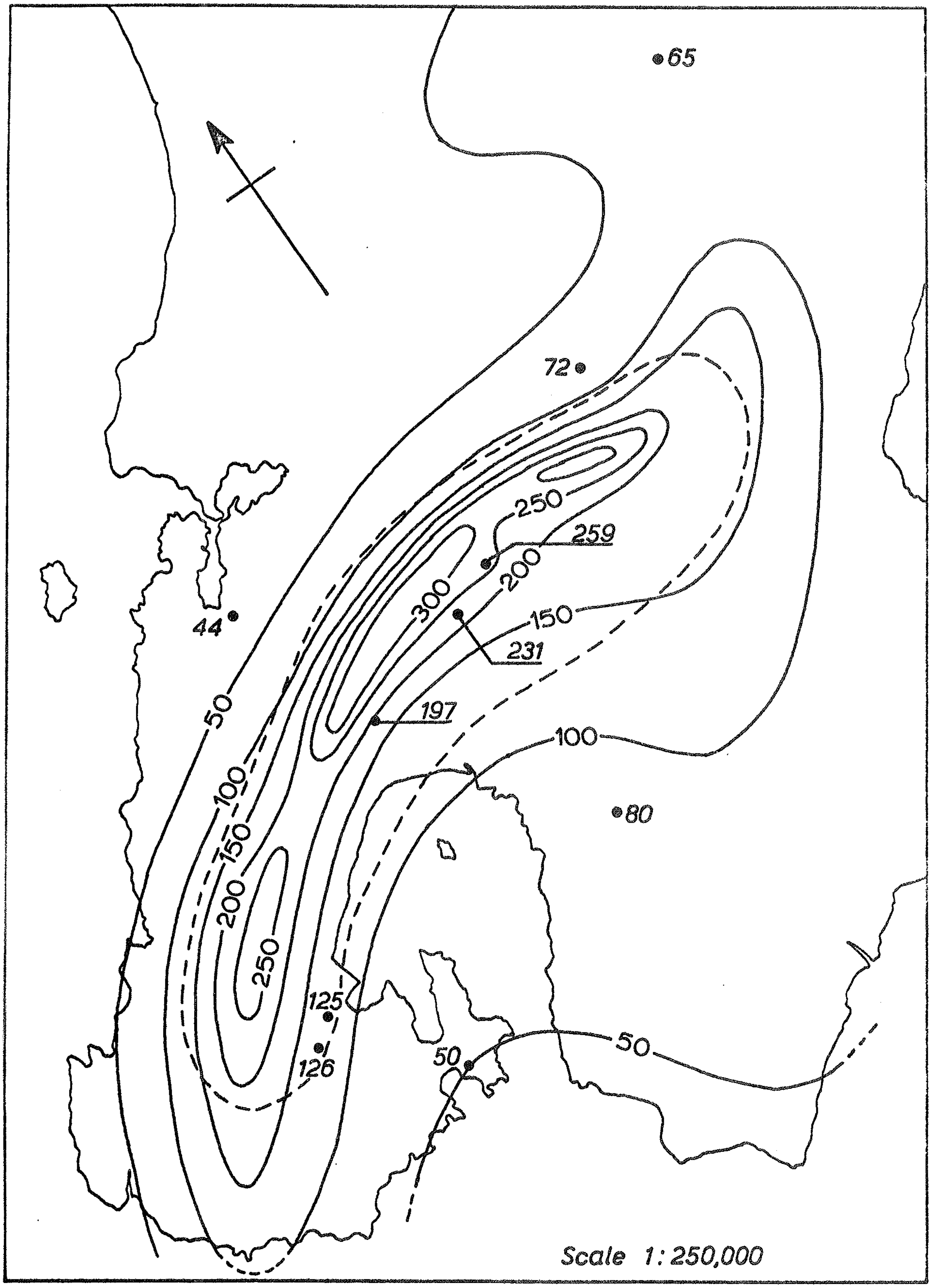


Fig. 4. The maximum recorded rainfall in 24 hours during 19 and 20 December 1976. The isohyets are drawn at 50 mm intervals. The locations of autographic rainfall recording stations are indicated by dots and the values recorded at these stations are plotted. All points within the dashed line received 24 hour rainfalls of return period greater than 50 years.



5. The maximum recorded rainfalls in 12 hours on 20 December 1976. The isohyets are drawn at 50 mm intervals. The locations of autographic rainfall recording stations are indicated by dots and the values recorded at these stations are plotted. All points within the dashed line received 12 hour rainfalls of return period greater than 50 years.

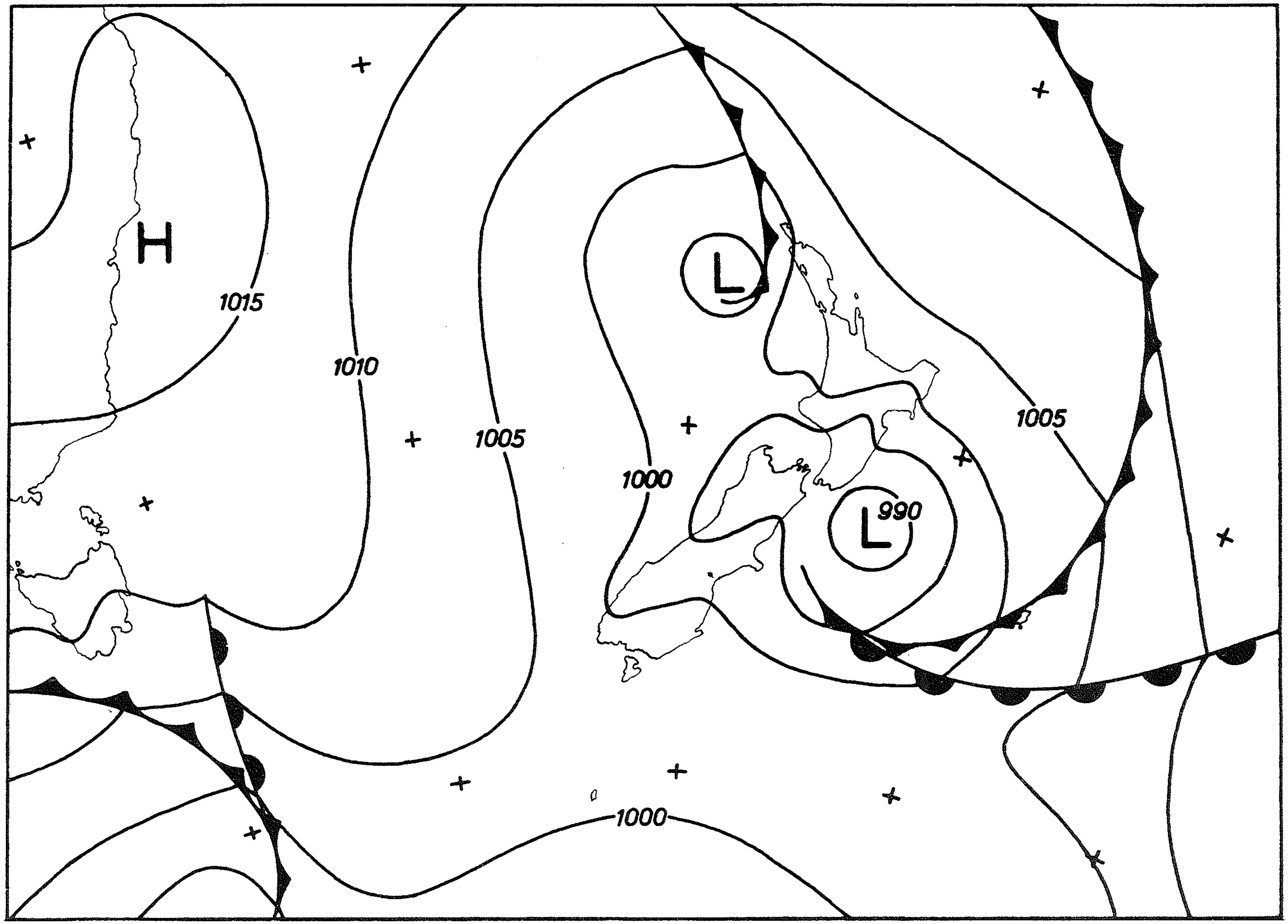


Fig. 6. The weather situation at 0600 hours on 20 December 1976. Isobars are labelled in millibars; centres of anticyclones and depressions are marked by H and L respectively; cold fronts and warm fronts are indicated as ▲▲▲ and ●●● respectively.

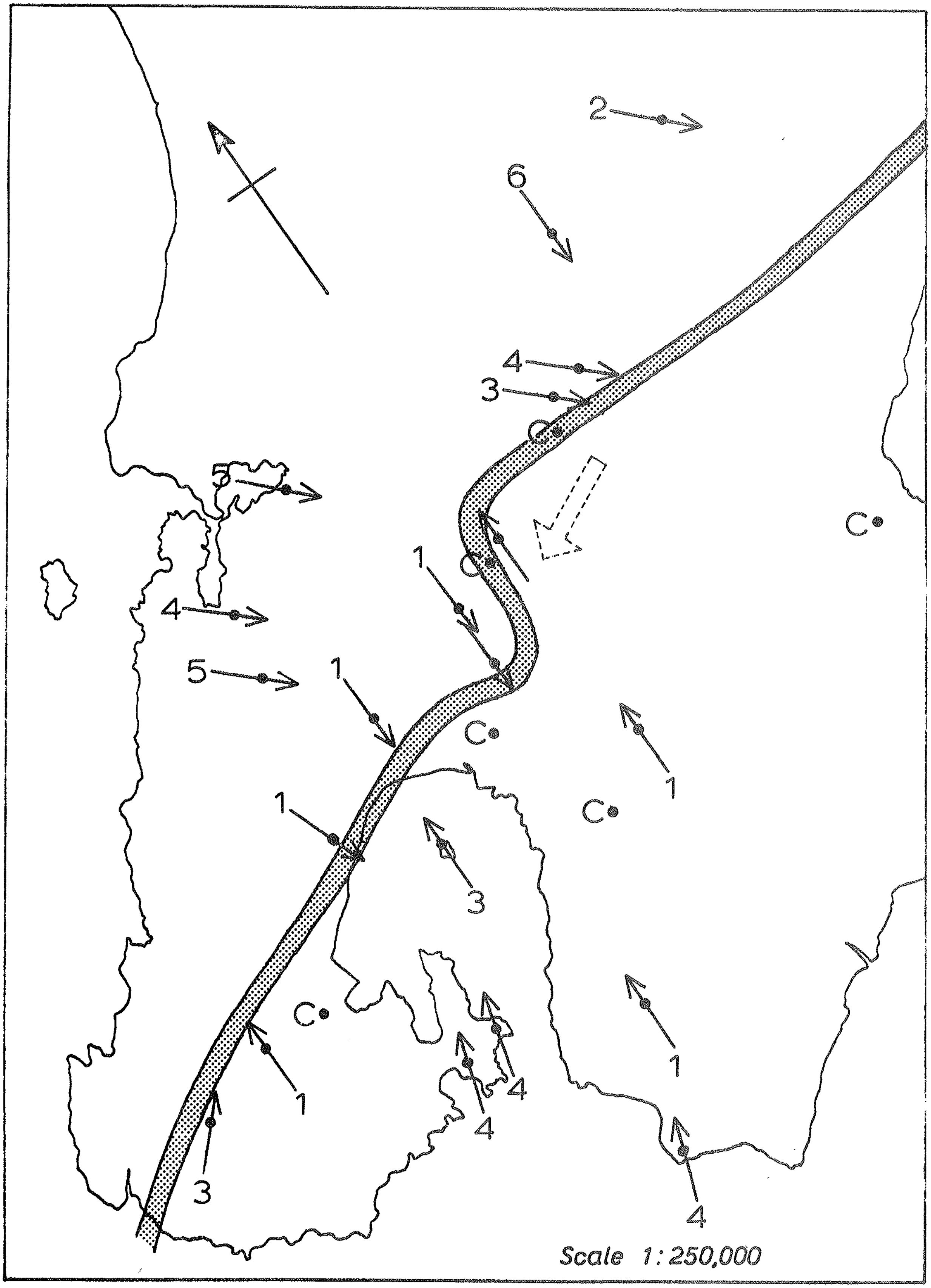


Fig. 7. Local wind velocities at 0900 hours on 20 December 1976. At each observation point (black dot) the arrow indicates the direction towards which the wind was blowing and the number is the Beaufort wind force (where C indicates calm conditions). The dashed arrow indicates the direction of the steering flow and the broad line is a line of convergence.

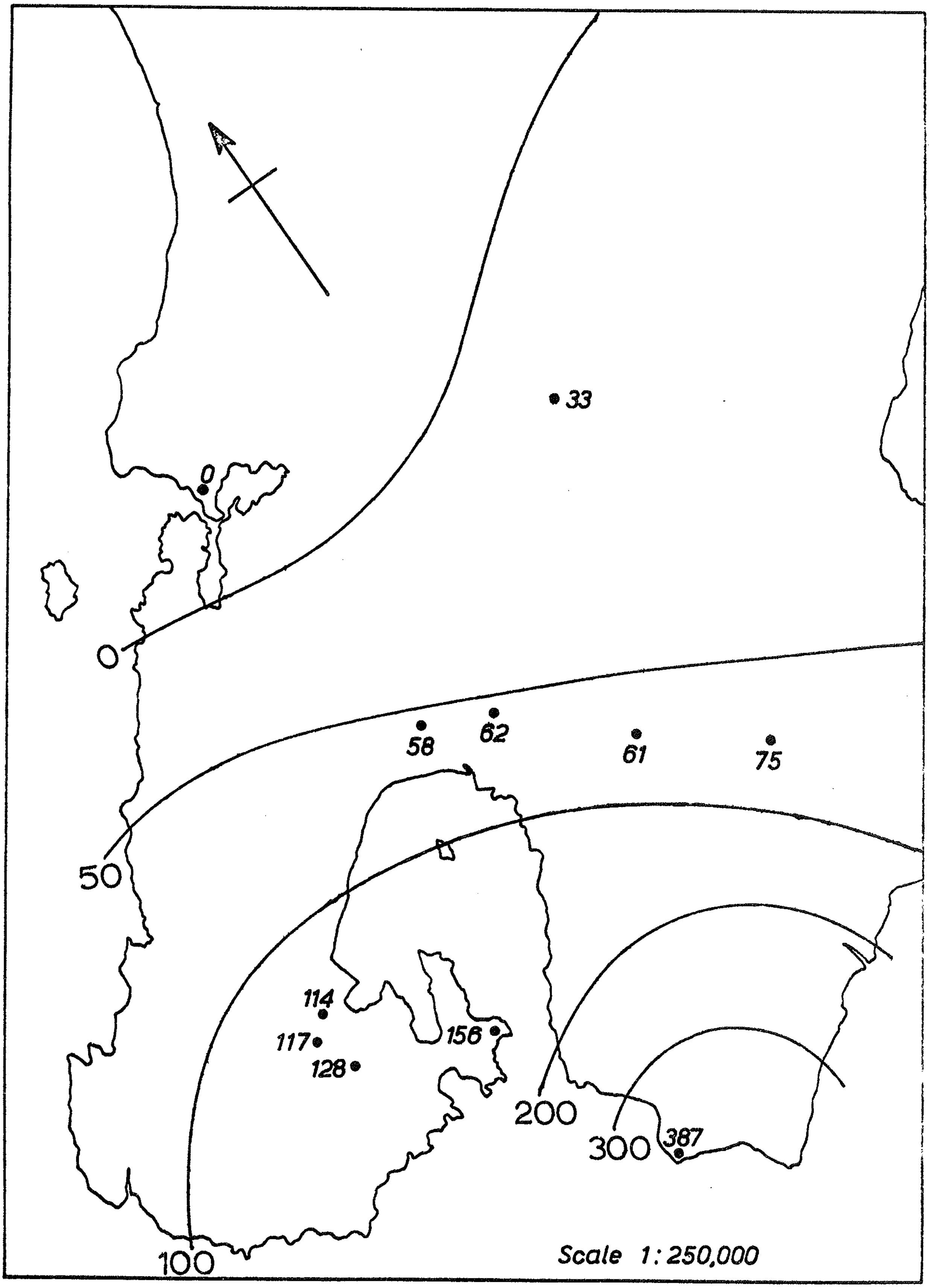


Fig. 8. Schematic isohyets for the daily rainfall on 26 December 1939. The isohyets (in mm) are based on the rainfall observations plotted on the map and the weather situation at that time.

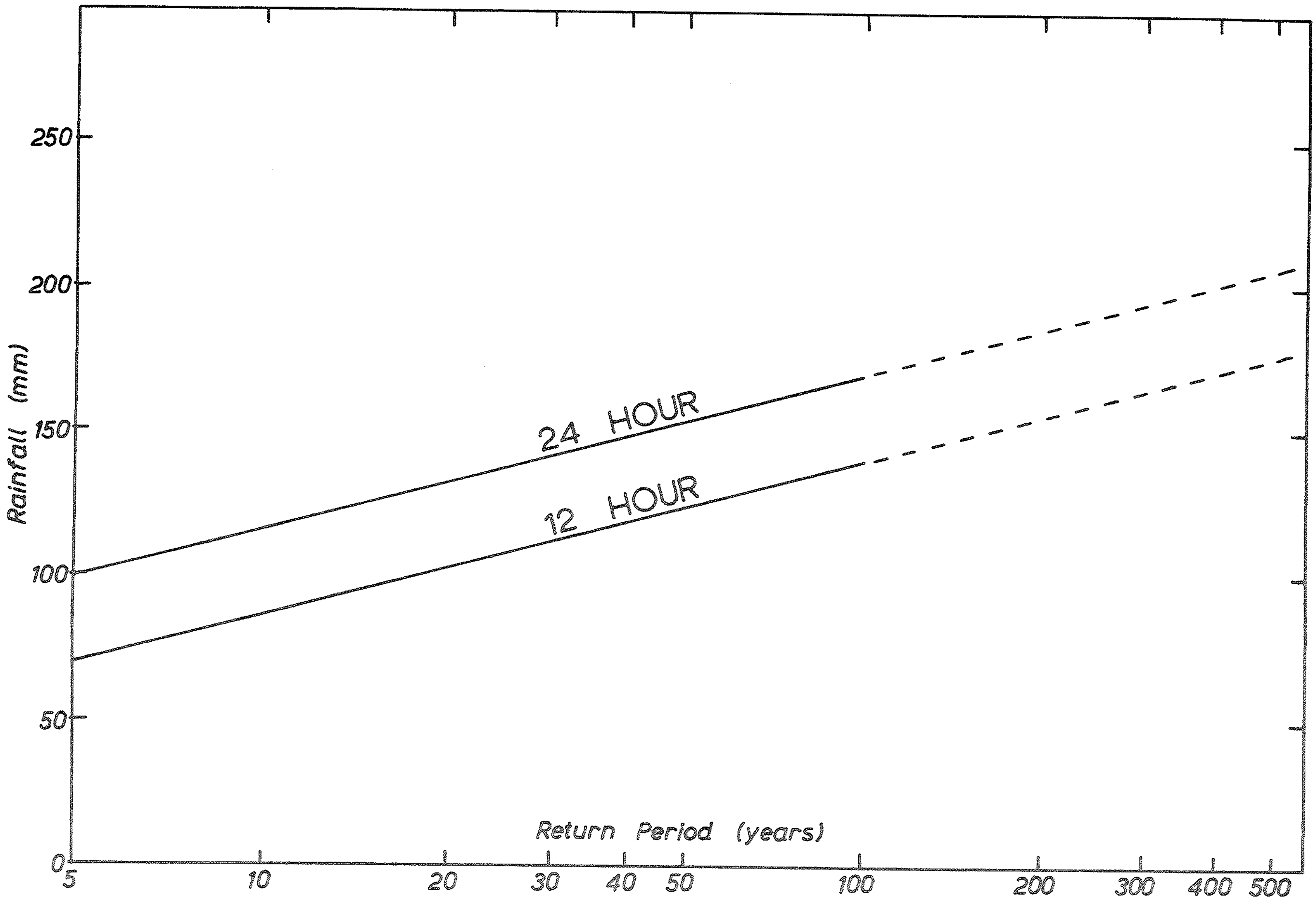


Fig. 9. Graphs of the return period of 24 and 12 hour rainfalls at sites on the floor of the lower Hutt Valley (and not immediately adjacent to the hills). For return periods above 100 years the graphs must be interpreted with caution (see section 5 of the text).