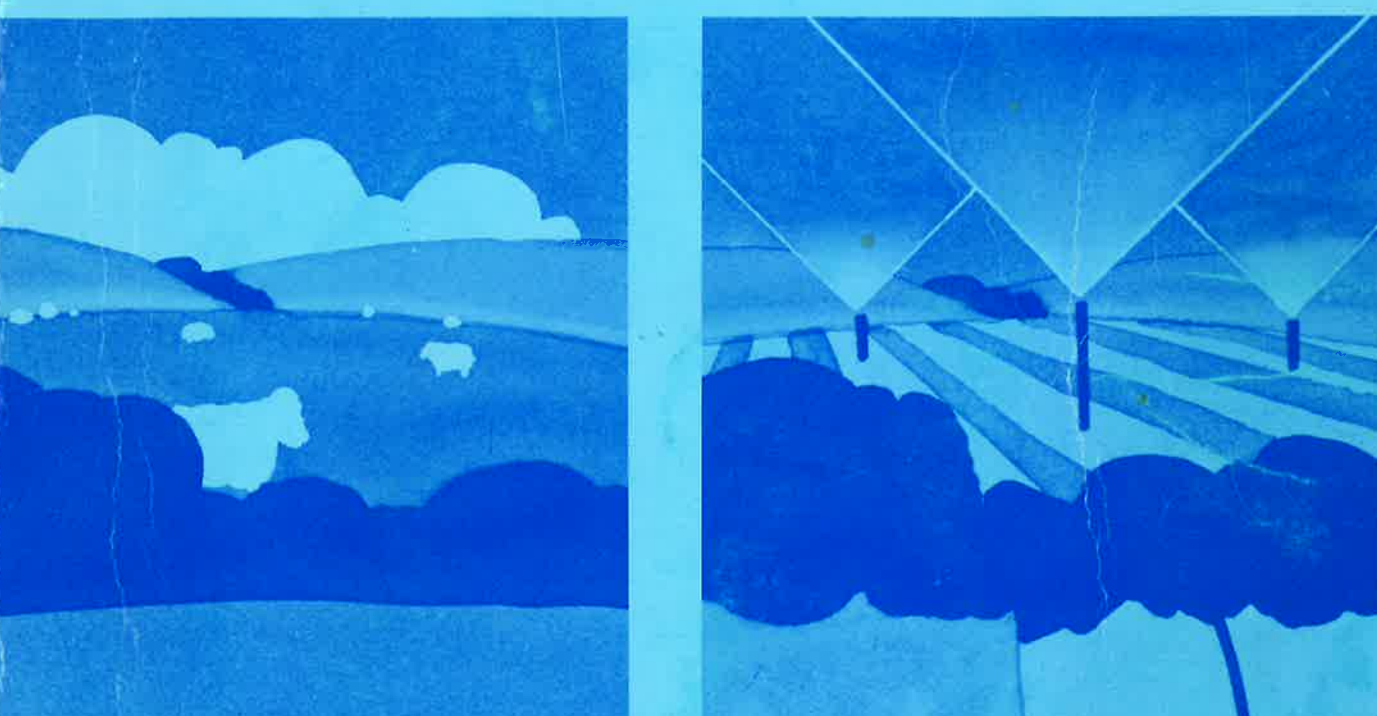
Specialist Report

FRESHWATER HYDROLOGY OF THE UPPER WAITEMATA HARBOUR CATCHMENT



Auckland Regional Authority

REPORT ON THE FRESHWATER HYDROLOGY OF THE UPPER WAITEMATA HARBOUR CATCHMENT

R.K. Smith

Water Quality Centre
Ministry of Works and Development
Hamilton

Water Quality Centre Report No. 2

Hamilton 1983

PREFACE

This report is one of a set of 10 Specialist Reports (listed below) on which the findings of the Upper Waitemata Harbour Catchment Study are based.

This and the other Specialist Reports have been heavily condensed to a corresponding set of Reviews which have been published in a format suitable for non-specialist readers, by the Auckland Regional Authority. The central document arising from this work is the Land and Water Management Plan.

The Upper Waitemata Harbour Catchment Study was promoted by the Auckland Regional Water Board although research in many topics was undertaken by other agencies. All the reports are published by the Auckland Regional Authority.

List of Specialist Reports

Ecology of Streams in the Upper Waitemata Harbour Catchment - I Briggs.

Energy Analysis, Upper Waitemata Harbour Catchment Study - G Knox.

Estuarine Ecology, Upper Waitemata Harbour Catchment Study - G Knox.

Land Resources of the Upper Waitemata Harbour Catchment - M R Jessen.

Legal and Planning Considerations in Land and Water Management - Planning Consultants Limited (extensively updated and amended by V Shaw).

Potential Effects of Catchment Use Change on Upper Waitemata Harbour Sediments - T M Hume.

Report on the Freshwater Hydrology of the Upper Waitemata Harbour Catchment - R K Smith.

The Flushing of Pollutants and Nutrients from the Upper Waitemata Harbour - B L Williams and J C Rutherford.

Urban Subdivision and Stormflows:Modelling and Management - P W Williams.

Water Quality in the Upper Waitemata Harbour and Catchment - M R van Roon.

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R.K. Smith
Water Quality Centre, Ministry of Works and Development, Hamilton

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ABSTRACT

The rainfall and hydrology of the Upper Waitemata Harbour Catchments are presented. Critical problems to future development in the Upper Harbour Catchments are the shortage of water for agriculture and horticulture and the control of peak storm runoff from urban areas.

KEYWORDS : Hydrology. Waitemata. Rain. Urban. Runoff.

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SECTION 1 : INTRODUCTION

Land development for urban use or intensified agriculture has the potential to cause severe damage to the environment. The Upper Waitemata Harbour Catchment Study was conceived as a means of preventing this happening to the harbour and surrounding catchments. A land and water management plan was considered the most suitable approach for implementing strategies for future land development. Such a plan requires an adequate data base for understanding the unique characteristics of the land and water resource. In the Upper Waitemata Harbour Catchment Study this data base was achieved through a number of specialist studies aimed at distinguishing the natural reponses to processes in both the catchment and estuarine environments.

Scope

The hydrological investigations brief contained four objectives (UWHCS Study Office 1978) :

1. To establish the existing hydrological conditions
2. To ascertain the hydrological regimes associated with existing land use practices in the area
3. To predict the effect of various land use changes on the existing regime
4. To provide a data base for engineering design of structures to cope with predicted flow

The two years records from the automatic water level recorders, which monitored 62% of the catchment, provided adequate data for describing the existing hydrological regime. The effect of different land uses on the hydrological regime could be ascertained in only very general terms because the lack of rainfall data in some catchments meant that rainfall-runoff relationships could not be established in detail.

The prediction of changes in the existing hydrological regime in response to changes in land use could only be established in general terms because of the partial success in (2). This study could only provide tentative prediction data on flows for engineering design, because of the lack of long term flow data within the study area. The Walkers site on the Rangitopuni River, which was installed in 1975, is the longest record available. Although the two-year record from the study sites provide data representative of the study period, predictions based on these records, must be regarded as tentative.

Approach

The objectives outlined in the study proposal were attained by means of rainfall and streamflow measurements both within the study area and from nearby sites with longer records (Fig. 1). Within the study area, the existing stream flow and raingauge network was upgraded by the installation of five new water level recorders and three automatic raingauges (Fig. 2). Albert Park (1872-1979) at Auckland City, and Riverhead Forest (1929-1980) raingauge records were used to establish the long term, annual, and seasonal characteristics. The automatic and manual raingauges throughout the study area provided information on areal and event rainfall characteristics. Flow sites were selected to monitor stream flow responses to events, including storms and dry periods, in catchments of differing land use. Site selection also aimed at recording flows from all major catchments to enable an assessment of the total discharge of freshwater into the Upper Waitemata Harbour to be made.

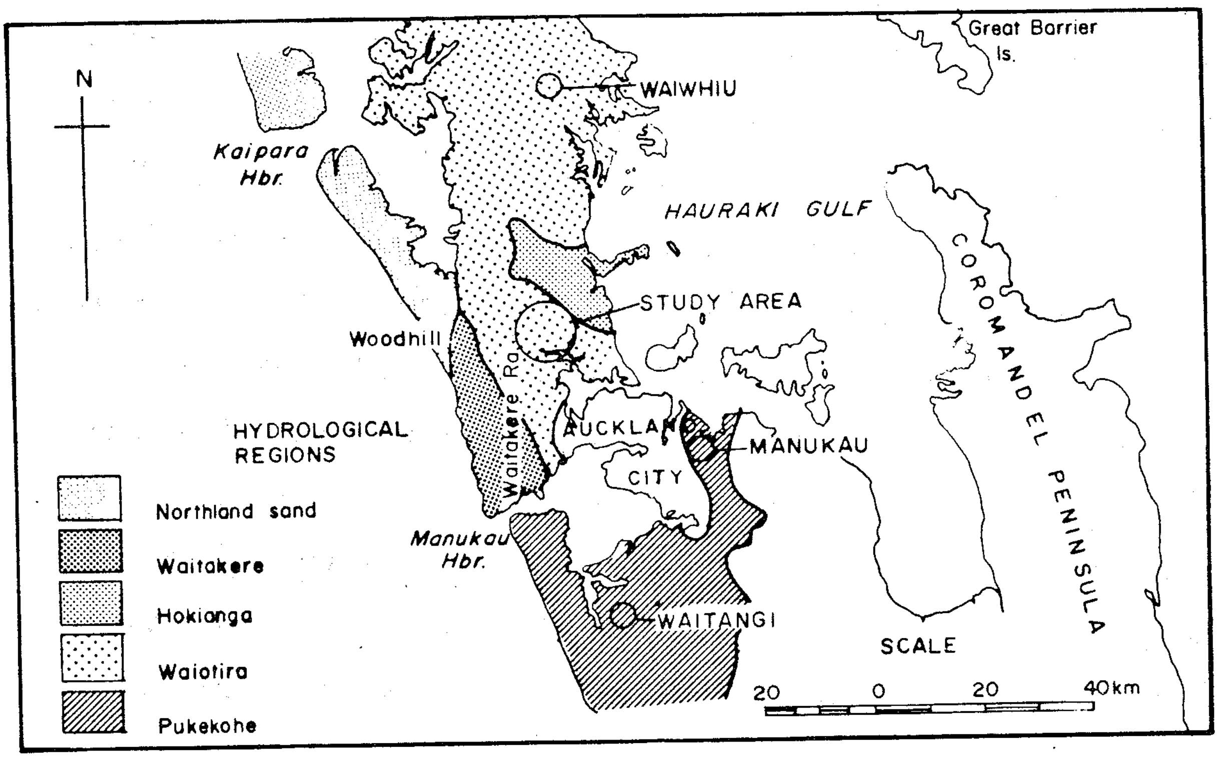

Figure 1 : Location of study area and nearby hydrological installations.

Geomorphology and Land Use

There are five principle drainage basins in the study area (Fig. 2). In order of size these are : the Rangitopuni (82.9 km^2); the Oteha (12.13 km^2); the Ngongetepara (11.18 km^2); the Paremoremo (7.59 km^2) and Lucas Creek (6.26 km^2). With the exception of a small area in the headwaters of the Ngongetepara, land over 60 m elevation is confined to the basins north of the Upper Waitemata Harbour. Highest elevations are in the west in Riverhead State Forest and also in the headwaters of the Paremoremo Stream, which is separated from the Rangitopuni by a ridge running southwestwards from east of Coatsville. The east and southeastern boundary of the study area is comprised of a narrow ridge with elevations between 60 m to 90 m (see Jessen 1983 for details of catchment geomorphology).

The steeper hill country is principally comprised of Waitemata Group Sandstones. This group of sediments are made up of alternating bands of sandstone and siltstone and are commonly contorted. Minor lithologies in the group include conglomerate, greensand, calcareous volcanic grit and volcanic breccia (Suggate 1978). The northern headwaters of the Rangitopuni catchment have outcrops of Mahurangi and Onerahi formations (Fig. 3). The Onerahi formation is fine grained, moderately impervious and has a small water storage capacity typical of the Waiotira hydrological region. Lower elevations throughout the study area are comprised of marine and fluvial terrace deposits (Schofield 1967). The terrace deposits have a small water storage capacity and are included in the Waiotira hydrological region (Waugh 1970).

Incised alluvial channels drain the catchments. The channel sides are usually stable though some bank erosion does occur during large infrequent

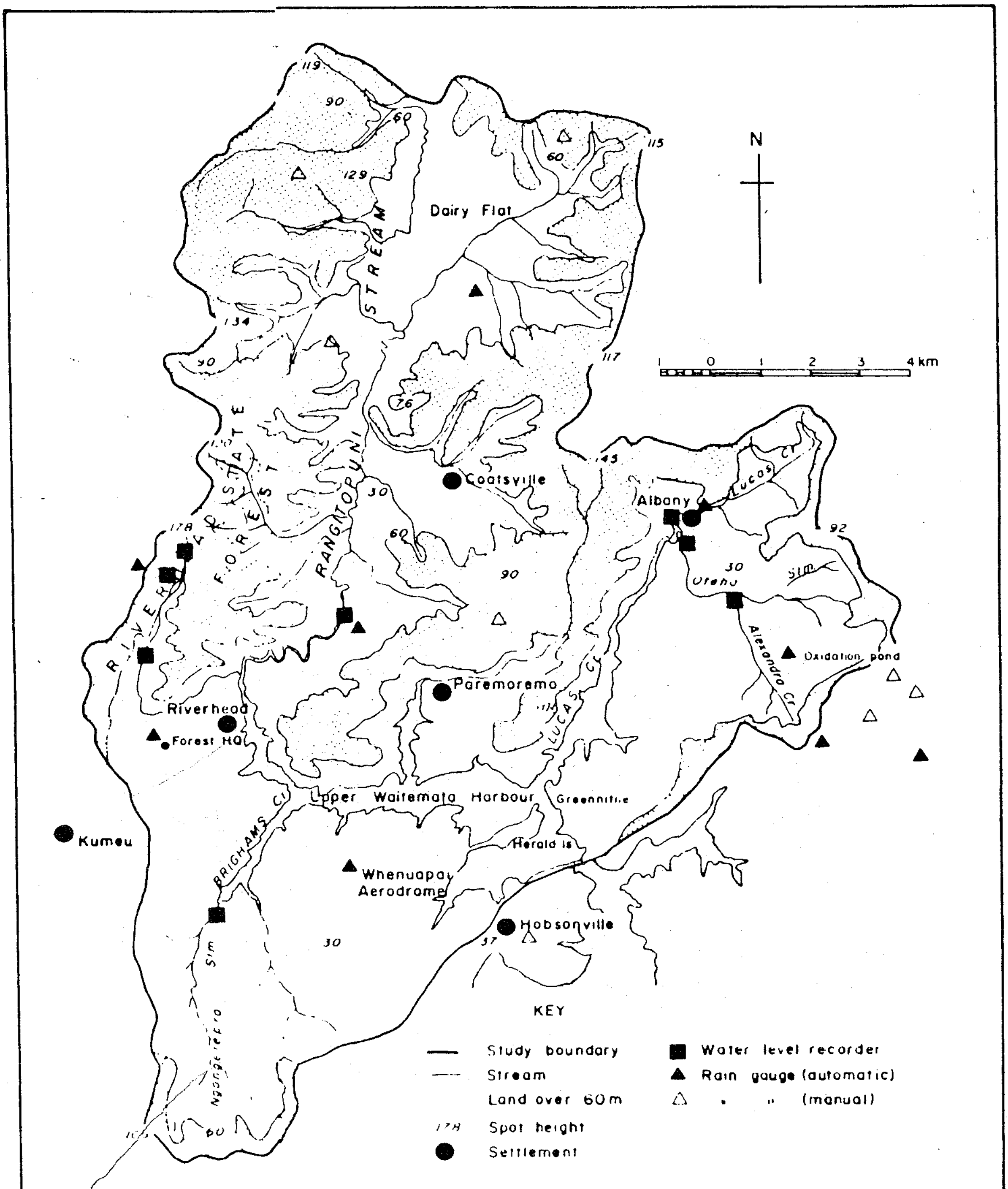

Figure 2 : Upper Waitemata Harbour Catchments

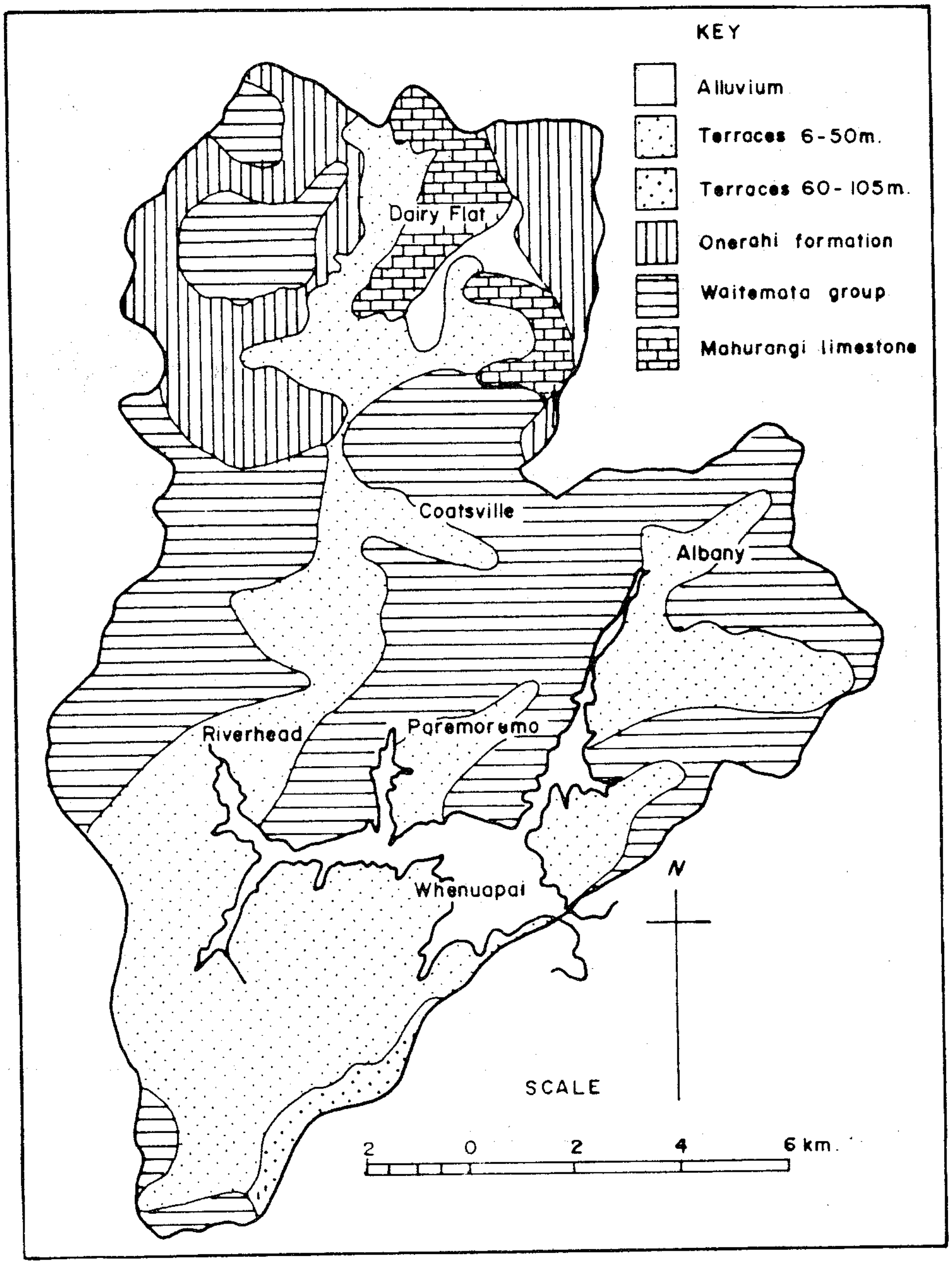

Figure 3 : Geological characteristics of the Upper Waitemata Harbour Catchments.

events. Stream headwaters are characterised by sand and shingle pool and riffle sequences. In the lower reaches the channel floor is comprised of the underlying basement sandstone and is characterised by deep pools, rock bars and alluvial channel sides. On the southern side of the harbour the stream channels are not so deeply incised and have areas of swamp in their middle reaches (refer Challis 1980 for further details).

The predominant land use on the terraces and hill country is pastoral. Horticulture occupies the easier terrace slopes and plains with exotic forest confined to the steeper hill country to the north and west of Riverhead. Urban settlements, together with the three land uses above, account for some 88% of the land use in the Upper Waitemata Harbour catchments (Armand 1980). The remaining 12% of the area is unproductive and covered with gorse, scrub and patches of native bush and is mainly confined to the steepest slopes.

SECTION 2 : RAINFALL CHARACTERISTICS

Long Term Trends in Rainfall :

As Albert Park has the longest rainfall record locally this gauge was used to establish the long term rainfall pattern for comparison with the Upper Waitemata Harbour catchment rainfall recorded during the study period. Since 1872, when daily rainfall records commence, there appears to have been an increase in the annual average rainfall (Fig. 4) ($r = 0.68$, $p = 0.001$).

The five year running mean for the period 1955-1970 is 300 mm higher than the 1941-70 normal rainfall (NZ Met. Ser. 1973). Heavy rainfalls (over 75 mm/24 hours), have become more frequent during the 20th century, particularly in the mid 1920s and 1930s and again in mid 1950s and 1960s (Fig. 5). Since 1970 events of this magnitude have been less frequent averaging just over two per year. Smaller more frequent events (10-20 mm and 30-40 mm per 24 hours) have also been found to show an increase in frequency ($r = 0.890$, $p = 0.001$ and $r = 0.804$, $p = 0.001$ respectively). Other intensity classes displayed no discernable trends in the 108 year record (Fig. 6).

The Albert Park record showed that dry periods, defined as the number of consecutive months when open pan evaporation exceeded the monthly rainfall, could vary in length between one and seven months (Fig. 7). The severity of the dry period was assessed by summing the excess of evaporation over precipitation (Fig. 8). The figure demonstrates a general trend for dry periods to be less severe in recent times, when compared to the late 19th century ($r = 0.299$ $p = 0.01$). As a general rule, the longer the dry period the larger the accumulated evaporation loss, although there have been some

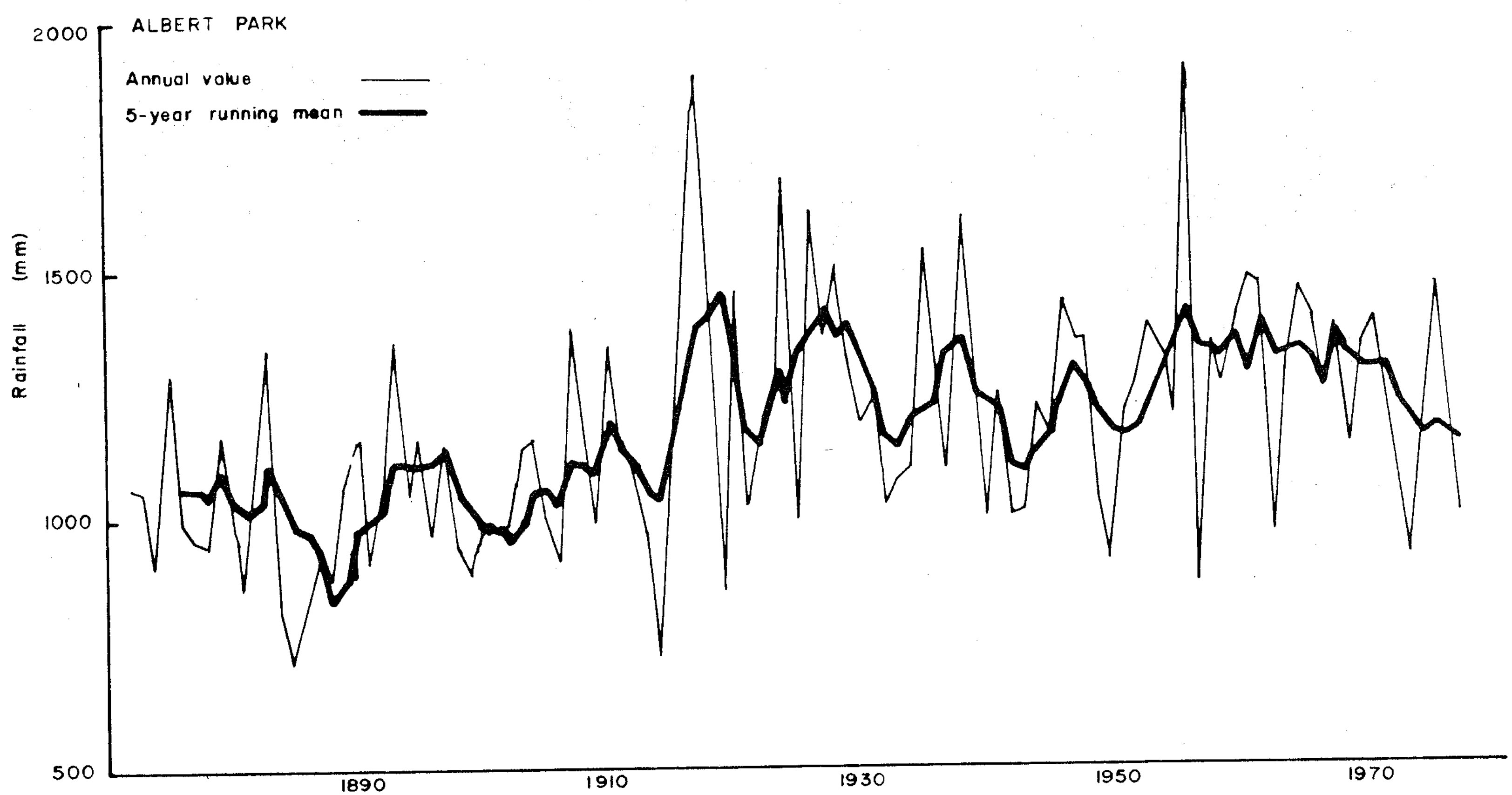

Figure 4 : Total annual rainfall and five year running mean for Albert Park rain gauge from 1872 to 1979.

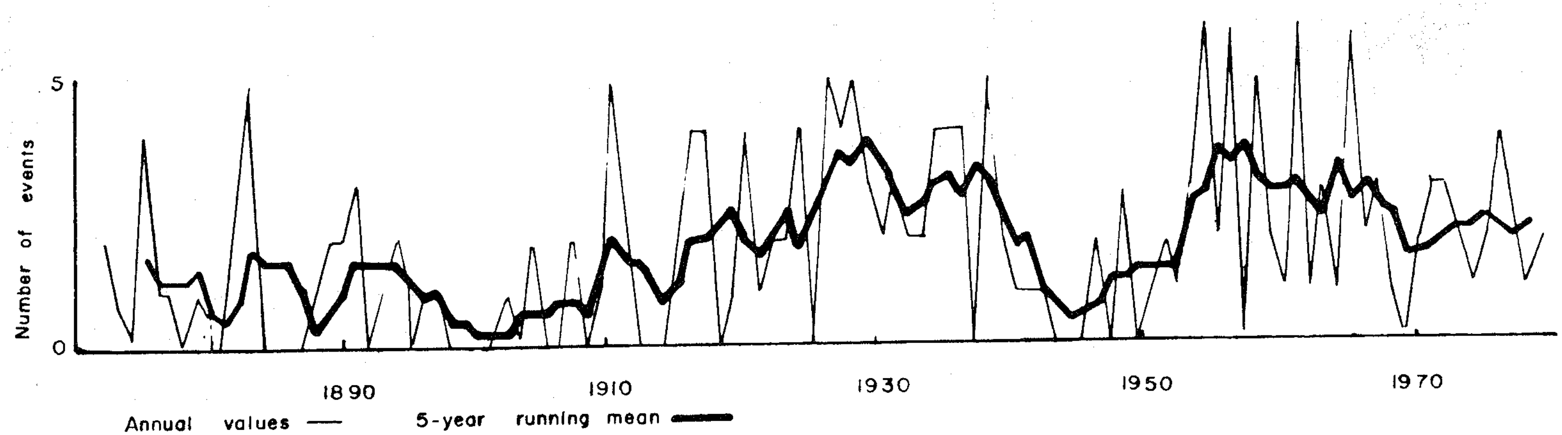

Figure 5 : Frequency of events in excess of 50 mm/24 hours, Albert Park 1872-1979. Heavy line is the five year running mean.

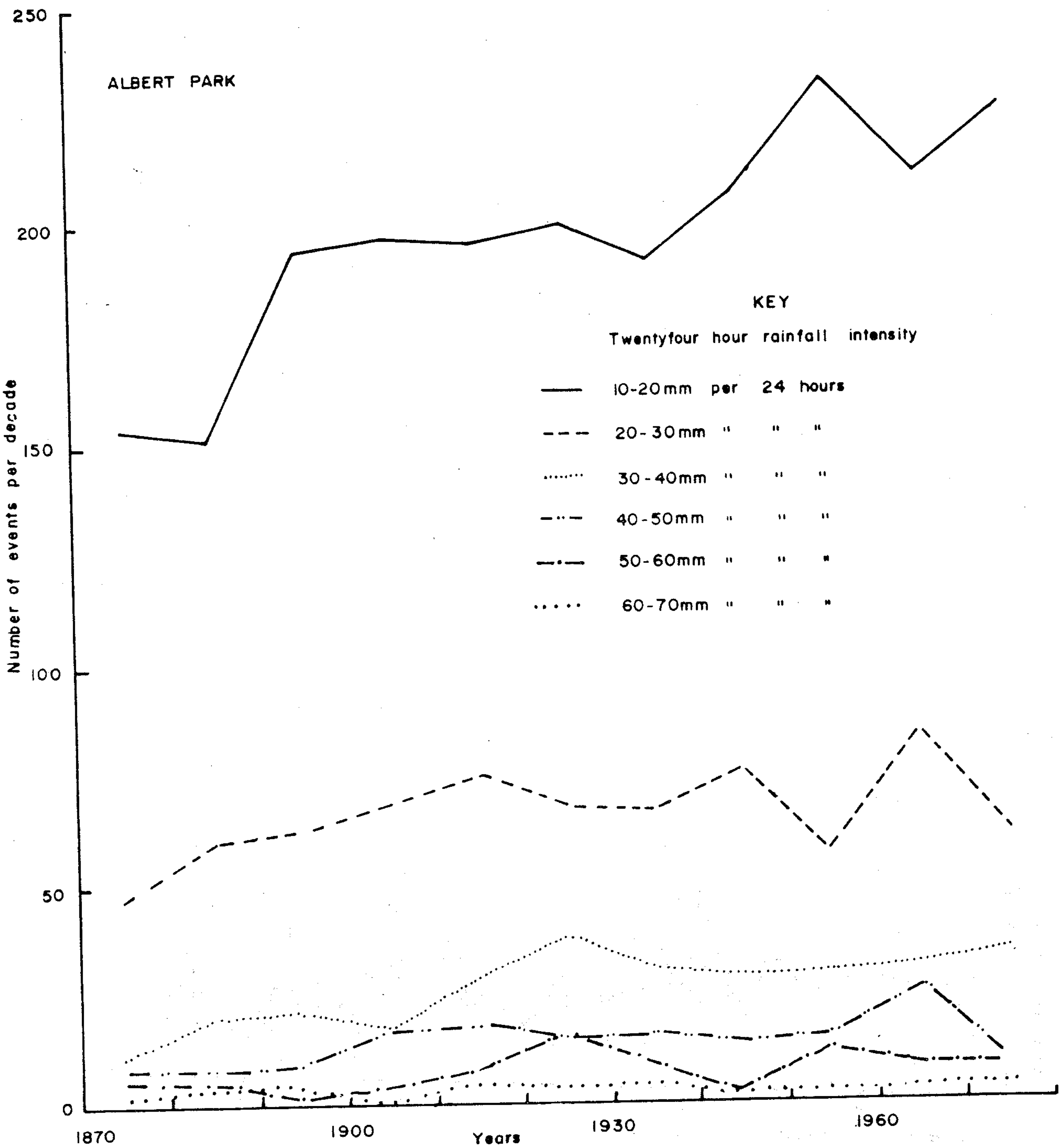

Figure 6 : Frequency diagram of rainfall intensities between 10 and 70 mm/24 hours for each decade, Albert Park 1872-1979.

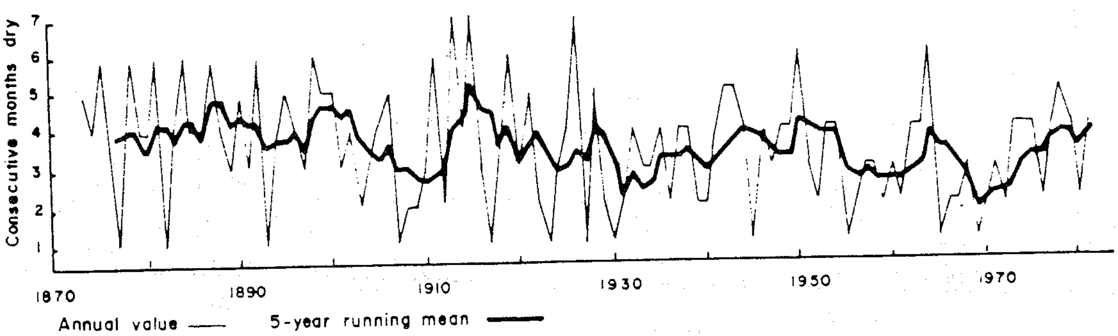

Figure 7 : The duration of dry periods, heavy line is the five year running mean, Albert Park 1872-1979.

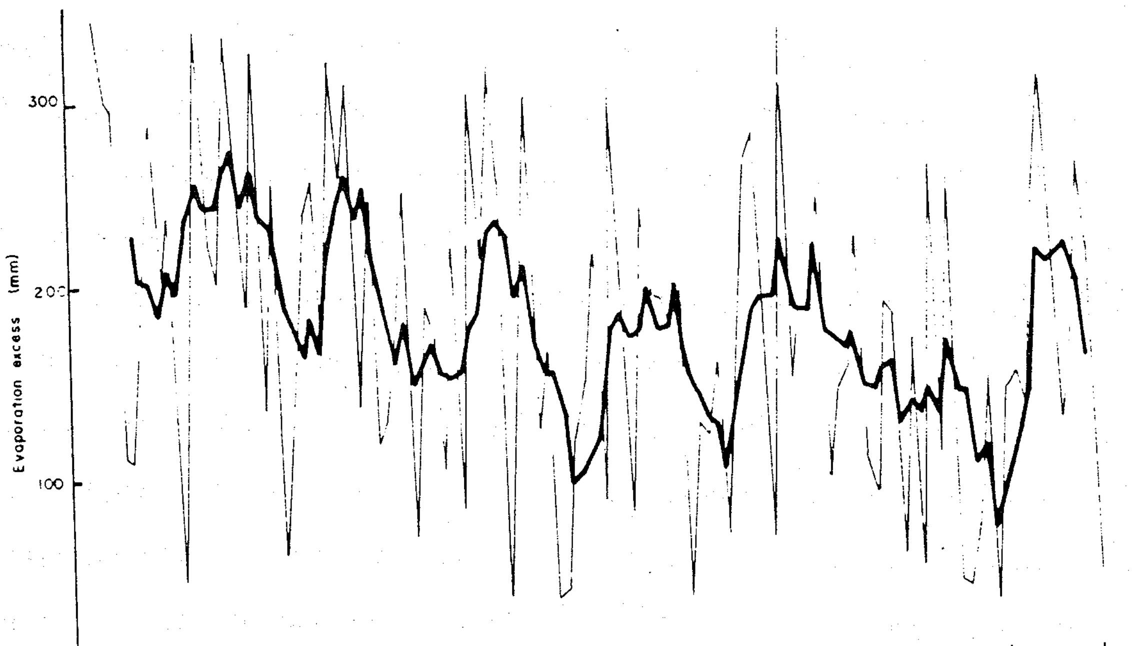

Figure 8 : Excess of monthly evaporation over monthly precipitation for annual maximum dry period, Albert Park 1872-1979.

occasions when short periods have produced very high losses. For example, a seven month dry period in the summer of 1914-15 resulted in 316 mm evaporation loss, whereas a four month dry period in the summer of 1945-46 resulted in a 333 mm evaporation loss. The longer the dry period the more severe are the effects, particularly on stream flows. In the Upper Waitemata Harbour Catchment the longer dry October-November period in 1982, compared to 1981, resulted in much smaller stream summer low flows (see Fig. 14).

Annual rainfall for both years of the study period was lower than both the 1941-70 normal (1268 mm) (NZ Met. Ser. 1973) and the 1872-1981 average annual rainfall. Rainfall for 1980 (1153 mm) was 9.1% and 3.4% lower respectively while 1981 (1088 mm) was 14.2% and 8.8% lower than the long term values.

Seasonal Rainfall Patterns :

Table 1 summarises monthly mean rainfall from Albert Park and Riverhead Forest Headquarters gauges as well as the calculated mean monthly rainfall for the Upper Waitemata Harbour catchments. The mean basin rainfall for the catchments was calculated by the isohyetal method. The Albert Park record indicates the summer months average 70 mm and the winter months over 120 mm. The standard deviations range from 40 mm - 70 mm and demonstrate the summer and autumn months are the most variable. The variability of rainfall throughout the year is depicted in Figure 9 which shows the summer and autumn months are the most variable. The spring months not only have higher monthly mean rainfall but also display less variability than the summer and autumn months.

Table 1 : Monthly rainfall for Albert Park, Riverhead Forest and calculated rainfall for the Upper Waitemata Harbour catchments

Figures in brackets are standard deviations

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
Calculated Average Rainfall for UWHS Catchments												
85.9	105.0	93.7	120.6	143.2	154.8	162.3	138.9	114.0	118.9	99.7	89.0	1426
Average Rainfall Albert Park 1872 - 1979												
71.9	87.9	78.4	100.9	119.9	129.6	135.8	116.3	95.4	99.5	83.4	74.9	1193.
(51.1)	(73.2)	(53.2)	(63.3)	(54.9)	(51.6)	(52.8)	(50.5)	(40.3)	(46.6)	(45.0)	(43.7)	
Average Rainfall Riverhead Forest 1928 - 1979												
84.7	107.1	92.3	123.1	144.4	163.8	168.9	141.7	112.2	109.9	97.6	91.9	1437.
(59.5)	(92.4)	(65.7)	(56.1)	(67.2)	(67.9)	(62.5)	(51.6)	(44.5)	(53.7)	(51.5)	(41.4)	

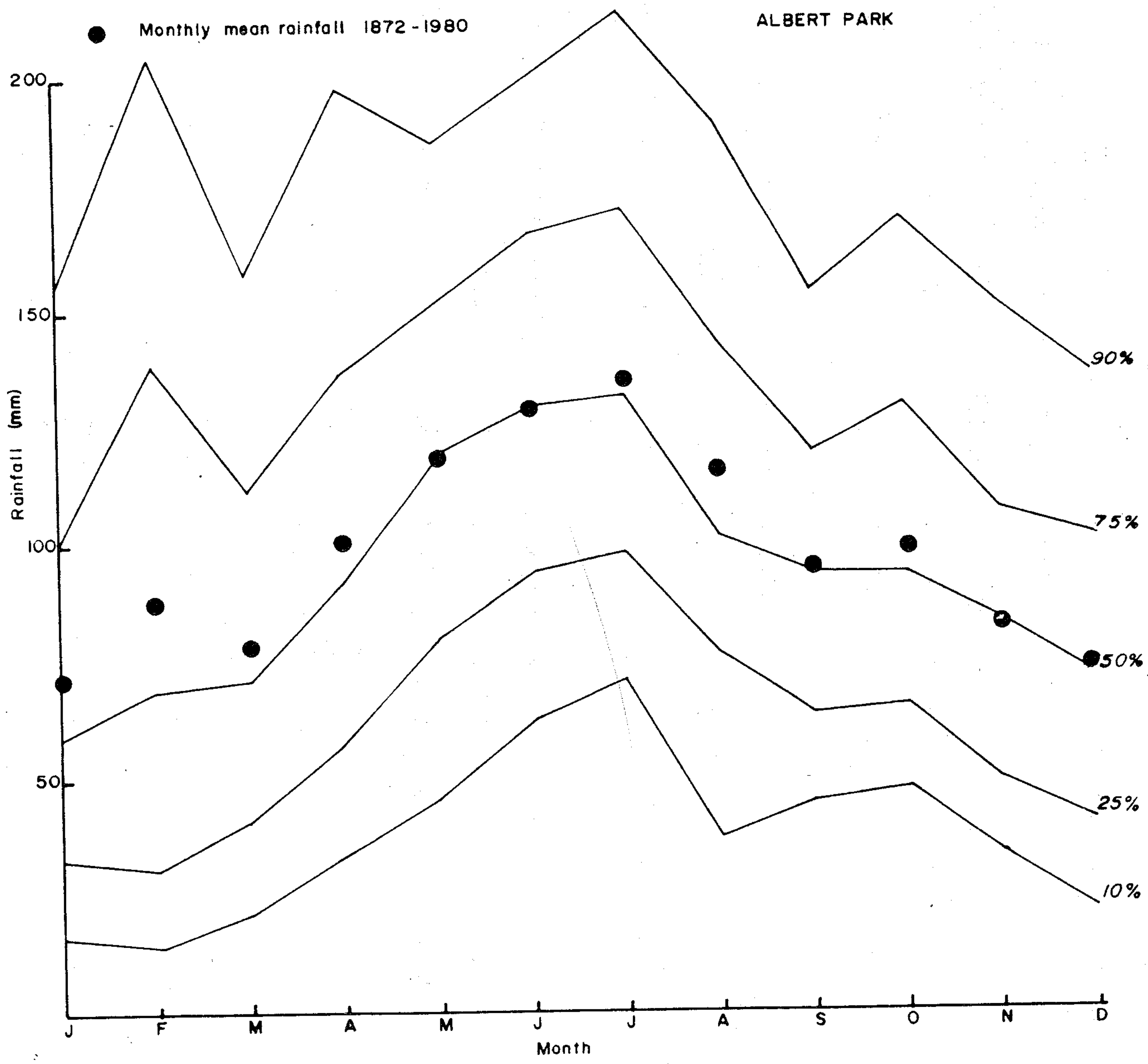

Figure 9 : The percentage probability of the monthly rainfalls being equal to or less than the value on the ordinate.

There is a seasonal distribution of rainfalls in excess of 50 mm in 24 hours (Table 2). Of the 193 events recorded, 66 occurred in the months of February and April. The spring months have the lowest frequency of heavy rainfall events. February, April, June and December are the only months when rainfalls in excess of 100 mm have been recorded. The heaviest rainfall, 162 mm, occurred on 1 February 1936. The severe storm of 15 March 1980 that produced considerable flooding and public concern in the Upper Watemata Harbour Catchment, recorded 80 mm rainfall. There have been 39 events equal to, or larger, in the 111 years of record. There is a 35% probability of a storm in excess of 80 mm occurring in any one year. March storms are usually much less severe, only 5 in excess of 80 mm have occurred since 1872. There is therefore, a 4.5% probability of an event of such size occurring during March in any one year. The effect of the March storm was to cause an unusual peak in the annual distribution of stream flows during the study period.

Rainfall in the Upper Waitemata Harbour catchments varies from 1600 mm in the north and west in Riverhead Forest, to 1204 mm in the south and east near Lake Pupuke (Fig. 10). Smith (1980) suggested there was an orographic effect on rainfall. The records from the long term gauges in Auckland City, the Upper Waitemata Harbour catchments and Waitakere Ranges confirmed a trend for increasing rainfall with increasing elevation ($r = 0.8506$ $p = 0.001$). Gauges below 30 m did not display any relationship with elevation ($r = 0.1106$) but did depict an east to west trend in rainfall with greater depths being recorded towards the west ($r = 0.9218$ $p = 0.001$). Beyond the western hills the rainfall decreases to values similar to the east coast. Woodhill Forest has a 1941-1970 normal annual rainfall of 1313 mm (NZ Met. Ser. 1973).

Table 2 : Monthly distribution of heavy rainfalls, Albert Park 1872-1979

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Events over 50 mm	11	34	20	32	21	11	19	13	3	10	12	7
Events over 100 mm		10	0	4	0	2	0	0	0	0	0	1
Max 24 hr rainfall	97	162	97	131	91	128	85	99	61	63	80	114

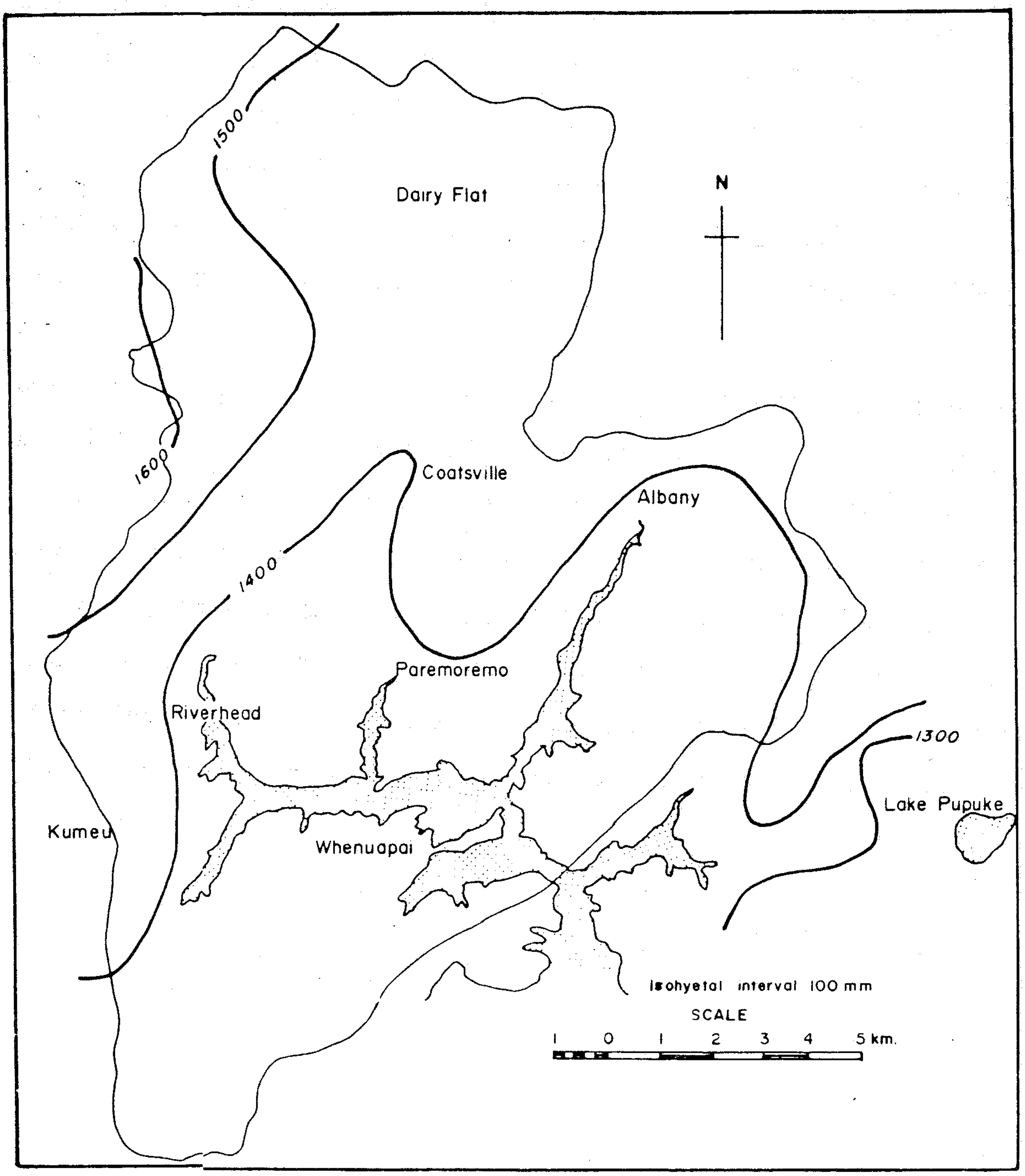

Figure 10 : Isohyetal map of the Upper Waitemata Harbour Catchments.

Implications for Management

While dry periods have been less severe in recent years, dry summer conditions are a factor that will limit development of intensive agricultual and horticultural land use. Dry periods of four to five consecutive months of low rainfall have a recurrence interval of five years and produces the conditons experienced during the summer of 1978 (see Section 3). Irrigation facilities will require sufficient storage to supply water for dry periods of up to five months to ensure minimal disruption of production. Winter rainfall is less variable than that of the spring and summer months and could provide a reliable source of water for storage for summer irrigation.

Heavy rainfalls occur most often in the summer when construction and land development activities are greatest. Sediment traps to prevent the discharge of material into streams and estuaries, should be designed to cope with these heavy rainfall events as the land is most prone to erosion processes during this development stage. The increased frequency of rainfall events of 10-20 mm/day and 30-40 mm/day indicate that to keep sediment erosion to a minimum the area of bare ground at any development site should be kept to the smallest practical size at all stages of development.

SECTION 3 : STREAM FLOW CHARACTERISTICS

Methods and Limitations

The stream flow characteristics of the Upper Waitemata Harbour catchments were established by means of stream flow measurements on numerous tributary streams together with continuous water level recordings at seven sites (Appendix 1).

The Upper Harbour catchments drain a total of 188.5 km^2 and the recorder sites measured flows from 129 km^2. The majority of the area consists of pastoral and horticultural land uses and most of the recorders monitored flows from these types of catchments. Two sites, Deacon Road and Rols, were installed in Riverhead Forest to ascertain the nature of flows in exotic forests and to determine sediment yields. A third temporary recorder was installed at the Control site to compare yields from small forest catchments.

Three levels of stream flow observations were maintained throughout 1980-81. Firstly, detailed flow records were obtained from the automatic water level recorders monitoring the major catchments and a variety of land uses. Secondly, observations were carried out at a number of uninstrumented sites to obtain a measure of total yield from all catchments entering the harbour. Finally, a third group of catchments was examined to ascertain the pattern of low flows during dry periods.

Water resources mapping, to determine the distribution of flows of various recurrence intervals throughout the study area, was attempted. The initial study (Smith 1980) mapped mean flows in the Rangitopuni catchment based on the correlation techngiue of Scarf (1972). Subsequent data collected in this study demonstrated the extreme variability in flows from the various catchments and found the approach was unsatisfactory. Table 3 summarises the differences between true and calculated flows for all the recorder sites and demonstrates the high degree of variability in the results.

Part of the variability between catchments during low flows can be attributed to water abstraction from the streams during dry periods for irrigation and stock watering. When gaugings took place the stream flows may have been reduced by abstractions or were recovering from a recent abstraction. For example on 12 March 1981 Lucas Creek at Gill Road and the adjacent tributary at Hotel, were gauged in the morning and afternoon. The Gills Road site had an 18% increase in discharge for the later gauging while the Hotel site recorded a 6.4% decrease in flow for the same period. No abstractions took place on the Hotel site tributary and the lower flow for the morning gauging at Gills Road is probably associated with water abstraction upstream.

Low flow measurements not only provided data on the total water yield at a critical time but also enabled an assessment to be made of the effects of irrigation demand on the streams. Because many of the catchments are small, usually about 10 km^2, flows are correspondingly small and abstraction can have a significant effect on the total flow. Even in the larger streams, such as the Rangitopuni, irrigation withdrawals can reduce the flow to zero, or near zero, during dry periods. The measured flow of 3.2 $l\ s^{-1}$ at Rangitopuni at Walkers on 18 February 1982 was caused by irrigation demand. Figure 11 demonstrates the effect of water abstraction on water levels in the Rangitopuni River at Walkers in February 1982. The

Table 3 : Variation between actual and calculated flow duration curves from monitored catchments

% Time	Mean of % variation	Std Dev	Max	Min
MAX	256.3	749.2	2716	-99
5	-32.2	34.5	36	-77
10	-34.0	36.8	50	-77
15	-24.8	45.6	63	-79
20	-24.4	44.5	63	-79
25	-24.6	43.8	61	-80
30	-24.5	45.2	61	-82
35	-21.9	46.7	72	-82
40	-19.7	46.6	71	-80
45	-15.3	45.8	67	-75
50	-13.4	42.9	68	-68
55	-12.4	41.6	67	-64
60	-9.8	41.3	68	-62
65	-6.4	40.0	67	-56
70	-2.2	39.1	69	-54
75	2.5	34.9	62	-49
80	10.3	35.9	70	-44
85	13.5	36.3	80	-33
90	19.3	39.6	85	-29
95	25.2	49.9	114	-33
100	773.7	1745.2	6400	-30

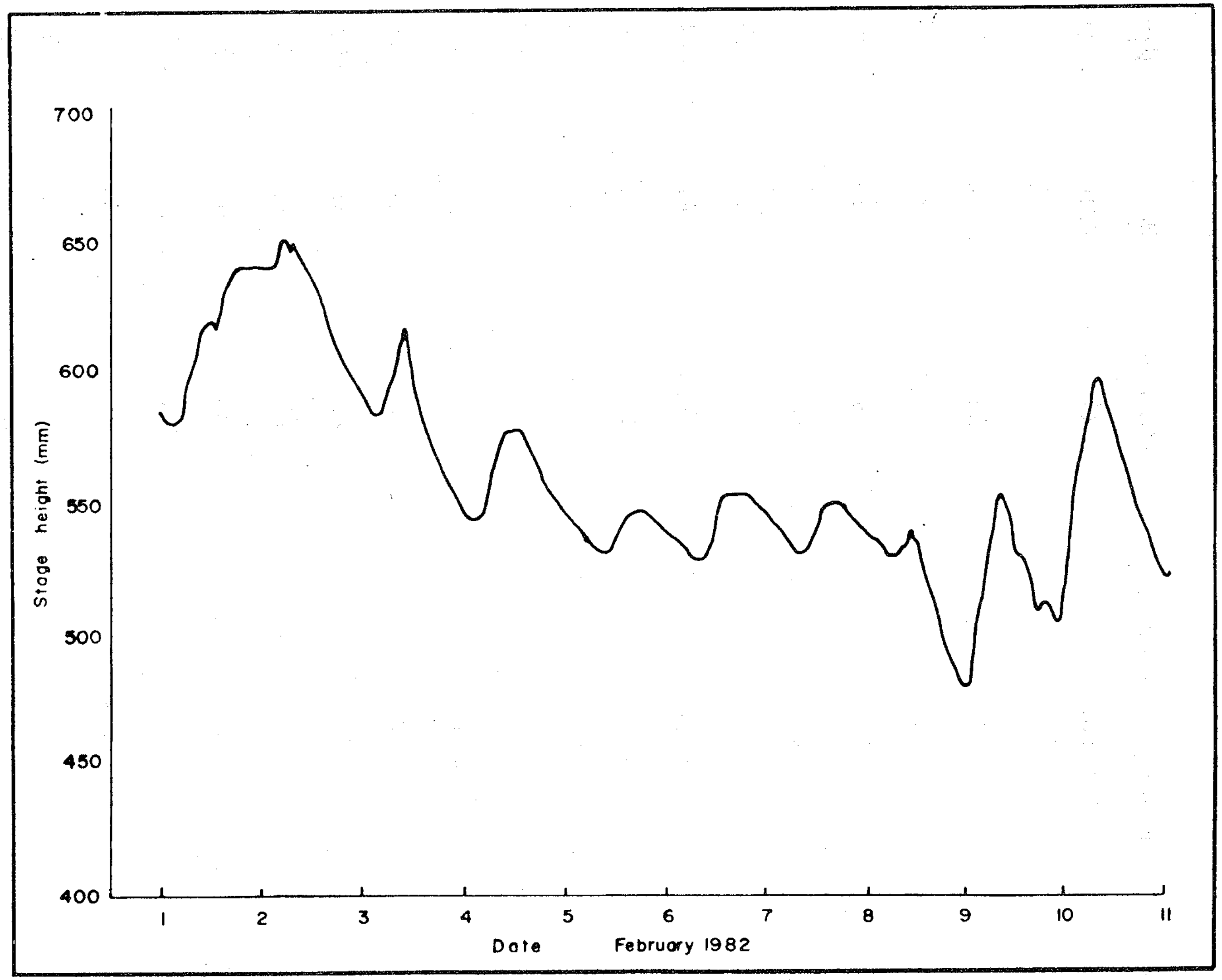

Figure 11 : The Rangitopuni River at Walkers showing the effects of water abstraction on the recession hydrograph, 1-11 February 1982.

smaller catchments in the Upper Waitemata Harbour that are not used for irrigation provide a measure of the true specific yield conditions during a dry period, and this figure can be used for planning future management of the larger streams.

An attempt was made to improve the predictive value of the flow data by relating the sites within the study area to nearby sites with longer records. All of the Upper Waitemata Harbour catchments lie in the Waiotira hydrological region (Fig. 1). The only long term site in this region is Waiwhiu Representative Basin, but this has been found not to be representative of the Waiotira hydrological region (Waugh 1970) and is therefore unsuitable for extending the Upper Waitemata Harbour records. Consequently the Upper Waitemata Harbour data were related to the Manukau Experimental and Waitangi Representative Basins to the south of the study area which, although in the Pukekohe hydrological region, appeared to have a similar flow regime to the catchments around the harbour.

Mean annual and flood flow data provide information on the annual pattern of water availability and waterway design requirements during high flows. This section describes the existing hydrological regime including the annual flow pattern, flood and low flows, and water availability in the catchments draining into the Upper Waitemata Harbour.

Mean Annual Discharge :

The pattern of mean annual water yield is similar throughout most of the Upper Waitemata Harbour catchments (Table 4), except that winter specific yields are generally lower in Riverhead Forest than in the predominantly pastoral catchments. Although May is usually the first wet month of the

Table 4 : Mean monthly and mean annual specific yields for the Upper Waitemata Harbour catchments and Wairau Creek 1980 - 1981

Site	Land use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Specific Yield l/s/km^2
Rangitopuni at Walkers	Pastoral	7.46	8.63	22.15	8.73	8.40	27.74	39.91	24.49	17.37	6.00	12.26	8.96	16.0
Ngongetepara at SH16	Pastoral	3.57	6.08	10.28	9.66	9.25	33.54	39.62	26.07	16.81	5.36	10.10	3.76	14.51
Oteha at Days Bridge	Pastoral	5.23	3.09	14.22	6.76	4.12	18.38	26.42	21.26	15.45	5.64	8.28	9.64	11.54
Alexandra at Rosedale Road	Pastoral	6.65	3.58	15.59	6.81	3.82	21.25	32.48	23.42	15.74	5.59	9.33	10.78	12.92
Lucas at Gills Road	Pastoral	5.67	3.18	1.29	7.31	5.40	22.12	32.91	28.03	15.65	7.91	11.58	11.50	12.71
Rangitopuni at Deacons Road	Forest	6.43	5.61	6.49	6.24	5.61	13.45	17.78	14.46	9.45	6.60	10.93	8.74	9.33
Rangitopuni at Rols	Forest	2.76	1.69	3.38	2.07	1.88	3.65	6.61	4.58	3.58	2.00	3.08	3.04	3.19
Wairau Creek at Motorway	Urban	12.11	10.73	25.09	13.30	9.54	30.46	33.07	25.4	18.99	8.67	17.93	17.24	18.54

year, flows do not show a corresponding rise until June, which suggests that most of the May rainfall is taken up replenishing groundwater storage. Once groundwater has been replenished rainfall then contributes during the winter to an increase in streamflow which peaks in June and decreases towards summer. For 1980 and 1981 the rainfall for Albert Park was 39% and 42% of the 1941-70 normal rainfall and it is probable that under normal rainfall conditions winter runoff would commence earlier than June.

The forest catchments are distinguished by a smaller than average seasonal variation in flows. There is a moderate peak in July but the low flows in late summer tend to be higher than those in the pastoral catchments. These moderate low flows in the forest during summer are principally drainage from swamps in the headwater sub-catchments. Aerial photograph analysis and ground checks found that some 16% of the Control catchment consisted of swamp which appeared to be contributing the majority of water during the summer dry period. Similar higher specific yields during low flow surveys were found in the Mikel, Yoe, Rangitopuni Road (all predominantly forested), and Richards Road (predominantly pastoral) catchments (Appendix 1) all of which have swamps within their headwaters. By contrast the swamps in the catchments draining the terraces on the southern side of the harbour did not display higher yields, suggesting that the underlying geology probably has a significant influence on summer mean flows.

Some of the variation in the monthly mean flows can be attributed to the short length of record and the occurrence of low frequency events during the study period. The unusually high values in March are the result of the storm on 15 March 1980. The Lucas Creek at Gills Road recorder was not installed at this time and the record is not effected by the flood. The

Lucas Creek record is probably a more accurate record of normal March specific yields for pastoral catchments. The long term rainfall record indicates that heavy falls of rain are most likely in February and April and it is possible that the average monthly specific yields shown here are underestimates of the normal monthly yields for these months. Similarly, October is consistently the month of lowest spring flows even though rainfall is usually reliable at this time of the year (Table 1). October rainfall for both years of the study was 54% and 42% below the average monthly total respectively.

Under normal average rainfall conditions the mean flow for October could be between 12 and 15 $l.s^{-1}$ or double the figures shown in the table.

Flood Flows :

With the exception of the Rangitopuni, the flow record in the study area was too short for the derivation of return periods for floods of various sizes. Using data from the Rangitopuni (7 years) and Waitangi Representative Basin (15 years) and the technique described by Langbien (1960), flood estimates for various return periods were obtained by relating partial flow duration curves to annual maximum flood series. However, although this approach is the most reliable, caution should be exercised when using results based on such a short observation period. The results obtained from this approach suggest that for the Upper Waitemata Harbour catchments the specific yield for flood peaks will approximate the values given in Table 5. The standard error of estimate could be 45-54% (Rantz 1971). Table 5 is based on catchments of 17.6 km^2 and 82.9 km^2 and is probably most apropriate for catchments of 10-100 km^2.

Table 5 : Specific yield for flood flows based on Walkers and Waitangi flow records

Recurrance Interval	Specific Yield $m^3 s^{-1} km^{-2}km$
2	0.35
5	1.02
10	1.52
20	2.03
50	2.69
100	3.20

The 10 year record from Manukau Experimental Basin demonstrates that compared to the larger basins, small rural catchments, less than 1 km^2, will have much higher flood yields (Table 6). This 0.3 km^2 catchment will, according to existing data, produce a peak flood yield of 20 $m^3\ s^{-1}\ km^2$ for a storm with a 50 year recurrence interval. A study of storm discharges from small catchments in Northland and Auckland (Waugh 1975) indicated that an event with a 10 year recurrence interval on a 0.3 km^2 catchment, would produce a peak flow of 2 cusecs per acre (139 l/ha). This is equivalent to 14 $m^3\ s^{-1}\ km^2$ which is nearly double the estimated 10 year event based on the partial duration series at Manukau Experimental Basin. Caution should be exercised because of the short record, but even if these estimates for the 10 and 50 year floods are 50% too high, the yields are still substantially different from that of larger catchments. The high yields from such small rural catchments result from high intensity rain which causes most of the catchment to contribute to overland flow. Flood peaks, particularly for the smaller and more frequent events will be increased by urbanisation because of changes in both overland flow and stream channel conditions (Anderson 1970, Carter 1961, Hollis 1974, 1975 and Leopold 1968). The effect of urbanisation on stream flows is further discussed under land use and the hydrological regime.

Low Flows :

Low flows were measured in March 1981 and February 1982. The probable recurrence interval for the dry period low flows of 1981 and 1982 low flows was estimated using both Albert Park rainfall data and also the low flow data from Waitangi Representative Basin. The dry periods had a 2.0 and 2.1 year recurrence interval respectively, based on Albert Park data (Fig. 12). Waitangi Representative Basin flow data indicated the probable recurrence

Table 6 : Specific yield for flood flows based on Manukau Experimental Basin

Recurrance Interval	Discharge $m^3\ s^{-1}$	Specific Discharge $m^3\ s^{-1}\ km^2$
2	0.7	2.33
5	1.58	5.27
10	2.55	8.50
20	4.2	14.00
50	6.0	20.00

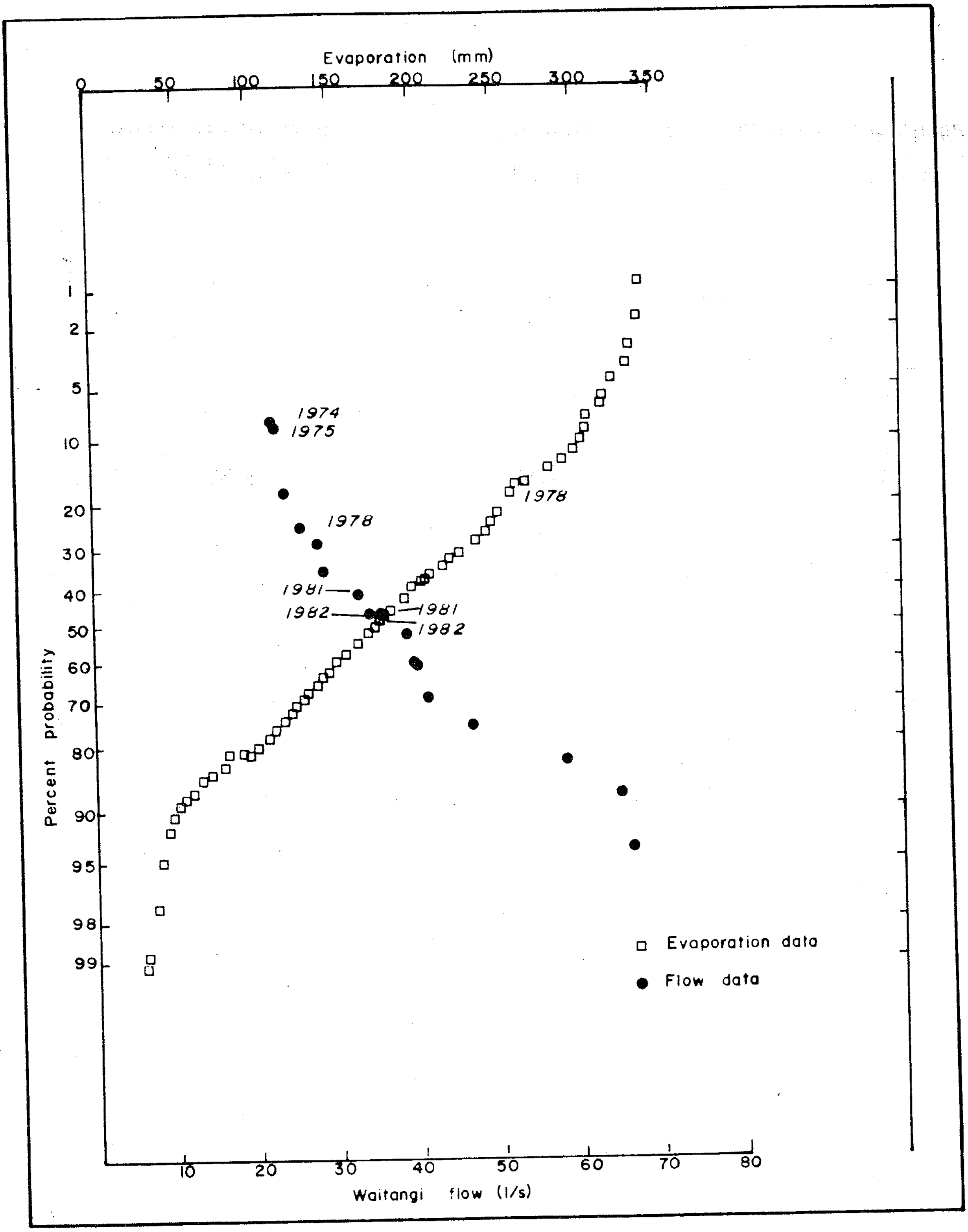

Figure 12 : The recurrence interval of the 1981 and 1982 dry periods based on rainfall data from Albert Park and flow data from Waitangi Representative Basin.

intervals to be 2.1 and 2.4 years respectively (Fig. 12).

Waugh (1970) demonstrated the importance of geology in influencing the low flow hydrological regime in the Northland peninsula. Low flow observations in the study area confirmed the influence of geology in determining the distribution of low flow water yields.

The flows on 15 March 1981 show an area of higher specific yield on the northern and western side of the harbour from the Waitemata formation. In the northern Rangitopuni catchment flows ceased from the Onerahi formation. To the south of the harbour, on the Pleistocene terraces, low yields predominated (Fig. 13). The total estimated freshwater inflow into the harbour on 15 March was 105 l s (Smith 1981).

During periods of low flow the Rangitopuni is the major source of freshwater for the Upper Harbour estuary. Streams draining Lucas Creek and Riverhead Forest catchments provide most of the remaining flows (Fig. 14). The total inflow into the harbour is a small percentage (about 0.5%) of the tidal prism but abstraction from either the Rangitopuni or Lucas Creek streams can cause a significant reduction in the freshwater supply, as occurred during the summer of 1982.

In 1982 many of the streams flowing into the Upper Harbour were effected by water abstraction. The exceptions were some small streams draining the western hills and Riverhead Forest. On 18 February the calculated inflow of freshwater was 43 l/s (Fig. 14). Despite the very low flows, the pattern of specific yields was similar to that of 1981, reflecting the geological control on base flows. The main difference from the previous

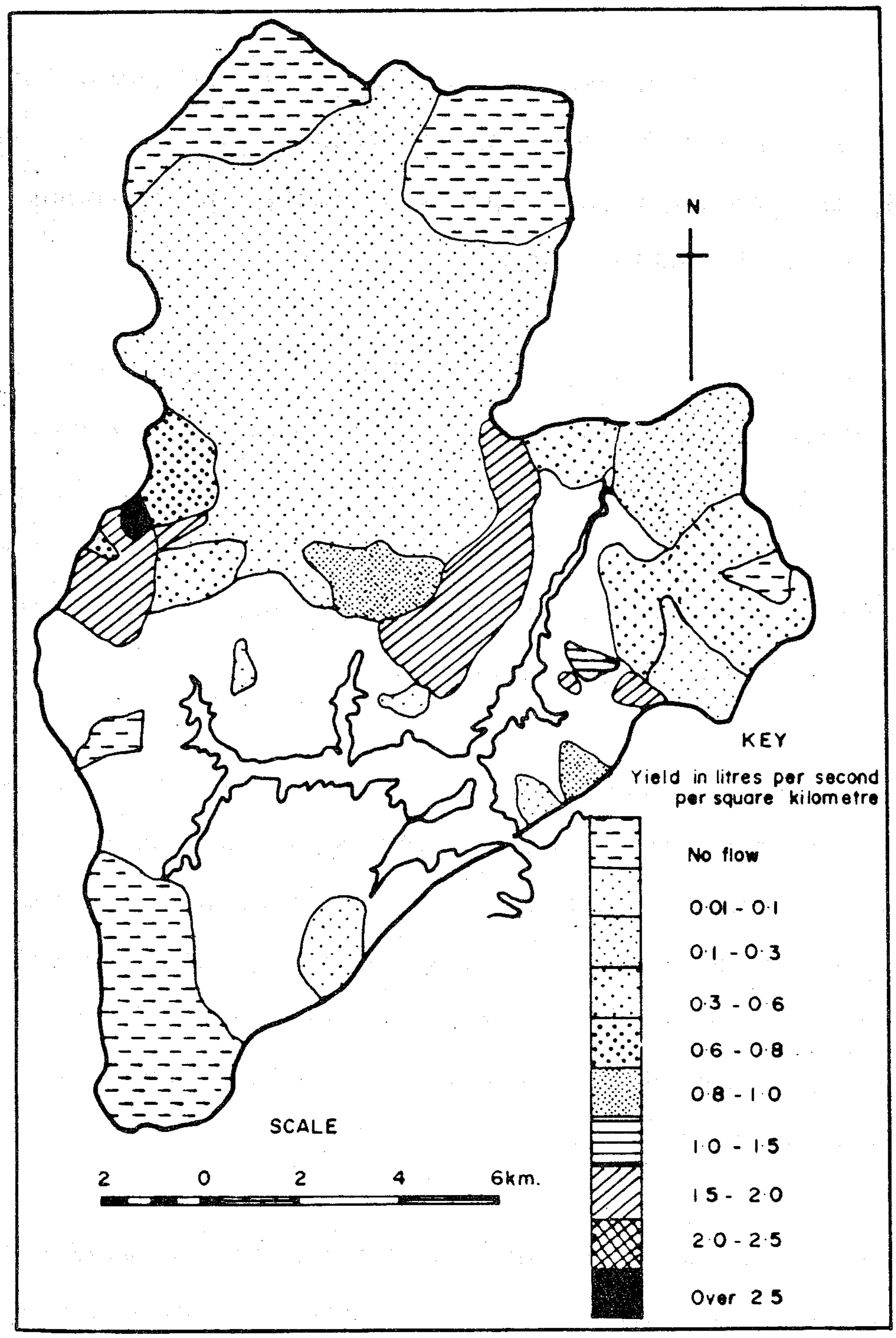

Figure 13 : Specific yields from gauged catchments for 15 March 1981.

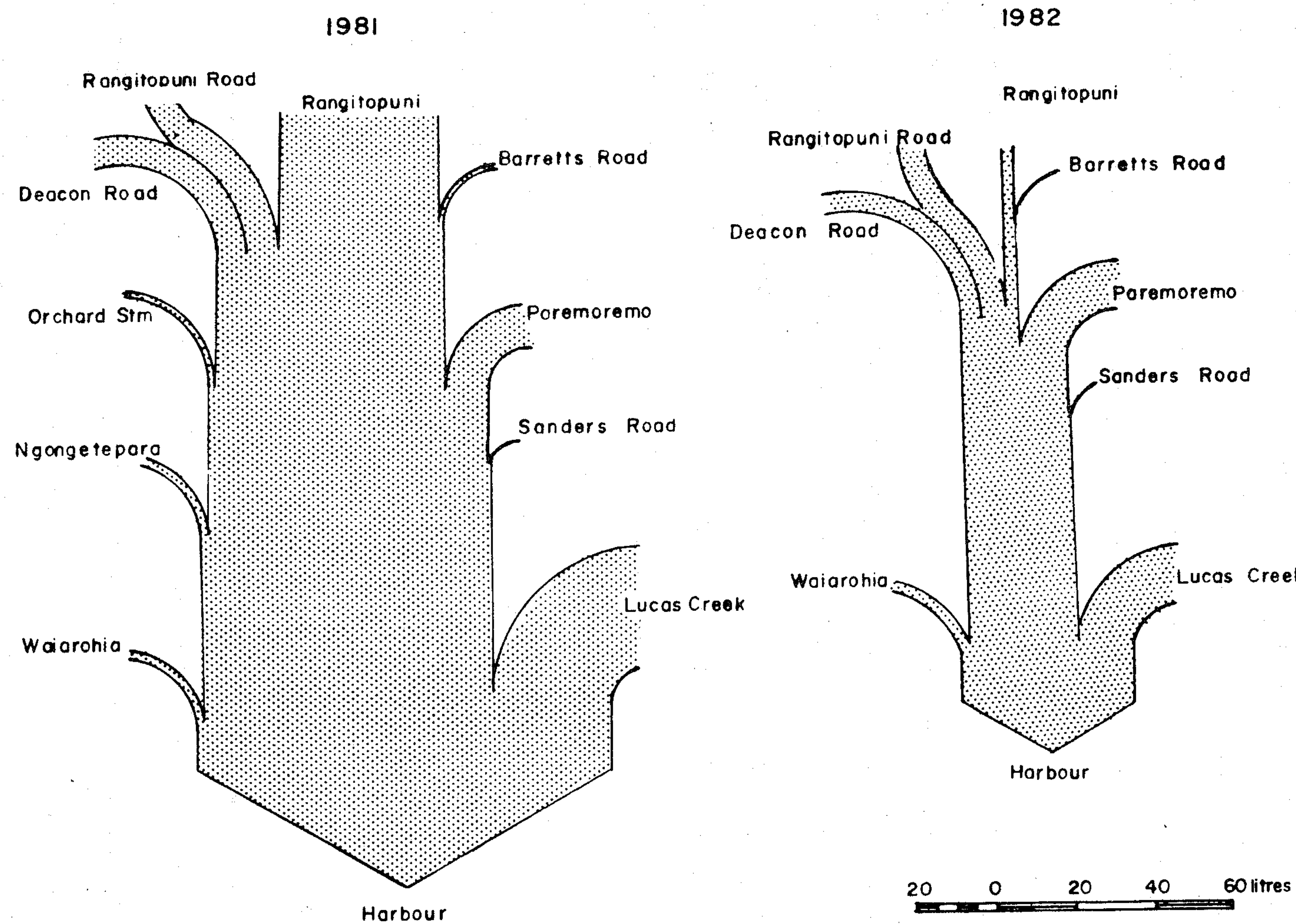

Figure 14 : Flow diagram of low flows entering the harbour in 1981 and 1982.

year was that contributions of the larger streams were reduced or completely absent as abstraction caused some streams to cease to flow.

Previous low flow surveys which included some of the Upper Waitemata Harbour catchments, were carried out annually from 1975 to 1978 inclusive, by the Ministry of Works and Development. The most comprehensive of these surveys, 1978, was made during the most severe drought measured.

The 1978 dry period had a recurrence interval of 5.6 years based on rainfall data and 4.1 years based on Waitangi flow data. A comparison of the low flows during the 1978 and 1982 dry periods present some conflicting results (Table 7), which are probably associated with changes in land use. The observed extreme low flow in 1982 at Walkers and the Ngongetepara sites were a result of water abstraction. The Mikel and Yoe sites have much lower yields in 1982 than either 1978 or 1981. This could be associated with the partial clearance and improved swamp drainage in these catchments during milling operations in Riverhead Forest. The Oteha River and Lucas Creek streams show little difference in flows between 1978 and 1982 which could be because of water abstraction though this is not certain.

Water Availability :

Future planning for proposed land use change requires data on the timing and availability of water supplies. Possible alternatives for a rural water supply are : (a) bulk water supply from outside the catchment, or (b) winter storage of excess stream runoff. Existing rural water supplies in the Upper Waitemata Harbour catchment barely meet present demand during summer low flow. There is a 75% probability of the Oteha, Nongetepara and Rangitopuni rivers producing specific yields of between 25 and

Table 7 : Low flows for the Upper Waitemata Harbour catchments 1978, 1981 and 1982

Specific Yields l s^{-1} km^2

	1978	1981	1982
Horseshoe Bush Rd	0.0	0.0	0.0
Bowdens Rd	0.0	0.0	0.0
Mikel (1)	1.66	1.56	0.68
Yoe	2.57	2.40	1.55
Blackmores	0.12	1.54	0.99
Walkers (1)	0.48*	0.44	0.04
Paremoremo (1)	1.05	1.34	1.58
Days Rd	0.48	0.61	0.45
Lucas Creek	0.15	0.52	0.15
Ngongetepara	0.11	0.09	0.0
Waiarohia	0.002	0.12	0.01

* from stage record only

(1) gauging by current meter 1981, 1982

40 l s^{-1} km^{-2} during the months of June to September (Fig. 15). Assuming that half of this flow could be made available for storage, these catchments could provide between 130,000 and 210,000 $m^3.km^{-2}$ of water during these winter months. These estimates should be used with caution because of the short record. Furthermore, as the study period was drier than usual it is probable that these volumes are underestimates. Storing part of the winter discharge for summer irrigation appears a practicable means of providing adequate water for some expansion of horticulture in the Upper Waitemata Harbour catchments.

The existing hydrological regime in the Upper Waitemata Harbour catchments presents some restraining conditions for future development. The seasonal variations in mean flows under present conditions depict a summer shortage and a winter surplus of surface water. Rainfall records suggest that summer flows are more variable than demonstrated by the present short record. The high frequency of heavy rainfalls in summer and autumn suggest that flood events are not uncommon at this time of the year. Erosion associated with these events could cause sedimentation problems in streams near new land developments. Specific yields for flood flows from catchments of 10-100 km^2 are not as large as yields from catchments of less than 1 km^2 because the proportion of the area contributing to overland flow is larger in the smaller catchments. The high yields occurring naturally from these small catchments pose a serious drainage problem in areas suitable for future urban develpment. Under existing conditions the shortage of water during the growing season is one of the most severe limiting factors for horticultural expansion. Storage of a proportion of the excess winter flow appears to be a practical solution to this problem.

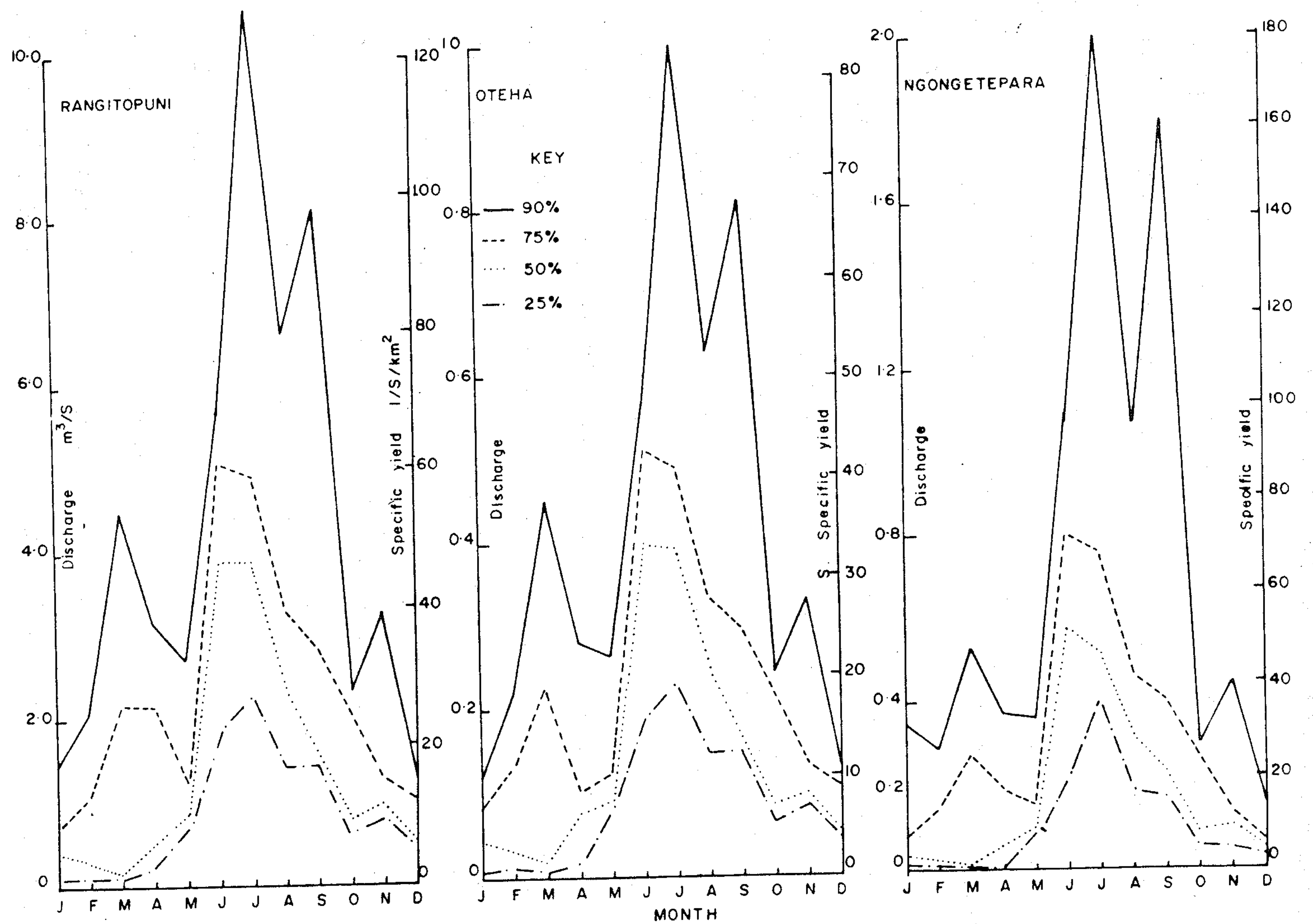

Figure 15 : Probable water availability in the Oteha, Ngongetepara and Rangitopuni Rivers.

SECTION 4 : CATCHMENT CHARACTERISTICS, LAND USE AND THE HYDROLOGICAL REGIME

Catchment Morphology and Hydrograph Characteristics

Hydrograph characteristics for each of the catchments in the Upper Waitemata Harbour and also Wairau Creek were established using the hydrograph separation technique (Hewlett and Hibbert 1967) (Table 10). Catchment physical characteristics were obtained from aerial photographs and topographical maps (Table 8). Four groups of physical characteristics were observed including; drainage, areal, altitudinal and shape factors. Table 9 demonstrates that in pastoral catchments, drainage pattern factors have the greatest effect on the form of the hydrograph. Increasing drainage density, stream frequency, and channel steepness all tended to reduce the time to peak. Increasing basin order was associated with an increase in the time to peak indicating that, as expected, the larger rivers tend to react more slowly to flood events. By contrast catchment area was found to have no significant relationship with the time to peak, though stream order and catchment area are strongly related ($r = 0.9628$, $p = 0.001$). Peak runoff was found to be related to areal factors, that is the larger the catchment the larger the peak flood discharge. Peak specific yields for flood events did not appear to be related to any of the basin physical characteristics.

The proportion of rain contributing to quick flow is influenced by the areal and drainage pattern characteristics of the catchments and is a measure of the proportion of the contributing area in each catchment. While this is true of events of average size, Waugh (1975) has demonstrated that for less frequent events small catchments will discharge a higher proportion of rainfall as quick flow than larger ones because of the more

Table 8 : Physical characteristics of the Upper Waitemata Harbour catchments

Catchment	Circularity	Mean Height (m)	Amplitude (m)	Length (km)	Area (km^2)	Drainage Density km/km^2	Channel Slope mm/m	Texture M/P	Longest Channel (m)	Width = A/L (km)	Basin Order	Stream Frequency N
Alexandra	0.57	56.4	62	2.8	2.54	5.63	0.917	6.28	3746	0.9	3	18.5
Oteha	0.68	50.6	75	4.6	12.13	4.09	0.0094	7.94	4572	2.6	4	9.81
Lucas	0.79	54.4	95	3.4	6.26	3.01	0.0124	5.82	4699	1.8	4	9.27
Rangitopuni	0.60	64.4	159	10.8	82.9	2.89	0.0030	6.5	22352	7.7	5	3.26
Deacon Road	0.72	92.4	160	3.1	3.65	2.31	0.0208	1.1	3408	1.2	2	2.47
Ngongetepara	0.64	87.4	175	4.8	11.18	3.57	0.0084	5.81	5588	2.3	4	7.69

Table 9 : Significant relationships between hydrograph characteristics and basin physical properties

	Drainage Characteristics					Areal Factors				Topographic Characteristics	
Time	Drainage Density	Stream Frequency	Channel Slope	Longest Channel	Basin Order	Area	Length	Width	Circularity	Height	Amplitude
Time to Peak	■	■	■		■						
Duration	■	■	■		■						
Peak Discharge		■	■	■	■	■	■				
Peak Specific Peak Discharge											
% of Rainfall as Storm Runoff	■	■		■	■	■	■	■			

Shaded areas are statistically significant relationships (p = 0.05 or better) rapid increase in the proportion of the catchment contributing to overland flow. Differing land use will also effect the proportion of rainfall contributing to quick flow.

Land Use and Hydrological Characteristics

Proposed land use changes in the Upper Waitemata Harbour catchmets include expanded urban development, intensified horticulture and continued forestry in the western hill country. Both Strahler (1958) and Wolman (1967) have demonstrated that changing landuse will produce changes in the hydrological regime. A number of changes can be expected in the hydrological regime of the catchments draining into the Upper Waitemata Harbour in response to the proposed land development. Where urban development takes place, both the frequency and the size of events can be expected to increase, as experienced in Wairau Creek (Williams 1976). Increased horticultural activity will probably be associated with higher sediment yields from cultivated land (Langbien and Schumm 1958).

Intensified land use may also effect water quality because effluents discharged in areas where saturated overland flow occurs will be rapidly transported into stream channels (Dunne and Leopold 1978, Kunkle 1970). Similarly a short period of high stream flows and sediment yields is likely to immediately follow forest clearance but this should be reduced as tree cover is established.

Removal of tree cover increases peak flows, low flows and maximum water temperatures (Pierce *et al* 1970, Swank and Helvey 1970, Soffer and Lynch 1970). In New Zealand, Adams (1910) and Henderson and Ongley (1929) have observed increased erosion and stream aggredation associated with land clearance in the Waipaoa catchment.

Jones and Howie (1970) and Schouten (1976) have described the changes in the hydrological regime and sediment characteristics in the Waipaoa Basin and Puketurua Experimental Basin respectively. Schouten (1976) found that increased runoff, due to scrub clearance, was equivalent to 13% of the annual rainfall. Land clearance appears to reduce evapotranspiration and infiltration and hence increase runoff (Selby 1973). Some land use practices may enhance infiltration. For instance, Schouten (1976) found runoff was reduced after discing but increased after roller drilling and grassing. A further reduction in the infiltration capacity of a catchment takes place with urban development of rural land (Hollis 1974, 1975; Leopold 1968). The increase in the volume of runoff in response to land clearance is usually accompanied by a reduction in lag time (Jones and Howie 1970). Williams (1976) has demonstrated the reduction in basin lag time with increasing urbanisation in Wairau Creek, Auckland. The time to peak decreased from 7 hours in 1963 to 5.5 hours in 1971. The duration of the event more than halved from 70.6 hours in 1963 to 32.7 hours in 1971. During 1980-81 the average time to peak was found to be 5.9 hours and the duration of the event 32.9 hours (Table 10).

Hydrological Characteristics of the Upper Waitemata Harbour :

The hydrograph characteristics of predominantly pastoral catchments were taken as being 'standard' responses to events, against which the hydrographs from forested and urban catchments were compared.

The average time to peak in the pastoral catchments in the Upper Waitemata Harbour varied between 3.18 and 7.2 hours and the average duration of an

Table 10 : Summary of hydrograph characteristics for the Upper Waitemata Harbour catchments and Wairau Creek 1980 - 1981

Subject	Alexandra	Oteha	Ngongetepara	Lucas	Rangitopuni	Deacon Road	Rols	Wairua Creek
Area (km^2)	2.54	12.13	11.18	6.26	82.9	3.65	0.26	10.98
Peak Q ($1\ s^{-1}$	164.6	855.7	628.8	744.7	9417.7	490.3	9.9	5053.1
T. to Peak (hrs)	3.18	4.35	6.2	6.52	7.23	6.08	0.9	5.95
Duration (hrs)	7.94	10.6	13.8	15.6	16.2	13.8	2.9	32.9
Event Rain (mm)	6.5	8.6	10.7	11.6	13.9	29.2	12.8	13.9
% Rain as runoff	6.5	6.2	7.3	14.1	12.4	3.8	0.5	36.2
Peak Q/Area $1\ s^{-1}\ km^{-2}$	64.8	70.5	56.2	118.9	113.6	134.2	38.4	495.3

event was between 7.9 and 16.2 hours (Table 10). For the forested catchments the time to peak and the duration of events ranged between 0.9 and 6.08 hours and 2.9 and 13.8 hours respectively. The difference in duration of events in the pastoral and forested catchments compared to Wairau Creek is caused by the differing efficiency of the drainage network. Storm water drains and concrete lined channels rapidly discharge surface runoff into the main channel and runoff from any showers associated with the main event become included in the event hydrograph, increasing the duration of the event.

With urbanisation flood peaks are higher and more frequent (Hollis 1975, Williams 1976). The observation period in this study was too short to provide such a comparison of event frequencies. Average event peak specific discharge was found to be similar for both pastoral and forested catchments but higher for urbanised Wairau Creek (Fig 16). The lack of difference between the pastoral and forest catchments is probably caused by the old age of the trees in the Deacon Road catchments. Younger trees would provide a more dense tree canopy and have a higher water demand which would probably result in lower peak specific yields.

The proportion of rainfall which formed quickflow indicated a difference between the three types of land use. Forested catchments released 0.5% to 3.8% of rainfall as quickflow, pastoral catchments 6.2% to 14.1% and the urban catchments 36.2%. These results indicate that clear felling the forest and further urbanisation will increase the volume of quickflow entering the harbour. However, as the area of cleared forest at any one time will be small, the effects of forest clearance are thought to be insignificant. By contrast, further urbanisation in the Albany Basin may

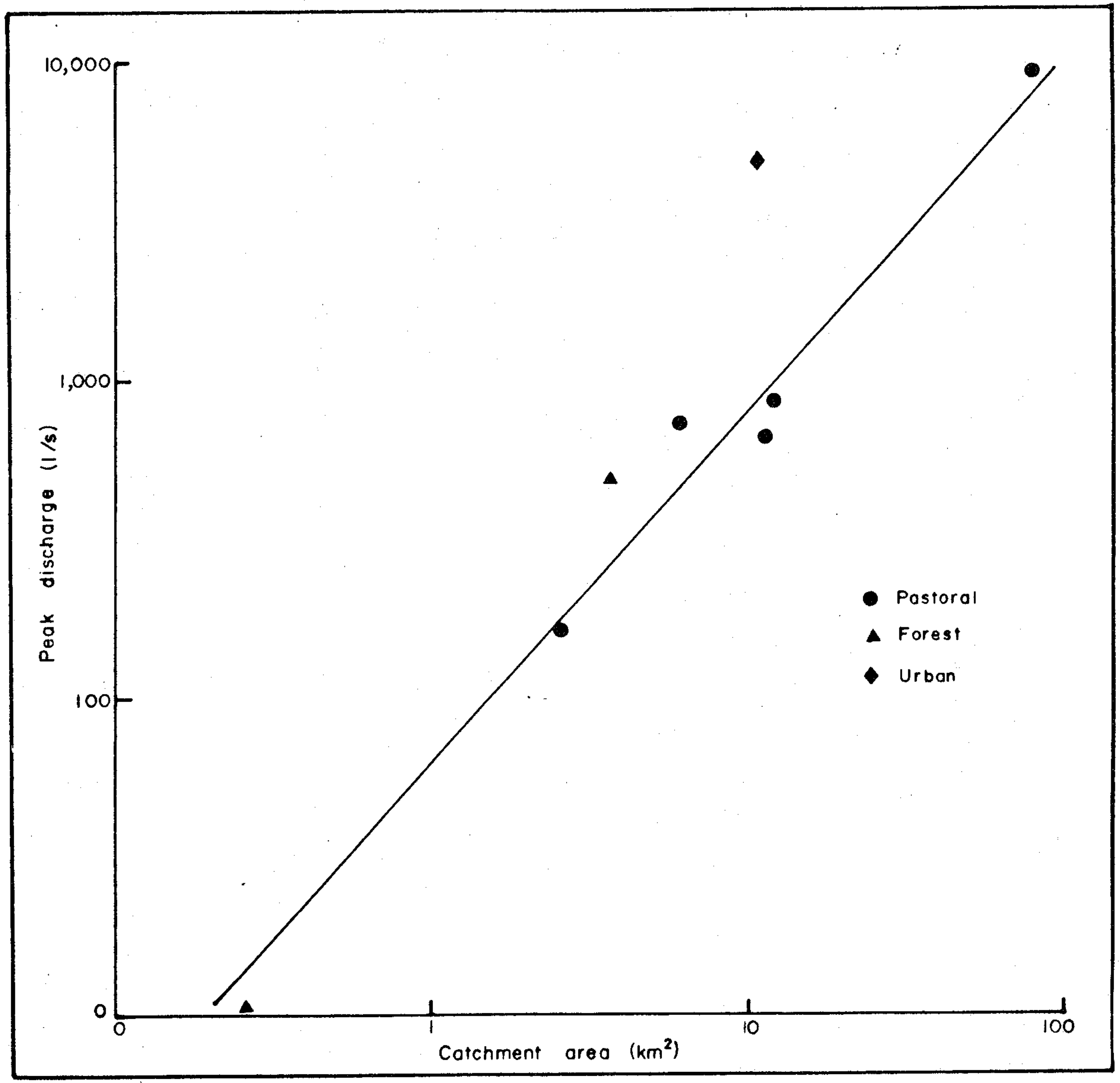

Figure 16 : Average peak specific flows for catchments of various size in the Upper Waitemata Harbour and Wairau Creek.

cause significant changes. Results from Table 6 suggest there will be between a three- and six-fold increase in the volume of quickflow from the Albany catchments associated with urban development which may result in stream channel changes.

The hydraulic geometry of a stream channel is determined by the dominant discharge, sediment discharge and the bed material composition (Leopold *et al* 1964). Park (1977) found that an increase in flood flows and the frequency of flood flows will cause significant channel changes and that stream channels below urban areas were larger than those from rural catchments of the same area. Most of the increase in channel size was found to be associated with an increase in depth (Park 1977). In the Albany Basin the streams flow over Waitemata sandstone for much of their length and as this material is more resistant than the alluvial sides, any increase in channel size is most likely to be achieved by bank erosion. Sediment so derived will be deposited in swamps in the channel network, for example the Alexandra Stream during this study; or in estuary headwaters as has occurred in Milford estuary at the mouth of Wairau Creek (Williams 1976).

The flow duration curves for each catchment (Fig. 17) indicate three overlapping groups of curves which appear to be related to land use. The forest catchments are characterised by low specific yields for storm flows and comparatively high specific yields during low flows. The urban catchment has very high specific yields during storm flows and low summer flows. The larger pastoral catchments have intermediate storm flow values and very low summer flows.

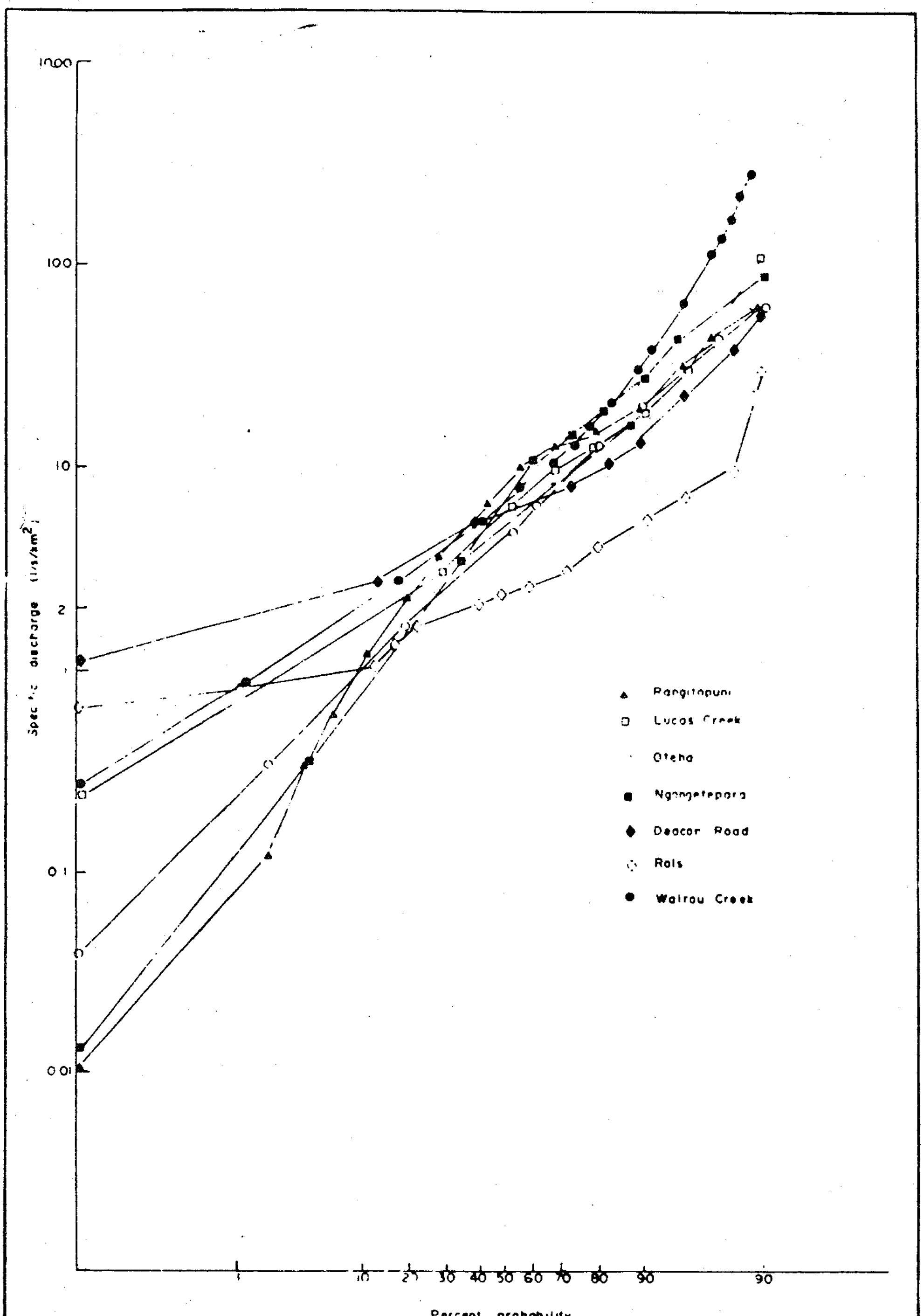

Figure 17 : Flow duration curves for the Upper Waitemata Harbour Catchments and Wairau Creek.

An examination of hydrographs indicated that base flow in the Rangitopuni commences at a discharge of approximately 180 l s^{-1} (a specific yield of 2.17 l s^{-1} km^{-2}). For the majority of the pastoral catchments and Rols, flows at, or below this value, occur for 20% (73 days) of the year. During the dry periods of 1981 and 1982 the average specific yield from catchments without water abstraction was 1.15 l s^{-1} km^{-2} and 0.12 l s^{-1} km^{-2} for catchments on the Waitemata formation and Pleistocene terrace material respectively. There was zero flow from the Onerahi formation.

Water temperature measurements were taken manually during every site visit, usually fortnightly, throughout 1980-81. For most of the year the temperatures in the streams with natural channels were between 10^{o}C and 20^{o}C displaying a predictable annual cycle (Fig. 18). Temperatures were highest in mid-to-late-summer, dropped rapidly in April-May and were coolest in July.

Forested catchments have a smaller range of temperatures and, except for the coolest months of the year, lower temperatures which are caused by the nearly continuous shade given to the water body by the forest cover. In contrast the shallow, artificial, concrete lined channel of Wairau Creek experienced a wide range of temperatures. A comparison of the results of temperature measurements in the study area with other sites in Northland indicate, with the exception of Wairau Creek, that the range and pattern of changes were typical of those experienced in this area (Mosely 1982).

Both the physical characteristics and the land use in the Upper Waitemata Harbour catchments influence the hydrological regime in each catchment. Drainage network efficiency, as measured by drainage density, stream

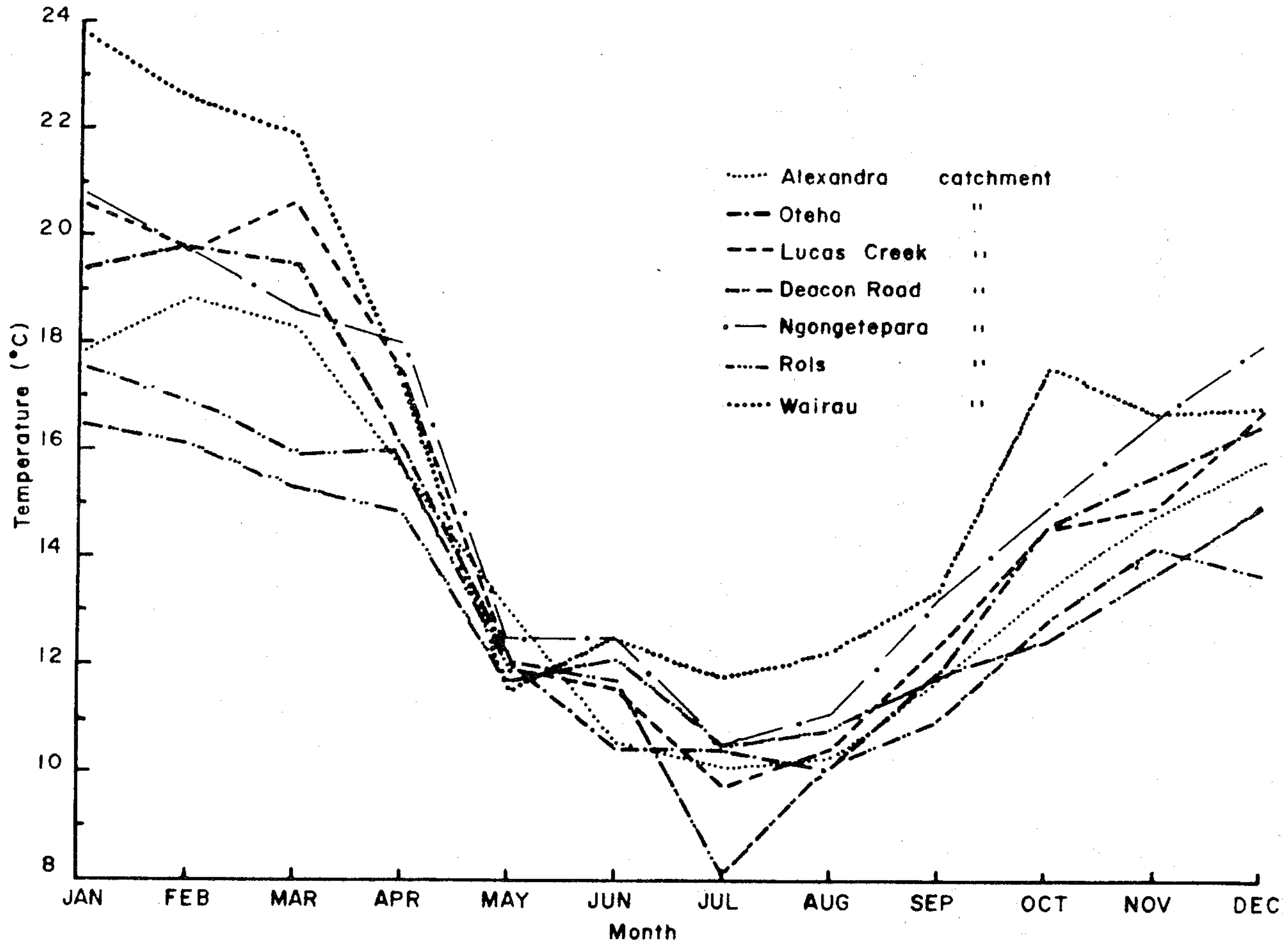

Figure 18 : Water temperature variation in the Upper Waitemata Harbour catchments and Wairau Creek.

frequency and channel slope, is the single most important influence in determinng the time to peak of the stream system. The peak flow of the event discharge is primarily affected by areal and landuse factors, given similar event rainfalls. The type of landuse can inhibit or accentuate the natural hydrological characteristics. The creation of a dense drainage network of concrete lined channels and piped waterways increases the channel efficiency causing a short time to peak, high peak specific yields and a regime of extremes of flow and temperature. In contrast, the exotic forest at Riverhead, inhibits surface runoff and maintains a regime with a minimum of variations. Between these two extremes, pastoral catchments have a moderately efficient drainage network but have extreme low flows because of water abstraction during the summer months.

SECTION 5 : SUMMARY AND CONCLUSIONS

Summary

The annual rainfall is greatest in the north and west and lowest in the east and south. Since 1872 there has been an increase in annual rainfall and a decrease in the severity of dry periods. Rainfall has a winter maximum and a summer minimum and is most variable during the summer and autumn months. Heavy rainfalls have increased in frequency and occur mainly in the summer and autumn. As this is during the construction season, these storms can cause severe erosion to areas of exposed bare ground.

Stream flows show a similar regime to rainfall with a summer minimum and a winter maximum. Sustained winter flows occur about one month after winter rains commence, usually in June. Flood flows, associated with storm events, occur mainly in the summer and autumn. Catchments between 10 and 100 km^2 have lower flood specific discharges than do smaller catchments; the often localised nature of the event means that a smaller proportion of the larger catchment contributes to overland flow than occurs in the smaller catchment.

Catchment geology has a strong influence on the pattern of low flows. The Onerahi and Pliestocene terrace material have a low water storage capacity. Consequently, the extreme north of the Rangitopuni catchment and the streams draining the southern side of the harbour have low, or no, flow during dry summers. The remaining catchments, which drain the Waitemata sandstones have more sustained low flows which range between 0.5 and 1.0 $l.s^{-1}.km^{-2}$ occur for about 70 days per year for a dry period with a

recurrance interval of two years. Where land use is more intensive low flows are further reduced through water abstraction for irrigation.

In the Upper Waitemata Harbour catchments three principle types of land use are dominant; pastoral and horticultural, forestry and urban. Records from Wairau Creek show that land use practices and stream channel construction (to hasten the discharge of flood waters) that accompany urbanisation, have the most effect on the hydrological regime. The regime becomes one of extremes, with higher flood peaks, more frequent events, rapid response to events and an increased range in water temperatures. In comparison natural channels scour deeper to cope with the higher flows, and this material is deposited downstream or in estuary headwaters. Bare ground associated with land development makes sediment more readily available for transport and sediment transport increases with the capacity of the flow.

By contrast, exotic forest management, tends to reduce the extremes of flow, temperature and sediment transport. Riverhead Forest although in the western hill country and in the area of highest rainfall, displays a regime noted for moderate responses. During events, the proportion of rainfall released as quickflow was lowest in the forest catchments. Event flows from pastoral catchments were higher, demonstrating that clear felling of the forest will increase event flows and possibly sediment yield, until canopy closure is achieved with the new plantings.

Pastoral and horticultural landuses could not be separated and had to be studied as a combined land use. Hydrological responses in these catchments were less extreme for flood events than in the urban catchment, but more extreme during low flows, than either the forestry or urban catchments, because of water abstraction for irrigation. Annual temperature variation was not as extreme as in the urban catchment. A small amount of bank erosion took place with a large flood event but generally the channels were very stable.

Conclusions

Planned landuse changes in the Upper Waitemata Harbour catchments could cause the following in the catchment hydrological regime. Urbanisation in the Albany Basin could cause a three- to six-fold increase in flood discharges, an increase in sediment yield, and enlargement of the stream channels providing there is no modification to the method of urban drainage that was used in the development of Wairau Creek. If methods of urban drainage are adopted which will reduce the rate of overland flow and attenutate flood discharges then the impact of urban development on the hydrological regime will be minimised. Besides the detention of flood flows, erosion from bare land areas during summer storms will have to be prevented by the use of adequate sized sediment traps.

Horticultural expansion will not be practical without a rural water supply. The existing flow regime has an excess of water during the winter months, June to September. Part of this excess could be stored for summer irrigation. The probable effects on the freshwater flows into the harbour would be to slightly reduce winter flows and increase the present summer flows in all but the most severe dry periods.

No change in the hydrological regime associated with forestry is predicted. Some short term variatons may occur when tree felling takes place, but these are not expected to be large enough or sufficiently long term to effect the Upper Waitemata Harbour estuary.

The flow record was too short to satisfactorily establish flood flow recurrence intervals. Catchments smaller than 1 km^2 have been shown to produce higher specific flood flows than the 10-100 km^2 catchments. Urbanisation in the Albany Basin will involve the development of catchments of less than 1 km^2 and engineering design will have to provide facilities which will ensure flows do not exceed the natural limits. Provided the engineering problems associated with urban drainage and irrigation storage can be overcome, further development of the catchments draining into the Upper Waitemata Harbour can take place with a minimum of disruption to the natural hydrological regime.

SECTION 6 : ACKNOWLEDGEMENTS

I wish to acknowledge the assistance given by the MWD Water and Soil Division staff of Auckland District during this study.

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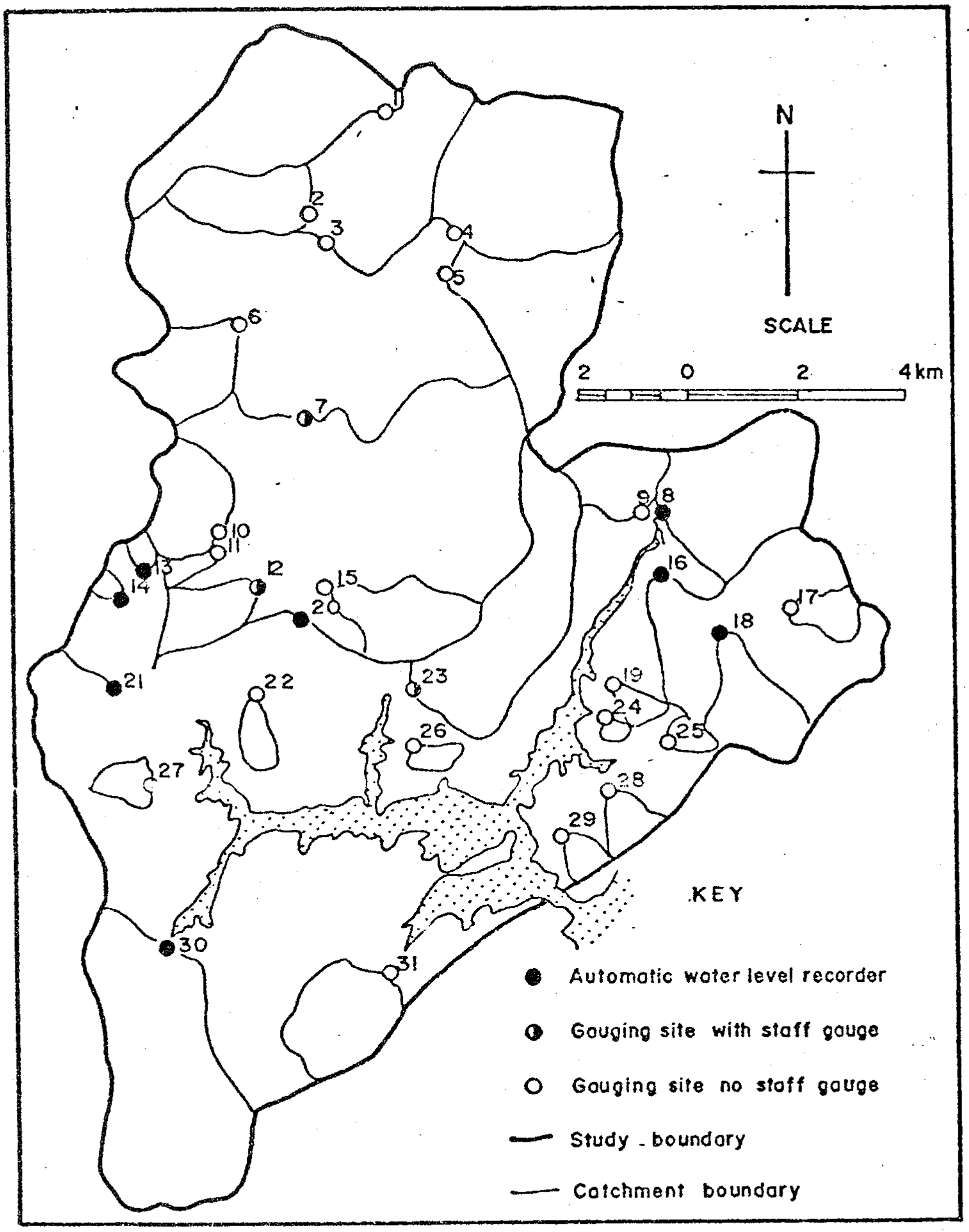
SECTION 8 : APPENDIX 1

List of Gauging Stations

Map No.	River	Site	Map Reference	Area km^2
1	Rangitopuni	Horseshoe Bush Road	N38 : 159844	7.67
2	Rangitopuni	Richards Road	N38 : 140780	2.99
3	Rangitopuni	Carmichaels	N38 : 147816	17.72
4	Dairy Stream	Dairy Stream Road	N38 : 172820	8.80
5	Dairy Stream	Bawdens Road	N38 : 172812	6.94
6	Rangitopuni	Blackbridge Road	N38 : 128803	2.82
7	Rangitopuni	Upstream twin bridges	N38 : 146782	38.10
8	Lucas Creek	Gills Road	N38 : 213759	6.26
9	Lucas Creek	Hotel	N38 : 211760	3.10
10	Rangitopuni	Mikel	N38 : 125755	2.94
11	Rangitopuni	Yoe	N38 : 125754	0.54
12	Rangitopuni	Rangitopuni Road	N38 : 133749	1.76
13	Rangitopuni	Control	N38 : 107748	0.42
14	Rangitopuni	Rols	N37 : 104744	0.26
15	Rangitopuni	Blackmores	N38 : 145747	3.36
16	Oteha	Days Bridge	N38 : 213747	12.13
17	Oteha	Riding School	N38 : 237739	1.21
18	Alexandra	Rosedale Road	N38 : 225736	2.54
19	Lucas Creek	Golf Course	N38 : 201725	0.53
20	Rangitopuni	Walkers	N38 : 140739	82.9
21	Rangitopuni	Deacon Road	N37 : 098728	3.65
22	Rangitopuni	Barretts Road	N38 : 128722	0.72
23	Paremoremo	Block Road	N38 : 163723	7.59
24	Lucas Creek	Crematorium	N38 : 199719	0.14
25	Lucas Creek	Kyle Road	N38 : 213714	0.45
26	Paremoremo	Sanders Road	N38 : 161713	0.77
27	Orchard Stream	S.H.18	N38 : 109700	0.56
28	Lucas Creek	Orwell Crescent	N38 : 202702	0.95
29	Lucas Creek	Statues	N42 : 193697	0.51
30	Ngongetepara	S.H.16	N42 : 113673	11.18
31	Waiarohia	Brighams Creek Road	N42 : 155666	2.35


N
SCALE
2 0 2 4km
KEY
Automatic water level recorder
Gauging site with staff gauge
Gauging site no staff gauge
Study boundary
Catchment boundary