Bob Curry

Ministry of Works and Development

REVIEW OF MANGAHAO POWER SCHEME HYDROLOGY

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REVIEW OF MANGAHAO POWER SCHEME HYDROLOGY

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Power Division
HEAD OFFICE

19 March 1981

Mr A V Hatrick
Chief Development Engineer
HEAD OFFICE

MANGAHAO POWER STATION
REVIEW OF HYDROLOGY

With this is a report on the hydrology of the catchment of the Mangahao power station. So far as is known it is the first study undertaken since the station was designed before 1921. The work has been carried out by Mr D C Riddell who has had to enquire widely for scarce fundamental data and has displayed considerable ingenuity in assembling and using it. The work has been under the general supervision of Mr Jowett.

The findings of the study merit consideration by those concerned in operating and maintaining the station.

While the station as designed is confirmed as meeting normal design flood requirements the fact that the earth section of No 2 dam has settled should be noted for remedial action, similarly the fact should be noted that a significant proportion of the water potentially available for generation is running to waste either by design or malfunctioning of the automatic spillway at No 2 dam.

The dams are all liable to be overtopped if a Probable Maximum Flood should occur. There is no means of forecasting the likely occurrence of such an extremely rare event, and there is no reason to expect that with proper maintenance catastrophic failure of any of the dams would occur, but a design review of the need for maintenance work may be judged desirable.

Rainfall data in the Tararuas is scarce and extremely difficult to obtain. During the past few years there has been established a network of high level raingauges. None is in the catchment and few adjacent. Also rainfall in the area is highly localised. However, a review of the data could be revealing if undertaken after 10 to 15 years, and a review of the current work is recommended in the 1990's.

In the meantime I recommend that this report be given the usual distribution and a copy be placed on the open list in the library.

G G Natusch

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REVIEW OF MANGAHAO POWER SCHEME HYDROLOGY

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1 INTRODUCTION

1.1 Location

That part of the Mangahao river catchment above the lower dam stretches SW-NE along the western side of the main ridge of the Tararua Ranges (Fig 1.1). The head of the Mangahao catchment is at latitude 40°45' south and the river drains north-eastwards except for a stretch two or three kilometres below the lower dam where the river flows eastwards via a gorge though the main Tararua ridge to the eastern side of the range. The river then continues in a north-easterly direction and joins the Manawatu River just south of Woodville.

1.2 History

A detailed account of Mangahao hydroelectric development is given in a souvenir descriptive pamphlet which was published for the official opening of the scheme in 1924 (Furkett, 1924).

The Mangahao appears to have been first investigated as a source of power in 1906, but it was late in 1915 before the first surveys, including rainfall and river gaugings were commenced. Road access was started in 1919, and construction work on tunnels and dams commenced in 1920.

1.3 General Layout

The layout of the scheme as it stands today is shown in Fig 1.2. Basically the scheme consists of two dams on the Mangahao River and a single dam (Arapeti) on the headwaters of the neighbouring Tokomaru River.

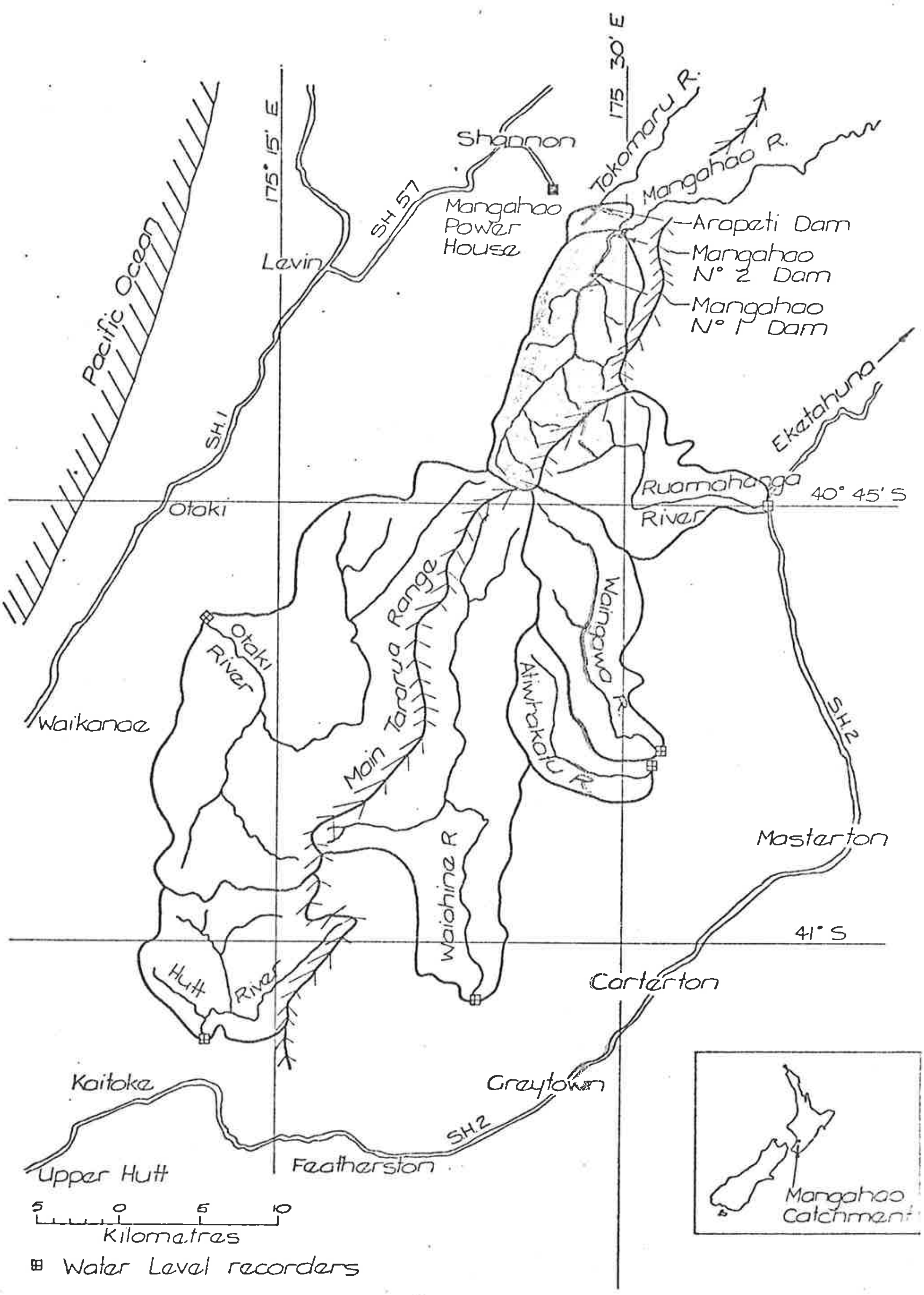

Fig. 1·1 Location of Mangahao and surrounding catchments

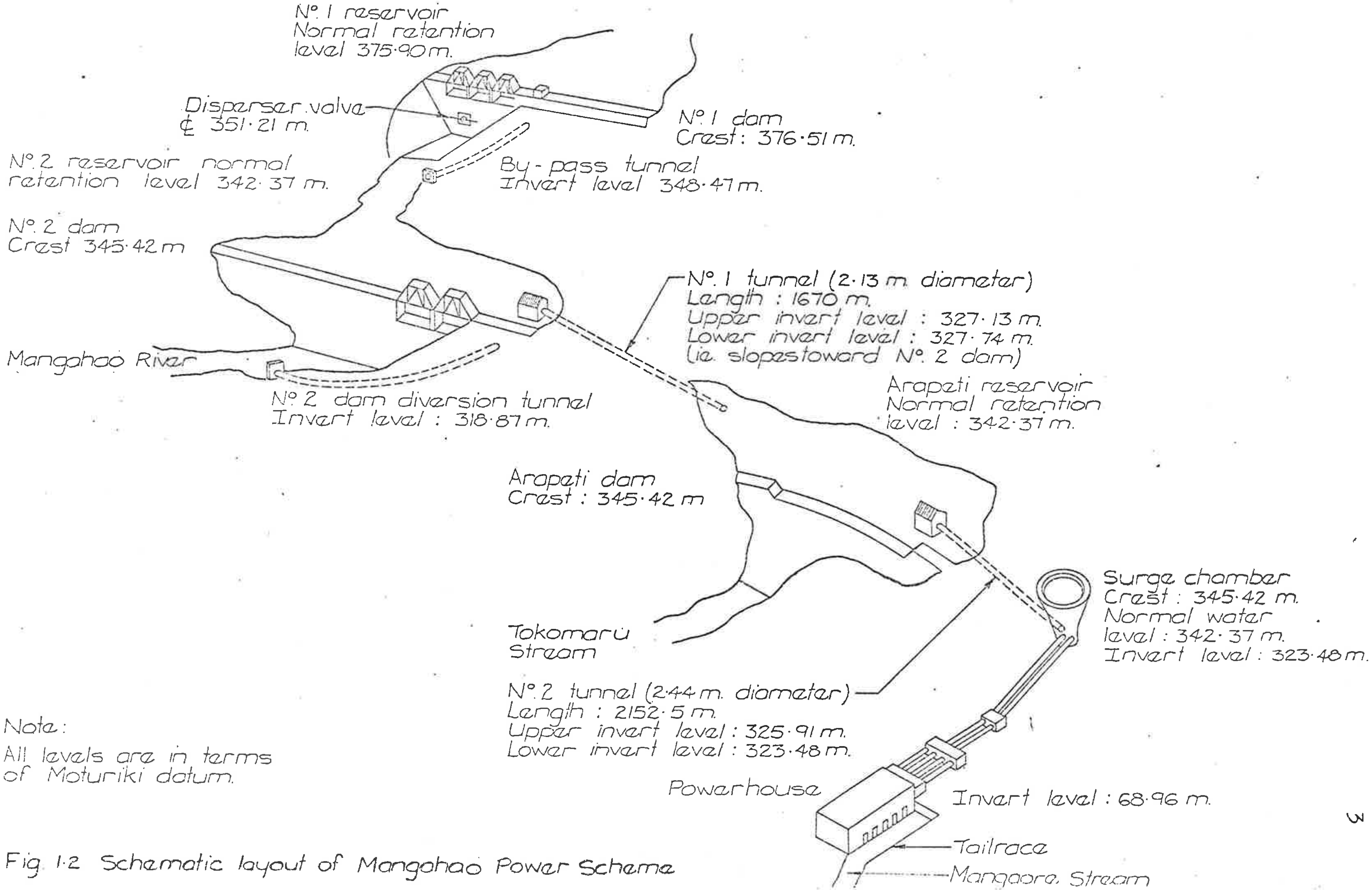

Fig. 1·2 Schematic layout of Mangahao Power Scheme

Water is diverted from the Mangahao into the Arapeti reservoir via a tunnel from the lower (No.2) Mangahao dam. From the Arapeti reservoir a second tunnel leads the water to a surge chamber, at the same level, on the western slopes of the Tararuas. From the surge chamber penstocks lead to the Mangahao powerhouse adjacent to the Mangaore stream.

Operating levels of the three reservoirs are:

Reservoir	Maximum Control Level m.a.s.l. Moturiki datum	Maximum Control Level feet Mangahao datum	Minimum Control Level m.a.s.l. Moturiki datum	Minimum Control Level feet Mangahao datum	Reservoir area (km^2) at max. control level
Upper Mangahao	375.87	1360	363.72	1320	0.440
Lower Mangahao	342.37	1250	339.32	1240	0.192
Arapeti	342.37	1250	340.87	1245	0.073

Normal retention level of the surge chamber is equal to the maximum control level of Arapeti (342.37 m). The invert level of the Mangahao power station is 68.96 m. (N.B. levels are to mean sea level Moturiki datum unless stated otherwise).

When officially opened on 3 November 1924 only the Arapeti and the lower Mangahao dams had been built, but the third dam was constructed in 1925-28.

Control of storage in the No.1 reservoir is achieved by operation of the disperser valve but flows in excess of the disperser valve capacity are spilt via three spillway gates which operate automatically with reservoir level.

All water from No.1 dam, whether spilt or passed through the valve, flows into No.2 dam, from where it is diverted into the Arapeti reservoir. Flows in excess of the tunnel capacity, or those required for generation, are spilt via two automatic gates (similar to those at the No.1 dam) down the Mangahao River.

1.4 Catchment Description

Total area of the Mangahao River catchment from its confluence with the Manawatu River is about 275 km^2, but the catchment area of the lower dam is 81.3 km^2. The catchment area of the upper dam is 72.1 km^2, and that of the Arapeti is 5.1 km^2.

Vegetation of the Mangahao catchment is nearly all native forest with only a small area of snow tussock at higher altitudes and a small cleared area between No.1 and 2 dams.

Geology of the western Tararuas comprises alternating dark grey argillite and greywacke sandstone of Jurassic age. Many faults run parallel to the Tararua Range; the upper Mangahao river lies along one fault line and another fault lies to the west of the catchment. While these two faults have shown no sign of late Quarternary movement, the Wellington fault which lies on the eastern side of the Tararua Range, and about 3 km east of the Mangahao catchment, is still very active (Kingma, 1967).

Elevation of the Mangahao catchment ranges from 1576 m (4975 ft) at Arete on the southern divide to 339 m (1113 ft) at No.2 dam. Four percent of the catchment lies above 1200 m, 19% lies above 900 m, and 62% lies above 600 m. Median elevation is about 600 m.

2 PRECIPITATION

2.1 General

Although most of the precipitation in the Mangahao occurs as rain, snow can occur on the higher altitude parts of the catchment during three or four of the winter months. No measurements are known to have been made of the seasonal Tararua snow pack and while the significance of the snow is not great, it has been observed at Mangahao that the thawed snow does augment the spring inflows into the reservoirs. Most of the thaw usually occurs before September.

2.2 Seasonal Distribution of Rainfall

In general rain occurs on more than half the days in a year. In the period 1960-1980 there were an average 174 rain-days (i.e. days with more than zero rainfall) at the Mangahao power station and 215 at the Upper Mangahao dam. At the Lower Mangahao dam there were an average 198 rain-days/year for the period 1967 to 1979. The seasonal frequency of rain-days for these three stations is shown in Fig 2.1 from which it is apparent that the greatest number of rain-days per month occur in July, September

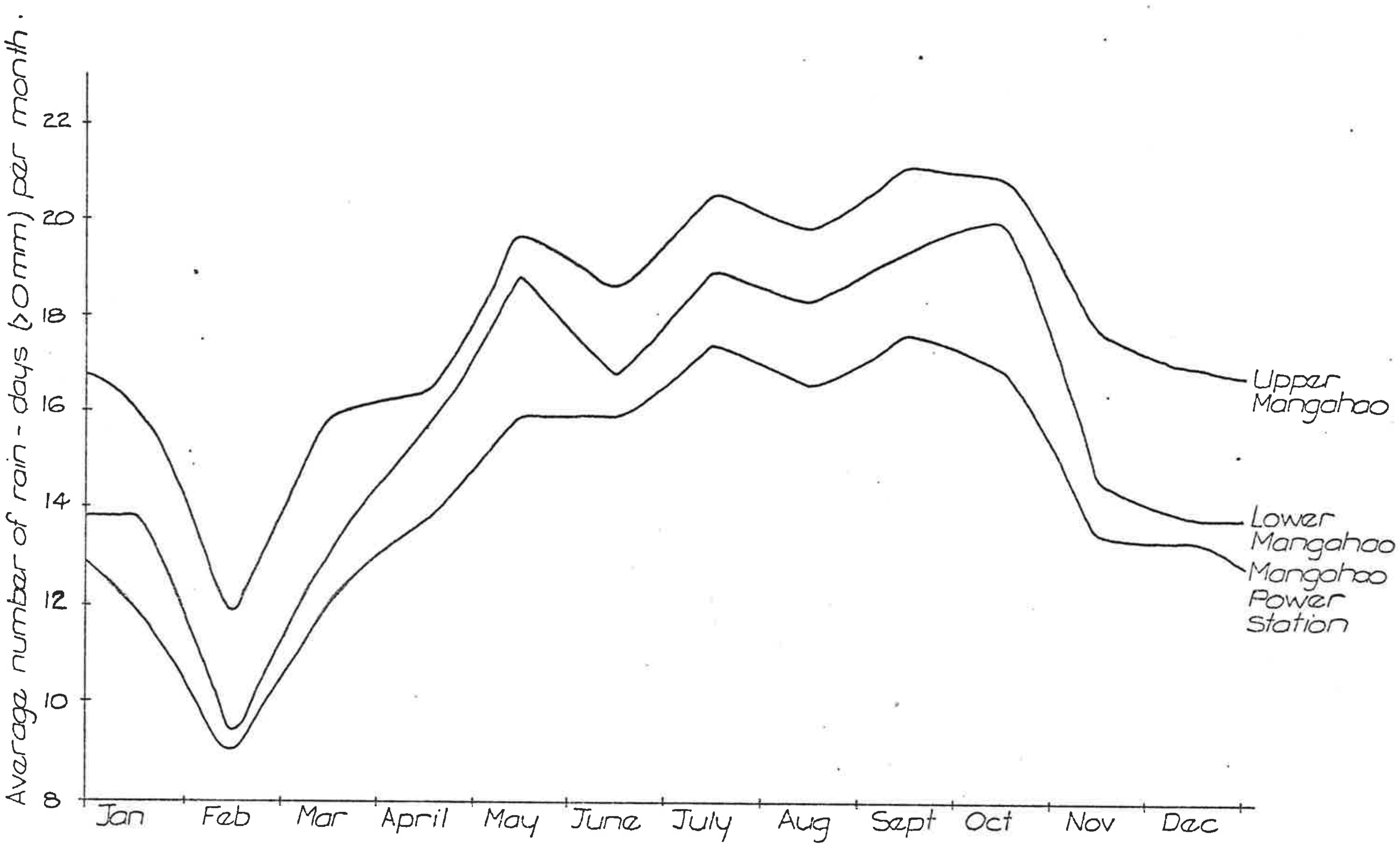

Fig. 2·1 Mangahao - Seasonal frequency of rain - days (1960 to 1980) and October. Conversely the least number of rain-days are experienced in the summer and autumn months of November to April inclusive, with February having the least of any month.

The seasonal distribution of rainfall has the same general pattern as the distribution of rain-days (Fig 2.2) with winter and spring being the wettest seasons and summer and autumn being the driest. February was the driest of all months. While the seasonal pattern of rainfall was similar at the three sites examined, the Upper Mangahao data showed an unusual peak in March (Fig 2.2). Another noticeable feature was that December rainfall was relatively high in relation to the number of rain-days in that month (Figs 2.1 and 2.2).

The seasonal frequency of rainfall is largely related to the frequency with which low pressure systems and fronts cross the Tararua region. Associated with these weather sequences are northwesterly and westerly winds with which most heavy rainfalls in the Tararuas are associated (Coulter 1966). A cursory examination of wind data recorded over many years at Levin, revealed that both wind gusts and daily wind run were highest in the winter and spring months. On average the windiest month was November and the least windy April; similarly the month with the most gusts of 34 knots or greater was October and the month with the least number of gusts was February.

2.3 Mean Annual Rainfall

The absence of a raingauge network in the Mangahao catchment meant that the average catchment rainfall for single storm events

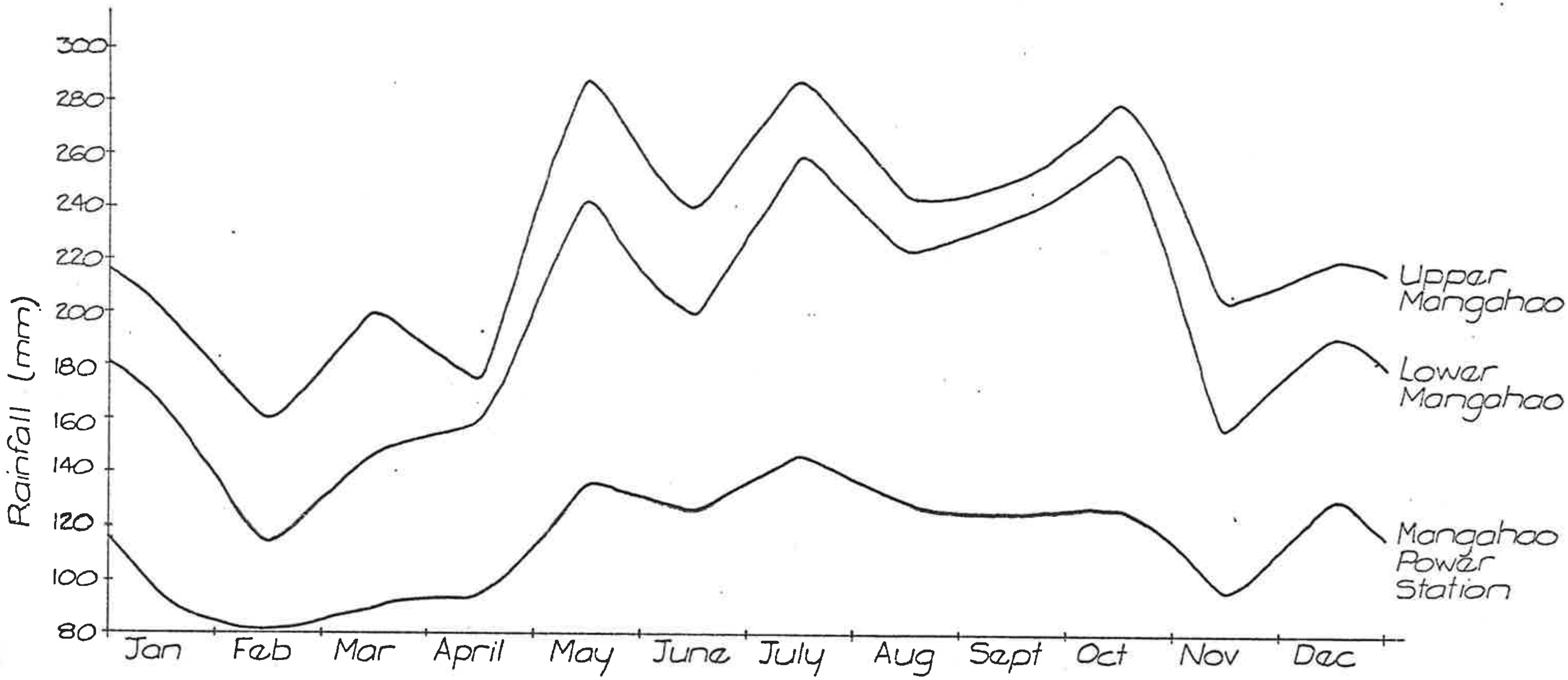

Fig. 2·2 Seasonal variation of mean monthly rainfall could not be accurately calculated. Mean annual rainfall was estimated from the records of 16 raingauges within a radius of 16 kilometres from the centre of the Mangahao catchment, including two storage gauges located on the southern high-altitude catchment divide. Isohyets were fitted through the point rainfalls and the mean annual rainfall obtained was 3750 mm (Fig 2.3).

Taking into account an estimate of water lost through the gate counter balance chamber at No.2 dam (see section 3.1) the mean outflow (1960 to 1980) from the No.2 dam and Arapeti catchments was approx. 8.6 m^3/s, a mean annual runoff of 3140 mm. Subtracting this from the mean annual rainfall estimate of 3750 mm gives an evaporation of 610 mm/year.

Comparison was made with the water balance of the Hutt River catchment where a network of raingauges was established in early 1972. The Hutt catchment, which is roughly the same area as the Mangahao, lies about 30 km SSW of the Mangahao catchment at the southern end of the Tararuas. Although in a different climatic region (Fig 1.1) and subject more to southerly than westerly weather, the annual evaporation should be similar to the Mangahao area. For the period 1972 to 1980 the mean annual rainfall for the Hutt was found, by fitting isohyets to the point rainfall, to be 3525 mm. Mean flow measured at Kaitoke (catchment area 88.8 km^2) for the same period was 8.2 m^3/s which is equivalent to a runoff of 2900 mm/year. Thus the mean evaporation from the Hutt catchment is 3525 - 2900 = 625 mm/yr which is only slightly more than that derived for the Mangahao. This confirms that the water balance derived for the Mangahao is acceptable.

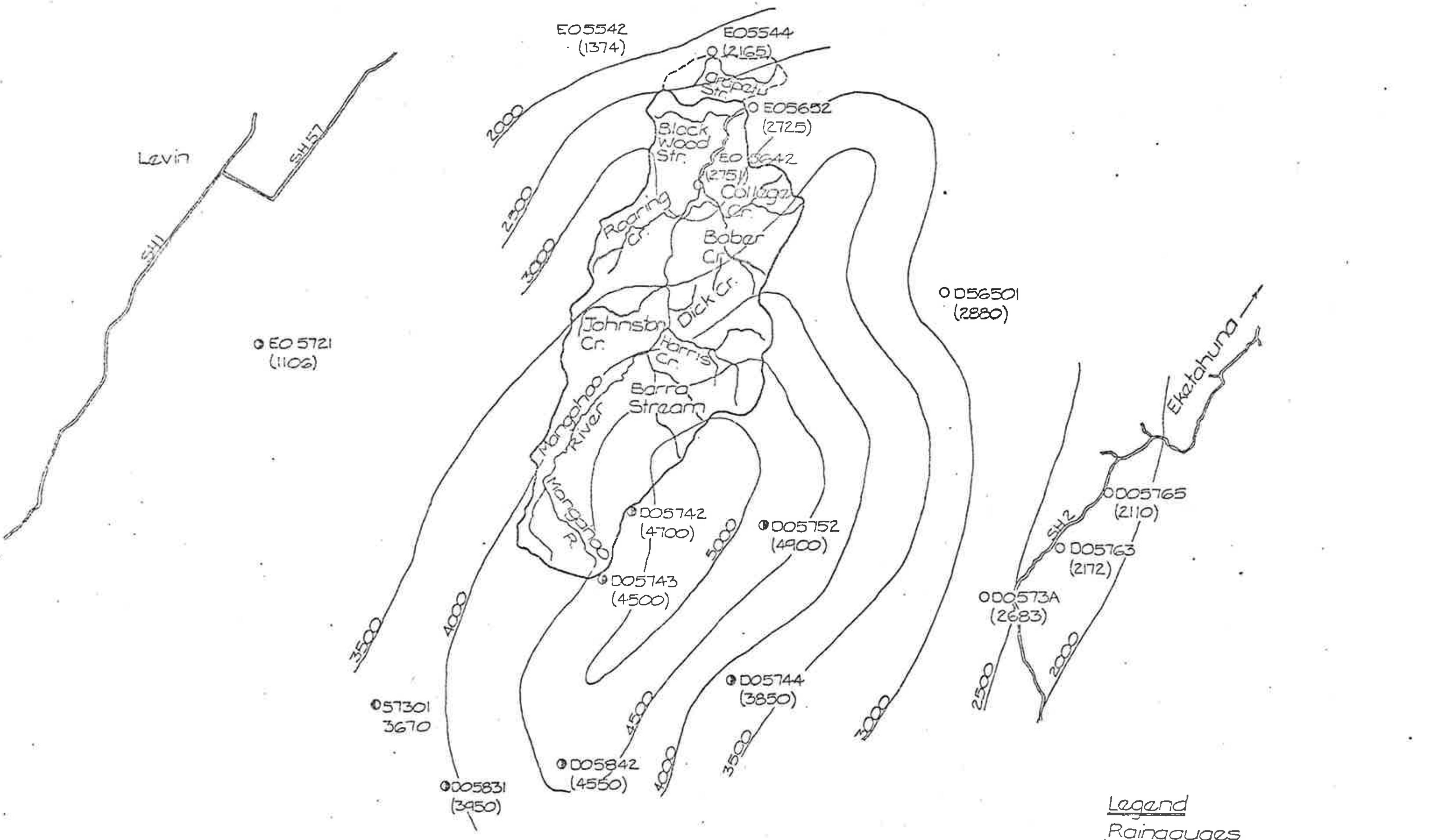

Fig. 2·3 Mangahao mean annual precipitation

Legend
Raingauges
⊗ NZMS closed
○ NZMS manual
◑ NZMS octapent
◐ MWD storage
E05542 station number
(1374) mean annual rainfall

2.4 Storm Events

Recording of rainfall on a regular basis was commenced in 1916 when gauges were established at each of the three dam sites (i.e. Upper and Lower Mangahao dams, and Arapeti), and at the Mangahao power station site. Daily readings of the power station and Upper Mangahao gauges have been taken since that time but much of the record of the Arapeti and Lower Mangahao gauges consists of readings taken at three or four day intervals.

The five largest one, two and three day (8:30 am to 8:30 am) rainfalls recorded at the Upper Mangahao dam since 1916, and their dates of occurrence are:

1 day	339 mm	22 December 1936
	287 mm	27 October 1935
	182 mm	28 October 1945
	171 mm	19 March 1942
	163 mm	15 May 1972
2 day	468 mm	27/28 October 1935
	407 mm	22/23 December 1936
	309 mm	5/6 February 1943
	289 mm	27/28 October 1945
	267 mm	12/13 January 1962

3 day	575 mm	27-29 October 1935
	416 mm	21-23 December 1936
	392 mm	5-7 February 1943
	376 mm	13-15 May 1972
	321 mm	26-28 October 1945

2.5 Synoptic Situations Associated with Large Rainfalls

Heavy rainfalls in the Tararua Ranges are typically associated with northwesterly and westerly air flows which move from the Tasman sea across the southern North Island.

The largest one day rainfall recorded at Upper Mangahao on 22 December 1936 occurred with a westerly airflow. According to information on Public Works Department file 9/6/1 the rainfall commenced about 3 a.m. on the morning of the 22/12/36, and was heaviest between 8.00 a.m. and 11.30 a.m. when more than 200 mm of rainfall was recorded (the raingauge had actually overflowed by the time it was emptied at 11.30 a.m.). For the 29 hours ending at 8.00 a.m. on December 23 the total storm rainfall recorded at Upper Mangahao was 407 mm. The situation which gave rise to this exceptionally large rainfall is depicted in Fig 2.4. An area of low pressure covered central New Zealand with centres of low pressure west of Westland and east of Cook Strait. From Fig 2.4 it is evident that associated with this low pressure area was a frontal zone which lay across southern North Island on the morning of 22/12/36. North of this zone the winds were west to north-west, and south of it southerly winds prevailed. The rain-

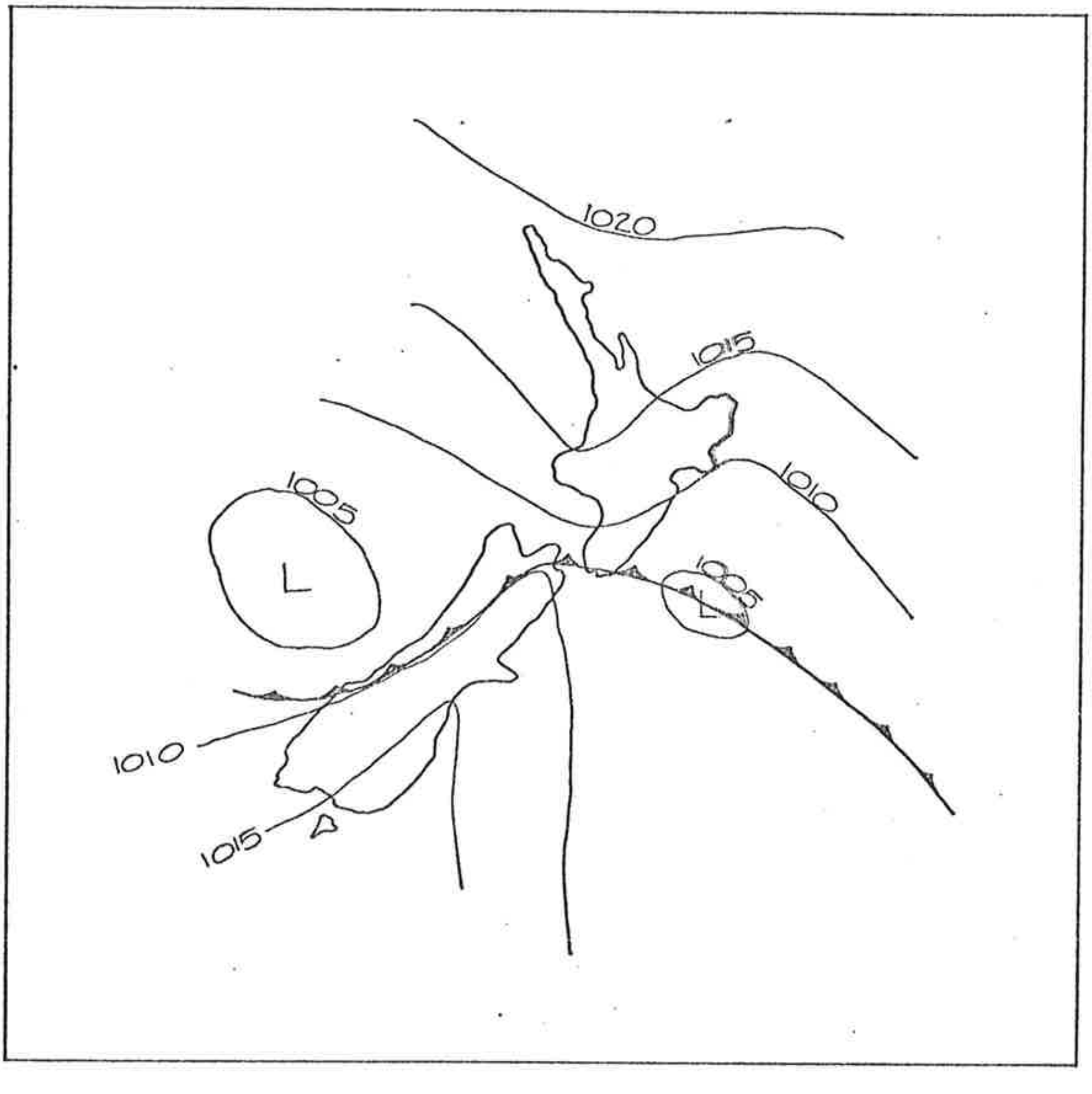

Fig. 2.4 Meteorological conditions on the morning of 22 December 1936

fall recorded at Mangahao appears to have resulted from intense convergence of these airflows ahead of the frontal zone. At Upper Mangahao light northerly winds were recorded at 8.00 a.m. on the 22 and a light southerly breeze was recorded at 8.00 a.m. on the 23. By this time the cold front had weakened and moved northwards to lie across the lower-central North Island.

The highest two and three day, and the second highest one day rainfall recorded at Upper Mangahao occurred in October 1935. The situation associated with this event is shown in Fig 2.5. A westerly airflow covered New Zealand and a cold front advanced eastwards onto the country (Fig 2.5a). Gradually this front developed into two low pressure centres, one on either side of the South Island, and a west to north-westerly airstream extended across the North Island (Fig 2.5b). The majority of rainfall recorded at Upper Mangahao fell in the 24 hours to 8.00 a.m. on October 29 (287 mm), but 181 mm fell in the previous 24 hours and 107 mm in the following 24 hours to 8.00 a.m. on October 30. Wind at Upper Mangahao on each of the three days was recorded as a slight to gentle nor-westerly. From Fig 2.5 it appears that north-westerly winds carried moisture-laden air onto the country and this was intercepted by mountain ranges such as the Tararuras. Rainfall on the 27-28 of October preceded passage of the front over the area but heavy rainfall on the 28-29 occurred when the front moved across the region. Similarly rainfall on the 29-30 accompanied the passage of the second front shown in Fig 2.5b. At lower altitudes the rainfall was not unusually high; for example at Kelburn (Wellington) only 43 mm was recorded over the five days from the 27 to 31 October.

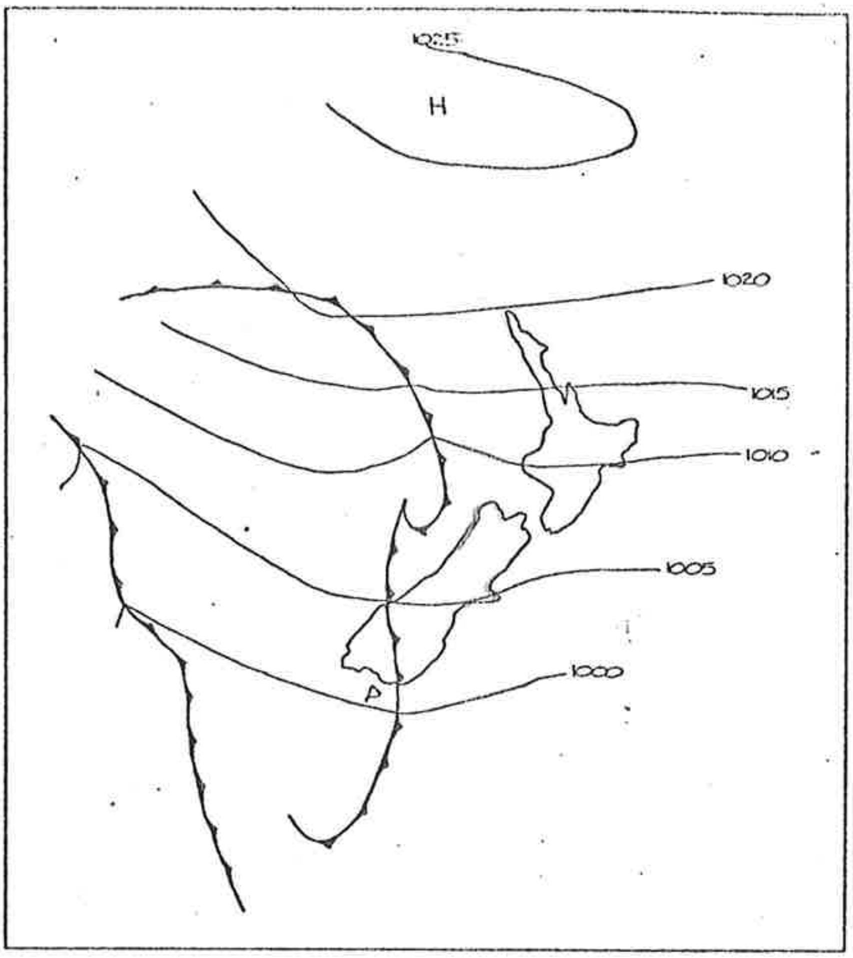

Fig. 2·5(a) Meteorological conditions on 28 October 1935

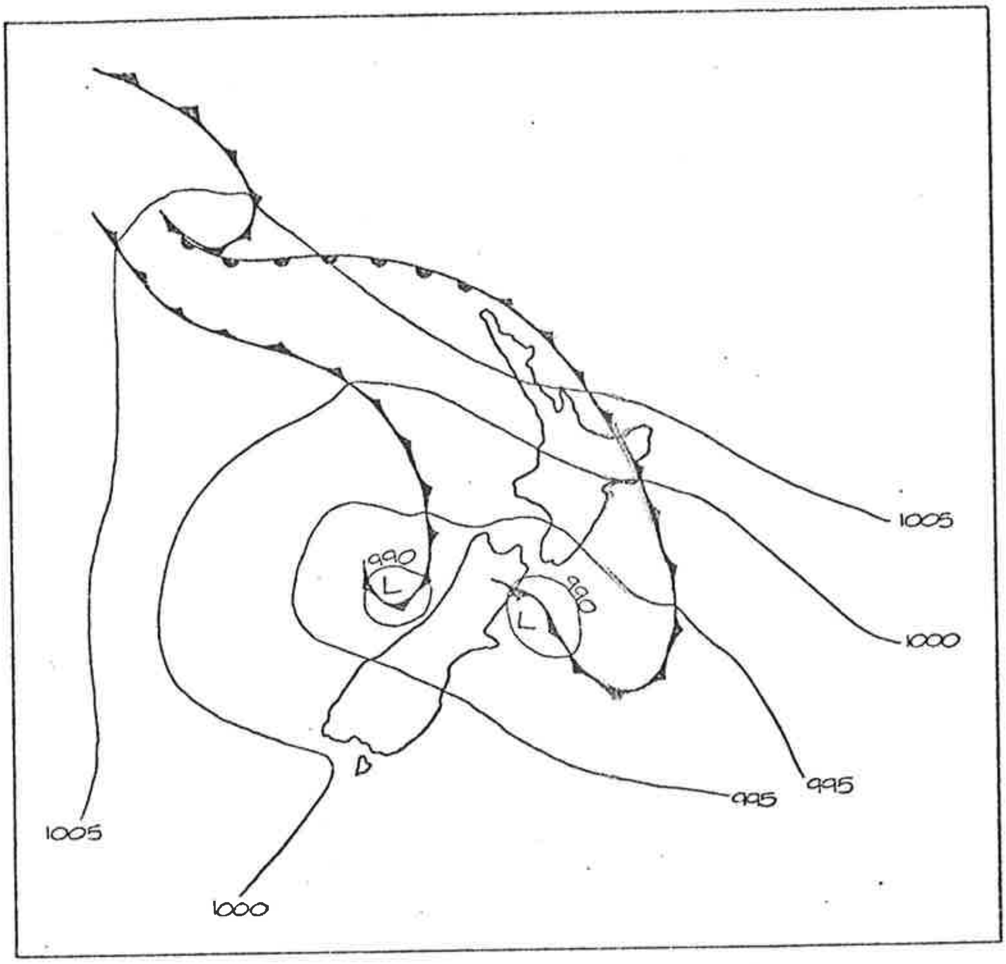

Fig. 2·5(b) Meteorological conditions on 29 October 1935

2.6 Rainfall Frequency Analyses

The one, two and three day annual maximum rainfalls from Mangahao Power Station, and the Upper and Lower Mangahao dams were analysed by Gumbel's frequency method. Results of these analyses are presented in Table 2.1 and depth-duration-frequency curves constructed from this data are shown in Fig 2.6.

TABLE 2.1: Rainfall Depth-Duration-Frequencies

Station	Duration (days)	Years of record analysed	Rainfall (mm) for return period (yrs)				
			2	15	100	500	1000
Upper Mangahao	1	54	120	203	271	330	355
	2	52	165	279	375	455	490
	3	52	187	312	415	505	540
Lower Mangahao	1	26	105	181	246	300	325
	2	25	139	250	347	425	460
	3	25	155	276	381	420	510
Mangahao Power Station	1	54	60	100	131	158	170
	2	53	78	131	176	213	229
	3	53	88	145	194	235	251

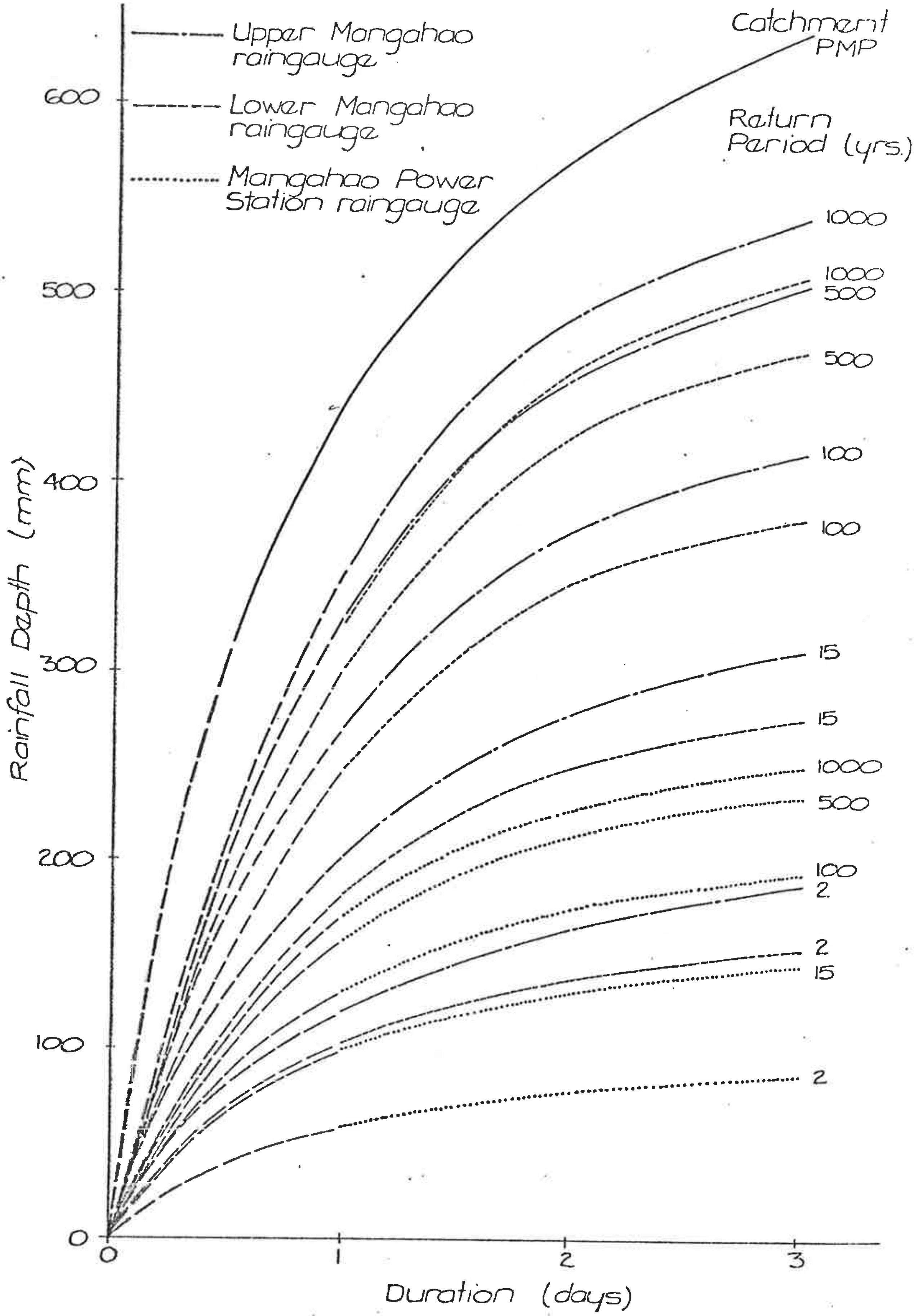

Fig. 2.6 Rainfall depth - duration - frequency curves

2.7 Probable Maximum Precipitation

Apart from empirical and statistical approaches two methods exist for estimating probable maximum rainfall. The first is maximisation of storms which have occurred within the catchment being looked at, and the second is the transposition and maximisation of storms which have occurred in climatically similar regions.

2.7.1 Mangahao probable maximum rainfall

The first method mentioned above, that of storm maximisation, was not possible in the Mangahao because insufficient rainfall records exist in the catchment to enable areal estimates of storm rainfall to be derived. Thus the only practicable approach was to transpose a storm into the Mangahao from some homogeneous region.

Undoubtedly the best documented, and one of the severest and damaging storms to have struck the lower North Island in recent times was that which caused the Wellington and Hutt Valley flood in December 1976. This storm was described by Tomlinson (1977) as having a recurrence interval of more than 100 years and possibly greater than 500 years. There can be little doubt that it must have approached maximum dynamic efficiency.

The situation which produced the Wellington-Hutt Valley storm was not unlike that which caused the heavy rainfall at Mangahao in 1936. The following notes were taken from Tomlinson's (1977) account of the 1976 storm. An area of low pressure covered New Zealand with centres of lowest pressure on either side of the

North Island (Fig 2.7). As the eastern low pressure centre moved southwards over the Cook Strait area a large and active thunderstorm indicated that areas of very unstable air existed in the general region of low pressure. Associated with the general air flow was a deep, well developed line of convergence lying northeast-southwest over the area, with southerly winds to the south of the line and north or northwesterly winds north of it. 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. The line of convergent airflows remained in much the same position for about 12 hours until the southerly winds reached sufficient strength to destroy the vertical structure of the convergent zone, after which time the zone assumed the normal characteristics of a cold front and moved northwards.

2.7.2 Wellington-Hutt Valley storm transposition and maximisation

Duration of this storm was effectively about 12 hours and the maximum recorded rainfall isohyets constructed by Tomlinson (1977) for this duration were transposed directly over the Mangahao catchment (Fig 2.8). The average catchment rainfall obtained from the isohyetal map in Fig 2.8 was multiplied by the maximisation factor Pm/Ps, where Pm is the precipitable water in the atmosphere at the maximum persisting dew point temperature, and Ps is the precipitable water in the atmosphere at the storm representative dew point temperature. Ps was derived from dew point temperatures recorded hourly at Kelburn (Wellington), and

Fig. 2·7 Meteorological conditions at 0600 hours on 20 th December 1976 (after Tomlinson, 1977)

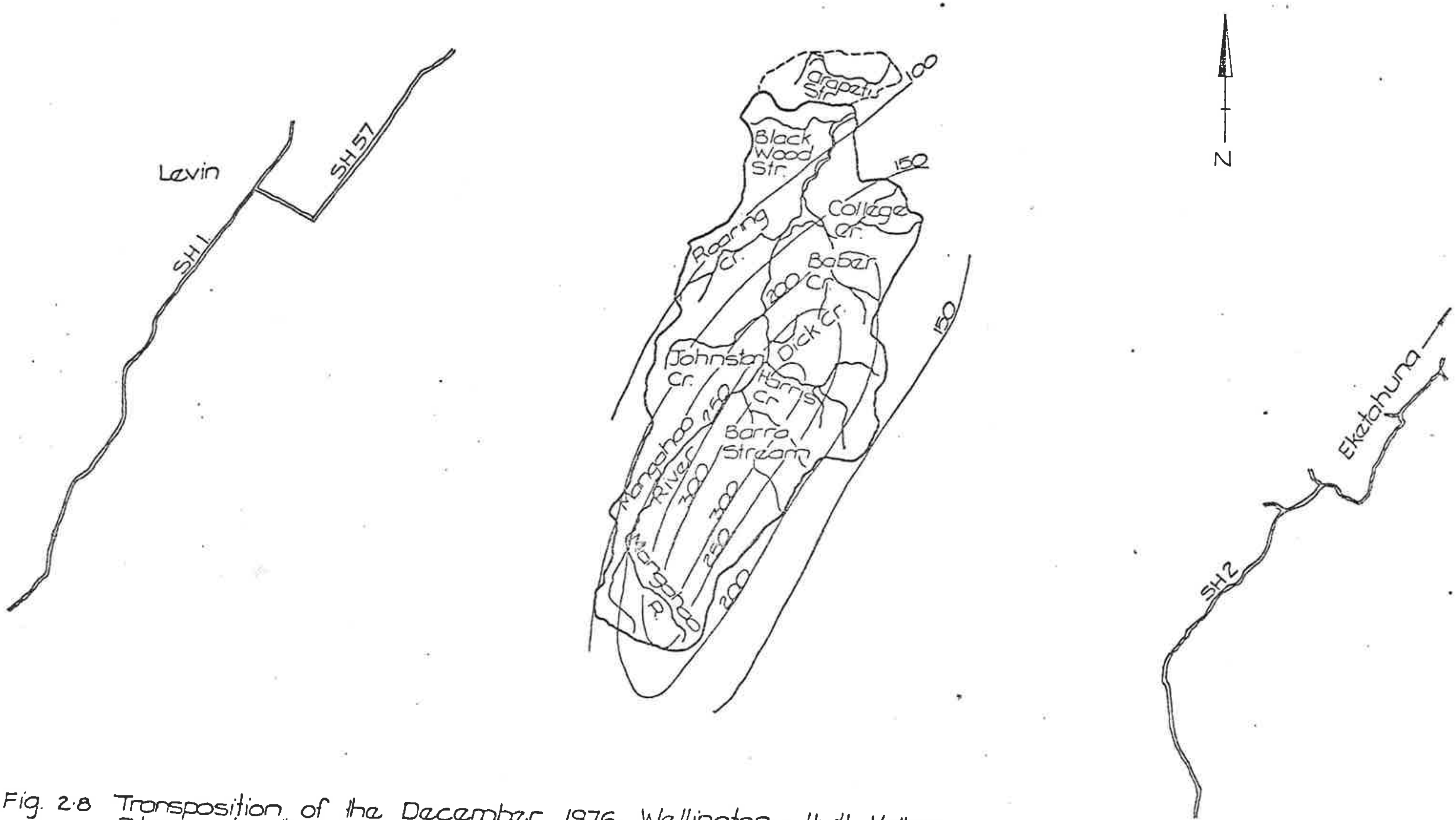

Fig. 2.8 Transposition of the December 1976 Wellington - Hutt Valley Storm to the Mangahao Catchment

Pm was derived by comparing maximum dew point temperatures measured at Kelburn with mean sea surface temperatures measured at a latitude $32^{o}S$ and longitude of 165 to $168^{o}E$. This comparison of temperatures, and those selected as maximum dew points, are listed in Table 2.2.

TABLE 2.2: Derivation of Maximum Persisting Dew Point Temperature

Maximum December dew point temperatures recorded at Kelburn (1962-1980) (°C)				Mean December sea surface temperature (°C)	Selected maximum persisting dew point temp. (°C)	
Hourly	12-hour Persisting	24-hour Persisting	9 a.m.		12 hr	24 hr
19	18	16	18	19	18	17

During the time of the Wellington-Hutt Valley storm in December 1976 the maximum persisting 12 hour dew point was 12°C. Taking the ratio of the precipitable water in the atmosphere for the maximum persisting, and storm representative dew point temperatures (from WMO 1973 Table A.1.1 and A.1.2), with adjustment for a higher inflow barrier, gave a maximisation factor of 1.57.

Average storm rainfall for the Mangahao catchment was calculated from the isohyetal map in Fig 2.8 as 200 mm and multiplied by the maximisation factor of 1.57 to give a maximised rainfall of 314 mm. This value was plotted on Fig 2.6 and to it was fitted a depth-duration curve with a shape similar to the other frequency curves. PMP estimates taken from this curve for different durations are listed in Table 2.3.

TABLE 2.3: PMP Estimates for No.2 Dam Catchment

Storm Duration (hrs)	PMP (mm)
12	314
24	445
48	575
72	640

3 FLOWS

3.1 Flow Records

Daily records of water used for power generation and of excess water spilt down the Mangahao river from No.2 dam were obtained from the Mangahao power station weekly load reports. Flow through the station machines was calculated by applying the cumecs per megawatt relationship of 0.5381 to the average daily power output from the station. This relationship was confirmed by a gauging of the tailwater flow from the station in August 1980. This gauging gave a flow of 10.75 m^3/s at a constant load of 20 MW, or 0.537 cumecs/MW, which is very near the relationship used.

Records of water spilt over No.2 dam are less reliable than the machine flow records. Spill flows have been recorded since the early 1930's by a resistance meter operated via a water-level float. Problems have frequently occurred with the floodmeter and consequently there are several missing records in addition to periods when the meter has under or over-recorded the volume of water spilt. Occasionally power supply to the meter has been disrupted as a result of lightning strikes and subsequent power failures. Unfortunately lightning induced power failures were usually associated with high runoff-producing storms.

A visit to the Mangahao No.2 dam in September 1980 revealed that a large volume of water was discharging from the gate counter-balance chamber orifice, and it was found (from NZE staff) that water discharged from the chamber at reservoir levels from 338.7 m upwards (i.e. above 1238' Mangahao datum).

Water should only enter the counter-balance chamber when the reservoir level reaches the gate crest (342.37 m Moturiki datum or 1250 ft Mangahao datum) and it appeared that the only source of discharge at lower reservoir levels could be from leakage around the gate seals. This leakage seemed to have been occurring for as long as anyone at the Mangahao power station could remember.

In order to get an idea of the amount of water being lost through leakage the flow just downstream of No.2 dam was gauged when the only discharge from the reservoir was via the counter-balance chamber. This gauging, in October 1980, gave a flow of 2.128 m^3/s at a reservoir level of 341.17 m. From this gauging the leakage was estimated for a range of lake levels via the formula:

$$Q = cH^{\frac{1}{2}}$$

where Q is the discharge from the counter-balance chamber orifice (m^3/s)

c is a coefficient of discharge

and H is the head on the chamber (m).

H was assumed to be the difference in levels between the reservoir water surface and the bottom of the gate (335.89 m). Thus for the gauged flow H was

$$341.17 - 335.89 = 5.28 \text{ m}$$

Therefore the coefficient c was

$$\frac{2.128}{5.28^{\frac{1}{2}}} = 0.926$$

Variation in leakage with reservoir level is plotted in Fig 3.1 and this rating was applied to the level record to give an estimate of leakage over the period of flow record examined.

Total mean outflow was 8.6 m^3/s, for the period 1960 to 1980 for the combined Mangahao/Arapeti catchment (total area 86.4 km^2) and was made up as follows:

powerhouse discharge	5.0 m^3/s
No.2 dam spill discharge	2.0 m^3/s
No.2 dam counter-balance chamber leakage	1.6 m^3/s

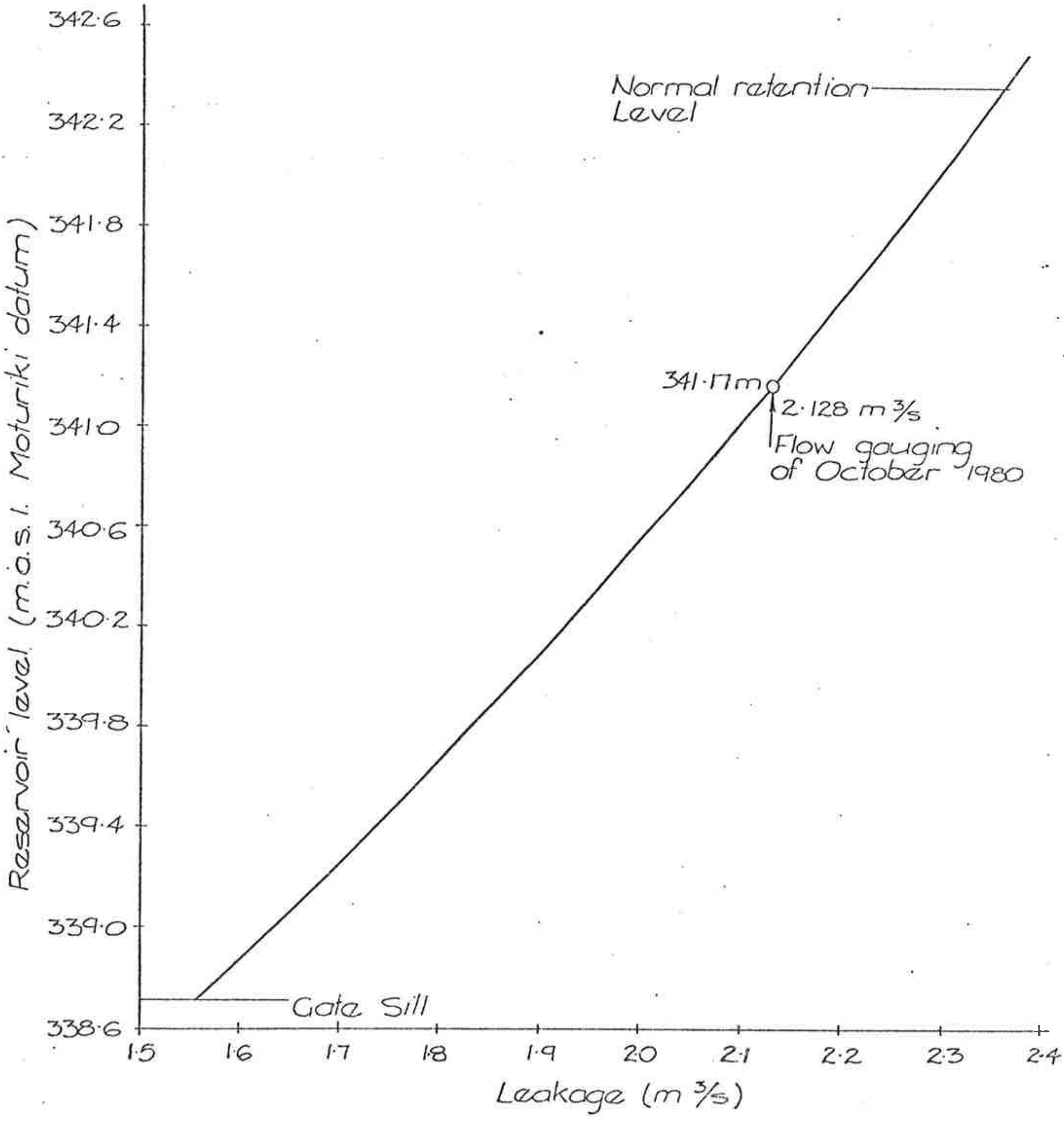

Fig. 3·1 N° 2 Dam – Variation of Gate Chamber Leakage with Reservoir level.

This is equivalent to a mean annual runoff of 3140 mm.

3.2 Inflow Calculation

Daily inflows to the Mangahao system were calculated using a MWD TIDEDA 'PSIMULATION' program, a listing of which is given in the Appendix of this report. The input data to the program consisted of

(1) Reservoir levels recorded daily at 8.30 a.m.

(2) Floodmeter readings recorded daily at 8.30 a.m.

(3) Powerhouse machine flows recorded daily for the 24 hours to midnight.

All of this data was extracted from the station weekly load reports. Inflows were calculated only for the period 1960 to 1980.

3.2.1 Brief description of inflow calculation procedure

(a) Storage at each reservoir level was derived from the level-storage rating curve. The storage curve used throughout was that surveyed in 1957-58. Although No.2 reservoir was flushed of sediment in 1974 the change in storage was not significant when calculating inflows on a daily basis.

(b) Daily change in storage in each reservoir was converted to flow and the three reservoirs accumulated.

(c) Leakage from the counter-balance chamber was calculated from lake level via the level-discharge rating in Fig 3.1.

(d) Machine discharge (m^3/s) was taken as being 0.5381 times the daily power output (MW) (from Section 3.1).

(e) Spillway discharge was calculated from the floodmeter readings. Floodmeter units were 62.5/35.3 x 10^6 m^3. Differencing the daily readings and dividing by 86400 gave the daily mean spill discharge.

(f) Total daily inflow was then the accumulation of:

(i) Change in storage converted to daily flow.

(ii) Daily machine discharge.

(iii) Daily spill discharge from No.2 dam.

(iv) Daily leakage from No.2 dam.

Flood meter and reservoir level readings taken at 8.30 a.m. were assumed to apply for the 24 hours ending at midnight on the previous days. Inflows were then calculated daily from midnight to midnight.

Minimum inflow was set at 0.05 m^3/sec and where the calculated inflow would have dropped below this it was assumed that there was an error in reservoir level and the No.1 reservoir level was adjusted accordingly. If sufficient storage could not be recovered in No.1 reservoir then No.2 and finally No.3 reservoir levels were adjusted.

3.3 Seasonal Flow Distribution

Seasonal variation of inflow and rainfall are depicted in Fig 3.2. All data shows a minimum in February and a maximum about July with secondary maximums in May and September-October. While the pattern of inflow closely follows the general rainfall pattern in the winter this is not so in the spring and summer. From August to November the ratio of monthly inflow to the yearly inflow is higher than the corresponding rainfall ratio. This indicates that the combined influence of snow and lower evaporation cause the catchment to become saturated and the baseflow higher.

In the summer the inflow ratio is consistently below the rainfall ratio until March-April. This is indicative of higher evaporation losses in the early summer months, and of groundwater replenishment in the late summer to early autumn period.

Seasonal flow distributions showing the percent of time given flows are equalled or exceeded are shown in Fig 3.3. This shows that the maximum median flow occurs in September with a secondary maximum in July and a minimum in February. For flows equalled or exceeded 33% of the time or less, the maximum is in July and secondary maximums occur in September-October and in May. The minimum is again in February. Similar patterns were observed with the average monthly flows.

A statistical analysis of daily inflows revealed that October, followed by July and December, had the highest number of days on

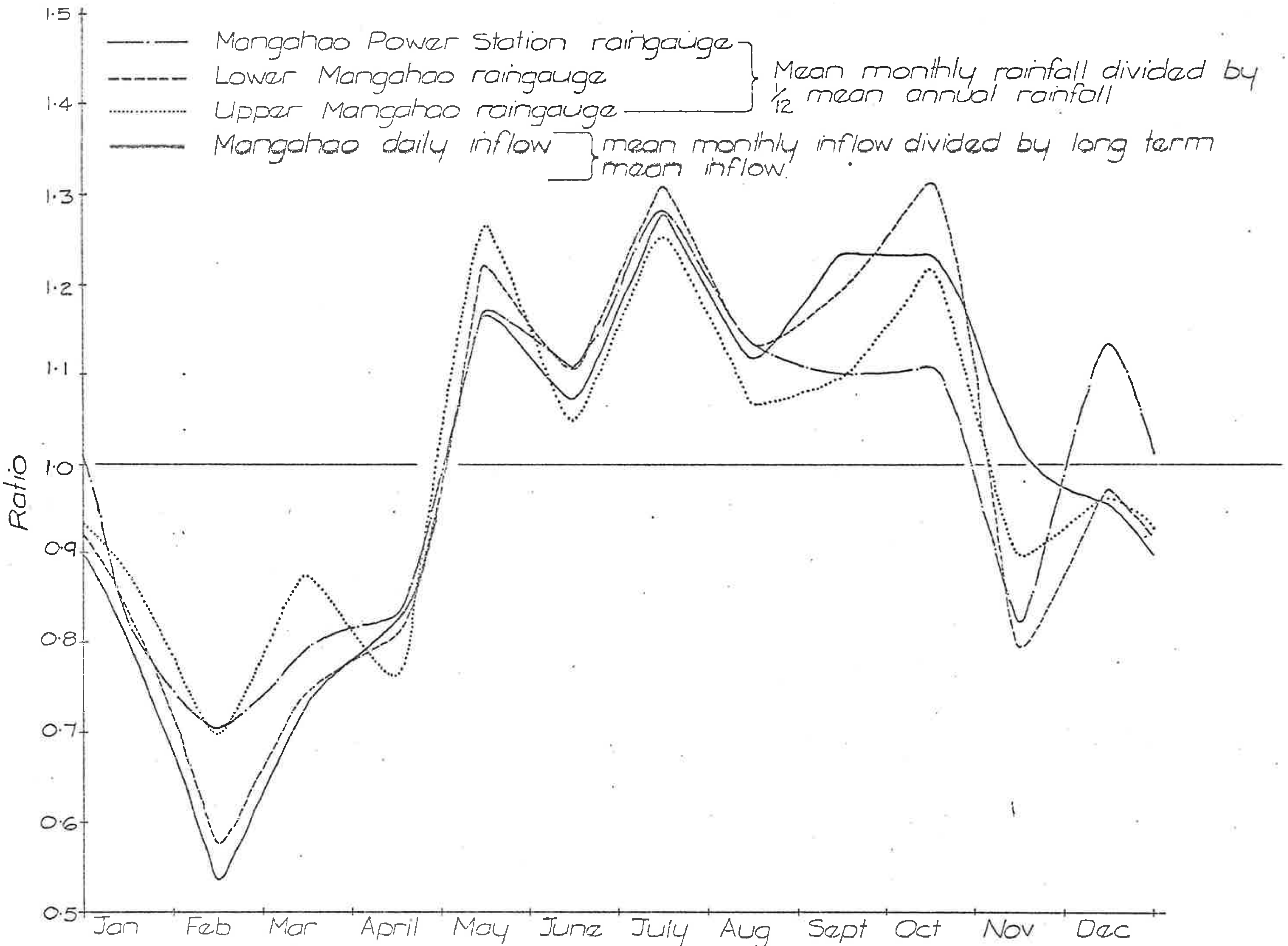

Fig. 3·2 Mangahao – seasonal variation of rainfall and inflow (1960 to 1980)

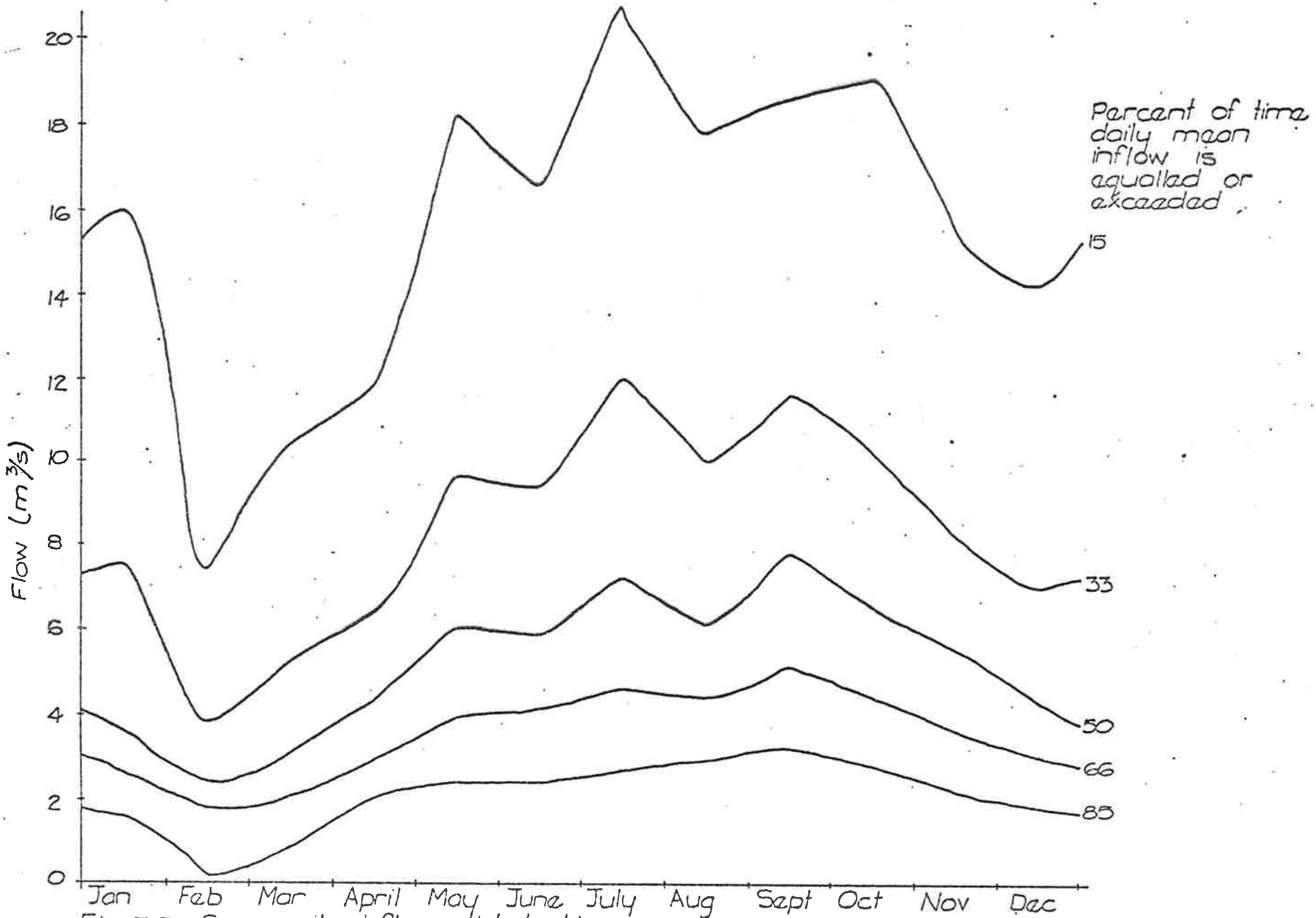

Fig. 3.3 Seasonal inflow distribution

which inflow exceeded 50 m^3/s. Months with the lowest occurrence of inflows over 50 m^3/s were February and August. Generally the seasonal pattern of occurrence of inflows greater than 50 m^3/s was similar to the seasonal pattern of mean flow.

3.4 Flood Flows

The maximum calculated daily inflow in the period 1960 to 1980 was 183 m^3/s on 13.01.62. From records which extend back to 1916 (before construction of the power scheme commenced) the largest known flood that has occurred was that on 22 December 1936. This flood occurred with the largest recorded daily rainfall at Upper Mangahao of 339 mm (13.36 inches) (see sections 2.4 and 2.5).

In this particular storm more than 200 mm of rain were recorded in three and a half hours and according to an observer the water level of the No.1 (Upper) reservoir rose two feet (from 1358 ft to 1360 ft Mangahao datum) in four minutes. These two feet represent a storage of approximately 0.27 x 10^6 m^3, which meant that the inflow for the four minutes was equivalent to 0.27 x $10^6/4/60$ = 1125 m^3/s (approximately 40,000 cusecs). The maximum reservoir levels recorded in the flood were 376.74 m (1362.75 ft Mangahao datum) at No.1 dam and 344.50 m (1257 ft Mangahao datum) at No.2 dam; these correspond to spillway discharges of approximately 785 m^3/s and 975 m^3/s over No.1 and 2 dams respectively. It is unlikely that the flow over No.2 dam would have been so much greater than that over No.1 dam and possibly there was an error in the measurement of one or other levels. Assuming the flood had a similar return period to the rainfall recorded at

Upper Mangahao (between 100 and 500 years) then the No.1 dam estimate of 785 m^3/s is probably a little low and that for No.2 too high. Correspondence on file (PWD 9/6/1) mentioned that the flood water was very discoloured and suggested that the high peak inflow into No.1 dam may have resulted from a landslip which had dammed the river and subsequently gave way. Although this flood occurred only ten months after a particularly devastating cyclonic storm in February of that year (the Rangitira storm), in which much of the bush in the Tararuas was uprooted, it is unlikely that a landslide damming the river would cause a sudden increase in inflow. The more likely result of a landslide would be a sudden decrease in inflow followed by a gradual rise as the slip was eroded. Water discolouration, which is indicative of sediment transport, occurs in any large flood, and in this flood a large volume of sediment was deposited in the Mangahao reservoirs.

3.5 Flood Frequency Analysis

The absence of flow data for durations less than daily, and lack of storm rainfall information for the majority of the upper catchment area made flood frequency analysis difficult. With the flow being in the form of daily means (from the station load reports) it was impossible to obtain unit hydrographs from actual data. Similarly because there was insufficient areal record of storm rainfalls, particularly in the middle and upper parts of the catchment, it was not possible to analyse rainfall-runoff relationships for storm events.

Frequency of Mangahao floods were therefore analysed by Gumbel's method and by comparison of the Mangahao flow data with data from other rivers in the Tararuas. Although the Mangahao is bounded by several rivers those most applicable for comparison are those lying to the west of the main Tararua Range. Unfortunately the most suitable river, the Otaki, had only a short period (approximately six years) of data available; this was not enough for detailed analysis. The river with the best record for analysis was the Hutt River, at the southern end of the Tararuas.

Hutt River flows recorded at Kaitoke from 1968 to 1980 were analysed by Gumbel for durations instantaneous, 3, 6, 12 and 18 hours, and one day. For each duration floods were calculated for return periods of 2, 15, 100, 500 and 1,000 years. Daily mean Mangahao inflows were also analysed and floods were calculated for the same return periods as the Hutt. Using this information flood values were derived for the Mangahao for several durations. The sequence of Mangahao flood frequency derivation is illustrated below.

1 Gumbel analysis of Hutt River flows for durations of instantaneous, three, six, twelve and eighteen hours and one day. Floods calculated for return periods of 2, 15, 100, 500 and 1,000 years and flood frequency - duration curves fitted.

2 Gumbel analysis of Mangahao daily mean inflow and floods calculated for return periods of 2, 15, 100, 500 and 1,000 years. For the purpose of flood estimation all flow was assumed to be from the No. 2 dam catchment.

3 Flood values read from frequency-duration curves of Step 1 for each duration were expressed as a ratio of the daily flood for the corresponding frequency.

4 Mangahao daily flood values were multiplied by the Hutt River ratios to give an estimate of floods for return periods of 2, 15, 100, 500 and 1,000 years for respective durations.

5 Mangahao 2, 15, 100, 500 and 1,000 year return period flood estimates were plotted on Gumbel probability paper for each duration and a straight line fitted through the points (Fig 3.4).

6 Flood values taken from these lines were plotted against duration for each return period (Fig 3.5).

The flood estimates calculated for the No.2 Mangahao dam are listed below in Table 3.1.

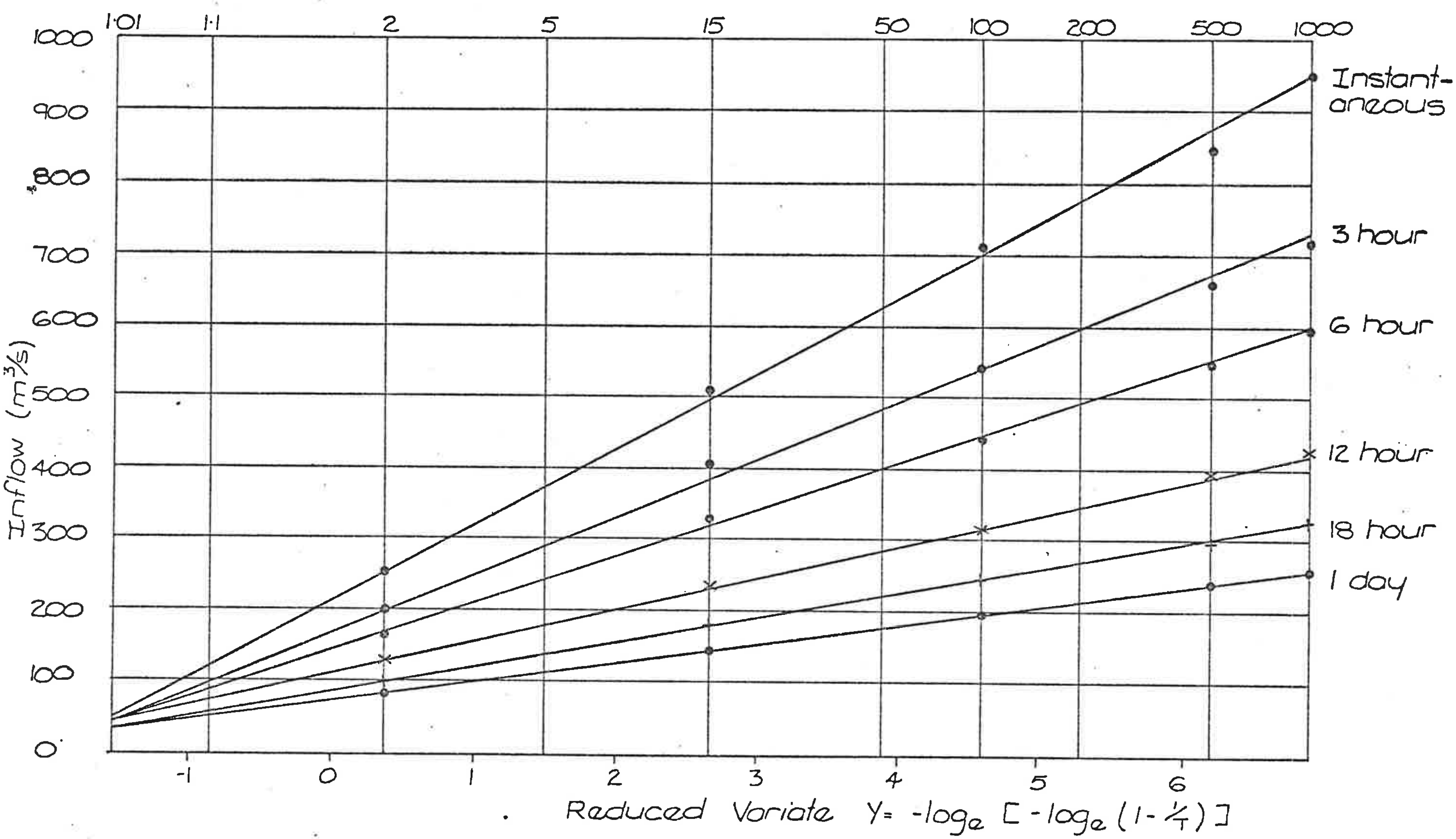

Fig. 3·4 Mangahao flood estimates derived from Hutt River data.

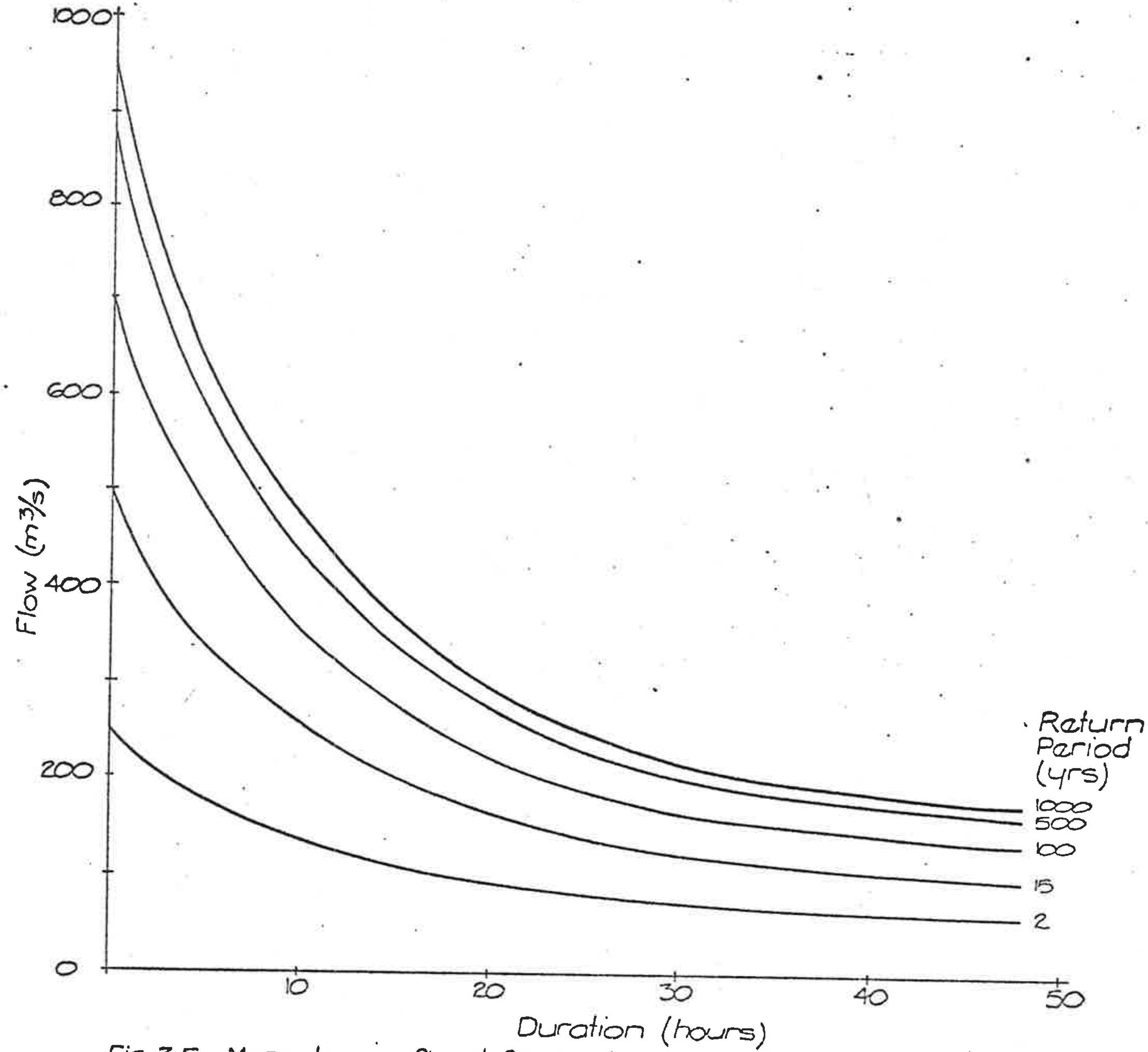

Fig. 3.5 Mangahoo – flood flow – duration – frequency curves

TABLE 3.1: Mangahao No.2 Dam Flood Estimates

Return Period (yrs)	Maximum Flows (m^3/s) for Durations				
	Instantaneous	3 hr	6 hr	12 hr	1 day
2	250	195	165	125	80
15	495	385	320	175	140
100	705	540	445	240	195
500	880	670	550	300	235
1,000	950	730	600	320	255

Specific instantaneous flood discharges calculated from Table 3.1 were compared with those of neighbouring catchments (Table 3.2). Although the records of these latter catchments were not absolutely reliable, they do provide some idea of the range of values and hence give a check on the Mangahao figures. All flood estimates were derived by Gumbel analysis.

Table 3.2: Comparison of Instantaneous Specific Flood Discharges ($m^3 s^{-1} km^{-2}$)

Return period (yrs)	Mangahao at No.2 Dam	Mangahao at Ballance	Hutt at Kaitoke	Otaki at Tuapaka	Atiwhakatu at Mt Holdsworth
2	3.1	2.6	2.7	3.0	2.7
15	6.1	4.8	4.6	5.3	4.6
100	8.7	6.6	6.2	7.2	6.1
500	10.8	8.1	7.2	8.8	7.4
1000	11.7	8.8	8.1	9.5	8.0
Catchment area (km^2)	81.3	266	88.8	309	38.8
years of record analysed	20	24	12	6	11

The Mangahao at No.2 dam has the highest specific flood discharges and although the Otaki has the next highest they are somewhat lower because of its larger catchment area and smaller proportion of high elevation terrain.

Lower specific flood discharges of the Hutt and Atiwhakatu rivers are due to their locations in the lee of the westerlies and north-westerlies. The same applies to the Mangahao at Ballance where the specific flood discharges are lower because of the large catchment area and because most of the catchment lies on the eastern side of the Tararuas.

Instantaneous flood estimates were also calculated using the NZ Flood Study (Beable and McKerchar, in pre.) regional equations.

The mean annual maximum daily inflow to the Mangahao for the period 1960 to 1980 was 88.7 m^3/s. From Fig 3.5 this has a return period of 2.4 years (cf the theoretical return period of the mean annual flood of 2.33 years), for which the instantaneous flood peak is 286 m^3/s. This value was fitted to two regional equations, the combined curve for western New Zealand, and the Manawatu-Rangitikei regional curve. These estimates are listed below (Table 3.3) together with the Gumbel estimates derived by comparison with the Hutt River data.

Table 3.3: Mangahao No.2 Dam Instanteous Flood Estimates (m^3/s)

Return period (yrs)	Western NZ combined curve	Manawatu Rangitikei curve	Gumbel
2	250	267	250
15	448	507	495
100	676	706	705
500	928	874	880
1000	1060	946	950

From Table 3.3 excellent agreement is apparent between the Manawatu-Rangitikei regional curve estimates and the Gumbel values (derived by comparison with the Hutt River) and slightly lesser agreement is evident between these and the western curve estimates.

Generally the regional flood estimates, and the comparative estimates from other Tararua rivers (Table 3.2) confirm the authenticity of the Gumbel estimates presented in Tables 3.1 and 3.3.

3.6 Probable Maximum Flood (PMF)

Rainfall analyses showed that the critical storm duration was likely to be less than 24 hours. The probable maximum storm was assumed to be one in which most of the rain falls in about 12 hours; the magnitude of the 12 hour PMP will be about 314 mm (Table 2.4) which is equivalent to an average 532 m^3/s if 90% direct runoff is assumed. Table 3.1 shows that the ratio of the 1000 year 12 hour flow to the 1000 year instantaneous peak is 1 to 2.97 so the PMF peak becomes 532 m^3/s x 3 or 1600 m^3/s.

3.7 Design Floods

Selected details of No.1 and 2 Mangahao dams are given below.

No.1 dam

Number of gates	3
Clear span of each gate opening	16.26 m (53'4")
Effective depth of each gate	3.05 m (10.0')
Crest level of dam	377.42 m
Normal retention level (= gate crest)	375.90 m
Sill level	372.85 m
Effective length of spillway	48.77 m

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No.2 dam

Number of gates	2
Clear span of each gate opening	19.51 m (64.0')
Effective depth of each gate	3.05 m (10.0')
Crest level of dam	345.42 m
Normal retention level (= gate crest)	342.37 m
Sill level	339.32 m
Effective length of spillway crest	39.01 m

In both dams the drum gates open automatically with rising water level. Full open position (gates right down) should occur with headwater level 152 mm (6") above the gate crest level (i.e. closed position).

With the drum gates fully open the spillways are effectively Ogee crests for which the discharge can be calculated by the formula:

$$Q = CLH^{3/2}$$

where Q = discharge

C = coefficient of discharge

L = effective length of crest

H = total head on crest

The coefficient of discharge (C) was conservatively assumed to be 2.16 (reference Davis 1952 and Fig 9.2 Linsley and Franzini 1979). Maximum spillway capacities of each dam were calculated as:

	Crest Level m	Spillway Discharge m^3/s
No.1 dam	377.42	1029
No.2 dam	345.42	1269

Although each Mangahao dam has a bypass tunnel these are normally used only in sediment flushing operations. With a maximum capacity of about 30 m^3/s they would be of little benefit in large floods.

The Arapeti dam, which has a catchment of only 5.1 km^2, has no built-in facilities for passing floods other than a low section in the centre of the dam. De-watering is carried out by allowing the water to back-flow through the tunnel to the Mangahao No.2 reservoir. This dam has been overtopped only occasionally; in the 1936 flood the depth of water was reported to be 150 mm deep over the crest of the dam which is equivalent to a flow of about 10 m^3/s.

3.8 Conclusion

Flood estimates were derived for No.2 dam by assuming there was no attenuation of the flood peak as it travelled through the reservoir. However routing the 100, 500 and 1,000 year floods (hydrographs obtained from Table 3.1) through both reservoirs showed that the peak discharges from both dams were somewhat less than the peak flows given in Table 3.1.

Allowing for attenuation of the flood peaks and also for the smaller catchment area of No.1 dam compared with No.2 dam, peak spillway discharges were derived (Table 3.4).

Table 3.4: Peak Spillway Discharges

Return Period (yrs)	Maximum Instantaneous Flood Discharge (m^3/s) No.1 Dam	No.2 Dam
100	645	675
500	785	815
1000	820	850

Thus both dams are capable of passing the 1,000 year flood. The maximum reservoir levels associated with a 1,000 year flood would be 376.78 m and 343.98 m for No.1 and 2 reservoirs respectively. These levels are 0.6 m and 1.4 m below the dam crests.

Even allowing for attenuation neither No.1 nor No.2 dam spillways would be capable of passing the probable maximum flood and both dams would be overtopped. At No.2 dam the point of failure would be the earth dam section to the right of the concrete gravity section containing the gates and spillway. This earthern section of dam, which has a concrete core, has settled significantly over the years and is now lower than the concrete section of the dam. No.1 dam has a small earth section on the left bank and a large concrete gravity section atop an earth base between this and the spillway on the right bank. Externally No.1 dam appears in good condition and no obvious settlement is apparent.

The low section in the centre of the Arapeti gravity dam would be overtopped by 400 to 500 mm in a 1,000 year flood, and by 600 to 700 mm in the PMF. This section of the dam is a metre or more lower than the end sections and is designed to allow for overpour.

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...     366755 803.7 368279 1033  369803 1330.1 371327 1683.9
...     372851 2080.1 374375 2547.0 375899 3141.3
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...     339323 339.6 340847 543.4 342371 820.7
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...     340847 778.3 342371 948.1
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...    616.9 365231  803.7 366755   1033 368279 1330.1 369803
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FUNC 5 0 319511   1 333227   28.3 334751   90.6 336275   192.4 337799
...     339.6 339323  543.4 340847   820.7 342371
FUNC 6 0 316463   1 327131   14.2 328655   50.9 330179   99.1 331703
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...     622.6 339323  778.3 340847   948.1 342371
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ASS M J
ASS N K
ASS X 1
ASS Y 2
ASS Z 3
ASS V 4
ASS S 5
ASS G 6
ASS U 7
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GET 8 D 5023
GET 8 E 5022
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COM O=D+E
INTER H A X
INTER J B Y
INTER K C Z
CON T EQ 0 26
COM P=(H-L)*1000/T*1000
COM Q=(J-M)*1000/T*1000
COM R=(K-N)*1000/T*1000
COM W=P+Q+R
COM I=O+W
CON I GE 50 19
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INTER A H V
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CON B LE 343000 10
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INTER B J S
INTER C K G
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INTER C K G
ASS Z 3
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END
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PRO 'PSI' 13 FIL 15
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...     366755 803.7 368279 1033   369803 1330.1 371327 1683.9
...     372851 2080.1 374375 2547.0 375899 3141.3
FUNC 2 319511     0   333227     0   334751 28.3   336275 90.6   337799 192.4
...     339323 339.6 340847 543.4 342371 820.7
FUNC 3 316463     0   327131     0   328655 14.2   330179 50.9   331703 99.1
...     333227 169.8 334751 249.0 336275 352.3 337799 476.9 339323 622.6
...     340847 778.3 342371 948.1
END
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INTER J B Y
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STO
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