Hydrology of the Wainuiomata Catchment

December 1998

THE REGIONAL COUNCIL

Hydrology of the Wainuiomata Catchment

Surface Water

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Cover:

Upper photograph: *Wainuiomata River water supply area above Morton Dam*

Lower photograph: *Wainuiomata River looking upstream from the mouth*

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1. Introduction

In 1993 the Wainuiomata Water Resources Statement (WRC, 1993) was produced. This document described the water resource and characteristics of the Wainuiomata Catchment. It identified strategic management issues that were likely to affect and influence the use and management of the water resource.

This report, Hydrology of the Wainuiomata Catchment, serves to restate the catchment characteristics and to update the surface water hydrology component of the Wainuiomata Water Resource Statement. An additional five years of rainfall and river flow data has been collected since its publication.

This report solely considers the surface water hydrology of the catchment. For information regarding the groundwater resource or water quality reference should be made to the Wainuiomata Water Resource Statement and annual groundwater and water quality reports produced by the Council.

1.1 Purpose and Objectives

The purpose and objectives of this report are:

- To collate all available information, data and past reports on the surface water resources of the Wainuiomata Catchment.
- To carry out analyses on hydrological data with currently accepted techniques, methodologies and computations.
- To present this hydrological data in a format suitable for use by the Council and other agencies in the resource consent process.

1.2 Report Structure

The hydrology of the Wainuiomata Catchment is analysed in two main components:

- Rainfall analyses
- Flow analyses

Wainuiomata Catchment

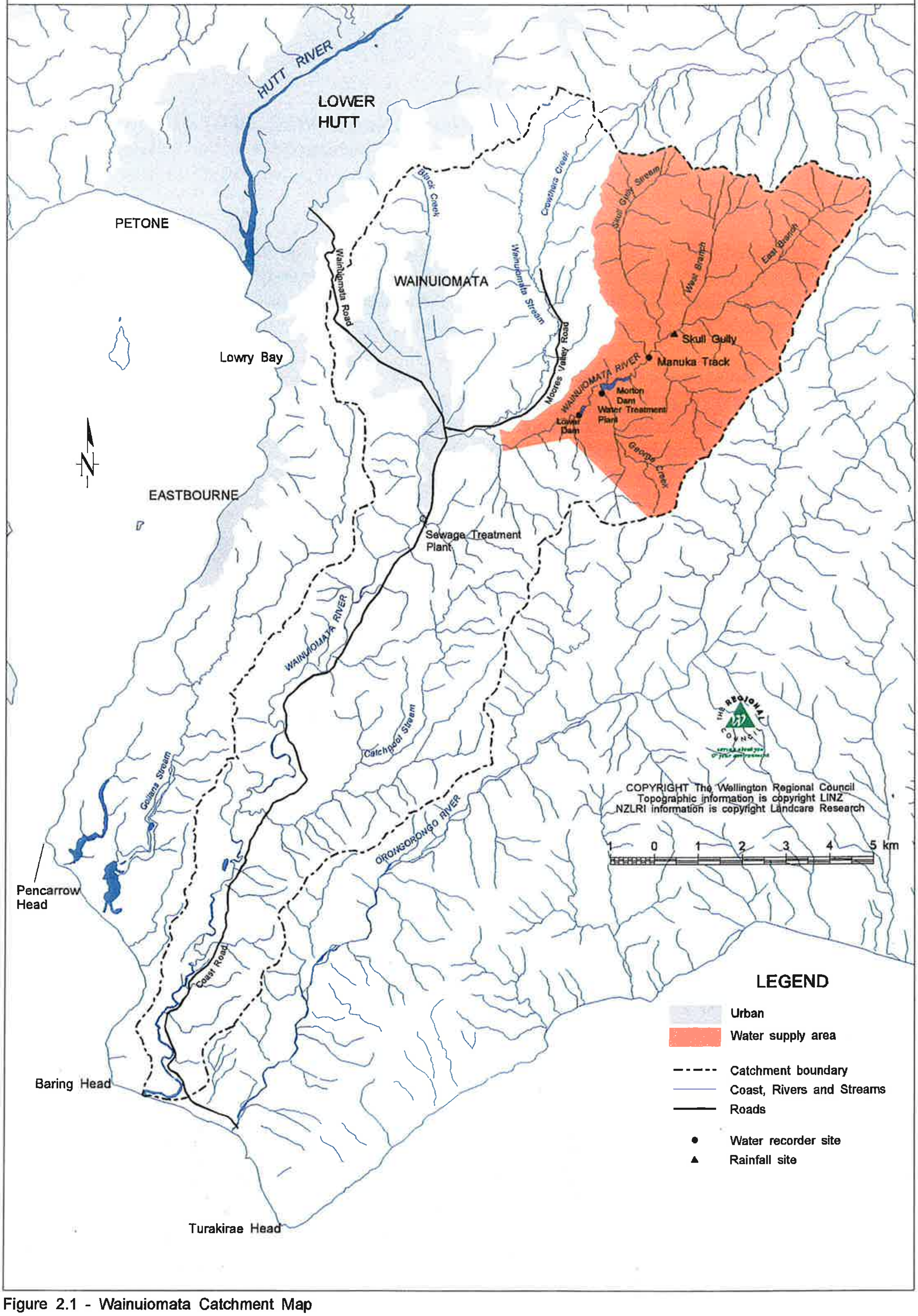


Figure 2.1 - Wainuiomata Catchment Map

2. Catchment Characteristics

The description of the catchment characteristics given in the following sections is based on existing published information. No new research or field studies were undertaken.

2.1 Physiography

The Wainuiomata Catchment (Figure 2.1) lies between Wellington Harbour and the southern part of the Rimutaka Range. The catchment drains to the south-west. The mouth of the Wainuiomata River is located between Baring Head and Turakirae Head. The area of the catchment is approximately 13,400 hectares and is predominantly rugged hill country.

Approximately 82 percent of the catchment has slopes of greater than 15 degrees. Fifty-six percent of this area has slopes in the range of 25 to 35 degrees. The distribution of slope angles within the catchment is shown in Figure 2.2. A summary of slope characteristics is presented in Table 2.1. The slope information is derived from the New Zealand Land Resource Inventory (NZLRI) database.

Table 2.1: Slope Data

Slope (Degrees)	Area (ha)	% of Total Area
0-3	1498	11.2
3-7	161	1.2
7-15	58	0.4
15-20	139	1.0
20-25	4000	29.8
25-35	6114	45.6
>35	731	5.5
Urban	707	5.3
Total	13408	100.0

The highest point in the Wainuiomata Catchment is 800 metres above sea level. The unnamed high point is on the divide between the Wainuiomata and Orongorongo Catchments.

The main tributaries of the Wainuiomata River are Black Creek, Wainuiomata Stream and Catchpool Stream. Black Creek and Wainuiomata Stream trend north in contrast to the dominant north-east valley trend. Black Creek is bounded to the east by a ridge rising to almost 400 m that separates Wainuiomata from Moores Valley. Numerous other streams drain the side slopes throughout the Wainuiomata Catchment.

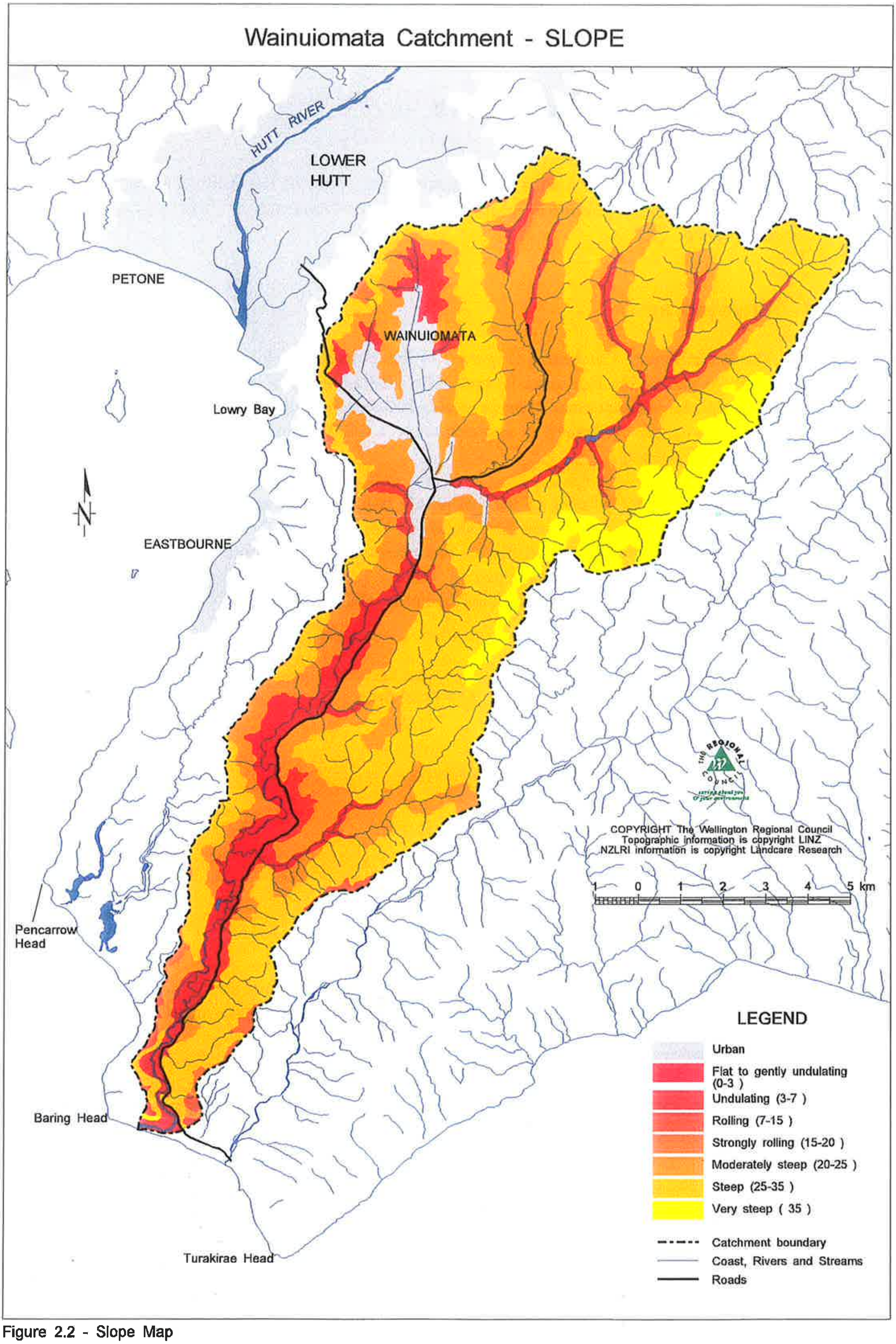


Figure 2.2 - Slope Map

2.2 Geology

Bedrock in the western part of the Wellington Region is Torlesse Supergroup rock of Mesozoic age (65-280 million years ago). The bedrock comprises interbedded sandstones and mudstones generally referred to as greywacke and argillite respectively.

Black Creek and Wainuiomata Stream are likely to have formed, as a result of preferential erosion, along north-south trending faults. The Wainuiomata River is also likely to have formed along a fault.

2.3 Soils

Five main soil groups have been identified in the Wainuiomata Catchment (Table 2.2). The distribution of the soil groups in the catchment is shown in Figure 2.3.

Table 2.2: Soil Groups

Soil Group	Area (ha)	% of Total Area
Podsolised yellow-brown earths	6907	51.5
Yellow-brown earths	4837	36.1
Yellow-grey and yellow-brown earths	298	2.2
Grey and yellow-brown earths	339	2.5
Recent soils (sands)	1027	7.7
Total	13408	100.0

Yellow-brown earths are the largest and most extensive group of soils in New Zealand. They are formed from rock material with a low ferromagnesian content. Approximately 90 percent of the Wainuiomata Catchment has yellow-brown earths. A wide range of climatic conditions for the formation of yellow-brown earths exist which results in a wide range in the soil properties. Yellow-brown earth soil types that are present in the Wainuiomata Catchment include:

- Belmont hill soils
- Heretaunga stony silt loams
- Judgeford hill soils
- Kaitoke hill soils
- Rimutaka steepland soils
- Ruahine steepland soils
- Taita hill soils
- Tawai steepland soils

Wainuiomata Catchment - SOIL GROUP

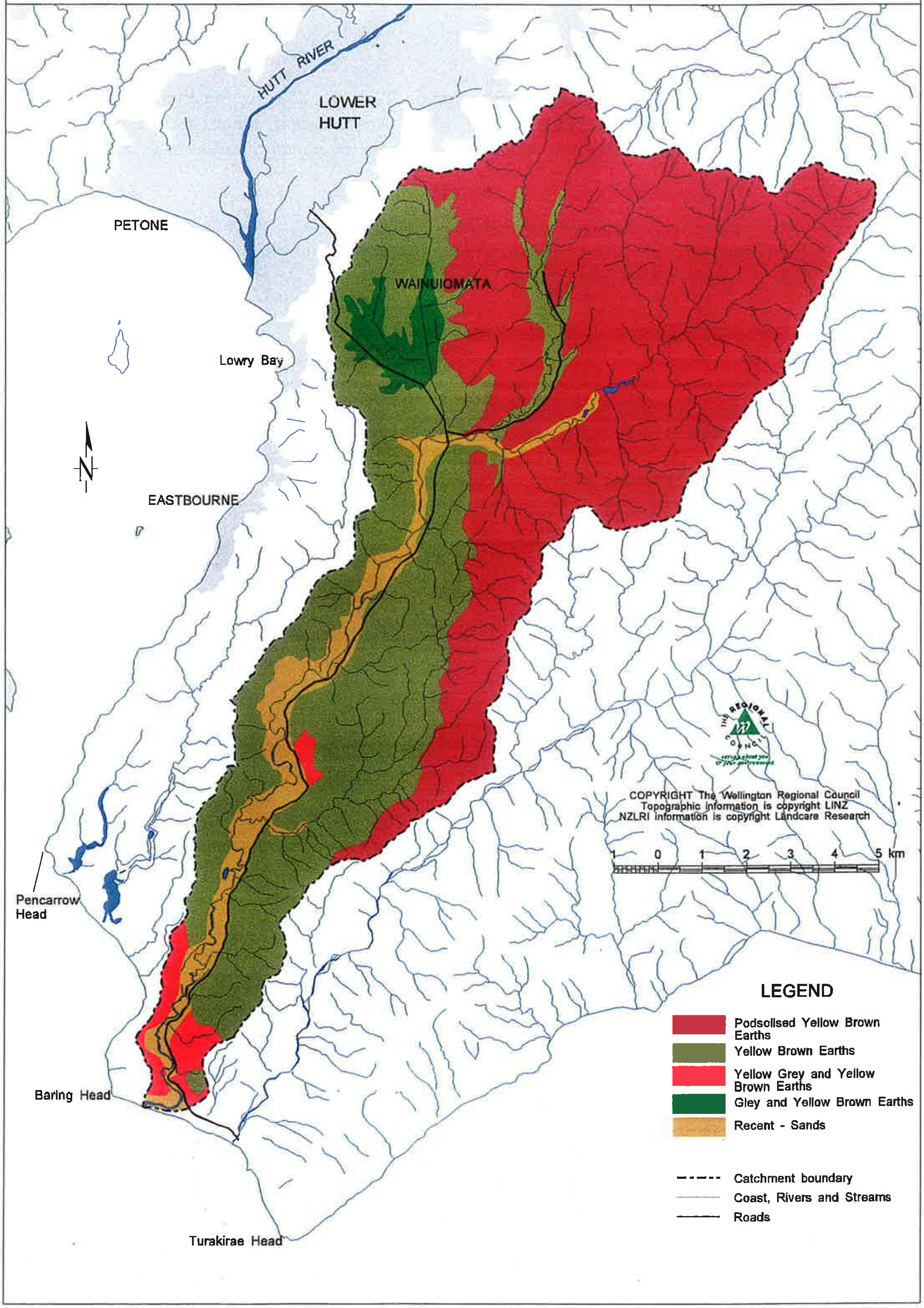


Figure 2.3 - Soil Group Map

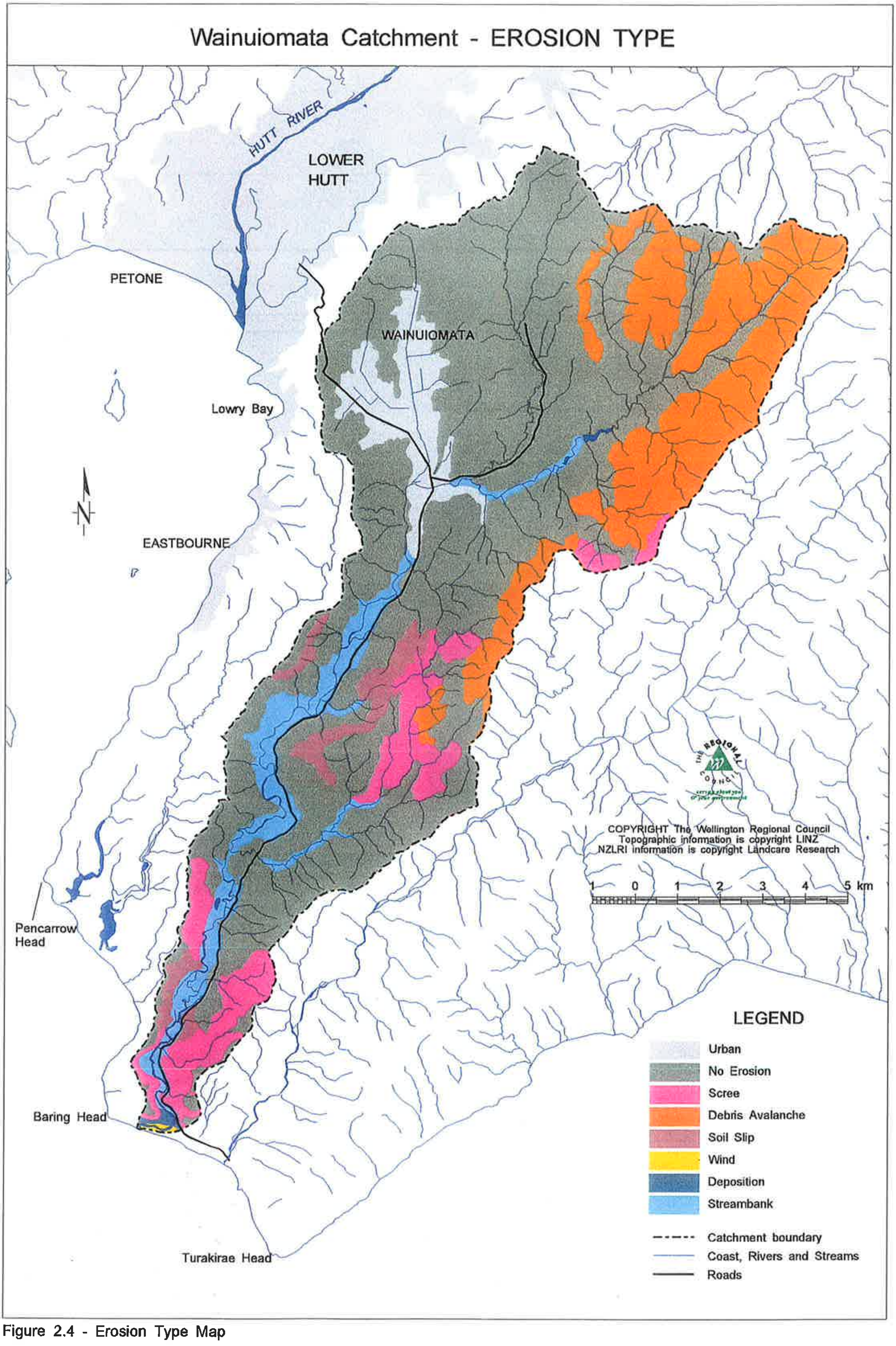


Figure 2.4 - Erosion Type Map

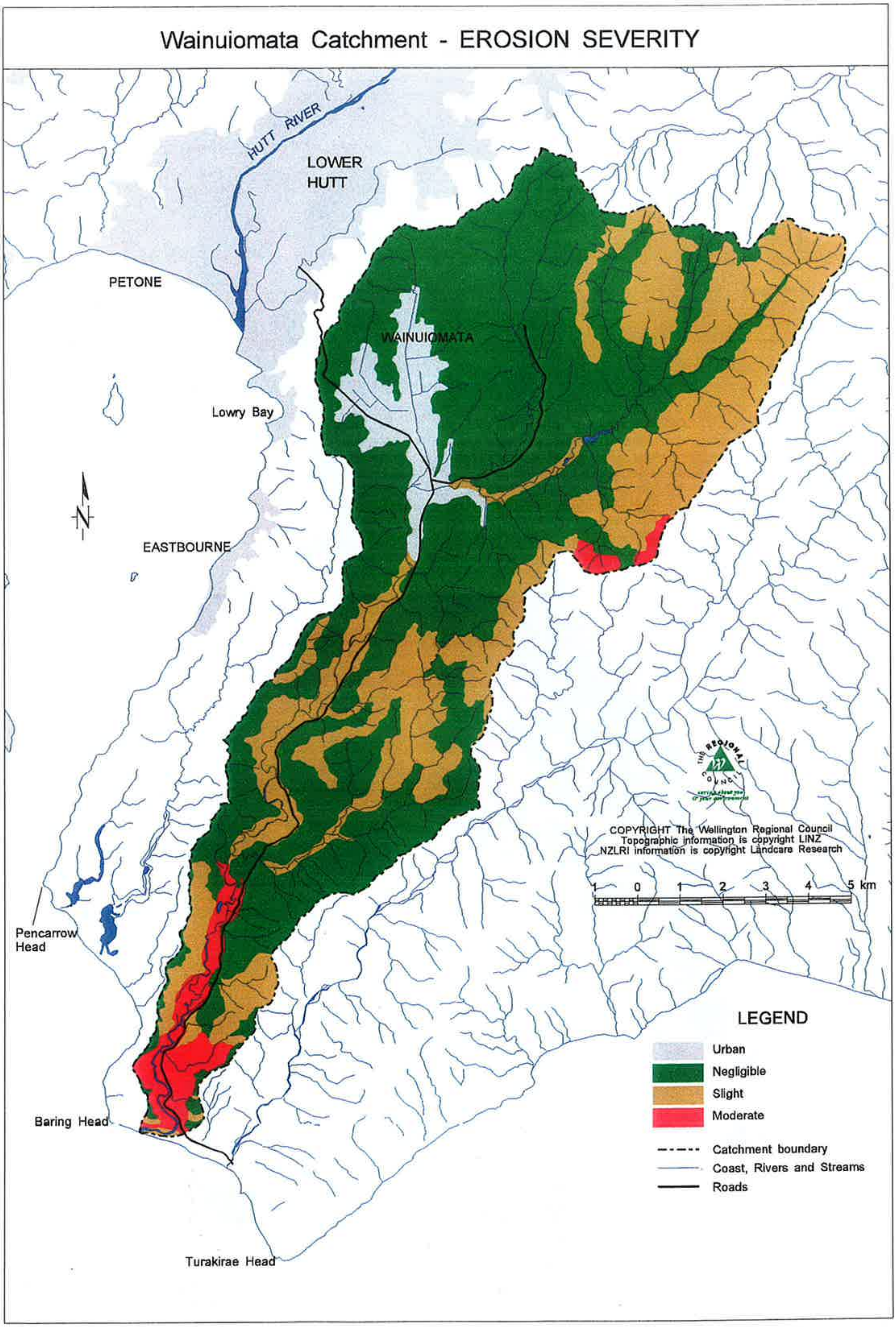


Figure 2.5 - Erosion Severity Map

2.4 Erosion

Five main types of erosion are present in the Wainuiomata Catchment. These are scree, debris avalanche, soil slip, wind and stream bank (Figure 2.4). Areas of urban development and sediment deposition are also shown in Figure 2.4. A summary of erosion type and erosion severity data is given in Table 2.3. The distribution of erosion severity within the catchment is shown in Figure 2.5.

Table 2.3: Erosion Type and Severity

Erosion Type	Area (ha)	% of Catchment
Scree:		
Slight	692	5.2
Moderate	282	2.1
Debris avalanche:		
Slight	2381	17.8
Soil slip:		
Slight	373	2.8
Wind:		
Slight	14	0.1
Stream bank:		
Slight	636	
Moderate	260	4.7
Deposition:		
Moderate	19	0.1
General erosion:		
Negligible	804	59.9
Urban	704	5.3
Total	**13408**	**100.0**

Scree erosion is the movement of fragmented rock and soil material. The rate of movement is variable according to slope, the nature of the binding material, and the size and shape of the material.

In contrast, debris avalanches (affecting 17.8 percent of the catchment) have rapid flow characteristics and normally occur on steep slopes. Debris avalanches occur within the colluvial material and uppermost metre or so of weathered bedrock. These slope failures are generally triggered by high intensity and/or long duration rainfall, and appear to be associated with seepage points and surface run-off channels.

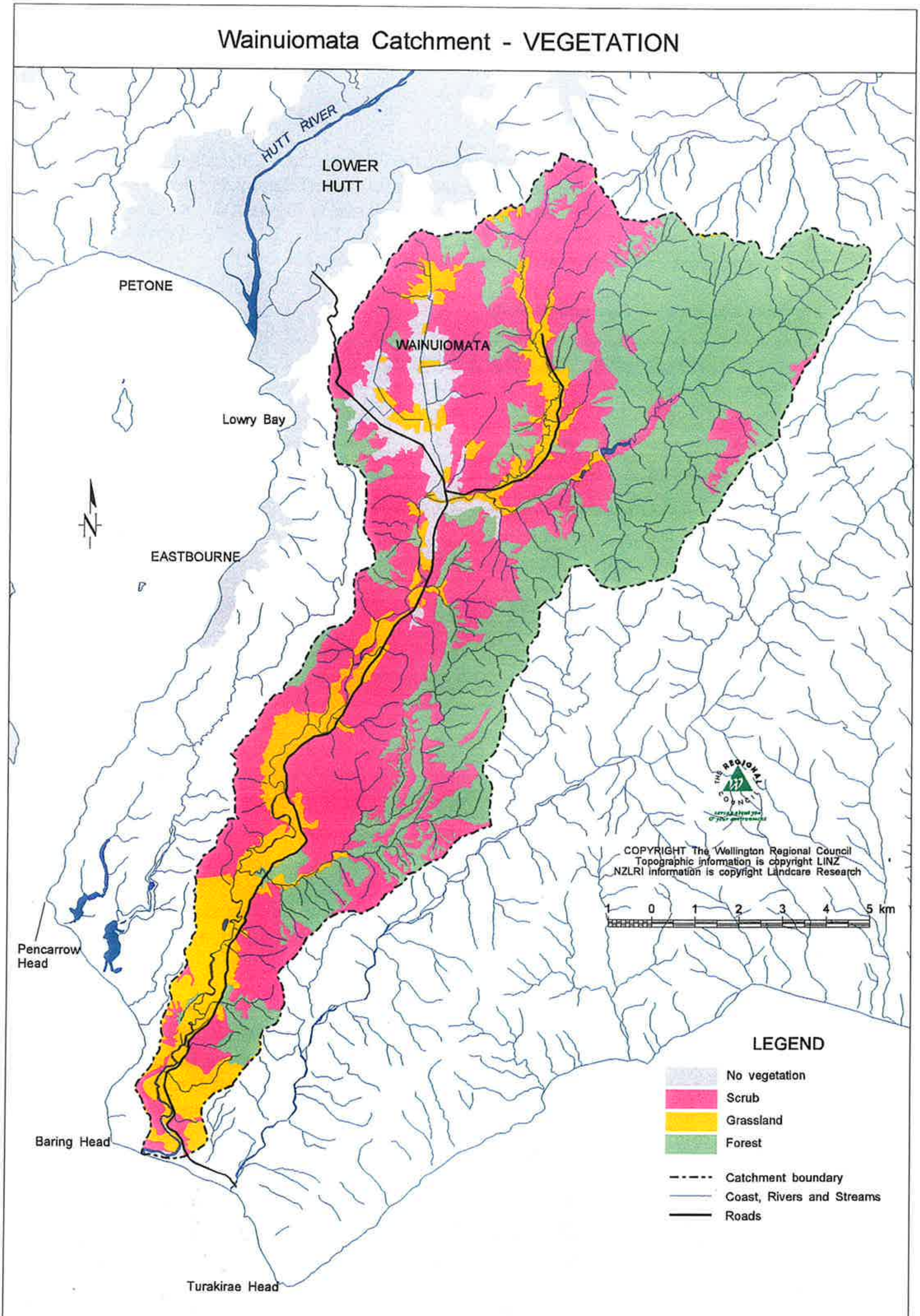


Figure 2.6 - Vegetation Map

2.5 Vegetation

Vegetation is predominantly forest and scrubland, as shown in Figure 2.6 and Table 2.4. The steeper slopes of the catchment are heavily forested (40 percent of catchment area). Lower slopes are covered by scrub (42 percent), and grassland has developed along Coast Road and Moores Valley Road.

Table 2.4: Vegetation Cover

Vegetation Type	Area (ha)	% of Catchment
Scrubland	5702	42
Forest	5395	40
Grassland	1690	13
No vegetation (primarily urban)	623	5
Total	13408	100

2.6 Land Use

Wainuiomata was first settled as a farming area in 1844. A small village centre developed consisting of a general store, church and dairy factory. Due to the topography of the area and the generally poor soil, farming is not highly profitable. The major valley floors have been progressively drained and developed primarily for residential use (Figure 2.7).

In addition to farming and a limited amount of commercial forestry, the area provides opportunities for rural-residential living in Moores Valley and along the Coast Road, and for a variety of recreational activities.

A landfill, sewage treatment plant and water treatment plant are situated within the catchment.

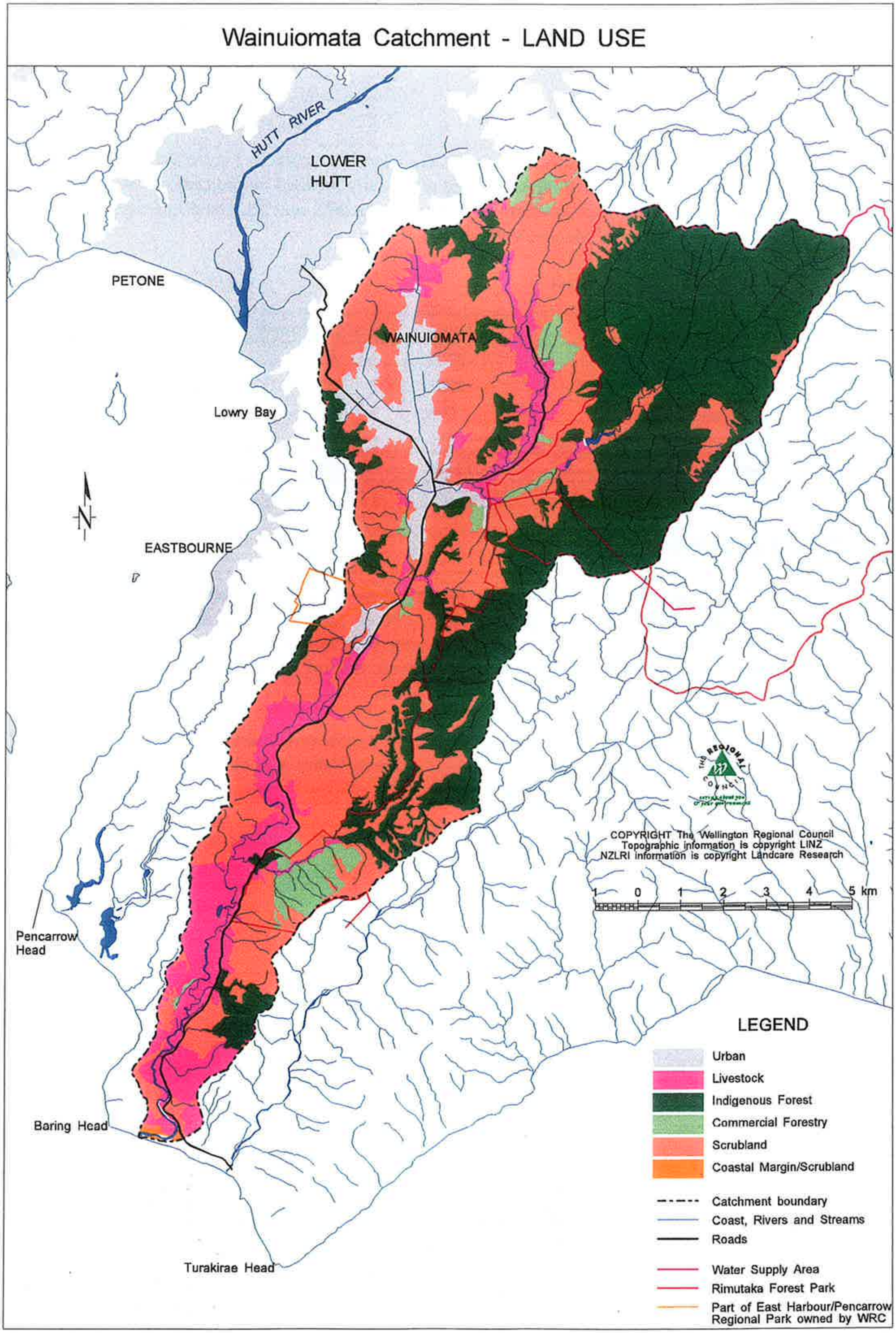


Figure 2.7 - Land Use Map

Figure 2.7 and Table 2.5 detail the present land use within the Wainuiomata Catchment. Scrubland and forest dominate.

Table 2.5: Land Use

Land Use	Area (ha)	% of Catchment
Urban	704	5
Livestock	1526	11
Indigenous Forest	4994	37
Commercial Forestry	410	3
Scrubland	5694	43
Coastal Margin/Scrubland	59	0.4
Other	21	0.2
Total	13408	100

Approximately 3,480 hectares in the north-east part of the Wainuiomata Catchment is set aside as a water supply area. The Council prohibits access to the water supply area to minimise the risk of pathogens entering the water supply system.

In addition, 1,700 hectares along the eastern boundary of the catchment is included in the Rimutaka Forest Park (13 percent of catchment).

Urban development is concentrated in the north-west and accounts for 5 percent of the land area.

2.7 Climate

The climate of the Wellington Region, as described in Goulter (1984), is characterised by strong variations in time and space reflecting the presence of Cook Strait and the rugged local topography. This results in large deviations from average values for wind, cloud, sunshine and rainfall distribution.

Regular meteorological observations were first made in the inner Wellington City in 1848. Since then Wellington's climatological station network has grown to ensure the Region has an excellent spatial distribution. Many of the stations have over 100 years of record. Based upon analyses of these records the following statistics have been determined.

Total annual sunshine hours over the Wellington Region range from 1700 hours to just over 2000 hours. These figures highlight the large spatial variations attributable to Wellington's complex climate system. The closest stations to the Wainuiomata Catchment that measure sunshine are situated at Wallaceville and Taita where approximately 1900 and 1850 hours of annual sunshine are measured respectively.

Cloud cover and the frequency of overcast skies are greatest in winter and generally least in mid-summer to late autumn. Diurnally, early morning hours exhibit most cloud cover, with least cloud cover in the afternoon.

Table 2.6 illustrates that out of seven urban low altitude stations the Wainuiomata station ranks second behind the Wallaceville station in terms of lowest mean annual air temperatures.

Mean monthly temperatures range from approximately 8 °C in July to 16.5 °C in January and February. While Wainuiomata has the lowest mean summer temperatures through December to February, it has either comparable or slightly higher winter mean monthly temperatures compared with other Wellington sites. In terms of extreme temperature ranges Wainuiomata has recorded temperatures in excess of 30 °C to below -2.9 °C. Nearer the coast, daily minimum temperatures rarely fall below 3 °C and rarely rise above 15 °C. These figures are comparable with recorded temperature ranges throughout the Region. Some of Wainuiomata's minimum temperatures can be attributed to the occurrence of frosts. Frosts are particularly prevalent due to the catchment being sheltered from the dominant north-westerlies and its vulnerability to ponding of cold air.

Wellington's closeness to Cook Strait leads to high frequencies of extreme wind speeds. These winds are gusty because the low level flow is strongly influenced by the Region's rugged topography. Predominant winds are from the north-west and south-east, with a marked lack of seasonal variation. Mean wind speed in the Wainuiomata Catchment is fairly uniform, with a slight increase in spring and a slight decrease in the late summer. The tops of the eastern ranges experience the highest mean winds speeds within the catchment. The predominant north-west wind flows run across the catchment. However, catchment alignment enhances wind during south to south-east flows.

In the period 1970-1986 snow was observed on the Wainuiomata Coast Road on three occasions - June and July 1976, and June 1983. In the upper catchment where altitudes exceed 600 m snow can be observed every winter.

Average rainfall is about 1200 mm to 1400 mm in the southern and western areas of Wellington, with steep rainfall gradients to the east and north where annual rainfalls exceed 2000 mm. This variation is due to topography which strongly influences the flow and pattern of precipitation.

Table 2.6: Monthly/Annual Mean Air Temperatures (°C)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Kelburn (1928-1980)	16.4	16.6	15.6	13.6	11.0	8.9	8.2	8.9	10.2	11.8	13.4	15.2	12.5
Paraparaumu (1953-1980)	17.1	17.2	16.2	13.8	11.3	9.1	8.3	9.2	10.7	12.4	14.0	15.9	12.9
Pauatahanui (1968-1978)	17.3	17.3	16.4	13.9	11.6	9.3	8.8	9.7	11.1	12.1	13.7	15.7	13.1
Porirua (1968-1980)	17.0	16.8	16.2	14.0	11.1	9.2	8.7	9.3	10.6	11.7	13.6	15.4	12.8
Wallaceville (1939-1980)	16.6	16.6	15.3	12.8	10.2	7.9	7.3	8.2	10.0	11.7	13.4	15.3	12.1
Wellington Airport (1962-1980)	17.4	17.5	16.6	14.2	11.8	9.7	9.0	9.6	11.1	12.7	14.3	16.2	13.3
Wainuiomata (1970-1980)	16.5	16.5	15.7	13.3	10.4	8.4	7.9	8.6	10.2	11.7	13.5	15.1	12.3

3. Literature Review

Four reports refer to hydrology in the Wainuiomata Catchment:

- Opus and Wellington Regional Council (1998), *Wainuiomata River Flood Hydrology.*
- Wellington Regional Council (1993), *Wainuiomata Water Resources Statement.*
- Thompson and McGann (1990), *Hutt River Flood Control Scheme Review Volume 4 - Climatology.*
- Mandeno, Chitty and Bell (1980), Report on the Development of the Water Resources of the Wainuiomata and Orongorongo Water Supply Reserves Part 4: Hydrology.

Opus and Wellington Regional Council (1998)

The *Wainuiomata River Flood Hydrology* is a joint report by the Wellington Regional Council and Opus International Consultants. The report produces design flood estimates for use in the Wainuiomata River Flood Hazard Assessment.

Three methods are employed to derive design flood estimates:

- At site (using recorded flow data).
- Regional (using the McKerchar and Pearson 1989 method).
- Rainfall run-off modelling (using design rainfalls and the RORB software).

Wellington Regional Council (1993)

The *Wainuiomata Water Resources Statement* documents the water resource of the Wainuiomata Catchment as part of the development of a Regional Plan.

The report includes an overview of the climate of the Wainuiomata Catchment, and details the physical characteristics of the catchment.

Hydrological analyses undertaken include:

- Drought rainfall analyses.
- Low flow frequency analyses.
- Flood frequency analyses, using at site analyses and regional estimation.
- High intensity rainfall analyses using depth duration frequencies.

The water resource of the catchment is described in terms of:

- Catchment characteristics.
- Surface water hydrology.
- Groundwater.

- Water use and consents.
- Water Quality.
- Biological resources.
- Recreation.
- Land use.
- Population, households and employment.
- Tangata Whenua interests.

This current report, *Hydrology of the Wainuiomata Catchment,* can be considered an update and companion document to the *Wainuiomata Water Resources Statement.*

Thompson and McGann (1990)

Thompson and McGann (1990) is one of a series of reports written by the National Institute of Water and Atmosphere (NIWA) as part of the *Hydrology and Climatology* component of the *Hutt River Flood Control Scheme Review.*

Thompson and McGann (1990) undertake rainfall analyses using rainfall stations in the Hutt Valley but some reference is made to sites in the Wainuiomata Catchment.

Mandeno, Chitty and Bell (1980)

This is one report in a series on the *Development of the Water Resources of the Wainuiomata and Orongorongo Water Supply Reserves. Part 4: Hydrology* includes:

- Instantaneous annual flood peaks at Morton Dam 1955-1971.
- A list of historical floods at Morton Dam prior to 1955 from file records.
- Flood flow estimation at Morton Dam by correlation of Morton Dam flow with rainfall intensities, frequency analysis, and unit hydrograph methods.

Investigations into the method of calculating the annual flood peaks presented by Mandeno, Chitty and Bell (1980) has revealed that the estimates may be too high.

4. Data Sources

The rainfall and river flow data used in this report are derived from databases managed by the Regional Council and National Institute of Water and Atmosphere (NIWA). All hydrological recording stations used in this report are detailed in Tables 4.1 and 4.2 and their locations illustrated in Figure 4.1. This report uses data up to 30 July 1998.

4.1 Rainfall Stations

Rainfall data has been collected in the Wainuiomata Catchment for over 100 years. Rainfall stations used in this study are listed in Table 4.1.

The Wainuiomata at Reservoir (E14294) rainfall station was installed in May 1884. The record initially consists of daily storage values, with the station upgraded to an automatic intensity gauge in 1954. Charts are available to determine intensity rates from 1954 onwards. A seven year period of charts from 1986 to 1993 has been digitised.

Table 4.1: Rainfall Stations in and Around the Wainuiomata Catchment

Site	Station	Catchment	Map Reference	Alt (m)	Period	Recorder Type	Status	Recording Authority
E1520A	Orongo Swamp	Orongorongo	R27:825937	420	2/10/80-30/6/98	Automatic	Open	WRC
E15204	Tasman Vaccine	Mangaroa	R27:790996	229	2/7/80-30/6/98	Automatic	Open	WRC
E15201	Skull Gully	Wainuiomata	R27:788929	150	3/7/80-30/6/98	Automatic	Open	WRC
E15202	Misty	Wainuiomata	R27:830996	545	1/10/89-2/3/98	Monthly Storage	Closed	WRC/ NIWA
E15203	Devine	Wainuiomata	R27:808965	610	1/10/89-30/6/98	Monthly Storage	Closed	WRC/ NIWA
E14294	Reservoir	Wainuiomata	R27:767912	125	1/5/1884 -2/3/98	Daily Storage/ Automatic	Open	WRC/ NIWA
E14296	Coast Road (1)	Wainuiomata	R27:733890	82	1/1/70-31/2/94	Climate	Open	NIWA
E14391	Coast Road (2)	Wainuiomata	R27:696817	60	1/12/73-30/9/84	Automatic	Closed	NIWA
E1429N	Kairanga	Wainuiomata	R27:717937	85	1/3/83-30/4/88	Automatic	Closed	NIWA

Wainuiomata at Misty (E15202) and Wainuiomata at Devine (E15203) are storage gauges read the first week of every month to give an approximate 30 day rainfall total. Misty (E15202), Devine (E15203) and Reservoir (E14294) are maintained to establish catchment conditions for water supply and forest fire purposes.

Wainuiomata Catchment - HYDROLOGICAL RECORDING SITES

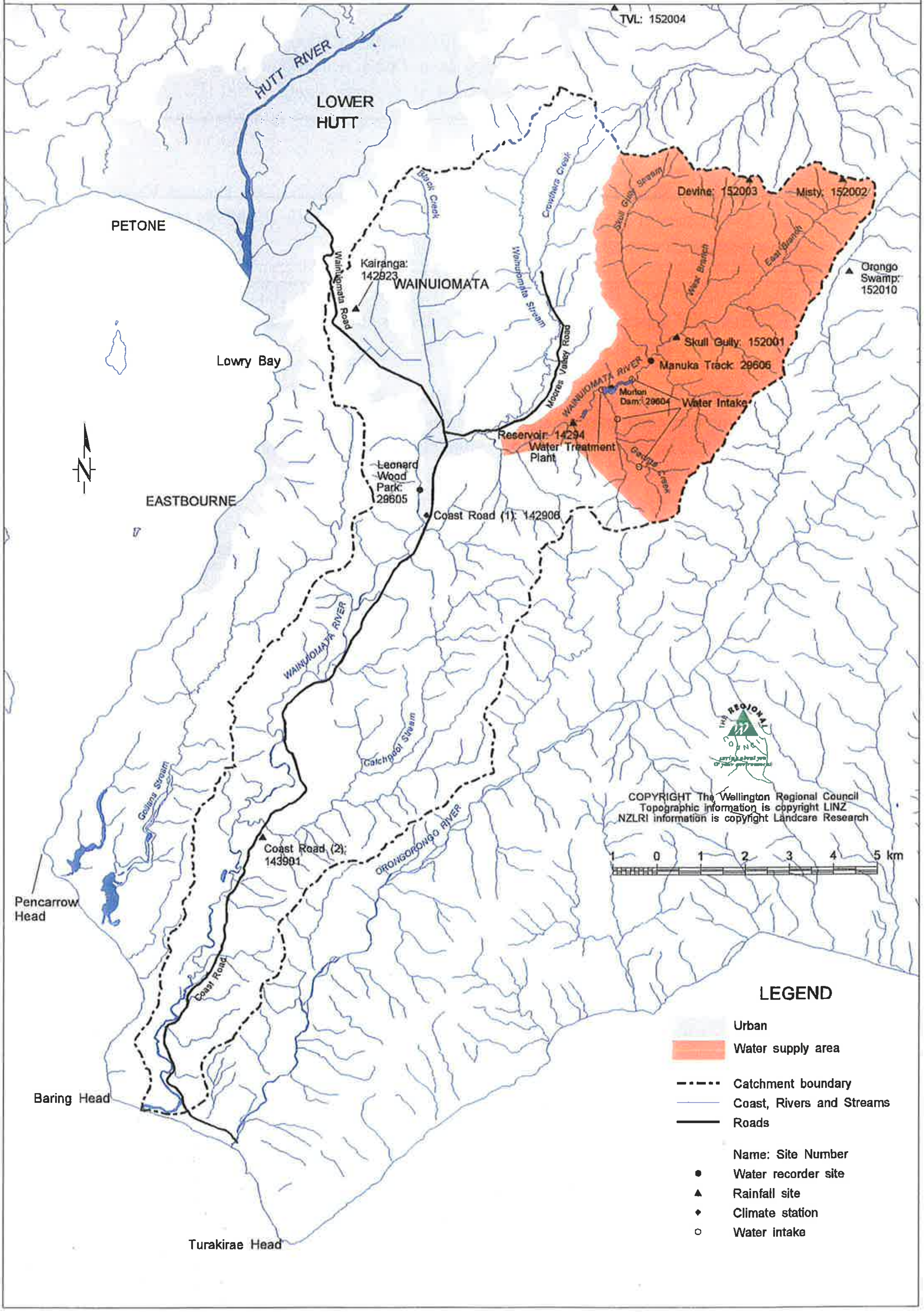


Figure 4.1 - Hydrological Recording Sites Map

The Wainuiomata at Skull Gully (E15201) rainfall station is centrally located in the water supply area and also operates as a flood warning station. Orongorongo at Orongo Swamp (E1520A) and Mangaroa at Tasman Vaccine Ltd (E15204) are also used for flood warning purposes, but in the Orongorongo and Mangaroa catchments respectively.

The data from Skull Gully (E15201), Orongo Swamp (E1520A), Tasman Vaccine Ltd (E15204), Misty (E15202), Devine (E15203), and Reservoir (E14294) (1991 onwards) have been reviewed by a TELARC registered auditor.

The quality of data from the rainfall stations Skull Gully (E15201), Orongo Swamp (E1520A) and Tasman Vaccine Ltd (E15204) is considered good. The quality of data from other stations in considered reasonable.

While many historical and current rain gauges exist within the catchment, there is a lack of intensity rain gauges especially in the mid to lower catchment areas. The Skull Gully (E15201) station is the only intensity rain gauge currently situated within the catchment area.

4.2 Water Level Stations

Three water level stations have operated in the Wainuiomata Catchment (Table 4.2).

Wainuiomata at Manuka Track (29606), Wainuiomata at Leonard Wood Park (29605) and Wainuiomata at Morton Dam (29604) are the stations used for hydrological analyses within this report.

Table 4.2: Flow Recorder Stations in the Wainuiomata Catchment

Site	Station	Map Reference	Drainage Area (km^2)	Period	Recorder Type	Status	Recording Authority
29606	Wainuiomata @ Manuka Track	R27:786924	27.1	10/6/82-31/12/97	Automatic	Open	WRC
29604	Wainuiomata @ Morton Dam	R27:772919	34	24/2/17-17/5/17; 28/7/28-31/3/53; 31/12/53-31/12/76	Daily	Closed	WRC
29605	Wainuiomata @ Leonard Wood Park	R27:731896	77.5	1/5/77-31/12/97	Automatic	Open	WRC

Manuka Track (29606) has operated since June 1982 and is also used as a flood warning station. Leonard Wood Park (29605) commenced recording in April 1977 but is not telemetered. At both sites the stage, ratings and gaugings are collected under a ISO:9002 registered quality system.

The Morton Dam (29604) flow record consists of mean daily values. The 1917 to 1953 records are derived from daily readings of the flow depth over the original Morton Dam cushion weir, change in reservoir storage and draw off to water supply.

The 1954 to 1976 data were measured by Lea recorders. A continuous flow recorder was situated at the Morton Dam cushion exit weir and a weir depth recorder was sited on the intake structure behind the dam. The continuous flow recorder is of no use for flood analysis as the weir was quickly inundated in higher flows. Instead the reservoir water depth recorder is used for flood analysis.

The water level charts and scour flows have been used to derive instantaneous flood peaks for Morton Dam (29604) (Lew and Harkness, 1998). Charts are available from 1955 to 1981 and comments on scour operation are found in various dairies and on the charts themselves. The recorder was situated in a stilling tower off the intake structure approximately 13 metres from the dam crest. This is a sufficient distance to be away from the drawdown effects of the crest.

The Morton Dam (20604) record on the Council's TIDEDA database consists of mean daily flow values calculated for the 24 hour period of 8.30 am to 8.30 am.

Based on the recording methods, data quality is not expected to be high. Mandeno, Chitty and Bell (1980) estimate error limits of 10-20 percent for data up to 1954 and a reduction to 5-10 percent after the introduction of the Lea recorders.

A flow record has been derived for George Creek at above Bottom Intake (29614) from correlation of concurrent gaugings at George Creek (29614) and Manuka Track (29606). Eighteen concurrent gaugings were used in calculating the correlation (Figure 4.2) and a R^2 of 0.46 attained between the two sites. All gaugings have been undertaken in periods of low flow, therefore the correlated record is a good representation of low flow in George Creek but should be treated with caution at higher flows.

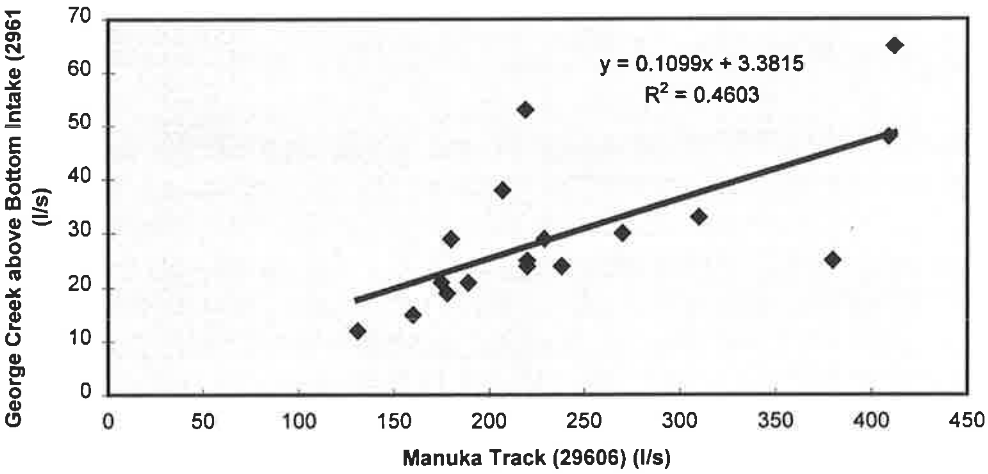


Figure 4.2: Manuka Track (29606) and George Creek (29614) Correlation

5. Data Quality

5.1 Rainfall Data

Table 5.1 shows that only short lengths of record are available for the automatic rain gauges in and around the Wainuiomata Catchment. It is evident that a reasonably consistent trend with altitude exists. The main anomaly is the Tasman Vaccine Ltd (E15204) gauge which only records 200 mm for its 229 m elevation. This has previously been identified in WRC (1995).

Table 5.1 also lists other rain gauges within the Wellington Region as a comparison.

Table 5.1: Twenty-four Hour 100 Year Depth Duration Frequencies

Station		24 hr 100 year Rainfall (mm)	Altitude (m)	Period of Record	Recorder Type
Wellington Aero	E14387	160	6	1961-1997	Auto
Avalon	E14195	166	15	1948-1989	Auto
Coast Road (1)	E14391	129	60	1973-1984	Daily
Coast Road (2)	E14296	129	82	1970-1997	Daily
Reservoir	E14294	275	125	1884-1997	Daily/Auto
Kelburn	E14272	163	125	1955-1997	Auto
Karori	E14271	143	141	1869-1997	Daily/Auto
Skull Gully	E15201	297	150	1980-1997	Auto
Tasman Vaccine	E15204	200	229	1980-1997	Auto
Phillips	E1502A	321	300	1973-1997	Auto
Orongo Swamp	E1520A	302	420	1980-1997	Auto
Centre Ridge	E15122	195	510	1984-1997	Auto

Source: Lew and Harkness, 1998

5.1.1 Rainfall Stationarity

Lew (1996) found non-Stationarity existed within long rainfall records at Avalon (E14195) and Kelburn (E14272). Stationarity is a statistical term that means individual maxima events are drawn from the same statistical distribution throughout the period of record. Any trends in the data (i.e., a disproportionate number of extreme storms in any one decade) breach the Stationarity assumption. Lew (1996) concluded that between 1978 and 1989 fewer critical duration rainfall events had occurred when compared to the longer records, and this lack of events is enough to decrease the rainfall depth duration frequency estimates by 10 percent.

The Kelburn (E14272) record over the 1981-1997 period exhibits a decrease in estimates for six, 12 and 24 hour durations when compared to the longer record of 1955-1997. A similar pattern is observed in the Wellington Aerodrome (E14387) record for the same periods.

This indicates that between 1981-1997 there were more extreme rainfall events with short critical durations of less than six hours. Extreme rainfall over medium to long durations (greater than six hours) were less frequent in the 1981-1997 period.

Avalon (E14195) was investigated and was found to exhibit across the board decreases of approximately 10 percent in rainfall amounts for the two, three, six, 12 and 24 hour durations from 1981 onwards. However, the Avalon (E14195) record ends in January 1992.

It is assumed that the decreases in rainfall over the medium to long duration events observed at Kelburn (E14272) and Wellington Aerodrome (E14387) also occurred over the Wainuiomata Catchment. Consequently, those rain gauges with records commencing in 1981 (Skull Gully E15201, Orongo Swamp E1520A, Tasman Vaccine Ltd E15204) will have their rainfall depths factored upwards by the average increase at Kelburn (E14272) and Wellington Aerodrome (E14387) to produce results indicative of a longer period of record (Lew and Harkness, 1998).

5.1.2 Skull Gully (E15201) and Reservoir (E14294) Rain Gauges

A correlation was produced of daily rainfall totals between Reservoir (E14294) and Skull Gully (E15201) for the period 1980-1997. The resulting equation with input and output units of micrometres (µm);

Skull Gully rainfall = 1.0082 x Reservoir rainfall + 38.37

was obtained with a R^2 of 0.93.

When this equation is used an estimate for the Skull Gully (E15201) 24 hour 100 year rainfall is calculated to be 277.3 mm. This is compares to the estimate of 297 mm from the Skull Gully (E15201) record (1981-1997). The fact that a good correlation can be obtained between the two sites indicates that if the Reservoir (E14294) record was digitised in the future, a longer period of record could be calculated for Skull Gully (E15201).

5.1.3 Storm Events

The five largest floods recorded at Manuka Track (29606) and Leonard Wood Park (29605) occurred on the following dates:

Five largest flows at Manuka Track (29606)

- 59.8 m^3/s 11 December 1982
- 54.4 m^3/s 4 October 1997
- 46.7 m^3/s 22 May 1983
- 41.7 m^3/s 13 March 1990
- 32.1 m^3/s 21 December 1982

Five largest flows at Leonard Wood Park (29605)

- 120.9 m^3/s 21 May 1981
- 93.6 m^3/s 22 November 1977
- 86.3 m^3/s 15 August 1994
- 80.9 m^3/s 5 March 1987
- 80.2 m^3/s 4 October 1997

It is surprising that only one event (4 October 1997) resulted high flood peaks at both stations.

The timing of the flood hydrographs and the response to the amount of rainfall were considered to be good. The largest events recorded at Manuka Track (29606) and Leonard Wood Park (20605) are commented on:

(1) The 11 December 1982 flood at Manuka Track (20606), the largest on record for this site, had rapidly rising and falling limbs on the hydrograph and was supported by 139 mm recorded at Orongo Swamp (E1520A) and 92 mm at Skull Gully (E15201) on 11 December. This event was not one of the five largest floods at Leonard Wood Park (29605). The lower rainfall totals at the rain gauges further down the catchment indicate that the heavy rain recorded in the headwaters of the Wainuiomata River was not consistent throughout the catchment, particularly the Wainuiomata Stream, and was evidenced in a less severe flood flow as recorded at Leonard Wood Park (29605).

(2) The storm event bringing about the largest recorded flood flow at Leonard Wood Park (29605) on 21 May 1981 shows more consistent rainfalls over all the rain gauges in the catchment. Falls of 114 mm and 168 mm were recorded at Orongo Swamp (E1520A) on 20 and 21 May 1998 respectively. Likewise for the same dates Skull Gully (E15201) recorded 82 mm and 213 mm, Tasman Vaccine Ltd (E15204) 39 mm and 157 mm, Reservoir (E14294) 130 mm and 60 mm, Coast Road (1) (E14296) 206 mm and 82 mm, and Coast Road (2) (E14391) 185 and 33 mm.

5.2 Flow Data

5.2.1 Flow Gaugings and Rating Curves

All data for Manuka Track (29606) and Leonard Wood Park (29605) have been checked and reviewed by a TELARC registered auditor. Data is collected, processed and archived under a ISO:9002 registered quality system.

An additional check was made of the gaps in the record of both sites. Cross checking with other sites was undertaken to ensure no annual maximum or minimum occurred during a gap in the record. It can be confirmed that there are no missing annual maximum flood peaks in either record and there are no missing annual minimum in the Manuka Track (29606) record.

The Manuka Track (29606) rating curve (Figure 5.1) is not well supported by high flow gaugings. Only 33 percent of the flow range has been gauged and therefore there is a large extrapolated section of the rating curve. The highest recorded flow is 60 m^3/s, with the highest gauged flow being 20 m^3/s.

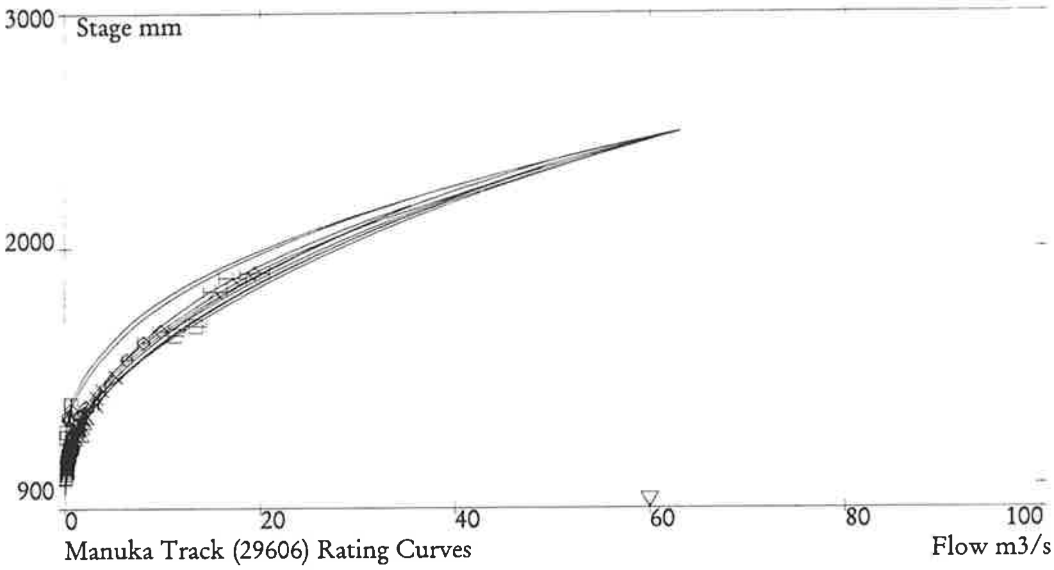


Figure 5.1: Manuka Track (29606) Rating Curves

The same problem is encountered with the Leonard Wood Park (29605) rating curve (Figure 5.2) with only 11 percent of the flow range having been gauged. The medium to high flow ratings have been constructed using a cross section survey and extended velocity curve. The Leonard Wood Park (29605) ratings have three main shapes influenced by major changes to stopbanks.

Both Manuka Track (29606) and Leonard Wood Park (29605) high flow ratings require confirmation. This is due to both flow stations historically being used for low flow information and no method available to measure flood flows. The Manuka Track (29606) slackline for flood gaugings was only installed in 1991. With the exception of the 4 October 1997 flood event, all annual flood peaks have been about or below the mean annual flood flow (approximately 20-30 m^3/s) and so opportunities for flood gaugings at the high end of the rating curve have been sparse.

At low to medium flows the rating shapes are fully representative of gaugings undertaken.

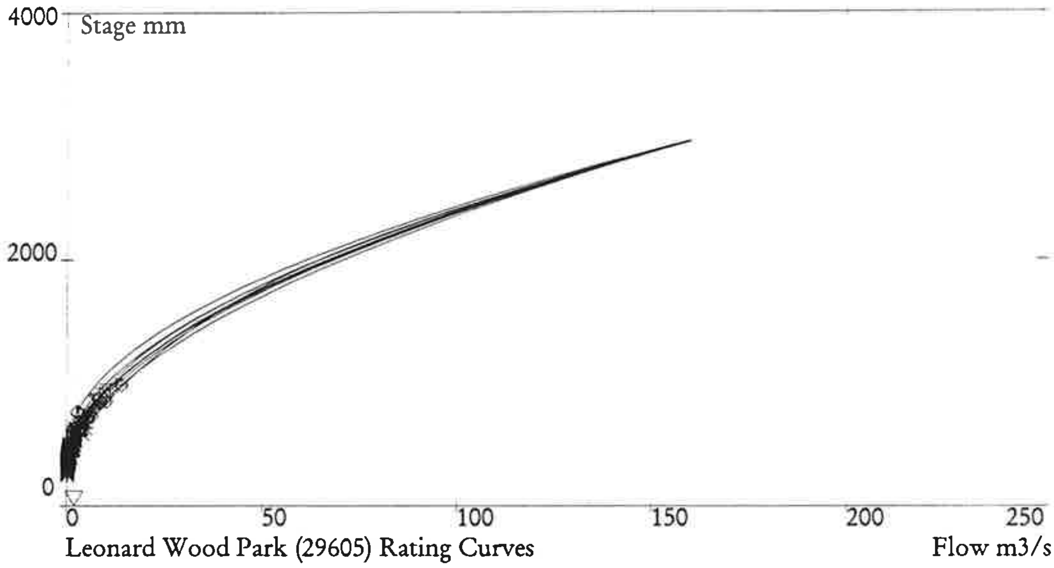


Figure 5.2: Leonard Wood Park (29605) Rating Curves

5.2.2 Effect of Morton and Lower Dams

It is unclear exactly what effect the Morton and Lower Dams have had on the Leonard Wood Park (29605) high flow record.

The Strategy and Assets Group of the Council indicates that, in its opinion, the Morton Dam is likely to have had little effect on major flood events. Only a small volume was available for flood water storage behind the dam. For major flood events the record at Leonard Wood Park (29605) may exhibit some initial upstream storage as the water level rises but once the dam has reached its capacity all endeavours were made to allow the peak to pass unaffected. The Morton Dam flood rules state that the natural flood must not be increased by lowering the reservoir below its normal level (WRC, 1987).

Morton Dam was decommissioned in November 1988. Leonard Wood Park (29605) flood peaks after this date are unaffected by the impediment of flow due to Morton Dam.

The Strategy and Assets Group also states that the Lower Dam currently acts as a minor flood retention structure, inhibiting the passage of flood flows and possibly having an effect on the timing of the Leonard Wood Park flood hydrograph.

Records show that the impoundment volume of Morton Dam (before decommissioning) and the Lower Dam are 485,000 m^3 and 123,000 m^3 respectively. The time taken to reach capacity and begin spilling obviously depends on the initiated headwater level at the beginning of the storm. If empty (the Lower Dam remains drained) a large flood hydrograph (Q_{50}/Q_{100}) could take up to 1.5 to 2 hours to fill Morton Dam and 0.5 hours to fill the Lower Dam. This would lead to considerable attenuation of flood hydrographs as they pass through the system. In addition the effect of hydrograph attenuation as a result of routing through the reservoir storage behind the dam needs to be considered. It is recommended that a full understanding of the effects of these dams, now and historically, be gained for the floodplain management process and before public consultation begins. This should include an assessment of the downstream effect of possible failure of the Lower Dam.

5.2.3 Effect of Water Supply Abstraction

The water supply abstraction from the Wainuiomata River downstream of Manuka Track (29606) and from George Creek leads to discrepancies in the flow record at Leonard Wood Park (29605), particularly during times of low flow.

The Leonard Wood Park (29605) flow record begins in 1977. The Morton Dam was not decommissioned until November 1988. This means that during times of water storage at Morton Dam, which at times reached 100 percent of the Wainuiomata River flow, Leonard Wood Park (29605) flows were solely sustained by the Wainuiomata Stream and Black Creek tributaries and this should be evident in the Leonard Wood Park (29605) flow record.

5.2.4 Accuracy of Morton Dam Data

NIWA (1997) has pointed out that calculation of the Morton Dam (29604) flow data over periods as short as a day can be inaccurate because small errors in the water level-capacity curve coupled with small errors in the measured water level combine to give large errors in the inflows.

A series of instantaneous annual flood peaks were calculated for Morton Dam (29604) by Mandeno, Chitty and Bell (1980) between 1955 and 1971. These were calculated using the height of the flood peak as read off the Lea water depth recorder charts.

There was found to be an error in the calculations where an inappropriate discharge coefficient had been used leading to an overestimation of larger flood events (Lew and Harkness, 1998).

All the Lea water depth charts from 1955 to 1971 were re-examined and the peak flow values calculated for each year using an appropriate discharge coefficient. An additional 10 years of charts up to 1981 were also located and analysed. Operational diaries and notebooks contained comments on when scours were operating and these were included in the calculation of discharge (Lew and Harkness, 1998).

6. Rainfall Analyses

The objectives of this section are:

(1) To examine spatial and temporal trends of rainfall in the Wainuiomata Catchment.

(2) To measure extreme rainfall events and predict the frequency of occurrences for given magnitudes of drought and high intensity rainfalls.

(3) To put periods of low river flows into a greater historical perspective by examining the longer duration rainfall records for droughts.

The nine rain gauges used in this study were analysed for the following:

- Mean annual rainfall.
- Mean annual rainfall isohyets.
- Mean monthly rainfall.
- Long-term temporal rainfall trends.
- Periods of low rainfalls.
- Rainfall drought frequency analysis.
- High intensity rainfall frequency analyses.

Figure 4.1 illustrates the locations of the rain gauges used in this section.

6.1 Mean Annual Rainfall

Mean annual rainfall is the mean of each calendar year of rainfall record. Analysis of mean annual rainfall gives an indication of both the temporal and spatial distribution of rainfall in the Wainuiomata Catchment. However, the difficulty of comparing rainfall records that have inconsistent periods is recognised. Also, some rainfall stations exhibit variability because of localised effects of topography and vegetation influences.

Mean annual rainfalls for all stations are presented in Table 6.1.

Table 6.1: Mean Annual Rainfall (mm)

Rain Gauge	Site No.	Period of Record	Altitude (m)	Mean Annual Rainfall (mm)
Skull Gully	E15201	1980-1997	150	2029
Reservoir	E14294	1890-1997	125	1933
Orongo Swamp	E1520A	1980-1997	420	2518
TVL	E15204	1980-1997	229	1480
Misty	E15202	1989-1997	545	1893
Devine	E15203	1989-1997	616	1949
Coast Road (1)	E14296	1970-1993	82	1702
Coast Road (2)	E14391	1973-1984	60	1741
Kairanga	E1429N	1983-1988	85	1349

The relationship between altitude and mean annual rainfall for rain gauges in the Wainuiomata Catchment, i.e., excluding Orongo Swamp (E1520A) and TVL (E15204), is poor ($R^2 = 0.19$)

6.2 Mean Annual Rainfall Isohyets

Figure 6.1 shows the Wainuiomata Catchment mean annual rainfall isohyets derived from the New Zealand Meteorological Service. Figure 6.1 should give a more consistent indication of mean annual rainfall in the Wainuiomata Catchment, as the isohyets are derived from the uniform period 1941 to 1970 and are a smoothed representation of rainfall.

Figure 6.1 shows that at the coast the mean annual rainfall is 1000-1200 mm. This is the driest area of the Wainuiomata Catchment. As elevation increases in a north-easterly direction the mean annual rainfall gradient increases to 3200-4000 mm. This is a result of orographic enhancement.

6.3 Minimum, Mean and Maximum Monthly Rainfalls

The minimum, mean and maximum monthly rainfalls for all stations are presented in Tables 6.2 to 6.9.

Due to the Misty (E15202) and Devine (E15203) storage rain gauges being serviced at durations of frequently longer than one month, the monthly values given below are evenly proportioned over the sampling interval to gain one month values. Therefore they are indicative values only.

Wainuiomata Catchment - MEAN ANNUAL RAINFALL

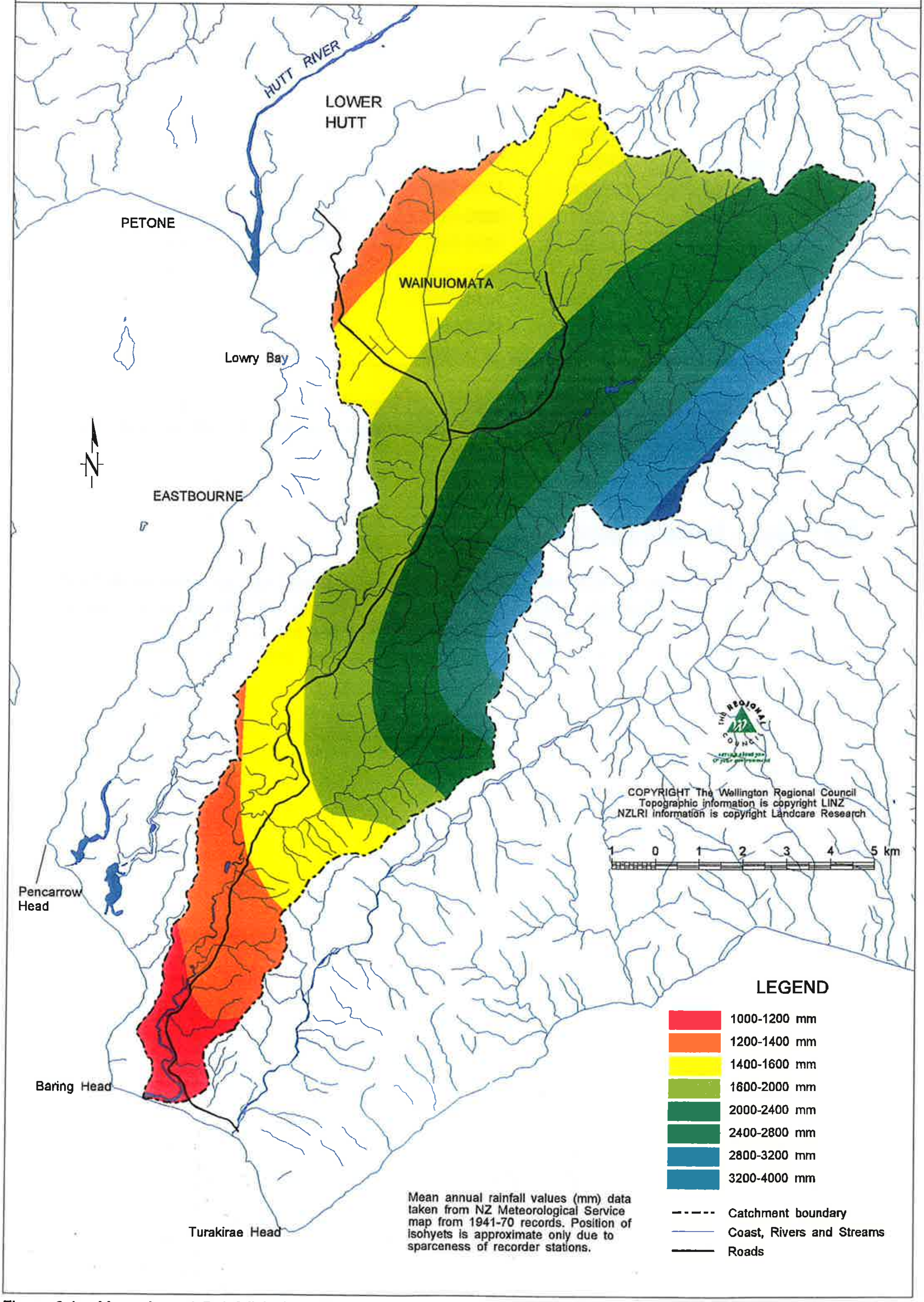


Figure 6.1 - Mean Annual Rainfall Isohyet Map

Table 6.2: Wainuiomata at Reservoir (E14294) Monthly Rainfall (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Min.	11	1	10	26	46	53	48	61	25	23	27	16	1238
Mean	106	108	127	154	214	211	230	209	161	163	127	133	1948
Max.	288	439	487	679	701	667	777	613	504	639	366	587	2840

Table 6.3: Wainuiomata at Skull Gully (E15201) Monthly Rainfall (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Min.	40	8	36	62	35	47	60	43	71	98	69	66	1576
Mean	105	98	151	133	216	243	235	200	149	199	160	133	2029
Max.	221	190	459	243	455	438	402	365	327	505	282	264	2624

Table 6.4: Orongorongo at Orongo Swamp (E1520A) Monthly Rainfall (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Min.	37	15	66	78	51	76	90	56	86	152	112	91	2056
Mean	133	132	202	156	246	282	291	238	183	243	219	202	2518
Max.	305	258	493	364	449	465	434	396	341	548	403	369	2709

Table 6.5: Mangaroa at Tasman Vaccine Ltd (E15204) Monthly Rainfall (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Min.	30	4	39	50	26	47	39	30	42	97	72	45	1261
Mean	88	86	111	107	155	175	161	145	118	153	135	107	1480
Max.	206	216	276	241	261	265	290	243	224	253	235	179	1784

Table 6.6: Wainuiomata at Misty (E15202) Monthly Rainfall (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Min.	74	36	40	39	40	143	69	91	97	106	92	63	1450
Mean	142	125	117	158	121	223	180	183	168	172	161	133	1893
Max.	217	220	189	260	190	308	281	282	231	293	260	234	2372

Table 6.7: Wainuiomata at Devine (E15203) Monthly Rainfall (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Min	82	33	44	43	44	126	73	100	93	102	96	78	1520
Mean	154	127	119	153	126	225	181	196	173	177	176	135	1949
Max	252	229	193	271	219	293	241	257	232	317	324	214	2276

Table 6.8: Wainuiomata at Coast Road (1) (E14296) Monthly Rainfall (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Min	16	11	35	27	43	40	42	50	38	62	29	0	1102
Mean	76	83	120	128	177	206	196	182	149	147	110	120	1702
Max	167	261	335	483	397	408	380	425	400	482	213	385	2658

Table 6.9: Wainuiomata at Coast Road (2) (E14391) Monthly Rainfall (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Min	12	10	37	55	61	28	116	54	58	58	32	65	1139
Mean	63	97	105	158	155	191	185	165	178	150	95	154	1741
Max	157	197	310	440	303	357	317	332	312	356	150	271	2483

Figure 6.2 illustrates mean monthly rainfall for the rainfall stations included in this report.

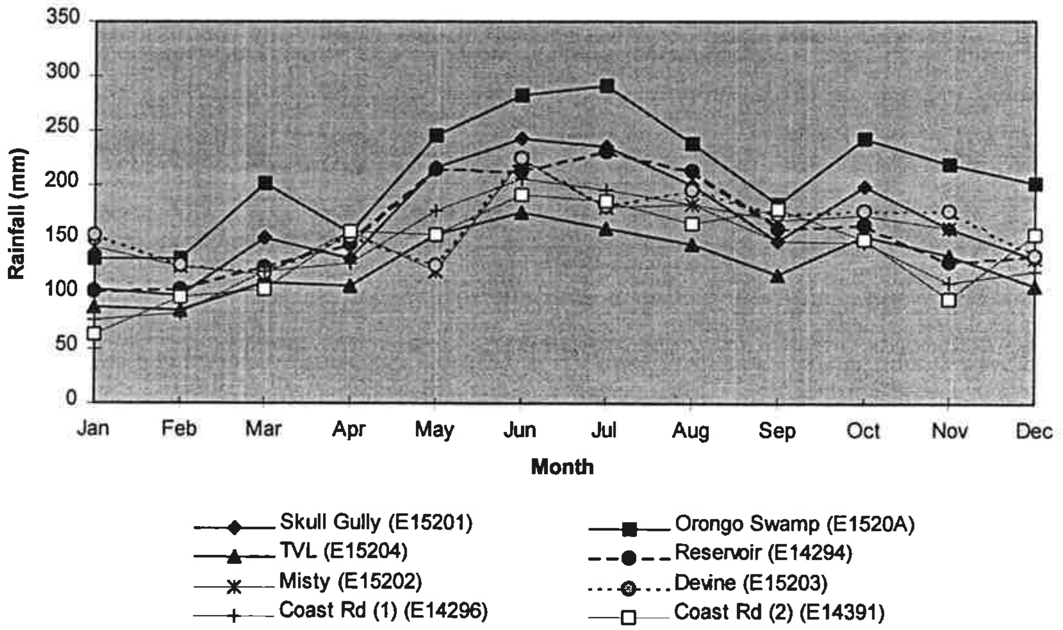


Figure 6.2: Mean Monthly Rainfall

Tables 6.2 to 6.9 and Figure 6.2 show that June and July are the wettest months and February is the driest month. While winter rainfall is consistent, summer rainfall can be highly variable from year to year. Summer rainfall is dependent on a regular procession of north-westerlies which can either be anticyclones, bringing dry weather, or more consistent depressions, bringing rain. Thompson and McGann (1990) have shown that, for the Hutt Catchment, summer rainfall has a coefficient of variation of 37 percent. The coefficient of variation is defined as the standard error of the seasonal rainfall as a percentage of its mean.

This variability in summer rainfall is evident in the Wainuiomata Catchment tabulated minimum and maximum recorded summer month rainfalls being widely spread about the mean monthly rainfall at most stations.

The minimum recorded monthly rainfall occurs consistently in February at all stations. The maximum recorded monthly rainfall tends to occur during the winter months.

Wainuiomata Reservoir (E14294) indicates that February 1908 is the driest month on record, registering only 1 mm of rainfall. This cannot be confirmed against any other rainfall record in the catchment.

6.4 Long-term Rainfall Trends

Long-term rainfall trends can be analysed by plotting the percentage difference from the normal and the cumulative departure from the mean annual rainfall. This has been carried out for the Wainuiomata Reservoir (E14294) site, the longest running rainfall station in the Wainuiomata Catchment.

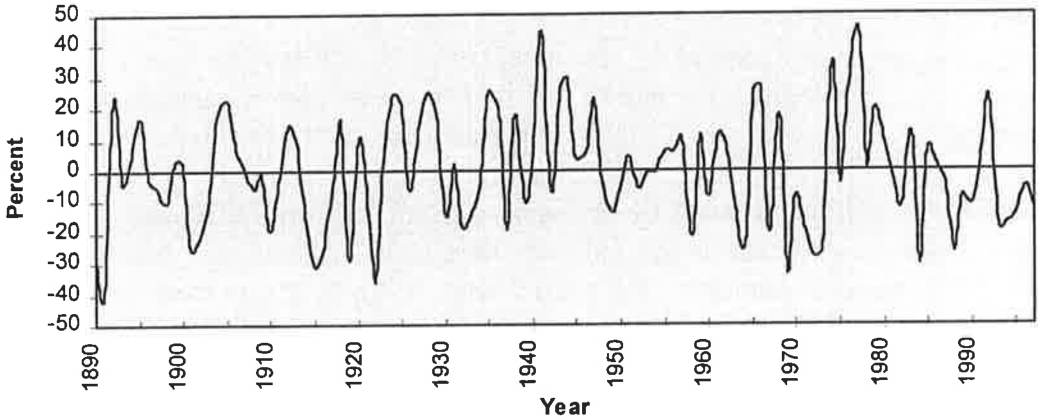


Figure 6.3: Wainuiomata Reservoir (E14294) Percentage Difference From Normal

Figure 6.3 plots annual rainfall as a percentage of the long term mean annual rainfall. Between 1890 and 1922 a number of severe drought events occurred at Wainuiomata Reservoir (E14294). The driest year on record was 1891 with over a 40 percentage difference from the normal rainfall.

Between 1923 and 1947 there were more years with above average rainfall than there were with below average rainfall. 1941 was a particularly wet year with 45 percent more rainfall than normal being recorded.

A period of below average rainfall from 1948 was broken by six years of higher than average rainfall in 1974.

From 1981 to the present the overall trend has been for below average annual rainfall.

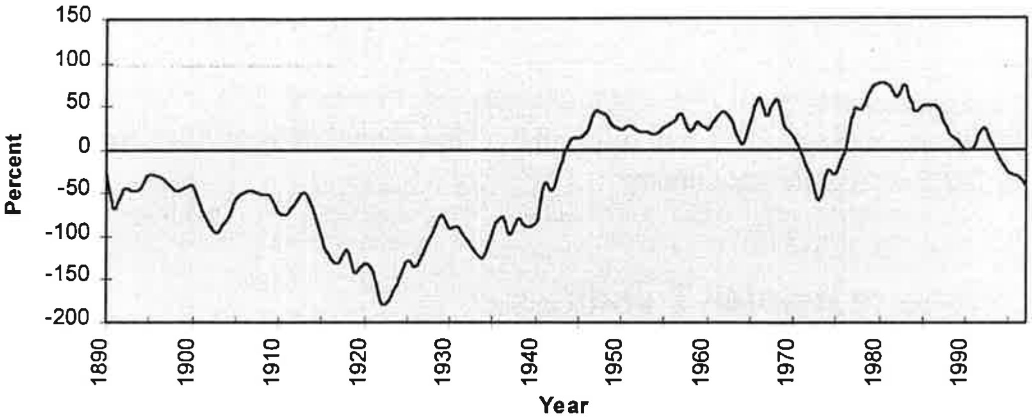


Figure 6.4: Wainuiomata Reservoir (E14294) Cumulative Departure from Mean

The relative slope of the cumulative departure line indicates variations in rainfall. A positive slope represents a period of years where increases rainfall has occurred and a negative slope is a period of decreased rainfall. When the line is approximately horizontal, this indicates a period of close to mean annual rainfall for the station's record.

Figure 6.4 exhibits a trend of declining rainfall between 1910 and 1922. Another strong decline in rainfall is noticed from 1966 to 1976, but is of a shorter duration than the 1910 to 1922 decline. The period from 1981 to the present shows a trend of decreasing rainfall.

An increase in rainfall is shown to have occurred between 1935 and 1947, while approximately mean conditions prevailed from 1950 to 1965.

6.5 Periods of Low Rainfall

The much longer rainfall records of stations in this study compared to flow records provides an opportunity to put periods of low river flows into a greater historical perspective. Thus, inferences can be made about the frequency and magnitude of recorded low river flows from recorded rainfall droughts.

The ten lowest minimum moving average for the following durations were extracted for all rainfall stations (Appendix 1).

- 30 days
- 60 days
- 90 days
- 120 days
- calendar year
- hydrological year

Results for the rain gauge at Orongorongo Headworks (E15301) (WRC, 1995) have also been included as the record for this station runs from 1928 to 1977 and can help to confirm drought rainfalls in the early Wainuiomata Reservoir (E14294) rainfall record.

The storage gauges Misty (E15202) and Devine (E15203) have been included in the analyses. The results from these stations must be treated with caution. Because the rainfall totals are only filed monthly the 30, 60, 90 and 120 day minimum moving averages will always begin at or near the beginning of the month. The totals for the minimum moving averages of 30 days are subject to greater inaccuracies than minimum moving averages of longer periods.

6.5.1 Minimum Moving Average 30 Day Rainfalls

Over a 30 day period variability is apparent in the years when minimum rainfalls occurred. There are, however, some 30 day periods that do predominate. These include the summers of 1928, 1934, 1981, 1985, 1990 and 1997.

A 30 day period without rainfall has not been recorded at any station in the Wainuiomata Catchment. Noticeable is how the storage gauges Misty (E15202) and Devine (E15203) record significantly higher minimum 30 day rainfalls than the other stations analysed. While this is mainly due to their higher elevation within the catchment, inconsistent measurement periods (some longer than 30 days) explain some of the discrepancy.

6.5.2 Minimum Moving Average 60 Day Rainfalls

Variability is again apparent with a lack of consistency in the periods of minimum 60 day rainfalls. The Wainuiomata Reservoir (E14294) station has the summers of 1908 and 1890 ranking one and three respectively. Confirmation of these periods cannot be given as no other rain gauge record begins this early.

Periods that recur at various stations are the summers of 1938, 1969, 1970, 1980 and 1983.

6.5.3 Minimum Moving Average 90 Day Rainfalls

The 90 day minimum rainfalls show the most consistency across all stations. Periods that predominate are the summers of 1939, 1969, 1971, the years 1980-1983, and 1998.

6.5.4 Minimum Moving Average 120 Day Rainfalls

Periods of 120 day minimum rainfalls that commonly occur at all rain gauges are the summers 1939, 1971, 1973, 1981, 1988, and 1989. Notable is the number of 120 day minimum rainfalls occurred at the Wainuiomata Reservoir (E14294) rain gauge between 1898 and 1920.

6.5.5 Minimum Calendar and Hydrological Year Rainfalls

Looking at the minimum yearly rainfall totals the years of 1915, the early 1970s and 1988 feature strongly. The minimum hydrological year rainfalls are generally less than the minimum calendar year rainfalls. This occurs because the summer season remains intact in a hydrological and is not divided between two calendar years.

6.6 Drought Rainfall Frequency Analyses

All rain gauges with over 15 years of record were analysed for drought frequency. The methodology for carrying out the drought frequency analyses is explained in Appendix 2. The minimum 30, 60, 90 and 120 day rainfalls were analysed on a hydrological year basis from 1 July to 30 June. The resultant drought frequencies are presented in Tables 6.10 to 6.14 and the lowest 30, 60, 90 and 120 annual minima are given in Appendix 1.

Table 6.10: Wainuiomata Reservoir (E14294) Drought Frequency (mm)

Return Period (years)	Average Annual Probability (%)	30 Day	60 Day	90 Day	120 Day
2	50	22	106	201	312
5	20	10	68	148	242
10	10	5	50	124	209
20	5	1	35	106	183
50	2	0	20	86	155
100	1	0	10	74	138

Table 6.11: Wainuiomata at Skull Gully (E15201) Drought Frequency (mm)

Return Period (years)	Average Annual Probability (%)	30 Day	60 Day	90 Day	120 Day
2	50	22	128	234	374
5	20	13	89	194	326
10	10	9	71	177	305
20	5	6	56	165	290
50	2	3	41	152	275
100	1	1	31	144	266

Table 6.12: Wainuiomata at Coast Road (1) (E14296) Drought Frequency (mm)

Return Period (years)	Average Annual Probability (%)	30 Day	60 Day	90 Day	120 Day
2	50	17	90	178	266
5	20	8	51	124	217
10	10	5	41	102	196
20	5	3	34	852	181
50	2	2	27	683	165
100	1	0	23	580	156

Table 6.13: Orongorongo at Orongo Swamp (E1520A) Drought Frequency (mm)

Return Period (years)	Average Annual Probability (%)	30 Day	60 Day	90 Day	120 Day
2	50	33	190	327	556
5	20	20	131	282	458
10	10	15	107	263	407
20	5	11	88	249	365
50	2	7	67	234	317
100	1	4	53	225	285

Table 6.14: Mangaroa at Tasman Vaccine Ltd (E15204) Drought Frequency (mm)

Return Period (years)	Average Annual Probability (%)	30 Day	60 Day	90 Day	120 Day
2	50	15	104	207	317
5	20	7	86	180	275
10	10	4	77	169	257
20	5	1	71	160	243
50	2	0	64	152	230
100	1	0	60	147	222

6.7 High Intensity Rainfall Analysis

High intensity rainfall frequency analyses have been carried out using the methodology detailed in Appendix 2 for the three automatic stations in and around the Wainuiomata Catchment for durations of 10 minutes to 72 hours (Tables 6.15 to 6.17).

Table 6.15: Wainuiomata at Skull Gully (E15201) Depth Duration Frequencies (1981-1997) (mm)

Duration	10 m	20 m	30 m	1 h	2 h	3 h	6 h	12 h	24 h	48 h	72 h
T2	7	12	15	22	30	38	54	91	122	183	214
T5	10	16	20	29	39	47	74	120	195	263	305
T10	11	18	24	34	44	54	83	131	223	321	363
T20	13	21	27	39	50	60	92	147	258	356	420
T50	14	24	31	45	57	67	104	179	322	445	498
T100	16	26	34	50	62	73	113	196	356	496	557
T200				53	67	78	120	213	392		

Table 6.16: Mangaroa at Tasman Vaccine Ltd (E15204) Depth Duration Frequencies (1981-1997) (mm)

Duration	10 m	20 m	30 m	1 h	2 h	3 h	6 h	12 h	24 h	48 h	72 h
T2	8	12	15	21	30	35	46	69	90	125	141
T5	11	16	20	28	38	46	67	94	137	172	192
T10	13	19	23	33	43	52	78	105	155	205	196
T20	15	22	26	38	48	59	89	119	177	225	224
T50	18	26	30	44	55	67	103	147	217	278	299
T100	20	28	33	48	60	74	113	163	240	307	333
T200				53	65	79	136	190	253		

Table 6.17: Orongorongo at Orongo Swamp (E1520A) Depth Duration Frequencies (1981-1997) (mm)

Duration	10 m	20 m	30 m	1 h	2 h	3 h	6 h	12 h	24 h	48 h	72 h
T2	7	11	14	22	32	40	57	92	124	190	200
T5	8	14	18	28	41	51	83	121	197	271	313
T10	9	15	21	33	47	58	97	132	226	330	371
T20	10	17	24	37	53	64	109	148	262	365	429
T50	12	19	27	43	60	73	127	181	328	456	507
T100	13	21	30	47	66	79	140	199	362	506	566
T200				50	71	85	148	216	400		

High intensity rainfall frequencies are provided for the daily storage gauges for durations of 24 hours to 72 hours (Tables 6.28-6.20).

Table 6.18: Wainuiomata at Reservoir (E14294) Depth Duration Frequencies (1884-1996) (mm)

Duration	24 h	48 h	72 h
T2	110	154	180
T5	155	222	260
T10	184	266	312
T20	212	309	362
T50	248	364	426
T100	275	406	475

Table 6.19: Wainuiomata at Coast Road 1 (E14296) Depth Duration Frequencies (1971-1997) (mm)

Duration	24 h	48 h	72 h
T2	75	108	128
T5	89	133	162
T10	99	150	185
T20	108	166	207
T50	120	187	235
T100	129	203	256

Table 6.20: Wainuiomata at Coast Road (2) (E14391) Depth Duration Frequencies (1974-1984) (mm)

Duration	24 h	48 h	72 h
T2	78	113	132
T5	92	135	161
T10	101	150	181
T20	109	164	200
T50	121	182	224
T100	129	196	243

6.8 Climate Change Impacts on Rainfall

Potential changes to the present rainfall regime of the Wainuiomata Catchment exist due to the greenhouse effect. The changes are caused by increasing atmospheric CO_2 concentrations. Assuming a doubling CO_2 concentration by 2040, the potential changes are:

(1) Increased summer dryness due to a reduction in the number of rain days per annum, which will result in more droughts. This is attributed to a decrease in the strength and frequency of westerly and north-westerly winds, and will ultimately give a slight increase drought frequency.

(2) Due to a 1.5 °C increase in temperature, again assuming a doubling of CO_2 concentration by 2040, dew point temperature will increase, resulting in an increase in water vapour content of about 15 percent from present levels. As a consequence rainfall intensities are expected to increase which will result in more storm events. It is possible that a 12 hour 100 year high rainfall frequency event could reduce in frequency to a 50 year event. (Thompson and McGann, 1990)

The extent to which (1) and (2) above will negate each other is not known.

6.9 Southern Oscillation Impacts on Rainfall and River Flow

The Southern Oscillation Index (SOI) has been found to have an influence on the occurrence of drought river flows in the Wainuiomata Catchment. Three reports (Lew, 1996; Lew, 1996 and Lew, 1997) investigating the relationship between the SOI and river flows in the Wellington metropolitan water supply catchments have been produced.

The SOI is described as a large scale shift of air across the Pacific, between Indonesia and Tahiti, principally in tropical and subtropical latitudes. The Southern Oscillation is recognised as being closely related to sea surface temperature variations, currents and thermocline depth in the equatorial Pacific Ocean.

The Southern Oscillation is described by an index (SOI). There are a variety of ways that have been developed to compute the SOI. The various SOI measures may incorporate one or more climatic variables such as pressure, rainfall, and temperature, calculated at various places. The most commonly used index uses sea level pressure differences between recording stations situated at Tahiti and Darwin.

When Darwin's pressure is up and Tahiti's is down, the SOI is said to be in its negative phase, known as El Nino. When Darwin's pressure is down and Tahiti's is up, the SOI is in a positive phase known as La Nina.

6.9.1 El Nino Weather

A strong negative SOI (El Nino) correlates with more frequent south-westerly flows over New Zealand and a ridge of high pressure to the north. Cooler than average temperatures, and below normal rainfall to the north and east of the country result.

The summer of 1982-83 was the strongest El Nino event of the last one hundred years as measured by the SOI. The El Nino event of 1997-98 did not reach the maximum SOI intensity of the 1982-83 event but was stronger in terms of the change in sea surface temperatures.

6.9.2 La Nina Weather

A strong La Nina correlates with more frequent north-easterly weather over the North Island and anticyclones in South Island latitudes.

Rainfall tends to be higher on the east coast and over Northland, and lower in west coast areas and Southland. Temperatures tend to be above average over the country.

The southward movement of the subtropical highs increases the tropical influence on New Zealand and increases the chance of tropical cyclones reaching North Island latitudes.

6.9.3 Southern Oscillation Index Forecasts

In the Wainuiomata Catchment a strong teleconnection exists between strong La Nina events and rainfall and river flow.

Forecasts have been developed for mean seasonal flow in the Wainuiomata River at Manuka Track (29606) using the preceding seasons mean Southern Oscillation Index (SOI) value. The forecasts are detailed below:

(1) If the **Winter SOI is in the range of 1 to 24** then the two year return period mean Spring flow of 1,042 L/s has a 63 percent probability of occurring.

(2) If the **Spring SOI is in the range of 3 to 21** then the two year return period mean Summer flow of 521 L/s has a 62 percent probability of occurring.

(3) If the **Summer SOI is in the range of 4 to 26** then the two year return period mean Autumn flow of 694 L/s has a 61 percent probability of occurring.

(4) If the **Summer SOI is in the range of 4 to 26** then the five year return period mean Autumn flow of 451 L/s has a 42 percent probability of occurring.

(5) If the **Summer SOI is in the range of 0 to 27** then the 10 year return period mean Autumn flow of 347 L/s has a 15 percent probability of occurring.

(6) If the **Summer SOI is in the range of 4 to 26** then the 20 year return period mean Autumn flow of 278 L/s has a 11 percent probability of occurring.

The probabilities presented in the forecasts are conditional probabilities. The unconditional probabilities for 2, 5, 10 and 20 year return period flows are 50, 20, 10 and five percent respectively. Therefore, the conditional probabilities derived for the above forecasts give an improved chance of predicting drought flows.

The first forecast, for example, provides a conditional probability of 63 percent that a two year return period flow will occur at Manuka Track (29606). The unconditional probability of such a flow is 50 percent. Therefore, there is a 13 percent greater chance of a two year return period flow being forecast.

6.10 Rainfall Analyses Conclusions

The main findings of the analyses carried out on rain gauges in and around the Wainuiomata Catchment are:

- The driest month on record (at Wainuiomata Reservoir (E14294)) is February 1908 where 1 mm was recorded. This cannot be confirmed against other rain gauge records. February 1890 and February 1990 are the next lowest with 8 mm and 9 mm recorded respectively.
- A trend of declining rainfall occurred between 1910 and 1922, and again between 1966 and 1976.
- From 1980 to the present rainfall has been below average.
- Rainfall drought events in excess of the 100 year return period have been recorded at Wainuiomata Reservoir (E14294).
- There is a strong teleconnection between a La Nina event and low rainfall and river flow in the Wainuiomata Catchment.

7. Flow Analyses

The objectives of this section are:

(1) To examine long term trends and seasonal patterns of the Wainuiomata River and its tributaries.

(2) To measure extreme low and high flows and predict the frequency of occurrences for given magnitudes of low and high flows.

(3) To estimate the flow contribution of major tributaries to the Wainuiomata River.

(4) To describe flow distribution characteristics and estimate water yields.

Flow analyses are presented for each of the Wainuiomata Catchment water level recorder stations. The extent of these analyses is dependent on available records and data. Where indicated, flow analyses are derived from flow records at the stations given in Table 4.2. In an effort to gain data for ungauged streams and tributaries, correlations of instantaneous gaugings are carried out and these correlations used to determine flow analyses.

7.1 Types of Analyses

7.1.1 Flow Statistics

Where available the following flow statistics are presented for each of the Wainuiomata Catchment water level stations:

- Minimum, mean and maximum monthly flows. Also given is the minimum, mean and maximum of the yearly means.
- Mean annual low flow. That is the mean of the lowest instantaneous flow for each calendar year of record.
- Minimum, mean, median and maximum recorded flows.
- Lowest gauged and recorded flows. The lowest gauged flow is a flow that has been physically measured, while lowest recorded is derived from a station's rating curves. This is also used to check rating curve extrapolation.

7.1.2 Flow Duration Curves and Tables

A flow duration curve is a cumulative frequency graph that shows the percent of time specified discharges are equalled or exceeded. As the hydrological records upon which the curves are based reasonably represent the short to medium term flow records of the Wainuiomata River and its tributaries, they may be used to predict the distribution of future flows for water management purposes.

At the high flow end, each curve is influenced by the amount of effective precipitation the catchment receives. Through the mid portion, the curves are determined by catchment characteristics such as geology, vegetation, and soil type, and their ability to initially store and then release water to maintain base flow during periods of no rainfall. During an extreme drought, the curves are more influenced by geology.

The numerical flow duration table showing actual values, equalled or exceeded, is also given.

7.1.3 Recession Curve Analyses

Another tool that can employed for low flow analysis is the recession curve. The diminishing discharge in the recession limb of a hydrograph reflects the depletion of stored water both surface and subsurface within a catchment. In effect, a recession curve is another way of illustrating, for a period of little or no rainfall, the rate at which a catchment releases water from storage to maintain stream flows. The rate of release is dependent on the catchment characteristics such as geology, vegetation and soil type. Recession curves can be used for low flow forecasting during prolonged dry periods.

A variety of methods have been used to describe the recession process, but all conform to the law of bacterial decay or the exponential law. The most common recession equation used has the form:

$$Q_t = Q_0 K_r^t$$

Where:

Q_t = discharge after time t, where t is in days
Q_0 = initial discharge
K_r^t = recession constant

From this equation the half life period (the time required for the base flow of a river to halve) can be calculated. The recession curves chosen do not necessarily represent the driest periods in each record. Instead, the most consistent recessions which are not interrupted by rainfall are analysed.

7.1.4 Concurrent Gaugings and Water Use

Concurrent flow gaugings are effectively simultaneous measurements of flow at various points on a river and its tributaries. They are carried out on the same day, while a river is in a recession phase and no rainfall has been experienced for some days. They aid in identifying:

- What percentage of total flow each tributary and catchment contributes.
- Correlations between tributaries and main channel.
- Whether water permit abstractions are operating within their legal limits.

When analysing concurrent gaugings, if water permit abstractions have not been physically measured by undertaking gaugings above and below the abstraction point, it is assumed that abstractions are operating at the time of the gaugings at the maximum allocation rates as described in the permit.

Permitted activities of up to 20,000 litres per day (0.23 L/s) may be cumulatively significant and if desired an estimation can be derived by looking at land uses and assuming 0.23 L/s per farm that does not have a dam.

7.1.5 Low Flow Frequency Analyses

Frequency analysis of low flow magnitude and frequency of occurrence is an important tool in effectively managing any water resource. For such analysis, estimates are produced of low flow magnitudes corresponding to specified return periods and durations of instantaneous 1, 7, 14 and 28 days. Analyses of the frequency of low flow periods in the Wainuiomata Catchment is particularly important from a water supply viewpoint. The Wainuiomata Catchment supplies approximately 20-25 percent of Wellington's metropolitan water supply (G Williams, pers comm. 1998). A low flow frequency analysis will indicate the statistical likelihood that water supply demands will not be met at any given time. Analysis of low flow frequency is also important from a water quality and recreational viewpoint (e.g., dilution rates for effluent and maintaining fish populations). The methodology used to estimate low flow frequencies is explained in Appendix 2.

7.1.6 Flood Frequency Analyses

The Wainuiomata River Flood Hydrology (Lew and Harkness, 1998) report is summarised to provide flood frequency analyses. The information is up-to-date and no new analyses have been undertaken in the compiling of this report.

7.2 Flow Statistics

There are currently two water level recorders operating in the Wainuiomata Catchment. Manuka Track (29606) and Leonard Wood Park (29605) are both situated on the Wainuiomata River (Figure 4.1).

A station operated at the Morton Dam (29604) from 1928 until 1981 was decommissioned. The Morton Dam (29604) flow record is recorded as a daily mean. Instantaneous flow measurements are not available, except for the annual flood peaks between 1955 and 1981 that were calculated from recorder charts (Lew and Harkness, 1998). Daily mean flow data is available from 1928 to 1976.

A correlated flow record has been derived for George Creek above Bottom Intake (29614) using a series of 18 concurrent gaugings between this site and Manuka Track (29606). An investigation focusing on George Creek (WRC, 1998) presented a correlated flow record for George Creek based on concurrent gaugings with the Big Huia Stream. The flow statistics presented here (Table 7.1) are considered superior as the correlated record is based on 18 concurrent gaugings, covers a longer period, and better represents low flow gaugings that have been measured in George Creek (Table 7.6)

The flow statistics for each station are presented in Table 7.1.

Table 7.1: Flow Statistics (L/s)

Station	Catchment Area (km^2)	Min.	Mean	Median	Max.	MALF
Manuka Track (29606)	27.1	89	897	571	59810	176
Leonard Wood Park (29605)	77.5	114	2129	1151	120874	233
Morton Dam (29604)	34.0	14	1170	712	40700	198
George Creek (correlated) (29614)	4.9	13	101	65	6576	22

Tables 7.2-7.5 give the minimum, mean and maximum monthly and yearly flows for all three stations.

Table 7.2: Manuka Track (29606) Monthly and Yearly Flows (L/s)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Min.	235	175	222	173	366	269	510	377	388	435	471	437	692
Mean	460	400	538	561	992	1207	1407	1176	937	1057	832	786	890
Max.	904	917	1957	1367	3260	1898	2540	1837	1888	3405	2254	2372	1252

Table 7.3: Morton Dam (29604) Monthly and Yearly Flows (L/s)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Min.	213	177	197	159	197	409	424	614	400	475	305	240	663
Mean	664	788	652	855	1420	1544	1880	1814	1521	1100	998	827	1169
Max.	2225	2865	3034	4333	6072	4001	5866	5934	5677	2599	3361	3608	1936

Table 7.4: Leonard Wood Park (29605) Monthly and Yearly Flows (L/s)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Min.	25	24	30	22	56	51	132	85	83	94	75	68	128
Mean	112	76	110	150	241	364	422	319	273	253	195	166	210
Max.	644	173	480	543	651	763	726	727	1111	937	469	457	324

Table 7.5: George Creek above Bottom Intake (29614) (correlated) Monthly and Yearly Flows (L/s)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Min.	29	22	27	22	43	33	59	44	46	51	55	51	79
Mean	54	47	62	65	112	136	158	132	106	119	94	89	101
Max.	102	104	218	153	361	212	282	205	211	377	251	264	141

February is the driest month at Manuka Track (29606) and Leonard Wood Park (29605) in terms of mean monthly flow.

The driest month on record at both Manuka Track (29606) and Leonard Wood Park (29605) was April 1985. The February and March minimum flows at Manuka Track (29606) both occurred in 1989. Morton Dam (29604) March and April minimum flows occurred in 1917.

Notable years for maximum flow were 1983 where at both Manuka Track (29606) and Leonard Wood Park (29605) the maximum May and July flows were recorded, and also in 1992 when Manuka Track (29606) recorded maximum September and October flows and Leonard Wood Park the maximum October flow.

Table 7.6 presents sites measured in the Wainuiomata Catchment and the lowest gauged and recorded flows at each.

Table 7.6: Wainuiomata Catchment Lowest Gauged and Recorded Flows (L/s)

Location	Site No.	Flow	Date	Map Reference
Manuka Track (gauged)	29606	108	22/03/89	R27:786924
Manuka Track (recorded)	29606	89	20/03/89	
Leonard Wood Park (gauged)	29605	127	17/04/85	R27:731896
Leonard Wood Park (recorded)	29605	114	25/02/85	

Location	Site No.	Flow	Date	Map Reference
Morton Dam (gauged)	29604	49	17/03/93	R27:772919
Morton Dam (recorded)	29604	14	04/10/32	
West Branch	29613	29	06/03/90	R27:792934
Below Intakes	29615	11	19/01/90	R27:780922
Wainuiomata Golf Course	29608	279	06/03/90	R27:721875
Above Catchpool	29622	119	17/02/59	R27:691822
Mouth	29626	469	19/03/98	R27:675766
George Creek @above Top Intake	29616	18	12/02/64	R27:780902
George Creek @above Bottom Intake	29614	12	03/04/85	R27:775913
Wainuiomata Stream @Confluence	29621	67	22/03/76	R27:747909
Black Creek @Main Road	29609	27	06/03/90	R27:737912
Catchpool @Coast Road	29623	0	17/02/94 & 19/03/98	R27:698818

7.3 Flow Duration

The Manuka Track (29606) and Leonard Wood Park (29605) flow duration tables and curves and presented below (Table 7.7 and Figure 7.1). The flow duration curves are truncated at approximately twice the mean flow.

Table 7.7: Manuka Track (29606) Flow Duration Table (L/s)

%	0	1	2	3	4	5	6	7	8	9
0	59810	5980	4094	3278	2757	2408	2179	2006	1872	1754
10	1659	1581	1507	1439	1374	1317	1267	1222	1180	1142
20	1106	1072	1043	1010	980	954	931	904	880	857
30	836	819	803	790	773	759	742	728	713	699
40	685	671	659	645	632	618	607	595	583	572
50	564	553	543	534	522	514	503	495	485	475
60	466	459	450	440	432	424	416	409	401	393
70	385	376	369	360	353	344	336	327	319	309
80	303	294	286	279	271	263	253	245	238	229
90	221	212	205	195	185	177	168	160	149	139
100	89									

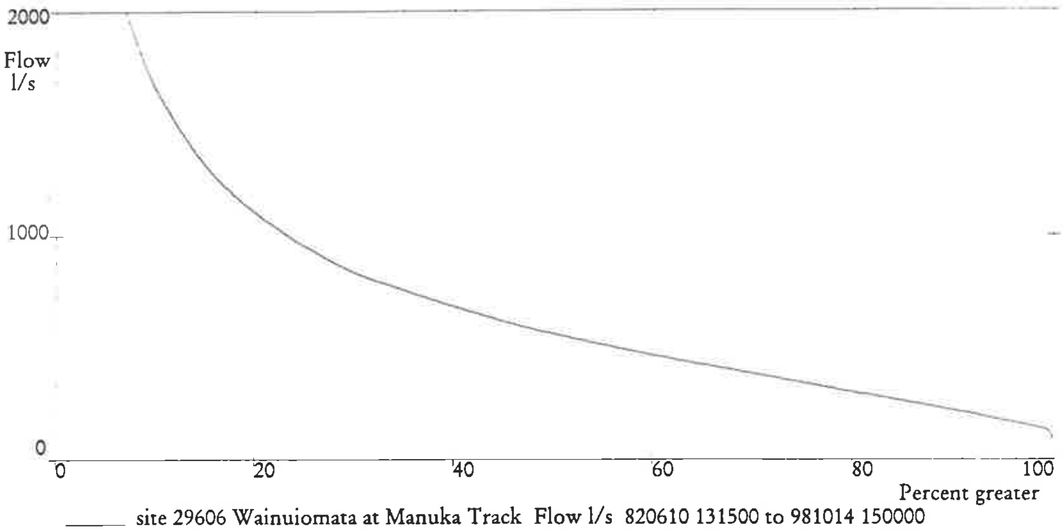


Figure 7.1: Manuka Track (29606) Flow Duration Curve (L/s)

Table 7.8: Leonard Wood Park (29605) Flow Duration Table (L/s)

%	0	1	2	3	4	5	6	7	8	9
0	86307	14982	10317	8264	7035	6193	5600	5094	4706	4360
10	4079	3831	3618	3437	3266	3106	2958	2826	2707	2606
20	2511	2428	2347	2274	2202	2143	2076	2010	1948	1887
30	1831	1769	1717	1669	1622	1577	1531	1488	1442	1403
40	1368	1332	1297	1264	1232	1201	1172	1146	1121	1094
50	1069	1044	1020	996	973	948	925	903	879	855
60	831	808	785	766	744	726	707	686	666	647
70	631	615	597	578	562	546	529	512	493	475
80	458	442	426	411	399	383	368	354	340	327
90	313	298	283	268	251	236	223	211	194	169
100	114									

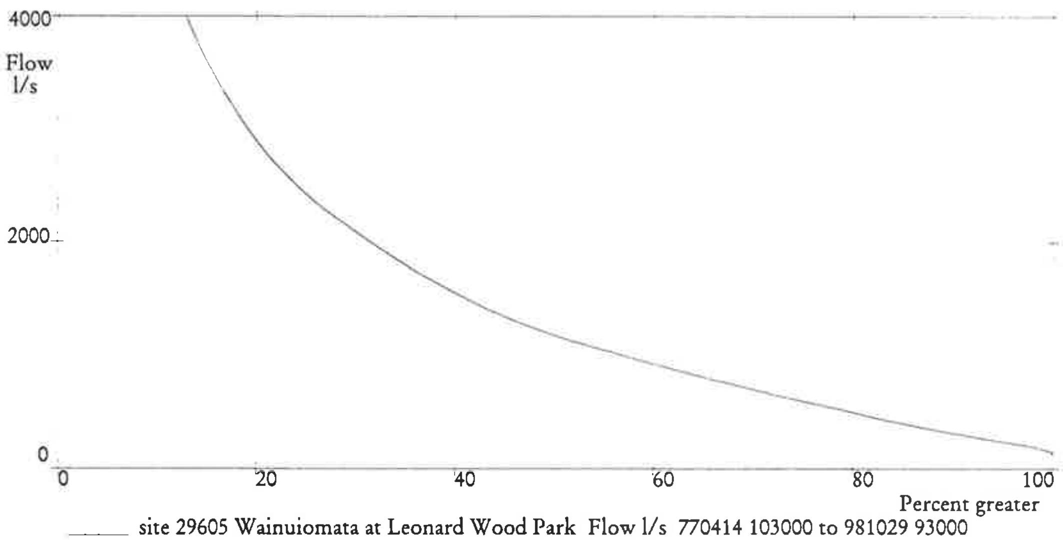


Figure 7.2: Leonard Wood Park (29605) Flow Duration Curve (L/s)

Table 7.9: Morton Dam (29604) Flow Duration Table (L/s)

%	0	1	2	3	4	5	6	7	8	9
0	40700	8260	5439	4404	3721	3342	3038	2770	2581	2435
10	2276	2135	2021	1929	1844	1743	1683	1596	1541	1473
20	1449	1384	1340	1315	1250	1220	1197	1148	1112	1102
30	1083	1053	1024	999	995	979	960	923	902	890
40	866	858	853	830	806	789	784	762	751	739
50	712	701	691	665	650	647	645	636	610	600
60	593	576	560	556	553	543	527	517	511	496
70	477	467	465	463	459	450	431	423	407	388
80	377	373	361	350	338	331	317	308	299	292
90	283	268	261	249	239	226	211	192	180	162
100	14									

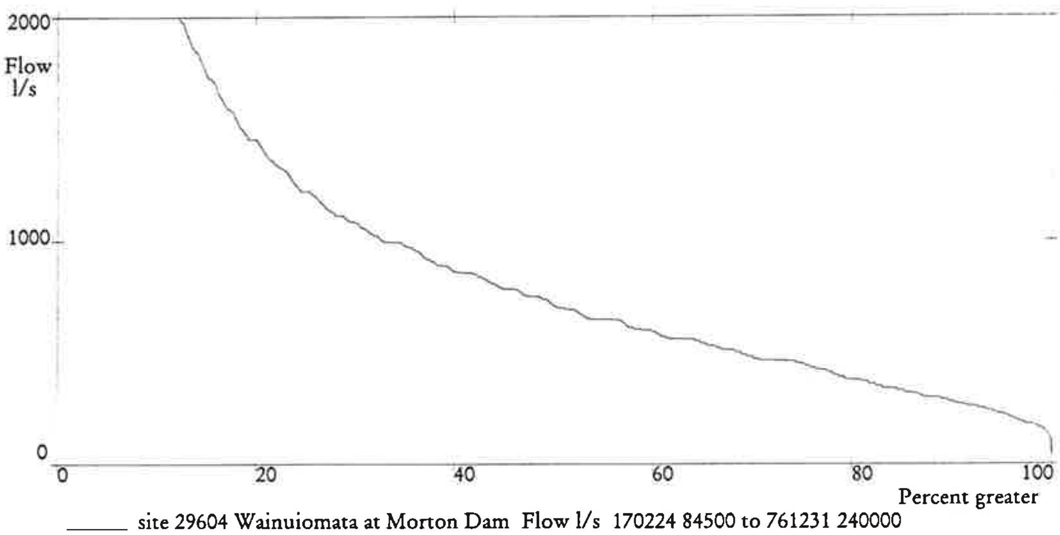


Figure 7.3: Morton Dam (29604) Flow Duration Curve (L/s)

Table 7.10: George Creek (29614) (correlated) Flow Duration Table (L/s)

%	0	1	2	3	4	5	6	7	8	9
0	6576	660	453	363	306	268	242	224	209	196
10	186	177	169	161	154	148	142	138	133	129
20	125	121	118	114	111	108	105	103	100	98
30	95	93	91	90	88	87	85	83	82	80
40	79	77	76	74	73	71	70	69	67	66
50	65	64	63	62	61	60	59	58	57	56
60	55	54	53	52	51	50	49	48	47	47
70	46	45	44	43	42	41	40	39	38	37
80	37	36	35	34	33	32	31	30	30	29
90	28	27	26	25	24	23	22	21	20	19
100	13									

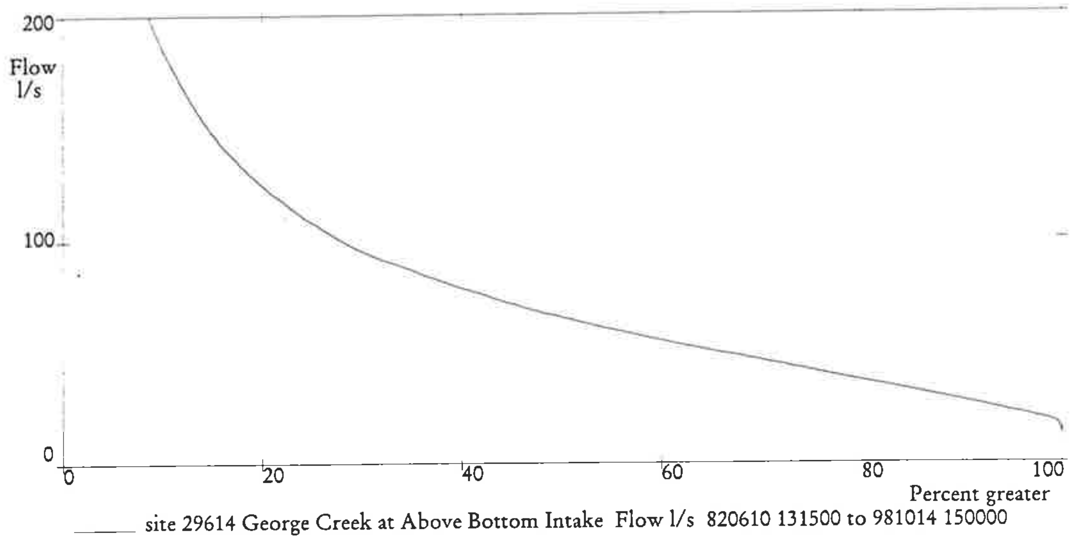


Figure 7.4: George Creek (29614) (correlated) Flow Duration Curve (L/s)

The flow duration curves for all three sites are similar in shape and vertical position indicating that there specific discharges are similar. This is indicative of the similar geology characteristics defined in Section 2.2.

The Leonard Wood Park (29605) flow duration curve shows a greater yield due to the larger catchment area.

7.4 Recession Curve Analysis

The most suitable recessions for analysis at the Manuka Track (29606) site are illustrated in Appendix 3. The recession start dates, recession constants (k), and half life (days) are given in Table 7.11.

Recession curve analysis was not undertaken on Leonard Wood Park (29605) and Morton Dam (29604) data as recessions at these two sites have been influenced by water supply abstraction.

Table 7.11: Manuka Track (29606) Recession Half Lives

Recession Start Date	Recession Duration (days)	Recession Constant (k)	Half Life (days)
16/03/85	34	0.98	33
06/02/89	14	0.97	23
20/07/89	10	0.96	17
01/02/90	34	0.97	25
28/04/97	28	0.96	19

Table 7.11 shows that the mean recession constants for Manuka Track are all greater than 0.95. A mean recession constant of 0.97 and a representative half life of 23 days are calculated from the five chosen recessions.

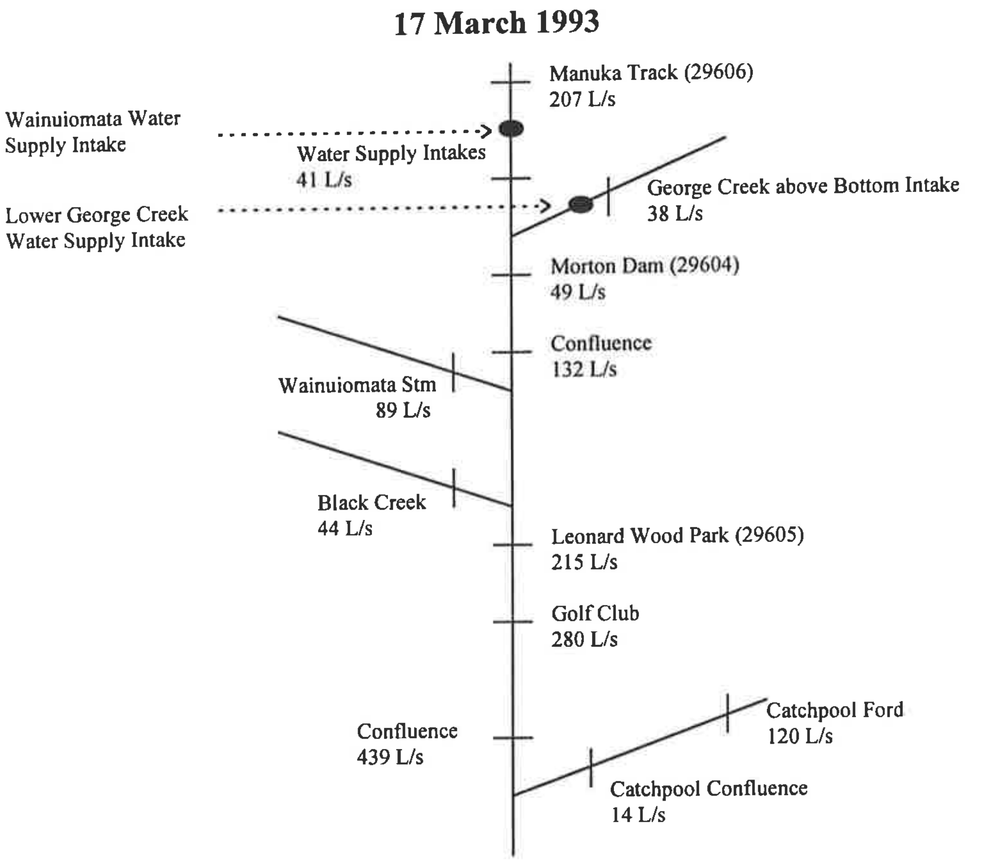
7.5 Concurrent Gaugings

Figures 7.5 and 7.6 are schematic diagrams of the Wainuiomata River and its main tributaries. Concurrent gaugings were carried out on 17 March 1993, 21 April 1993, 17 February 1994 and 19 March 1998.

Abstraction for water supply accounts for discrepancies in flow between Manuka Track (29606) and Morton Dam (29604). Abstraction is calculated from the concurrent gauging runs as 166 L/s and 30 L/s at the Wainuiomata Water Supply Intakes and the Lower George Creek intakes respectively on 17 March 1993, 179 L/s and 28 L/s on 21 April 1993, and 155 L/s and 6 L/s on 17 February 1994.

From the confluence of the Wainuiomata River and Wainuiomata Steam down to Leonard Wood Park (29605) there is a loss in flow. This can be attributed to groundwater recharge. The loss is measured to be 50 L/s on 17 March 1993, 19 L/s on 21 April 1993, and 21 L/s on 17 February 1994.

A loss in flow is also recorded in the Catchpool Stream. On 17 March 1993 and 17 February 1994 losses of 106 L/s and 114 L/s were measured between the Catchpool Ford and Catchpool Confluence sites. Zero flow has been recorded at the Catchpool Confluence on two occasions, 17 February 1994 and 17 March 1998, and is believed to have dried up during other dry periods as well.



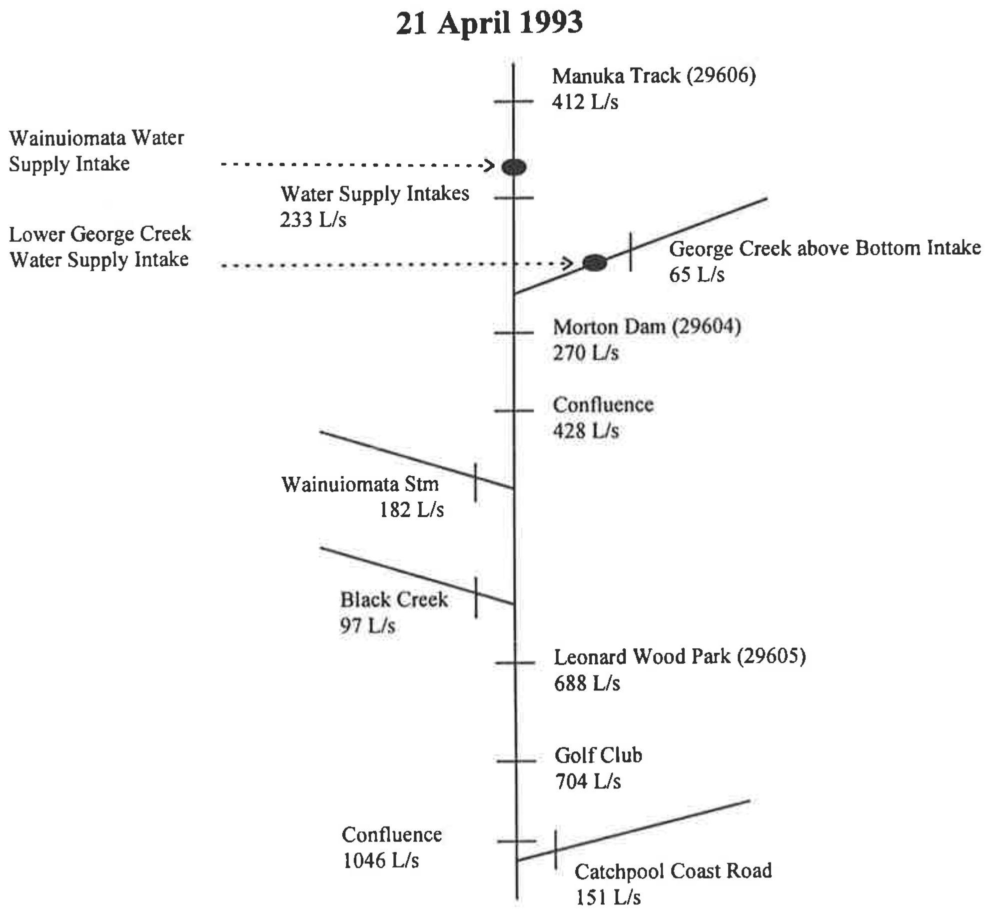
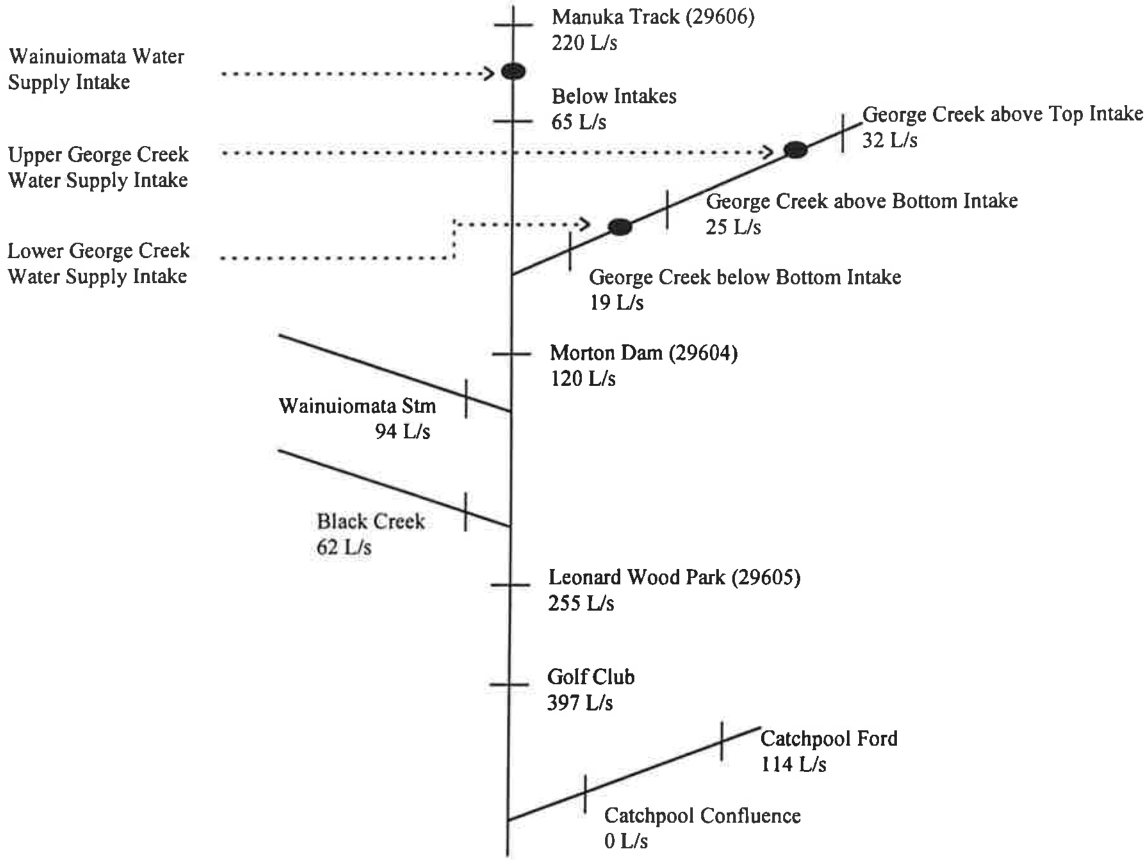


Figure 7.5: Wainuiomata Catchment Concurrent Gauging Runs

17 February 1994



19 March 1998

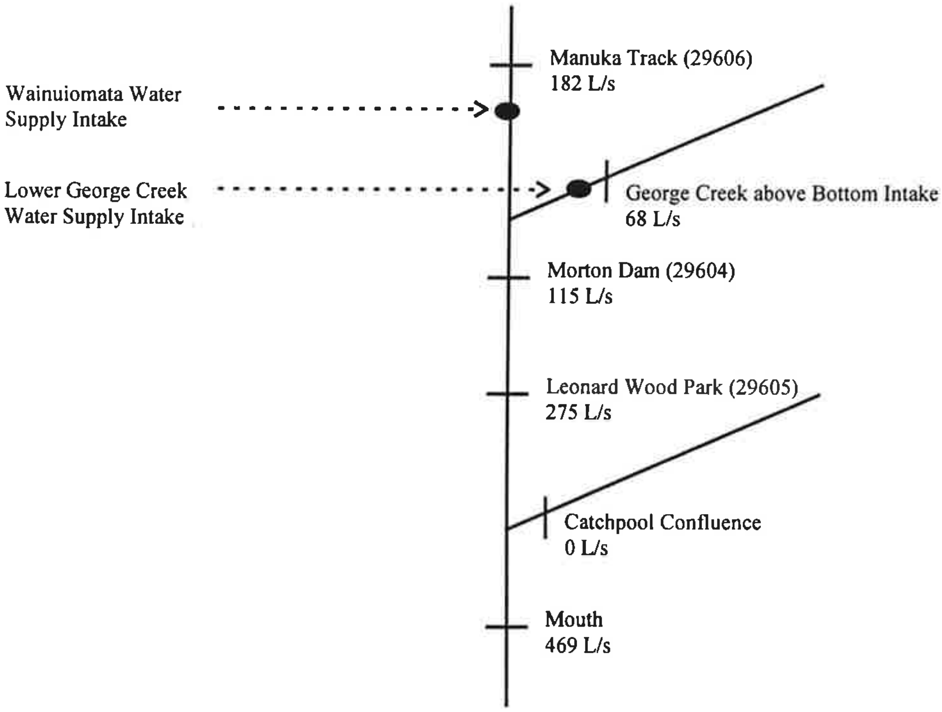


Figure 7.6: Wainuiomata Catchment Concurrent Gauging Runs

7.6 Water Use

The predominant water use from the Wainuiomata Catchment is for public water supply. The Council's Strategy and Assets Group operates three run of the river takes on George Creek (upper and lower intakes) and the Wainuiomata River. Until 1988 water was taken from an intake at the Morton Dam.

Consented surface water takes currently operating on the Wainuiomata River are detailed in Table 7.12. Consent number WGN 77010001 allows abstraction from the Wainuiomata River and lower George Creek intakes, and consent number WGN 77010101 allows abstraction from the upper George Creek intake as well as all abstraction points in the Orongorongo Catchment.

Table 7.12: Current Surface Water Takes

Consent No.	m^3/day	L/s	Use	Map Reference	Status
WGN 77010001	27,300	316	Public Water Supply	R27:767911	Notified Use
WGN 77010101	22,750	263	Public Water Supply	R27:802879	Notified Use

7.6.1 The Morton Dam

Two dams have been constructed on the Wainuiomata River for provision of public water supply (Figure 2.1). A small earth dam known as the Lower Dam was constructed in 1884 with a storage capacity of 123,000 m^3, and the water piped 30 km to Wellington City. By 1900, however, severe water shortages were being experienced in Wellington City and construction of Morton Dam (named after City Engineer, Mr W H Morton) commenced in 1908. The dam, a concrete buttress type, was completed in 1911. The lake formed by the dam had a storage volume of 485,000 m^3. The collected water was piped to Wellington City.

In the 1920s the supply was supplemented by water collected at a weir on the neighbouring Orongorongo River and piped through a 3.2 km tunnel constructed between the Orongorongo and Wainuiomata valleys to Wellington City. At this time 20,000 m^3 per day was supplied to Wainuiomata and Wellington from these sources.

Morton Dam was decommissioned in 1988 following concerns about the structural stability, and spillway capacity during high flows. It was recommended that run of the river takes be constructed on the Wainuiomata River and George Creek upstream of the Morton Dam and that a residual flow be left in the river below the Wainuiomata Intake of 10,000 m^3 per day (116 L/s) from May to July (fish spawning season), and 5,000 m^3 per day (58 L/s) below the dam from August to April.

The Morton Dam structure still remains in place but a low level spillway has been constructed acting as an artificial rapid that slopes down to the downstream bed level.

The right to take water for public supply is by a *notified use* pursuant to section 21(2) of the Water and Soil Conservation Act 1967. This right was transferred from the Morton Dam intake to the run of the river intakes. The notified use right did not have an expiry date under the Water and Soil Conservation Act 1967, but the Resource Management Act 1991 imposed an expiry date of 1 October 2001 on all notified uses authorised under the Water and Soil Conservation Act 1967 unless a regional plan sets an earlier date.

7.6.2 Wainuiomata Water Treatment Plant

The Wainuiomata Water Treatment Plant was constructed by the Regional Council to treat water abstracted from the Wainuiomata and Orongorongo catchments to a quality consistent with the standard of water supplied from the Council's other sources at Te Marua and the Hutt artesian system.

The Wainuiomata and Orongorongo intakes supply about 22 percent of the total water supplied for consumption in the Wellington metropolitan area. Up to 40,000 m^3 of water is abstracted daily, with 15,000 m^3 originating from the Orongorongo intakes and the remaining 25,000 m^3 from the George Creek and Wainuiomata intakes.

7.6.3 Proposed Regional Freshwater Plan

Under the Proposed Regional Freshwater Plan for the Wellington Region (PRFWP) minimum flows and stepdown allocations have been set for the Wainuiomata River at Manuka Track and Leonard Wood Park. Table 7.13 details the conditions.

Table 7.13: Proposed Minimum Flows and Stepdown Allocations (L/s)

Location of Desirable Minimum Flow	Wainuiomata at and below Manuka Track	Wainuiomata at Leonard Wood Park
Minimum Flow	100	300
Core Allocation	0	65
Flow Required for Supplementary allocation	100	485
Flow below which first stepdown allocation takes effect	-	360
First Stepdown Allocation	-	60
Flow below which second stepdown allocation takes effect	-	345
Second stepdown allocation	-	50

Figures 7.7 and 7.8 show the flow hydrographs for Manuka Track (29606) and Leonard Wood Park (29605) from July 1996 to Jun 1998 overlain with the Minimum Flow and Stepdown Levels as set out in the Proposed Regional Freshwater Plan (Table 7.13).

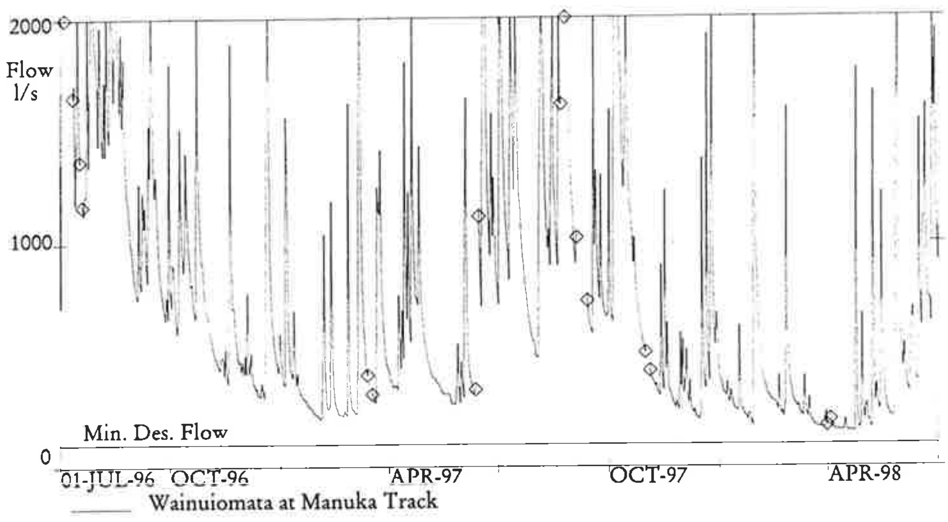


Figure 7.7: Manuka Track (29606) Flow and PRFWP Levels

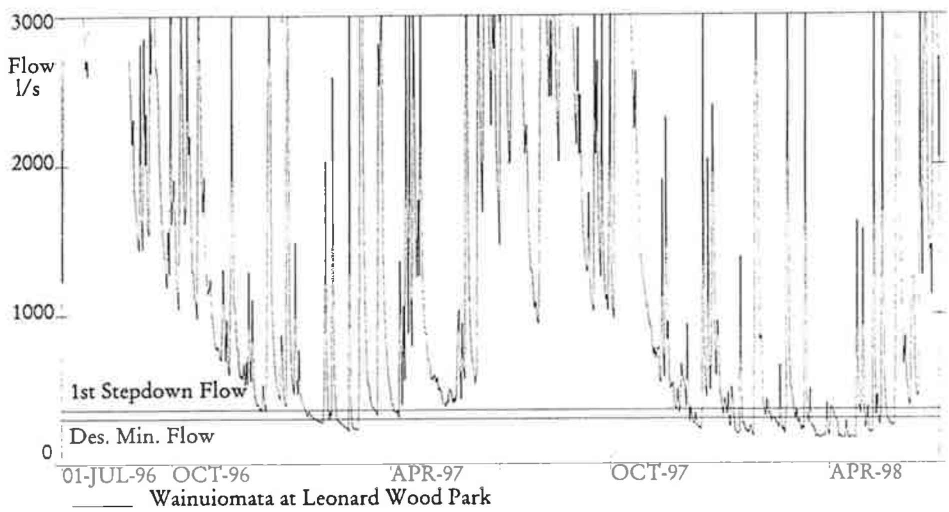


Figure 7.8: Leonard Wood Park (29605) Flow and PRFWP Levels

Leonard Wood Park (29605) flow falls below the First Stepdown and Minimum Flow for much of the summer months, particularly in 1998 (Figure 7.8).

Daily abstraction data from July 1996 to June 1998 from the Wainuiomata Catchment (Wainuiomata and George Creek intakes) was added to the daily Leonard Wood Park (29605) flow data to create a naturalised flow record for Leonard Wood Park. Figure 7.9 shows that if no water was abstracted from the Wainuiomata Catchment above Leonard Wood Park then the flow level would only briefly fall below the levels set out in the Proposed Regional Freshwater Plan.

Figure 7.8 clearly shows that the conditions set out in the Proposed Regional Freshwater Plan are not currently being met. This will need to be addressed when the Plan becomes operative.

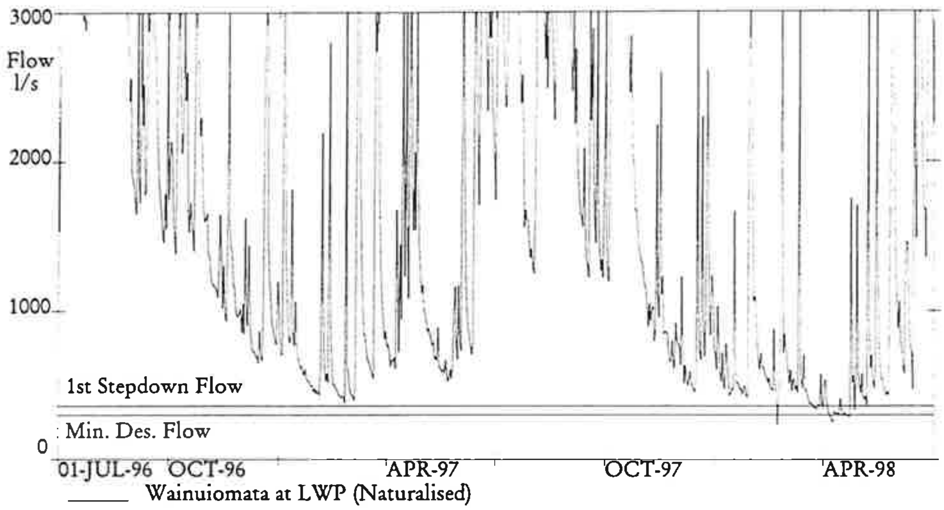


Figure 7.9: Leonard Wood Park Naturalised Flow and PRFWP Levels

7.7 Low Flow Frequency Analyses

The Manuka Track (29606) low flow frequency estimates and plots are presented below (Table 7.14 and Figure 7.10). Estimates are not produced for Leonard Wood Park (29606) as water abstraction to the Water Treatment Plant interferes with the flow record and erroneous results will be produced.

Table 7.14: Manuka Track (29606) Low Flow Frequency Estimates (1982-1998) (L/s)

		Flow for Selected Duration (L/s)				
Return Period (Years)	Average Annual Probability (%)	Instantaneous	1 Day	7 Day	14 Day	28 Day
2	50	156	158	169	190	224
5	20	128	130	138	146	168
10	10	116	117	124	126	144
20	5	108	108	115	112	127
50	2	99	99	105	98	109
100	1	93	93	98	89	98

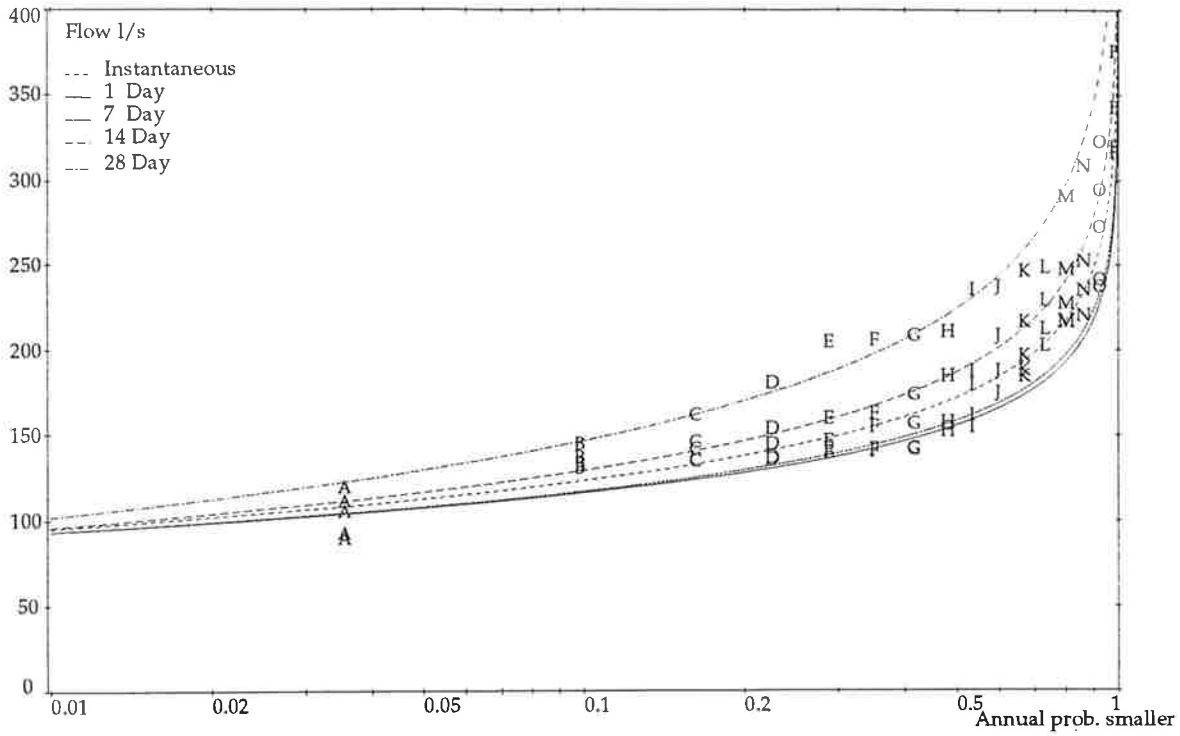


Figure 7.10: Manuka Track (29606) Low Flow Frequency Plot (L/s)

7.8 Flood Frequency Analyses

7.8.1 At-site Annual Flood Maxima

The annual maxima series for Manuka Track (29606) was derived from flow records available from 1982 to 1997. The annual maxima are listed in Table 7.15.

Table 7.15: Manuka Track (29606) Annual Maxima (m^3/s)

Date	Annual Maxima
11/12/82	59.8
22/05/83	46.7
18/10/84	16.4
28/07/85	26.9
03/07/86	8.5
04/03/87	25.8
14/09/88	9.4
18/10/89	14.0
13/03/90	41.7
07/08/91	21.7
16/10/92	25.4
05/09/93	19.6
08/11/94	30.7

Date	Annual Maxima
30/06/95	19.7
07/02/96	27.6
04/10/97	54.4

The annual maxima series for Leonard Wood Park (29605) was derived from flow records available from 1977 to 1997. The annual maxima are listed in Table 7.16.

Table 7.16: Leonard Wood Park (29605) Annual Maxima (m^3/s)

Date	Annual Maxima
22/11/77	93.6
20/04/78	36.5
29/12/79	77.2
10/04/80	62.2
21/05/81	120.9
26/06/82	67.0
22/05/83	66.6
18/10/84	34.8
28/07/85	66.4
03/07/86	34.8
05/03/87	80.9
08/09/88	26.2
18/10/89	51.5
13/03/90	76.0
11/04/91	60.6
16/10/92	77.7
05/09/93	41.1
15/08/94	86.3
30/06/95	55.0
07/02/96	38.9
04/10/97	80.2

All water level charts from the Morton Dam (29604) weir depth recorder (1955-1981) were examined and annual maximum flows calculated. These are presented in Table 7.17 and supersede those presented by Mandeno, Chitty and Bell (1980).

Mandeno, Chitty and Bell (1980) give four estimated historical floods that have been quantified at Morton Dam (29604). These are detailed in Table 7.18.

Table 7.17: Morton Dam (29604) Annual Maxima (m^3/s)

Date	Annual Maxima
02/09/55	28.5
15/07/56	74.9
17/05/57	60.8
12/05/58	29.1
18/05/59	23.6
23/06/60	23.6
09/08/61	40.2
26/12/62	48.7
08/08/63	25.8
13/06/64	15.2
07/11/65	51.5
27/04/66	66.7
03/02/67	27.6
10/04/68	74.9
01/06/69	11.7
22/08/70	21.3
17/08/71	79.7
13/05/72	14.5
22/10/72	14.8
28/04/74	37.2
18/06/75	40.0
19/06/76	15.6
23/11/77	41.5
21/04/78	19.3
29/12/79	20.0
21/01/80	24.8
21/05/81	77.1

Table 7.18: Morton Dam (29604) Estimated Historical Flood Peaks (m^3/s)

Date	Flood Peak
11/12/39	79
28/06/47	90
15/07/50	65
26/03/52	30

Source: Mandeno, Chitty and Bell (1980)

7.8.2 Regional Flood Frequency Analyses

McKerchar and Pearson (1989) developed a methodology for calculating regionalised flood frequency estimates from contour maps. Pearson (1990) updated these contour maps for the Wellington Region. The results from the Pearson (1990) regionalised flood frequency contours are given in Table 7.19.

Table 7.19: Regional Flood Frequency Results (m^3/s)

Site	Area (km2)	Q2	Q5	Q10	Q20	Q50	Q100	Q200
Manuka Track (29606)	27.1	36.0	47.6	55.2	62.4	72.2	79.4	86.6
Morton Dam (29604)	34.0	41.5	56.4	66.4	75.6	88.8	98.3	107.8
Leonard Wood Park (29605)	77.5	64.0	88.7	105.0	120.7	141.5	156.9	172.2

7.8.3 At Site Flood Frequency Results

The Wainuiomata River Flood Hydrology (Lew and Harkness, 1998) report carried out a series of flood frequency analyses on the data available at Manuka Track (29606), Leonard Wood Park (29605) and Morton Dam (29604). Table 7.20 presents the flood frequency estimates derived from the report.

The Manuka Track (29606) record is lengthened by using the annual maxima of Manuka Track (29606) and the annual maxima of Morton Dam (29604) factored by specific discharge. As a result 59 years of record are available for analysis and the results of the Manuka Track (29606) flood frequency analysis are accepted without pooling with the regional estimates.

The Leonard Wood Park (29605) at site flood frequency estimates are pooled with the regional estimates in Table 7.20. This is because the Leonard Wood Park (29604) record only covers 20 years. The method used to undertake the pooling is detailed in McKerchar and Pearson (1989).

Table 7.20: At Site Flood Frequency Estimates (m^3/s)

	Q2	Q5	Q10	Q20	Q50	Q100	Q200
Manuka Track (29606)	26.3	41.4	51.3	60.9	73.2	82.5	91.5
Morton Dam (29604)	33.8	53.7	66.9	79.6	96.1	108.4	120.5
Leonard Wood Park[1] (29605)	59.9	82.6	97.4	111.1	129.9	143.0	156.3

Note [1] = Pooled estimates (after McKerchar and Pearson, 1989)

7.8.4 RORB Flood Frequency Estimates

RORB is a rainfall run-off, stream-flow routing program which is used for flood estimation. A RORB model can be used to generate design hydrographs at any node within a catchment.

A RORB model has been set up for the Wainuiomata Catchment. Model parameters for the catchment were obtained by matching estimated model flood hydrographs to recorded flood hydrographs at Manuka Track (29606) and Leonard Wood Park (29605) (Lew and Harkness, 1998).

Results from the RORB modelling are detailed in Table 7.21.

Table 7.21: Accepted (RORB) Flood Frequency Estimates (m^3/s)

	Manuka Track	Morton Dam	U/S Wainui Stream	Wainui Stream	U/S Black Creek	Black Creek	Leonard Wood Park	U/S Catch-pool Stream	Catch-pool Stream	River Mouth
Q_2	31	33	35	15	47	15	44	46	11	57
Q_5	50	57	63	25	88	26	96	98	23	122
Q_{10}	61	71	79	35	113	35	125	130	29	159
Q_{20}	72	84	96	43	138	43	156	166	38	202
Q_{50}	92	112	129	52	181	62	237	254	58	316
Q_{100}	105	128	149	65	212	72	279	305	70	381
Q_{200}	119	146	171	71	245	83	325	360	81	451
PMF	350	423	514	259	790	324	989	1162	210	1583

Note: A baseflow is required to be added to these flood frequency estimates.

Source: Lew and Harkness, 1998

7.8.5 Flood Frequency Conclusions

Similar results were obtained for all three sites (Manuka Track (29606), Morton Dam (29604) and Leonard Wood Park (29605)) when the at site and regional estimates are compared. Due to the long record when the historical flood peaks are considered at Manuka Track (29606) and Morton Dam (29604), the at site estimates were not pooled with the regional estimates. Pooling was carried out for Leonard Wood Park (29605) as the record of annual maxima is somewhat shorter. For Manuka Track (29606) and Morton Dam (29604) the RORB results were generally up to 20 percent higher than the at site results.

A considerable discrepancy exists between the RORB and at the site Leonard Wood Park (29605) estimates. It is hypothesised that Morton Dam and the Lower Dam are attenuating flood hydrographs (in the records) at this site resulting in underestimates of design floods using the at site method. As the regionalised contour uses Leonard Wood Park (29605) data, this will also be affected.

Giving consideration to error margins in the at-site analysis and the good fit of the RORB results with accepted flood frequency data in the western Wellington Region and historical design data for the Wainuiomata River it is recommended that the RORB flood frequency estimates be used for design purposes.

8. Recommendations and Future Work

- The historical Reservoir (E14294) rainfall record should be digitised to allow extension of the Skull Gull (E15201) record, and to allow further short duration (less than one day) frequency analyses of the Reservoir (E14294) record.

- If future large flood events at Manuka Track (29606) and Leonard Wood Park (29605) cannot be gauged, slope area measurements should be performed. First preference is for a concerted effort to be made to gauge the higher flows by current meter.

- When the Proposed Regional Freshwater Plan becomes operative close monitoring of Leonard Wood Park (29605) flows will be required to ensure the policies regarding minimum flows and step down flows are not breached. It is recommended that the site be telemetered by 2001.

- An automatic rain gauge be installed in the mid Catchment area. This could be located at the sewage treatment plant as this area is secure.

- Investigation into the relationship between SOI and rainfall in the Wainuiomata Catchment will supplement the work already undertaken on SOI and river flows.

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Appendix 1:

Lowest 30, 60, 90 and 120 Day Hydrological Year Rainfall Minima

Minimum 30 Day Rainfalls

Rank	30 Day Period Beginning	Rainfall (mm)
Wainuiomata Reservoir (E14294)		
1	23/11/1934	1.5
2	14/01/1928	1.6
3	31/01/1908	2.1
4	10/01/1904	2.6
5	11/03/1939	3.0
6	05/11/1970	3.0
7	19/03/1985	3.4
8	06/02/1981	3.6
9	17/02/1942	3.9
10	12/02/1916	4.1
Skull Gully (E15201)		
1	20/03/1985	3.5
2	26/04/1997	6.4
3	30/01/1990	8.3
4	08/02/1983	12.1
5	29/12/1980	15.3
6	22/12/1986	19.0
7	11/09/1985	19.8
8	15/02/1989	21.0
9	19/01/1982	22.3
10	15/03/1998	22.6
Orongo Swamp (E1520A)		
1	26/04/1997	10.4
2	20/03/1985	12.6
3	30/01/1990	14.5
4	07/02/1981	18.1
5	05/01/1983	21.6
6	11/09/1985	26.1
7	29/12/1980	27.9
8	08/02/1989	27.9
9	08/02/1983	34.0
10	05/01/1997	35.0
Tasman Vaccine Ltd (E15204)		
1	20/03/1985	0.5
2	30/01/1990	4.5
3	27/10/1992	5.5
4	26/04/1997	6.0
5	07/02/1981	6.8

Rank	30 Day Period Beginning	Rainfall (mm)
6	07/09/1985	9.3
7	08/02/1983	12.3
8	19/01/1982	14.8
9	05/01/1997	17.8
10	07/05/1991	18.7
Misty (E15202)		Monthly Data only
1	30/04/1997	37.7
2	01/02/1990	38.5
3	29/01/1994	45.1
4	01/05/1991	50.3
5	30/11/1995	68.7
Devine (E15203)		Monthly Data only
1	30/04/1997	40.6
2	01/02/1990	43.0
3	29/01/1994	45.0
4	01/05/1991	51.3
5	30/11/1995	76.0
Coast Road (1) (E14296)		
1	22/01/1971	2.4
2	19/03/1985	3.8
3	14/12/1974	5.2
4	06/02/1981	6.2
5	16/02/1978	8.0
6	16/01/1973	9.5
7	21/12/1986	10.0
8	04/01/1983	10.3
9	29/01/1990	10.7
10	14/01/1982	11.6
Coast Road (2) (E14391)		
1	26/02/1976	4.9
2	04/01/1983	5.2
3	14/01/1982	8.3
4	14/12/1974	9.2
5	30/01/1981	9.5
6	16/02/1978	11.9
7	04/01/1979	16.2
8	31/12/1977	17.2
9	07/02/1983	17.4
10	22/07/1982	17.9

Rank	30 Day Period Beginning	Rainfall (mm)
Orongorongo Headworks (E15301)		
1	15/01/1928	4.6
2	19/02/1969	6.6
3	24/11/1934	6.8
4	19/02/1947	9.4
5	26/01/1929	18.1
6	23/01/1971	18.1
7	22/01/1964	18.8
8	22/12/1954	21.1
9	15/12/1974	21.3
10	22/10/1969	23.9

Minimum 60 Day Rainfalls

Rank	60 Day Period Beginning	Rainfall (mm)
Wainuiomata Reservoir (E14294)		
1	31/12/1907	21.9
2	04/01/1983	29.8
3	16/01/1890	33.0
4	18/12/1927	38.0
5	16/02/1969	40.9
6	28/12/1980	42.6
7	31/12/1938	46.2
8	11/11/1897	46.4
9	01/02/1919	51.8
10	05/11/1970	53.0
Skull Gully (E15201)		
1	07/01/1983	38.4
2	14/03/1985	79.8
3	24/02/1998	84.7
4	04/12/1986	90.4
5	16/10/1997	96.1
6	20/12/1981	99.7
7	11/09/1994	105.4
8	22/11/1989	113.7
9	05/01/1990	127.6
10	27/11/1995	136.3
Orongo Swamp (E1520A)		
1	29/12/1980	71.0
2	05/01/1983	71.6
3	14/03/1985	111.9
4	16/12/1984	126.1
5	25/02/1998	130.1
6	22/11/1994	134.1
7	04/12/1986	137.9
8	09/01/1989	141.8
9	16/10/1997	154.5
10	20/12/1981	166.0
Tasman Vaccine Ltd (E15204)		
1	14/01/1981	54.4
2	14/03/1985	58.8
3	19/01/1983	80.4
4	22/11/1994	84.8

Rank	60 Day Period Beginning	Rainfall (mm)
5	10/01/1989	85.5
6	15/10/1997	97.4
7	15/06/1993	97.7
8	24/02/1998	98.8
9	03/12/1986	101.0
10	05/08/1987	103.9
Misty (E15202)		Monthly Data only
1	01/02/1990	77.0
2	30/11/1995	137.0
3	01/07/1993	159.7
4	01/12/1994	186.1
5	01/02/1993	190.1
Devine (E15203)		Monthly Data only
1	01/02/1990	85.0
2	30/11/1995	152.0
3	01/07/1993	164.6
4	01/12/1994	190.8
5	01/02/1993	196.3
Coast Road (1) (E14296)		
1	28/12/1980	28.4
2	04/01/1983	29.0
3	13/03/1985	49.8
4	03/12/1986	50.0
5	25/12/1972	50.2
6	23/01/1971	53.5
7	22/12/1981	55.9
8	15/11/1974	59.3
9	10/02/1978	64.1
10	05/01/1990	79.8
Coast Road (2) (E14391)		
1	04/01/1983	23.7
2	28/12/1980	25.6
3	23/12/1981	42.7
4	14/12/1978	71.5
5	22/07/1982	97.7
6	12/02/1978	100.4
7	27/09/1982	102.1
8	29/04/1984	110.4
9	17/07/1984	110.7
10	08/02/1976	113.6

Rank	60 Day Period Beginning	Rainfall (mm)
Orongorongo Headworks (E15301)		
1	04/11/1934	68.4
2	29/09/1975	74.2
3	17/02/1969	90.3
4	25/02/1930	104.2
5	19/09/1969	104.2
6	23/01/1971	109.3
7	15/11/1974	119.3
8	01/01/1973	120.4
9	28/12/1938	124.3
10	17/11/1943	143.4

Minimum 90 Day Rainfalls

Rank	90 Day Period Beginning	Rainfall (mm)
Wainuiomata Reservoir (E14294)		
1	15/01/1939	69.8
2	29/11/1907	79.0
3	24/12/1980	88.9
4	01/02/1919	97.0
5	03/01/1916	112.7
6	17/01/1969	114.3
7	14/11/1970	114.6
8	01/12/1972	117.3
9	11/01/1890	119.2
10	09/01/1917	120.7
Skull Gully (E15201)		
1	07/01/1983	148.4
2	12/12/1988	182.2
3	24/02/1998	193.8
4	02/02/1985	196.6
5	19/11/1981	208.3
6	22/11/1994	209.4
7	29/12/1992	219.7
8	18/10/1997	227.5
9	25/10/1986	230.9
10	18/01/1984	239.9
Orongo Swamp (E1520A)		
1	27/12/1980	189.9
2	14/01/1985	256.6
3	22/11/1994	267.5
4	18/01/1984	269.9
5	31/01/1998	274.4
6	13/12/1988	288.0
7	20/11/1981	294.8
8	30/12/1992	326.2
9	02/12/1986	330.4
10	14/12/1982	338.5
Tasman Vaccine Ltd (E15204)		
1	24/12/1980	104.9
2	07/12/1988	153.1
3	24/02/1998	171.0
4	31/12/1981	181.0

Rank	90 Day Period Beginning	Rainfall (mm)
5	22/11/1994	182.4
6	30/12/1992	185.0
7	25/10/1986	186.9
8	18/01/1984	192.5
9	08/02/1988	201.3
10	07/12/1989	205.0
Misty (E15202)		Monthly Data only
1	01/02/1990	116.0
2	30/01/1994	299.4
3	02/11/1995	301.0
4	01/12/1994	315.1
5	02/01/1993	315.8
Devine (E15203)		Monthly Data only
1	01/02/1990	128.0
2	30/01/1994	299.3
3	02/01/1993	324.7
4	02/11/1995	327.0
5	01/12/1994	335.1
Coast Road (1) (E14296)		
1	24/12/1980	62.7
2	02/12/1972	91.8
3	11/01/1971	109.1
4	04/01/1983	121.7
5	18/11/1981	132.1
6	28/01/1989	144.1
7	02/02/1985	154.5
8	07/12/1971	155.5
9	15/11/1978	155.7
10	31/12/1977	156.3
Coast Road (2) (E14391)		
1	23/12/1980	58.9
2	19/11/1981	90.6
3	04/01/1983	110.3
4	15/11/1978	140.3
5	17/12/1977	142.3
6	10/12/1983	167.1
7	01/04/1984	169.2
8	22/07/1982	184.1
9	09/02/1976	205.4
10	03/03/1982	234.2

Rank	90 Day Period Beginning	Rainfall (mm)
Orongorongo Headworks (E15301)		
1	29/09/1975	112.4
2	12/01/1971	205.4
3	16/01/1939	205.9
4	18/01/1969	208.0
5	16/02/1930	209.6
6	03/12/1972	210.3
7	04/11/1934	227.3
8	23/08/1969	234.6
9	30/10/1933	267.6
10	19/01/1948	286.9

Minimum 120 Day Rainfalls

Rank	120 Day Period Beginning	Rainfall (mm)
Wainuiomata Reservoir (E14294)		
1	12/11/1907	126.1
2	11/11/1897	163.9
3	05/11/1970	166.6
4	16/01/1919	172.2
5	19/12/1938	172.4
6	07/12/1915	184.7
7	28/12/1980	200.4
8	29/11/1916	210.9
9	09/11/1972	211.2
10	15/01/1930	217.4
Skull Gully (E15201)		
1	07/12/1988	280.6
2	17/12/1984	306.2
3	31/12/1987	318.0
4	14/10/1986	336.6
5	26/12/1982	347.7
6	10/01/1994	353.2
7	27/12/1983	354.2
8	10/11/1981	356.4
9	22/11/1994	368.3
10	30/11/1992	373.2
Orongo Swamp (E1520A)		
1	29/12/1980	312.2
2	16/12/1984	332.0
3	27/12/1983	399.6
4	24/12/1997	411.7
5	13/10/1986	484.2
6	31/12/1987	494.5
7	19/10/1995	525.2
8	10/01/1994	545.1
9	25/10/1981	549.6
10	27/10/1996	556.5
Tasman Vaccine Ltd (E15204)		
1	29/12/1980	194.2
2	07/12/1988	246.2
3	31/12/1987	246.5
4	27/12/1983	257.6

Rank	120 Day Period Beginning	Rainfall (mm)
5	31/12/1981	277.1
6	07/10/1986	292.5
7	29/12/1997	301.9
8	10/01/1994	322.9
9	20/11/1996	323.4
10	09/11/1989	327.0
Misty (E15202)		Monthly Data only
1	01/02/1990	154.0
2	01/12/1994	424.1
3	03/10/1995	438.0
4	31/12/1993	452.2
5	03/09/1990	455.7
Devine (E15203)		Monthly Data only
1	01/02/1990	171.0
2	30/01/1994	447.0
3	02/01/1993	460.0
4	02/11/1995	479.3
5	01/12/1994	487.9
Coast Road (1) (E14296)		
1	13/12/1972	172.5
2	28/12/1980	175.0
3	05/01/1971	190.5
4	13/10/1986	221.3
5	12/07/1988	224.8
6	09/11/1981	229.0
7	07/12/1971	233.9
8	16/12/1977	237.7
9	15/11/1973	244.9
10	14/11/1978	245.5
Coast Road (2) (E14391)		
1	28/12/1980	144.5
2	30/11/1981	185.6
3	13/12/1982	211.1
4	16/12/1977	218.1
5	26/10/1978	236.6
6	26/12/1983	240.1
7	15/02/1976	277.0
8	20/01/1975	309.3
9	09/05/1984	357.2
10	29/08/1975	364.9

Rank	120 Day Period Beginning	Rainfall (mm)
Orongorongo Headworks (E15301)		
1	08/09/1975	220.1
2	16/01/1930	332.7
3	10/12/1968	348.1
4	10/11/1972	.58.5
5	15/11/1970	374.5
6	22/10/1984	393.5
7	04/12/1947	409.5
8	09/10/1933	411.3
9	16/01/1939	415.4
10	25/08/1969	422.9

Minimum Calendar Year Rainfalls

Rank	Year	Rainfall (mm)
Wainuiomata Reservoir (E14294)		
1	1891	1154
2	1922	1238
3	1969	1300
4	1915	1338
5	1984	1355
6	1919	1382
7	1972	1405
8	1988	1427
9	1973	1429
10	1916	1445
Skull Gully (E15201)		
1	1984	1576
2	1988	1661
3	1994	1945
4	1982	1959
5	1997	1969
Orongo Swamp (E1520A)		
1	1984	2056
2	1993	2318
3	1997	2379
4	1990	2542
5	1986	2560
Tasman Vaccine Ltd (E15204)		
1	1984	1261
2	1988	1308
3	1989	1414
4	1987	1522
5	1981	1526
Misty (E15202)		Monthly Data only
1	1990	1450
2	1993	1734
3	1994	1815
4	1997	1886
5	1995	1928

Rank	Year	Rainfall (mm)
Devine (E15203)		Monthly Data only
1	1990	1520
2	1993	1803
3	1995	1941
4	1997	1941
5	1991	2004
Coast Road (1) (E14296)		
1	1972	1102
2	1973	1114
3	1984	1139
4	1988	1290
5	1971	1363
6	1987	1367
7	1993	1465
8	1982	1481
9	1990	1553
10	1975	1597
Coast Road (2) (E14391)		
1	1982	1139
2	1983	1376
3	1978	1517
4	1981	1555
5	1975	1606
Orongorongo Headworks (E15301)		
1	1969	2060
2	1975	2178
3	1930	2314
4	1964	2357
5	1972	2414
6	1973	2423
7	1934	2455
8	1971	2531
9	1939	2547
10	1963	2616

Minimum Hydrological Year Rainfalls

Rank	Hydrological Year Beginning	Rainfall (mm)
Wainuiomata Reservoir (E14294)		
1	01/07/1914	1056
2	01/07/1972	1234
3	01/07/1915	1275
4	01/07/1970	1268
5	01/07/1987	1286
6	01/07/1948	1397
7	01/07/1902	1502
8	01/07/1953	1544
9	01/07/1993	1573
10	01/07/1949	1588
Skull Gully (E15201)		
1	01/07/1993	1841
2	01/07/1983	1891
3	01/07/1982	1935
4	01/07/1991	1959
5	01/07/1984	1989
Orongo Swamp (E1520A)		
1	01/07/1995	2145
2	01/07/1997	2283
3	01/07/1993	2414
4	01/07/1983	2415
5	01/07/1984	2470
Tasman Vaccine Ltd (E15204)		
1	01/07/1987	1253
2	01/07/1997	1454
3	01/07/1996	1488
4	01/07/1981	1532
5	01/07/1988	1536
Misty (E15202)		Monthly Data only
1	01/07/1990	1846
2	01/07/1991	1847
3	01/07/1996	1882
4	01/07/1995	1911
5	01/07/1994	1919

Rank	Hydrological Year Beginning	Rainfall (mm)
Devine (E15203)		Monthly Data only
1	01/07/1993	1816
2	01/07/1991	1822
3	01/07/1996	1941
4	01/07/1995	1960
5	01/07/1990	1961
Coast Road (1) (E14296)		
1	01/07/1972	967
2	01/07/1987	1058
3	01/07/1991	1448
4	01/07/1982	1420
5	01/07/1971	1482
6	01/07/1984	1486
7	01/07/1988	1587
8	01/07/1989	1611
9	01/07/1983	1621
10	01/07/1986	1644
Coast Road (2) (E14391)		
1	01/07/1982	999
2	01/07/1983	1298
3	01/07/1981	1443
4	01/07/1980	1510
5	01/07/1975	1524
Orongorongo Headworks (E15301)		
1	01/07/1972	2089
2	01/07/1976	2262
3	01/07/1970	2273
4	01/07/1975	2370
5	01/07/1929	2393
6	01/07/1932	2417
7	01/07/1963	2433
8	01/07/1968	2495
9	01/07/1933	2510
10	01/07/1948	2523

Appendix 2:

Frequency Analysis of Extreme Events Methodology

The following is a description of the methodologies used to estimate the frequency of extreme hydrological events in the Wainuiomata Catchment.

When carrying out a frequency analysis the following statistical methods must be applied:

- Frequency Distribution
- Fitting Method
- Plotting Position

Within each of these statistical methods a variety of techniques are available. The following sections justify the techniques which have been employed in this study, and gives a background to the methodologies used.

Selection of Frequency Distribution

A frequency distribution is a statistical model of measured data. This model allows the magnitude of a design hydrological event to be inferred from a given sample of measured data. Thus when modelling hydrological data a theoretical frequency distribution should represent long term mean conditions and allow for extrapolation into frequencies and magnitudes past these mean conditions.

Flood and High Intensity Rainfalls

Tomlinson (1980), Beable and McKerchar (1982), and McKerchar and Pearson (1989) are the most comprehensive studies of high intensity rainfall and flood frequencies in New Zealand. When initially choosing a frequency distribution Tomlinson (1980) and Beable and McKerchar (1982) evaluated the main distributions applied throughout the world to extreme value analyses of stream flow and rainfall data. This consisted of the following frequency distributions:

- Log Pearson Type 3
- Log Normal
- General Extreme Value
- Extreme Value Type 1 (Gumbel)

To evaluate each distribution the following four criteria were considered:

1. The frequency distribution should fit the whole of the series, and particularly the upper half, well.

2. The frequency curve should not necessarily pass through the largest values in the series as there is a very large sampling variation with such values.

3. The frequency curve should appear to produce a good estimate of the 100 year value.

4. The Chi-squared value for goodness of fit should not be abnormally high.

In conclusion Tomlinson (1980) states that for high intensity rainfalls the Extreme Value Type 1 (EV1) or Gumbel distribution satisfied the above four criteria in the majority of cases. This work has been verified by Pearson and Griffiths (1993) who also adopted the Gumbel distribution when analysing high intensity rainfalls in the Christchurch area.

McKerchar and Pearson (1989) reached a similar conclusion with New Zealand flood series. They showed that of the 275 flow stations analysed around the country, 32 showed a tendency towards the EV2 distribution, 15 to the EV3 distribution, and the remainder conformed to the EV1. The EV2 stations were grouped mainly in the South Canterbury/North Otago area in the South Island, and he volcanic ash area of the North Island. Some of the EV3 stations were clustered in the north-west of the South Island. Thus, it can be assumed that the Wellington area conforms to the EV1 distribution. This has been confirmed by Pearson (1990).

The fact that the EV1 distribution was applicable to the Wellington area was largely expected, as it recognises that while only a few extreme high intensity rainfall or flood events are experienced a large number of smaller magnitude events occur. This gives a positive skew when compared to the normal distribution and is consistent with Wellington conditions.

Low Flows and Drought Rainfalls

While estimation of flood frequencies has been widely addressed in New Zealand hydrological literature, the statistical estimation of droughts has not received the same attention. The Council has investigated the problem and devised a methodology for estimation of drought frequency.

Nathan and McMahon (1990) summarise the problem of estimating low flow frequencies in the Wellington Region:

> *In fitting a distribution to the minima series it is assumed that the sample considered represents the low-flow extremes of observed stream flows, and thus the usual approach is to fit the probability distribution to all the observed minima of the required duration. Preliminary investigation of probability plots for a random selection of streams indicated that he first few (most frequent) values often described a much steeper line than the remaining values.*

Nathan and McMahon go on to state that the higher frequency flows are not drought flows but rather:

> *flows blending back to normal conditions. It thus may be inferred that these values belong to a different distribution and consequently they should be excluded from the frequency analysis.*

Other studies including Velz and Gannon (1953), Institute of Hydrology (1980) and Tollow (1987) have encountered the same problem. In these studies the break between true low flows and higher frequency flows occurs at exceedance probabilities of 65 (1.5 year return period) and 70 percent (1.4 year return period). Nathan and McMahon (1990) identified that the break in the frequency curve for 134 catchments in south eastern Australia was at an exceedance probability of 80 percent (1.25 year return period).

Wainuiomata Low Flow Series

The phenomena described by Nathan and McMahon (1990) is evident in some of the Wainuiomata Catchment minima series. To overcome this the following methodology was developed:

1. Return period plots using the Gringorton plotting position (described below) were constructed for the instantaneous, 1, 7, 14 and 28 day duration low flows at each station.

2. Any *breaks* in the frequency plots were determined.

3. The software program EVAN (Event Analysis) written by NIWA was used to evaluate the goodness of fit of the following frequency distributions:

   - General Extreme Value
   - EV1

   When applying these distributions the EVAN options FMAX was employed. FMAX allows a break in the frequency plots to be nominated ands the above frequency distributions to be influenced by only the true low flow minima.

   The frequency distributions are applied to the return period plots and the goodness of fit evaluated. In some cases the distribution that best fits the data cannot be used due to the distributions crossing. So in some situations the choice of the distribution was constrained by the prevention of this problem.

Selection of a Fitting Method

There are many ways of fitting a frequency distribution to sample data. This includes graphical, methods of moments, maximum likelihood, least squares, maximum entropy, probability weighted moments, etc. Current hydrological literature (e.g., Hosking and Wallis, 1993; Pearson, 1991; Wallis, 1989 and Hosking, 1990) shows that the recently developed Linear (L) moments are often superior to other estimation techniques. L moments have superseded those reviewed and chosen by Tomlinson (1980), Beable and McKerchar (1982), and McKerchar and Pearson (1989) because:

1. L moments are linear combinations of ranked observations and thus do not involve the squaring or cubing of observations that other techniques require. As a result, L moment estimates of variation and skewness coefficients are almost unbiased and have a near normal distribution/

2. Hosking (1990) states:

> *The main advantage of L-moments over conventional moments is that L-moments, being linear functions of the data, suffer less from the effects of outliers in the data and enable more secure inferences to be made from small samples about an underlying probability distribution.*

3. In conclusion, Stedinger et al (1993) state:

> *Thus in a wide range of hydrological applications, L moments provide simple and reasonably efficient estimators of the characteristics of hydrological data and of a distributions parameters.*

Calculation of L Moments

The L moments are defined as linear combinations of expected values of order statistics (Hosking, 1990) where:

- The first L moment (L1) = the mean of the dataset
- The second L moment (L2) = the standard deviation of the dataset
- The third and fourth L moments are determined by the ratio of these moments to L2. The resultant L moments rations are denoted as T3 (skewness) and T4 (kurtosis).

The L moments are then used to gain the location (u) and scale (a) parameters of each dataset.

Selection of Plotting Position

A plotting position is used to gain the return period (T) for each individual event in a series. This allows the graphical evaluation of a fitted distribution to the recorded series on Gumbel probability paper. Too often statistical distributions are fitted to the data without the graphical evaluation of a return period plot. Thus, outliers are not identified, which may be potential errors in a series. Since the development of the first plotting position formula by California (1923) a multitude a of formulae have been developed (Table 1).

Author	Year	Formula
California	1923	$T = \frac{N}{M}$
Hazen	1930	$T = \frac{2N}{2M-1}$
Weibull	1939	$T = \frac{N+1}{M}$

Author	Year	Formula
Beard	1943	$T = \dfrac{1}{1-0.5^{yn}}$
Chegodayev	1955	$T = \dfrac{N+0.4}{M-0.3}$
Blom	1958	$T = \dfrac{N+0.25}{M-0.375}$
Tukey	1962	$T = \dfrac{3N+1}{3M-1}$
Gringorton	1963	$T = \dfrac{N+0.12}{M-0.44}$
Cunnane	1978	$T = \dfrac{N-0.40}{M+0.2}$
Log Pearson Type	1975	$T = \dfrac{N+0.2}{M-0.4}$
APL	Unknown	$T = \dfrac{N-0.35}{M}$
Median	Unknown	$T = \dfrac{N-0.3175}{M+0.365}$

Where:

T = Return period
M = Rank (1 = largest event)
N = Number of events

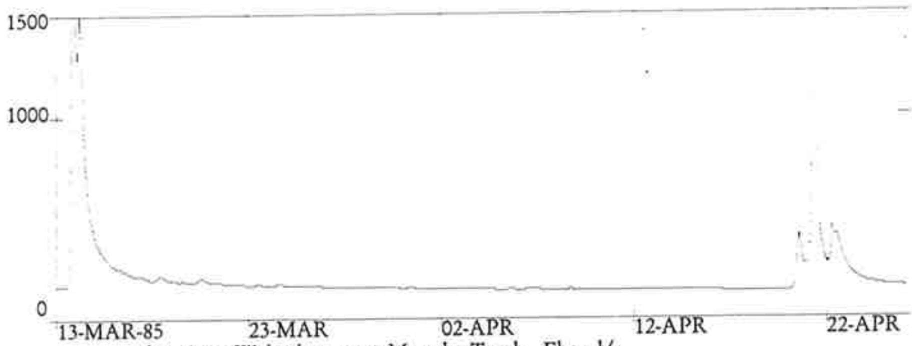
Source: Adapted from Stedinger et al (1993)

Depending on the plotting position, large differences in return period (T) estimates can be calculated. Therefore, justification is required for the choice of plotting position.

Stedinger et al (1993) state the Gringorton plotting position is optimised for the EV1 distribution while the Blom plotting position is unbiased for the normal distribution. Since the Wainuiomata Catchment conforms to the EV1 or Gumbel distribution, the Gringorton plotting position formula is mathematically correct to apply.

Appendix 3:

Recession Curves



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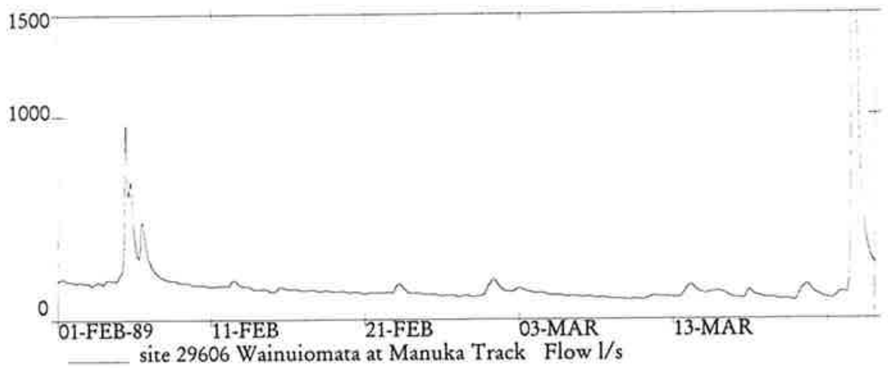

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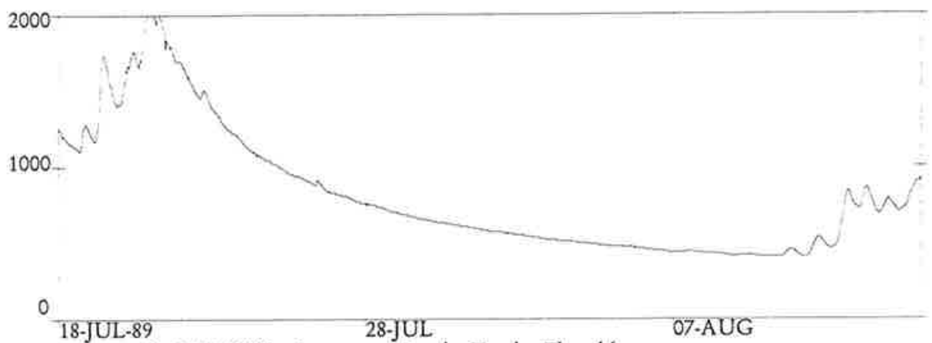

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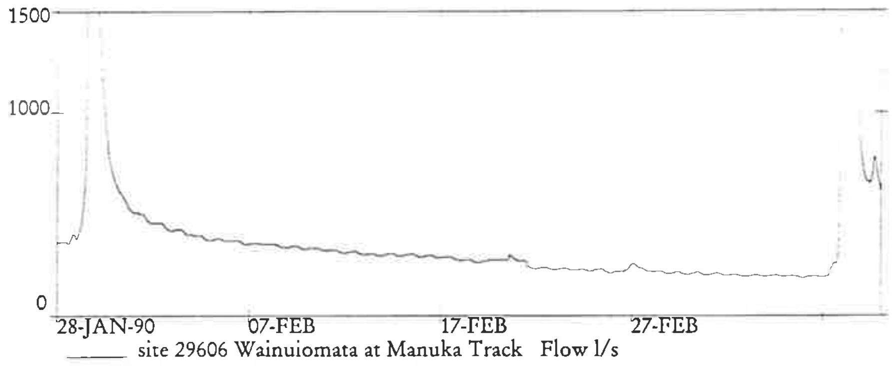
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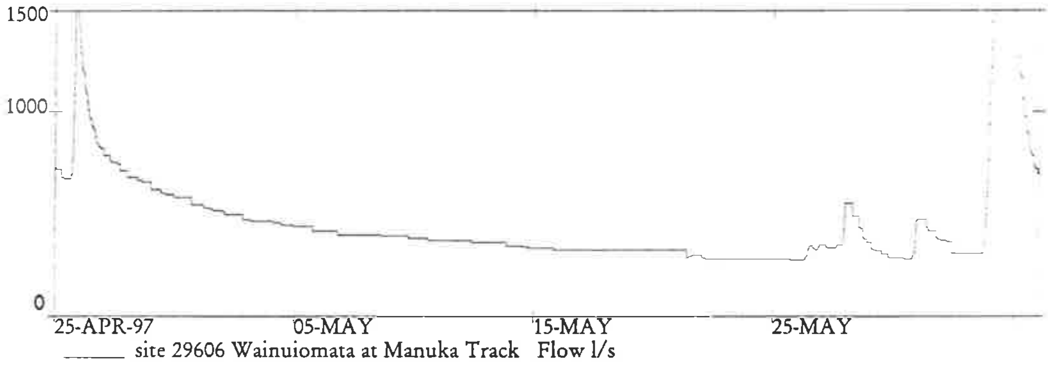
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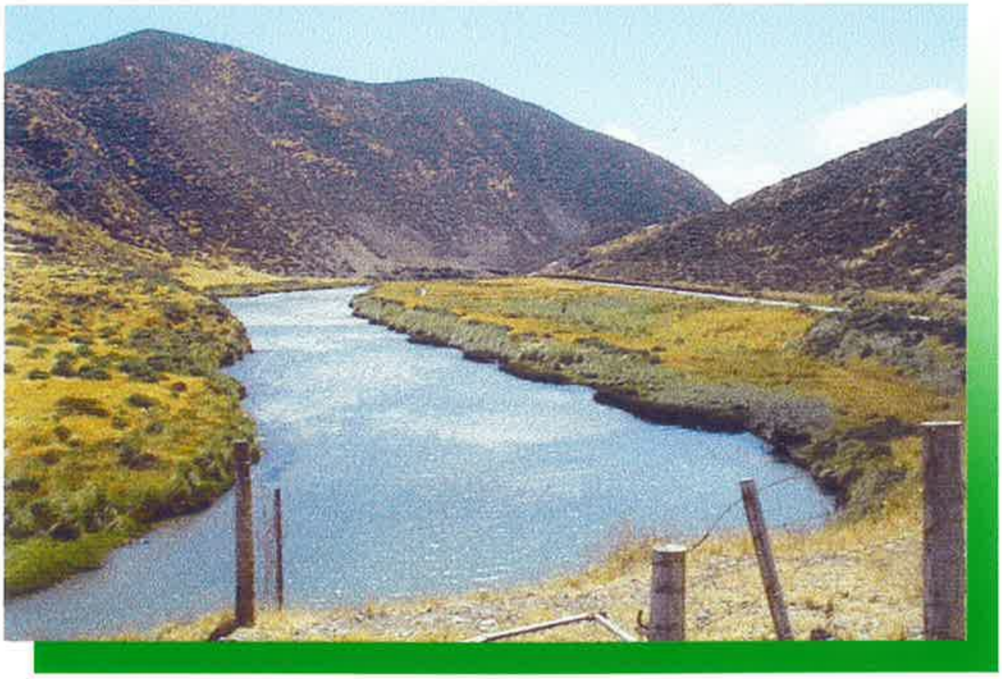
Hydrology of the Wainuiomata Catchment



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THE REGIONAL COUNCIL