4. CATCHMENT HYDROLOGY AND CALIBRATION

In this section, an analysis is made of the rainfall and streamflow data so far collected from the Experimental Area, with a view to establishing the precision of calibration relationships for water yield, water quality and bedload between individual catchments.

4.1 Rainfall

4.1.1 Consistency of rainfall data

Since it is essential to first establish the reliability of the rainfall data before proceeding with any calibration analysis, consistency of the data in both time and space has been examined. The established technique to examine consistency in time is to plot accumulated rainfall for the station of interest against the accumulation rainfall of a group of base stations. (Linsley et al. 1949). The base stations chosen are Melbourne Regional Office, Black Spur, Coranderrk, Maroondah Weir, O'Shannassy Weir and Warburton Post Office. Melbourne Regional Office is an obvious standard; the other base stations have been closed because they are nearby, and have similar rainfall to the Reefton Experimental Area.

The double mass curves for accumulation annual rainfall (19641980) from these stations have been plotted against Melbourne Regional Office (Figure 4.1). The relationships appear satisfactory, apart from a small cyclic variation, and it is concluded that the rainfall data from these stations are consistent in time.

Bulk gauges 1 and 2 have the longest record in the Reefton Experimental Area (Table 3.1). These gauges are situated in close proximity to each other. Gauge 1 has been tested for consistency against the mean of five of the local base stations. Melbourne Regional Office has been excluded because its rainfall is substantially lower, and because it is more distant than the other stations. The five-station mean procedure minimises any minor variations in the local base stations. The double mass plot of annual data, 1964-1980, is shown in Figure 4.2, and is consistent. As a more sensitive check, a linear regression of these data has been established. The relationship is as follows:

$$Y = 1.086\,X - 231.34 \qquad (r = 0.938)$$

where Y = accumulated annual rainfall (1964-1980) at gauge 1,
X = mean accumulated annual rainfall
(1964-1980) for the five base stations.

The standardised residuals are plotted in Figure 4.3. The mean of the residuals is close to zero and the spread is uniform apart from two outliers. This is the expected pattern from consistent data. It is therefore concluded that rain gauge 1 is consistent in time, and that the rainfall data are reliable. Monthly rainfall records for gauge 1 from 1971 to 1980 are listed in Appendix I.

Consistency of the rain gauges across the Experimental Area has been tested by two methods. Firstly, double mass curves have been plotted for individual rain gauges against gauge 1. Secondly, linear regressions have been determined for each rain gauge against gauge 1. These regressions have been examined for a high coefficient of determination (which indicates that the regression line closely fits the data) and the residuals have been tested for trends with time or quantity of rainfall (both of which are undesirable).

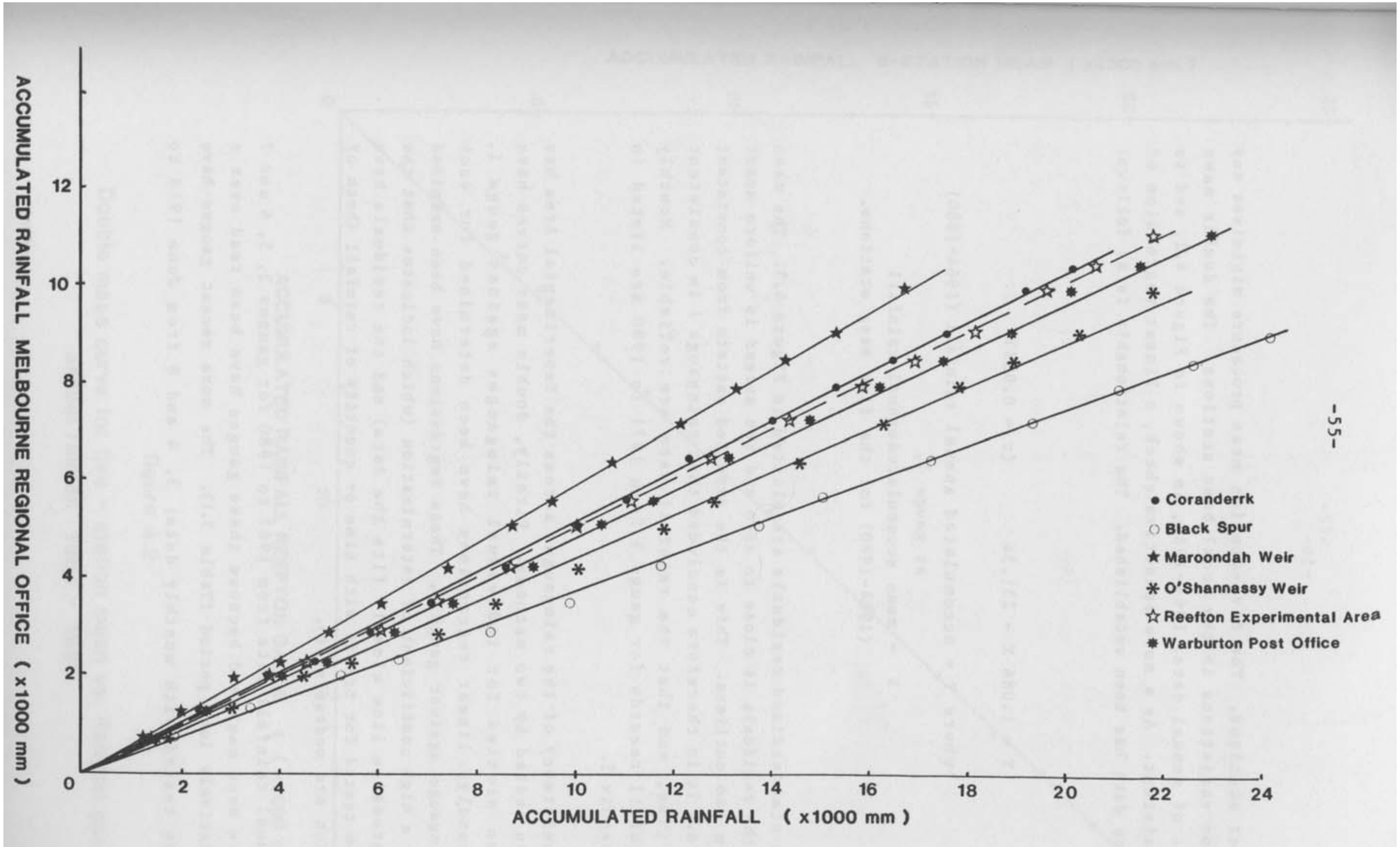


Figure 4.1 - Double mass curves for base stations vs. Melbourne Regional Office annual rainfall 1964 - 1980

Annual rainfall data from 1967 to 1980 for gauges 2, 5, 6 and 7 have been analysed because these gauges have been read over a relatively long period (Table 3.1). The more recent gauges have been tested with monthly data; 3, 4 and 8 from June 1978 to December 1980, and 31 and 32 from August 1981 to December 1982. The tower gauges 9 to 13 on the traverse will be analysed in a separate study.

Double mass curves have been plotted in Figures 4.4 and 4.5. The values of the regression equations are entered in Table 4.1; high correlation coefficients are evident for all relationships. No gauge shows abnormal patterns of residuals. It is concluded that the rain gauges are consistent across the Experimental Area, and that the rainfall data are suitable for further analysis.

4.1.2 Variation of rainfall measured by rain gauges

The next step in analysis is to determine the effects of site parameters on individual rain gauge catch. Regression analyses have been made on the average annual rainfall of ten individual rain gauge versus site elevation, slope and aspect. The site parameters used are entered in Table 4.2, and the correlation coefficients are shown in Table 4.3. No significant correlation has been found. To further examine this question, a study of rainfall variability across catchment 3 has been initiated (de Laine 1969). The data from this study are now being analysed and will be published elsewhere.

4.1.3 Derivation of catchment rainfall

Water balance studies on the catchments require a knowledge of the average rainfall incident on them. Textbooks cite the isohyetal method, Theissen polygons and the Reciprocal Distance Squared method (RDS) as ways of deriving average catchment rainfall. Langford and O'Shaughnessy (1977) compared the RDS and Theissen polygon methods and found that the former method gave marginally higher catchment rainfalls, and that both methods had similar accuracy. The method of Theissen polygons has been used to derive average catchment rainfall because of its simplicity and proven accuracy. The principles of the Theissen method are detailed in Linsley et al. (1949) and Chow (1964). Re-determination of the Theissen network is necessary following Theissen polygons for the original network are shown in Figure 4.6. Limitations of this network are (0 catchments rainfall for catchments 1-4 are all estimated from gauge 1, and (ii) gauges 5, 6 and 7 are distant from the centre of their region of influence.

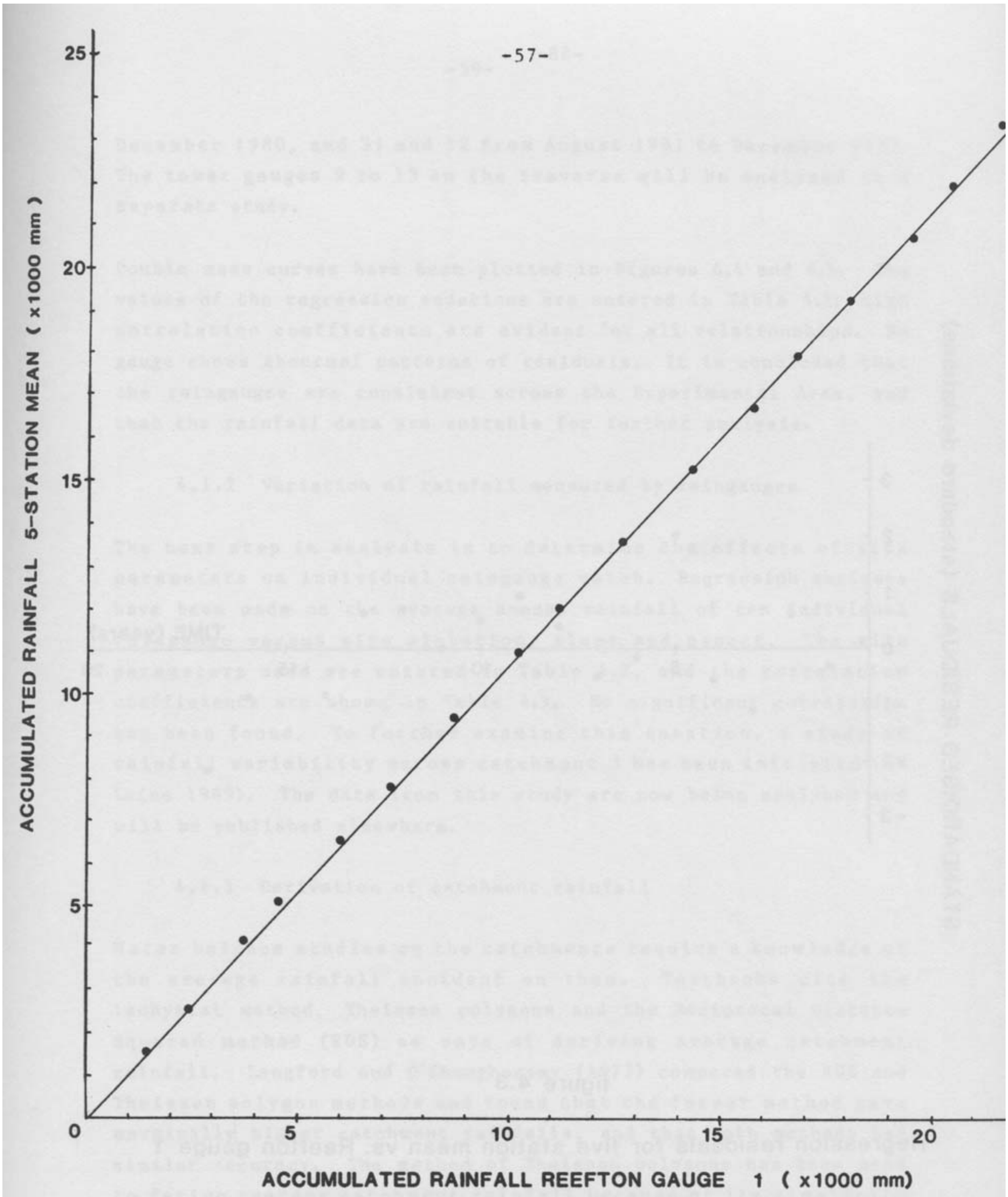


Figure 4.2 - Double mass curve for five - station mean vs. Reefton gauge 1 annual rainfall 1964 - 1980

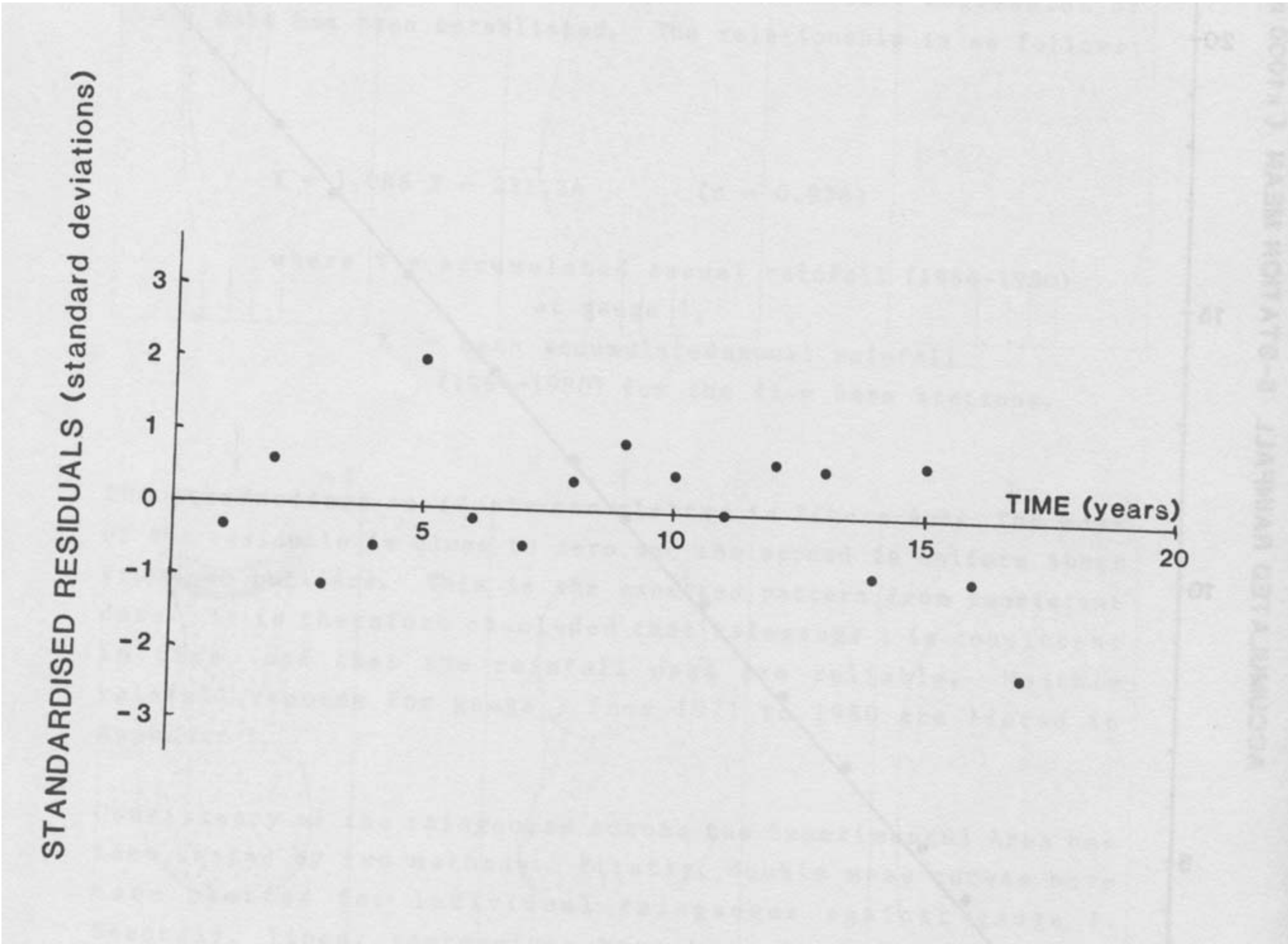


Figure 4.3 - Regression residuals for five station mean vs. Reefton gauge 1

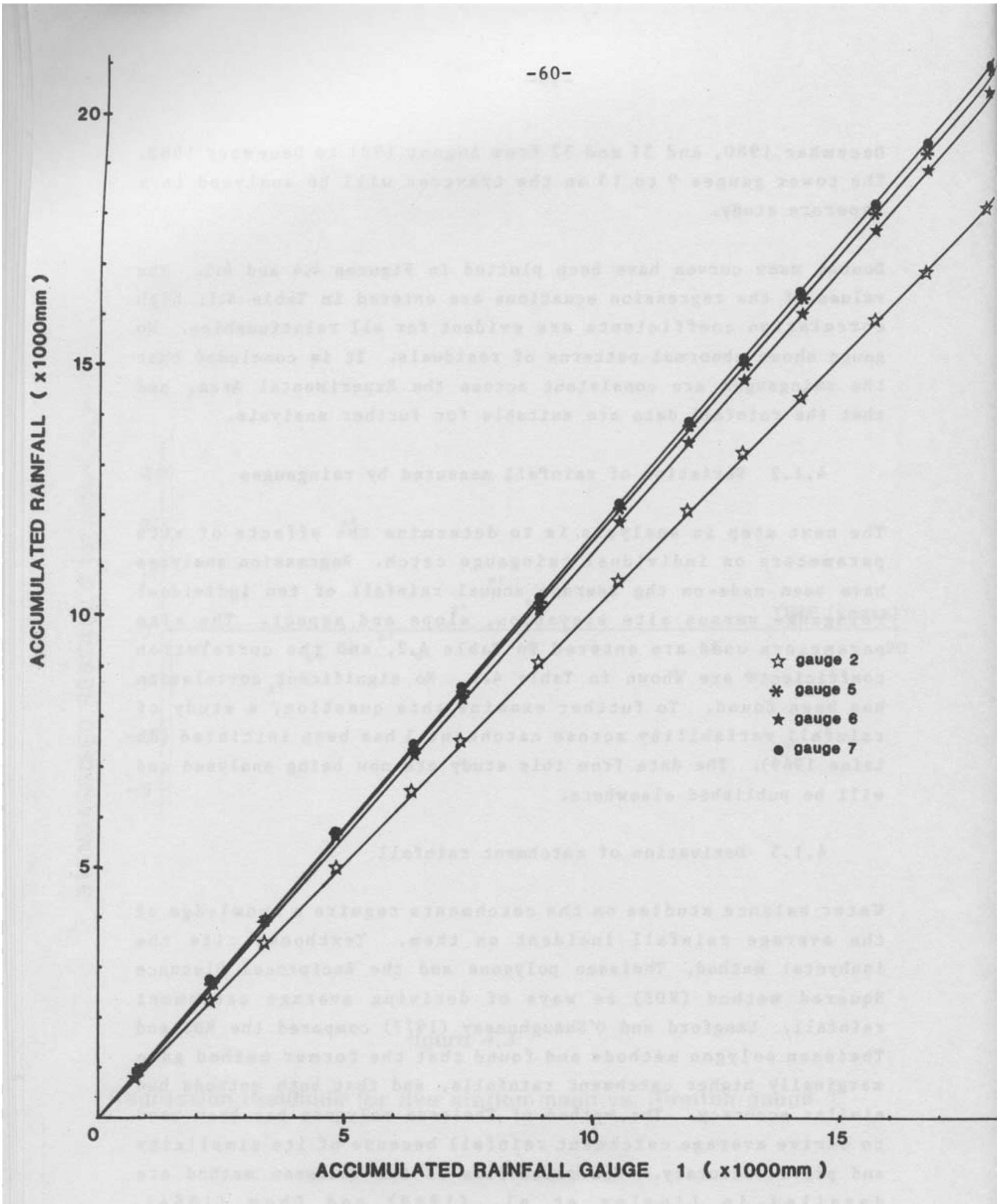


Figure 4.4 - Double mass curves for gauges 2, 5, 6 & 7 vs. 1 annual rainfall 1967 - 1980

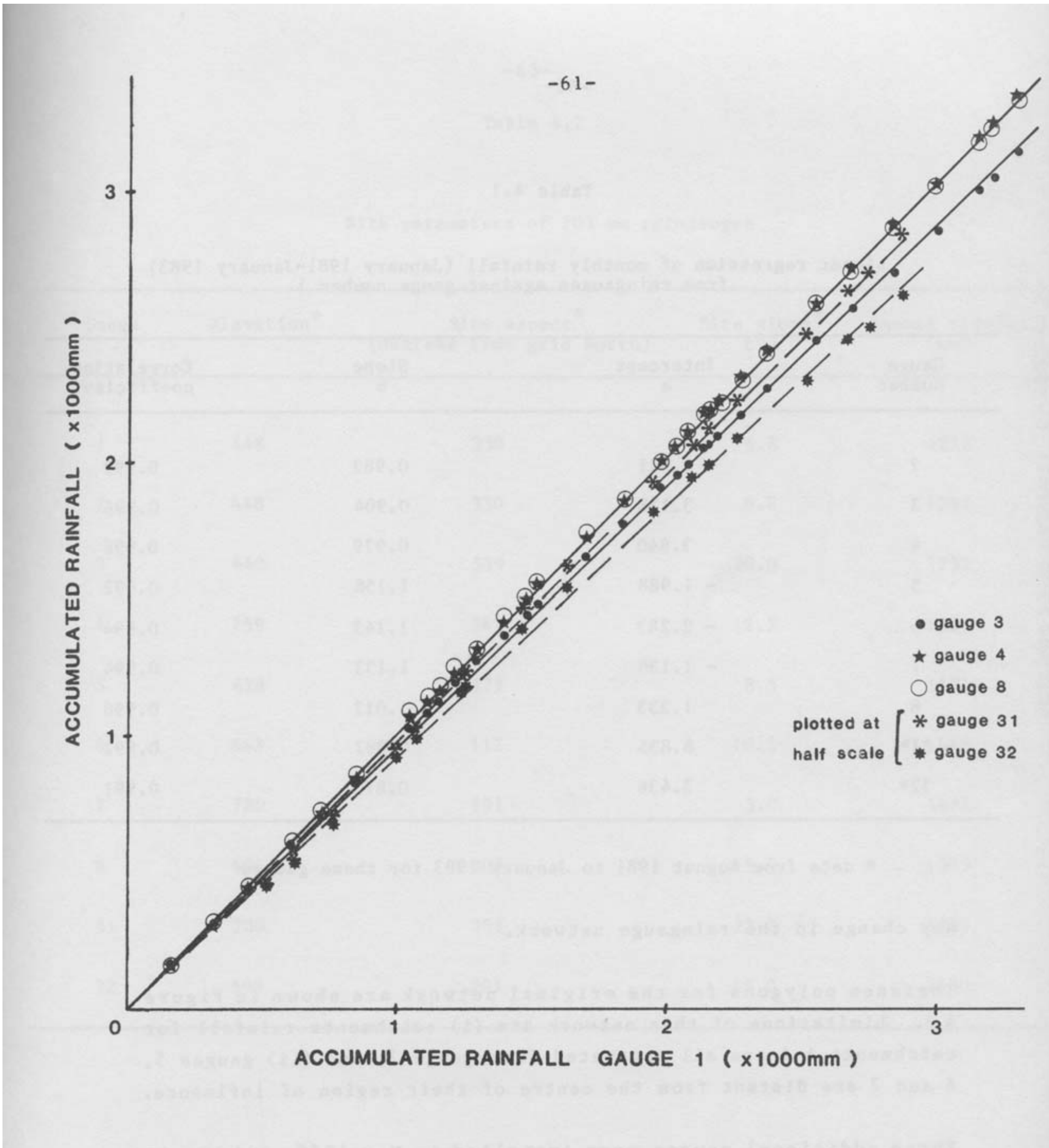


Figure 4.5 - Double mass curves for gauges 3, 4, 8, 31 & 32 vs. gauge 1

3, 4, 8 (June 1978 - December 1980) monthly rainfall
31, 32 (August 1981 - December 1982)

Table 4.1 - Linear regression of monthly rainfall (January 1981-January 1983) from rain gauges against gauge number 1

Gauge number	Intercept a	Slope b	Correlation coefficient
2	1.521	0.983	0.999
3	3.138	0.904	0.996
4	3.840	0.979	0.996
5	- 1.988	1.158	0.992
6	- 2.283	1.143	0.994
7	- 1.130	1.133	0.994
8	1.233	1.012	0.998
31*	8.835	0.887	0.992
32*	3.436	0.873	0.991

* data from August 1981 to January 1983 for these gauges any change in the rain gauge network.

Three additional gauges were installed in May 1978, and two in July, 1981, to minimise these limitations. Theissen polygons for the current network are shown in Figure 4.7. Mean annual catchment rainfall has been determined using Theissen weightings for the gauges (from the areas in Figure 4.7) and the mean annual rainfall for the respective gauge (Table 4.2). Values are shown in Table 4.7.

Table 4.2 - Site parameters of 203 mm rain gauges

Gauge	Elevation+	Site aspect* (degrees from grid North)	Site slope* (°)	Annual rainfall (mm)
1	448	330	6.8	1272
2	448	330	6.8	1287
3	640	339	20.0	1232
4	759	341	12.5	1320
5	628	171	8.5	1491
6	663	112	10.3	1446
7	780	191	5.0	1477
8	686	307	15.0	1303
31	700	351	22.0	1281
32	692	201	16.0	1180

+ data from contour map (1:8000)
* data from field measurements

Table 4.3 - Correlation matrix for present rain gauge network (10 gauges)

	Rainfall	Elevation	Slope	Aspect
Rainfall	1.0	0.2538	- 0.2993	- 0.5359
Elevation		1.0	0.1962	- 0.3546
Slope			1.0	0.4369
Aspect				1.0

Table 4.4 - Linear regression of catchment rainfall vs gauge 1*

Catchment	Intercept	Slope	Correlation coefficient
1	3.029	0.907	0.997
2	4.095	0.917	0.998
3	5.579	0.919	0.997
4	1.574	0.961	0.997
5	2.015	1.002	0.998
6	- 0.369	1.097	0.996

4.1.4 Prediction of catchment rainfall from meteorological station data

Although the gauges in the current network are read weekly, catchment water balance studies require a smaller time interval. Therefore, it is important to relate catchment rainfall to the Reefton Meteorological Station (Site 1, Table 3.1) where continuous rainfall is recorded. Linear regressions of monthly catchment data have been determined against the data from the Meteorological Station. The slope, intercept and correlation coefficients for these relationships are given in Table 4.4. The data are highly correlated. Although rainfalls for catchments 5 and 6 have been derived in terms of the Reefton Meteorological Station rainfall for completeness, it will be more practical to relate these catchments to Site 7 when pluviograph data from this Station become available.

* derived from monthly data, August 1981 to January 1983 for catchments 1 to 4, and January 1981 to January 1983 for catchments 5 and 6.

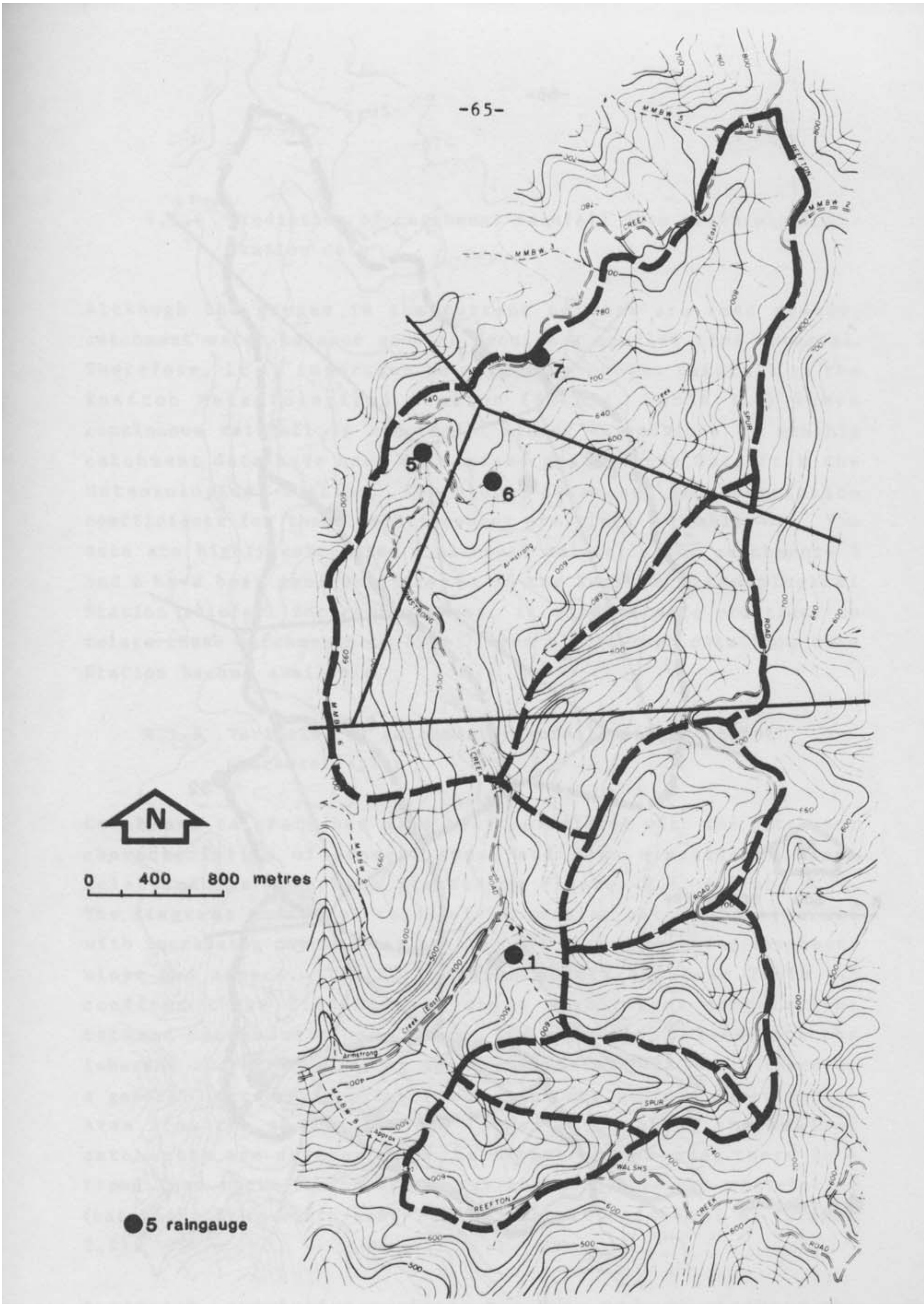


Figure 4.6 - Theissen polygons for the original rain gauge network

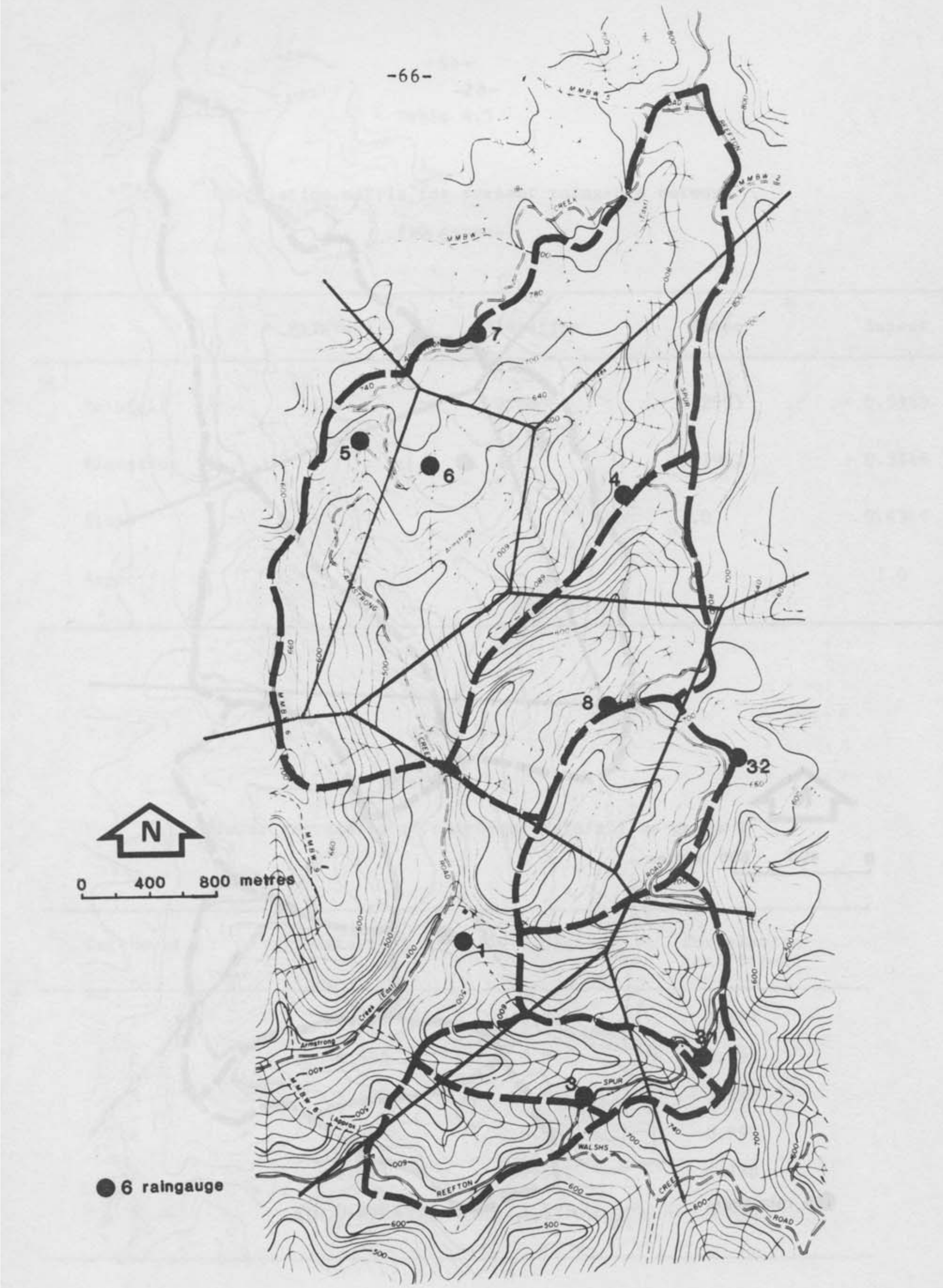


Figure 4.7 - Theissen polygons for present rain gauge network

4.1.5 Variation of catchment rainfall with catchment characteristics

Catchment rainfall has also been correlated with the catchment characteristics of aspect, slope and mean elevation. These relationships have been plotted in Figures 4.8, 4.9 and 4.10. The diagrams indicate trends of increasing catchment rainfall with increasing catchment elevation and with decreasing catchment slope and aspect. The correlation matrix shown in Table 4.5 confirms these findings and shows significant correlations between catchment slope, aspect and elevation. These are the inherent characteristics of the Experimental Area, viz. there is a general increase in elevation through the Reefton Experimental Area from the smaller to the larger catchments; the smaller catchments are steeper than the larger catchments; there is a trend from north-facing aspect (catchment 1) through west-facing (catchment 2) to south-west-facing aspect (catchment 6). (Table 2.1).

A partial correlation analysis has been made to separate the effect of catchment slope, aspect and elevation. Second order partial correlation coefficients have been calculated using the method defined by Mills (1955), and are listed in Table 4.6. No value is significant.

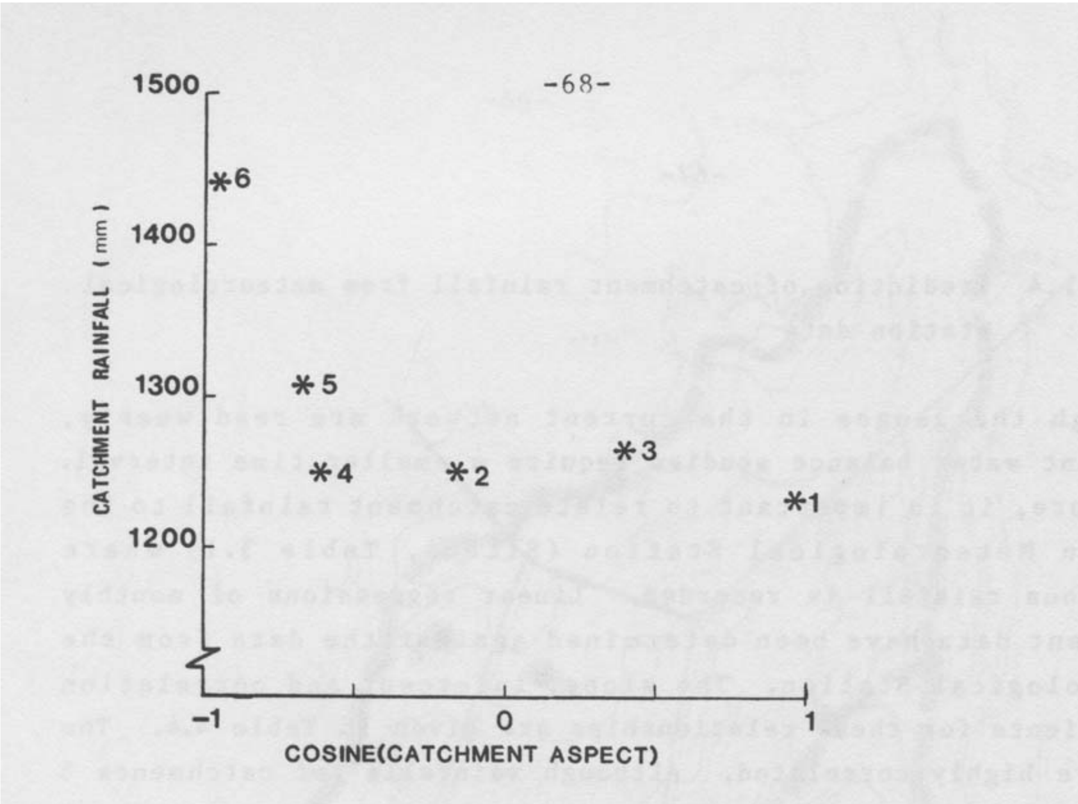
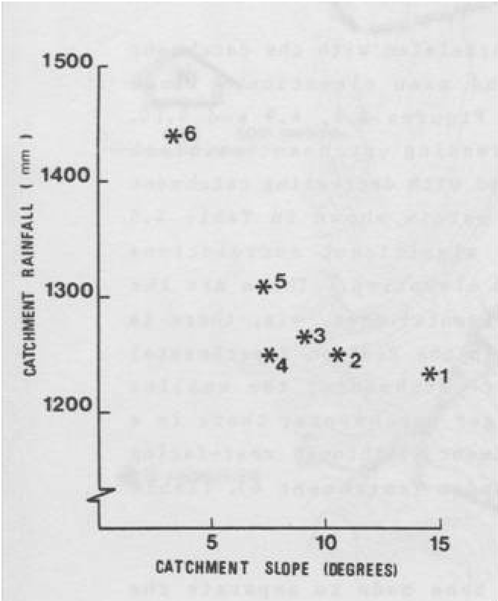


Figure 4.8 - Catchment rainfall vs. aspect



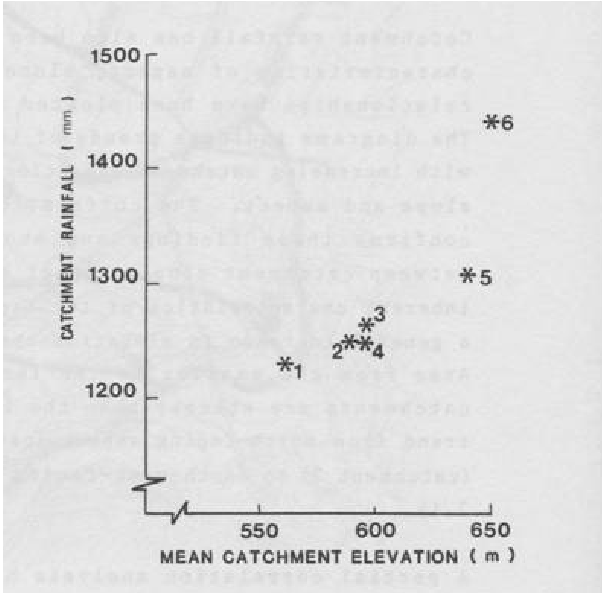


Figure 4.9 Catchment rainfall vs. slope

Figure 4.10 - Catchment rainfall vs. mean elevation

Table 4.5 - Correlation matrix for catchment rainfall and certain catchment characteristics

	Catchment rainfall	Elevation	Aspect	Slope
Catchment rainfall	1.0	0.8620*	-0.6813	-0.8314*
Elevation		1.0	-0.8587*	-0.9129*
Aspect			1.0	-0.9135*
Slope				1.0

* significant at 95% level

Table 4.6 - Second order partial correlation coefficients relating catchment rainfall and certain catchment characteristics

Second order partial correlation coeff.		Effects held constant
Rainfall-aspect	0.469	slope, elevation
Rainfall-slope	-0.465	aspect, elevation
Rainfall-elevation	0.545	slope, aspect

Lack of strong relationships between catchment rainfall and catchment characteristics known to influence this parameter may be attributed to the following factors:

(i) Because Reefton Experimental Area contains only six catchments, any proposed relationship would need to be quite good to have a statistically significant correlation. The correlation coefficient at the 95% level of significance with 4 degrees of freedom is 0.811.

(ii) There may be a "rain-shadow" effect by the higher mountains to the west and north-west of the Reefton Experimental Area. These mountains may be exerting a much stronger influence on catchment rainfall than the catchment characteristics themselves. In this locality "Westerlies are the main winds in summer hut there is also a significant proportion of easterlies; north-westerlies predominate in winter" (Bureau of Meteorology, 1968).

4.2 streamflow

Several aspects of catchment streamflow will be considered in this section before presenting the calibration relationships between catchments.

4.2.1 Mean annual flows vs. catchment characteristics

Initially, the relationships of mean annual streamflow (in surface mm) and some catchment characteristics are studied. Obvious discrepancies in these relationships can provide information on leakage of weirs or catchments, and aid in the selection of control catchments.

Some characteristics for the Reefton catchments are summarised in Table 4.7. Average catchment rainfall has been determined as described in Section 4.1. Average annual streamflow has been derived from streamflow data for years 1971 to 1980 except that 1972 data have been excluded due to large no-record-periods for weir 1 (Figure 3.8), and the 1975 data have been excluded because the floor of weir 1 stilling pool was being repaired. Average annual catchment loss is defined as the difference between catchment rainfall and streamflow.

Catchment streamflow for each catchment is plotted against the individual catchment rainfall (Figure 4.11), mean catchment elevation (Figure 4.12) and catchment aspect (Figure 4.13). Average annual catchment loss is plotted against the individual catchment rainfall (Figure 4.14).

Streamflow values for the six catchments lie within +80mm of their mean value (Table 4.7). There is no catchment obviously giving greater or lower streamflow. Both catchment slope (Figure 4.13) and rainfall (Figure 4.11) are significantly correlated to streamflow, but the relations for aspect and mean catchment elevation (e.g. Figure 4.12) are not significant.

The concept of catchment loss makes allowance for the different rainfall incident on each catchment. Therefore, catchment loss could be an indicator of catchment leakage. The values for the Reefton catchments form a relatively uniform set: all values for average annual catchment loss lie within + 70mm of the overall mean value (Table 4.7). Thus, there is no catchment showing abnormally high or low catchment loss. Catchment loss is significantly correlated to catchment rainfall (figure 4.14); however, elevation, aspect and slope effects are not significant. These general findings indicate that the catchments respond as a uniform group.

Table 4.7 - Mean annual streamflow and some catchment characteristics

Catchment number	Area (ha)	Mean annual rainfall (mm	Mean annual streamflow (mm)	Mean annual catchment loss (mm)	Mean catchment elevation (m)	Catchment aspect (°)	Catchment slope (°)
1	70.42	1233	180	1053	559	341.1	14.4
2	76.08	1250	258	992	588	269.1	10.6
3	95.10	1265	209	1056	596	292.7	9.0
4	107.24	1249	234	1015	594	231.9	7.5
5	156.21	1308	228	1080	640	227.5	7.2
6	521.24	1440	318	1122	651	197.9	3.3

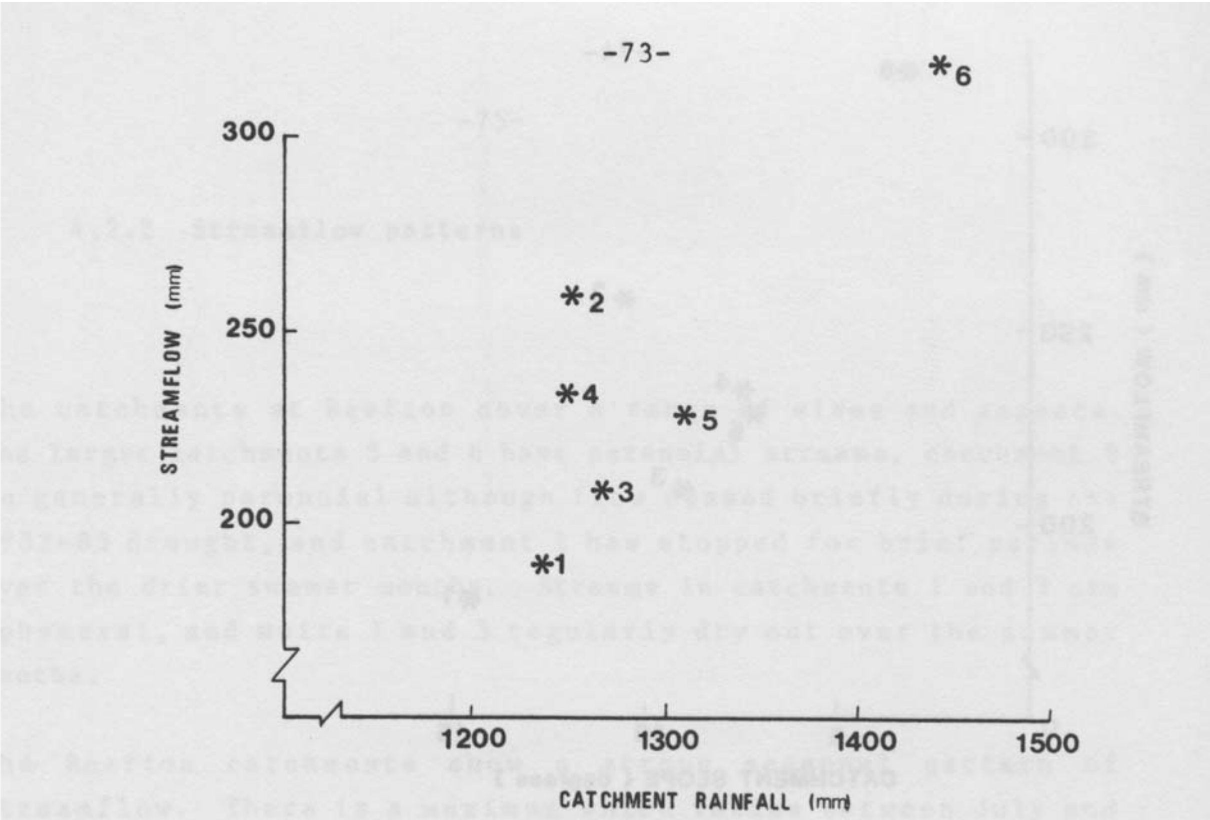


Figure 4.11 - Streamflow vs. catchment rainfall

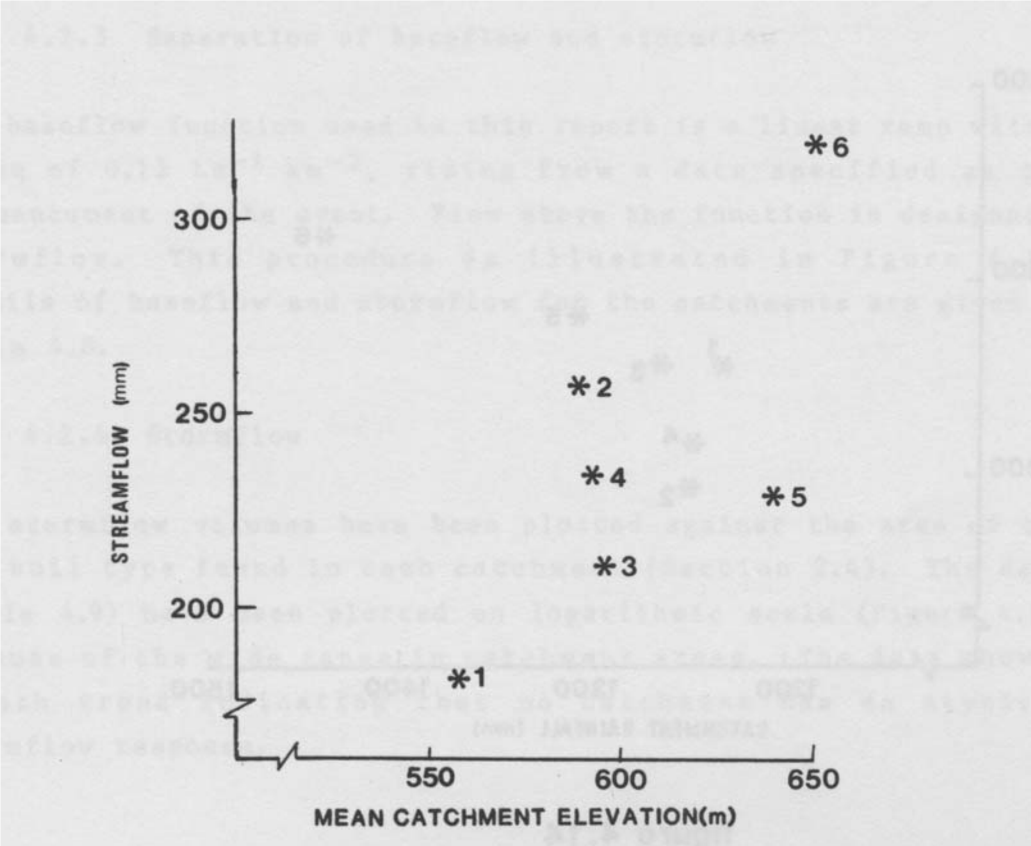


Figure 4.12 - Streamflow vs. mean catchment elevation

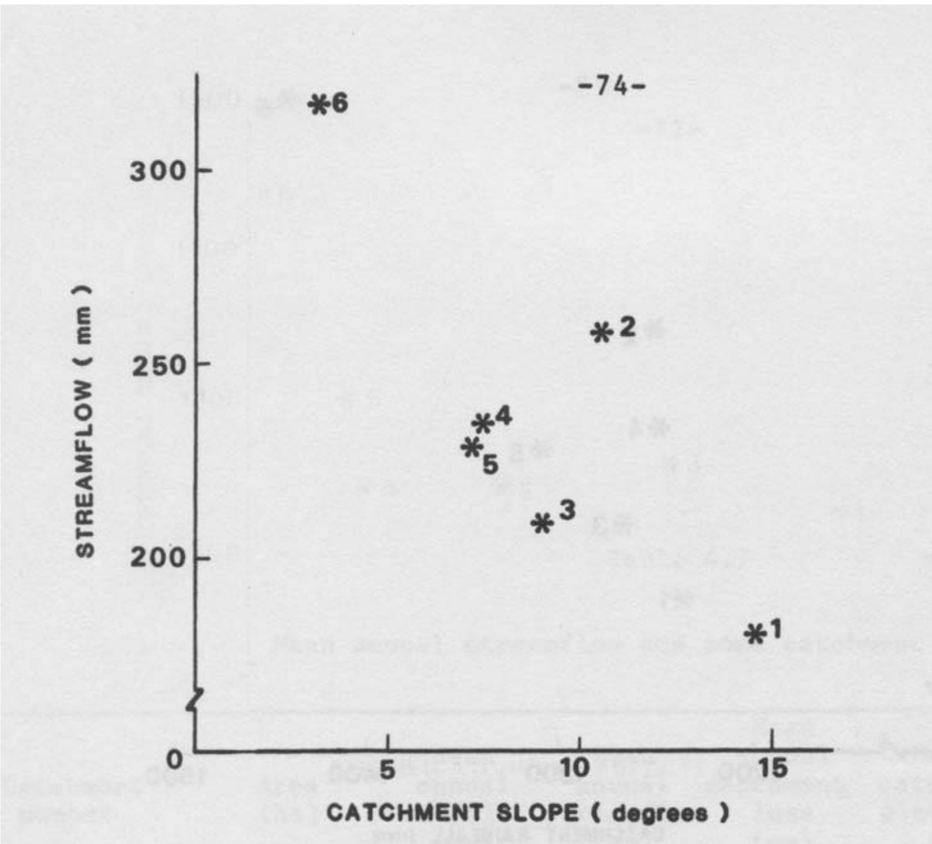


Figure 4.13 - Streamflow vs. catchment slope

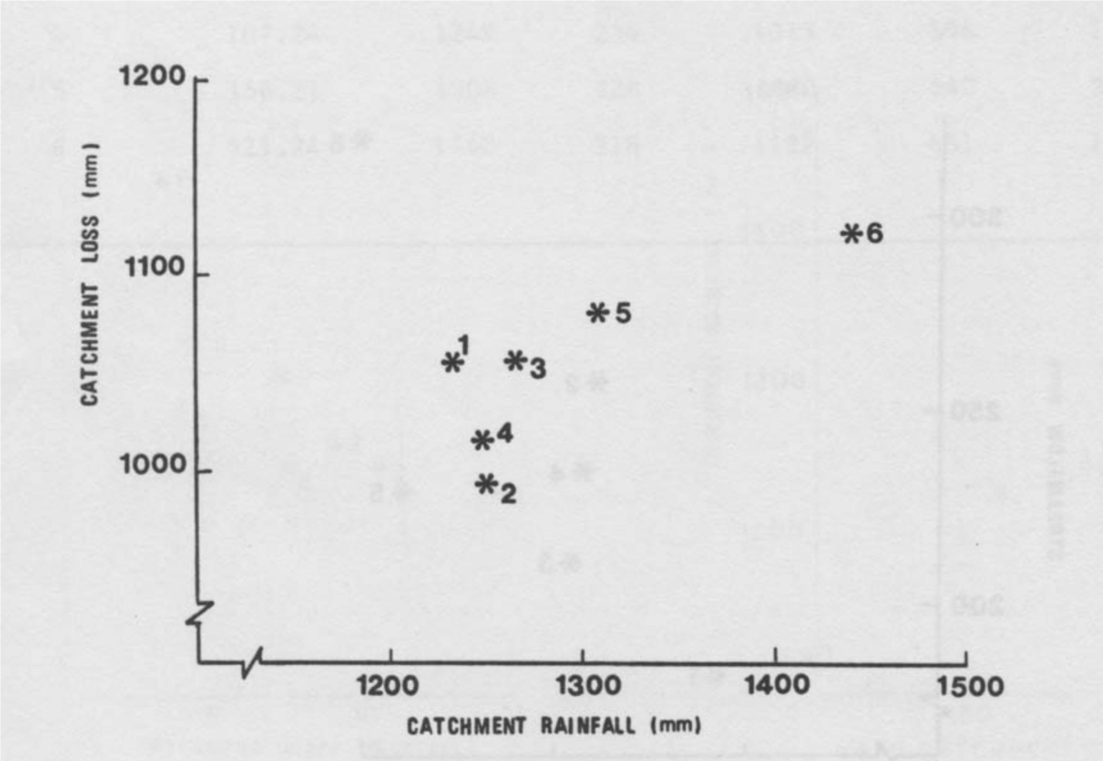


Figure 4.14 - Mean catchment loss vs. catchment rainfall

4.2.2 Streamflow patterns

The catchments at Reefton cover a range of sizes and aspects. The larger catchments 5 and 6 have perennial streams, catchment 4 is generally perennial although flow ceased briefly during the 1982-83 drought, and catchment 2 has stopped for brief periods over the drier summer months. Streams in catchments 1 and 3 are ephemeral, and weirs 1 and 3 regularly dry out over the summer months.

The Reefton catchments show a strong seasonal pattern of streamflow. There is a maximum which varies between July and October, and a rapid fall to low flows in February and March. Secondary peaks have been caused by individual rainfall events. The monthly runoff for catchment 2 over a nine-year period is plotted in Figure 4.15. Monthly runoff in millimetres for all catchments (1971-1980) is given in Appendix II.

4.2.3 Separation of baseflow and stormflow

The baseflow function used in this report is a linear ramp with a slope of 0.12 Ls-1 km-2, rising from a date specified as the commencement of the event. Flow above the function is designated stormflow. This procedure is illustrated in Figure 4.16. Details of baseflow and stormflow for the catchments are given in Table 4.8.

4.2.4 Stormflow

The stormflow volumes have been plotted against the area of the wet soil type found in each catchment (Section 2.4). The data (Table 4.9) have been plotted on logarithmic scale (Figure 4.17) because of the wide range in catchment areas. The data show a smooth trend indicating that no catchment has an atypical stormflow response.

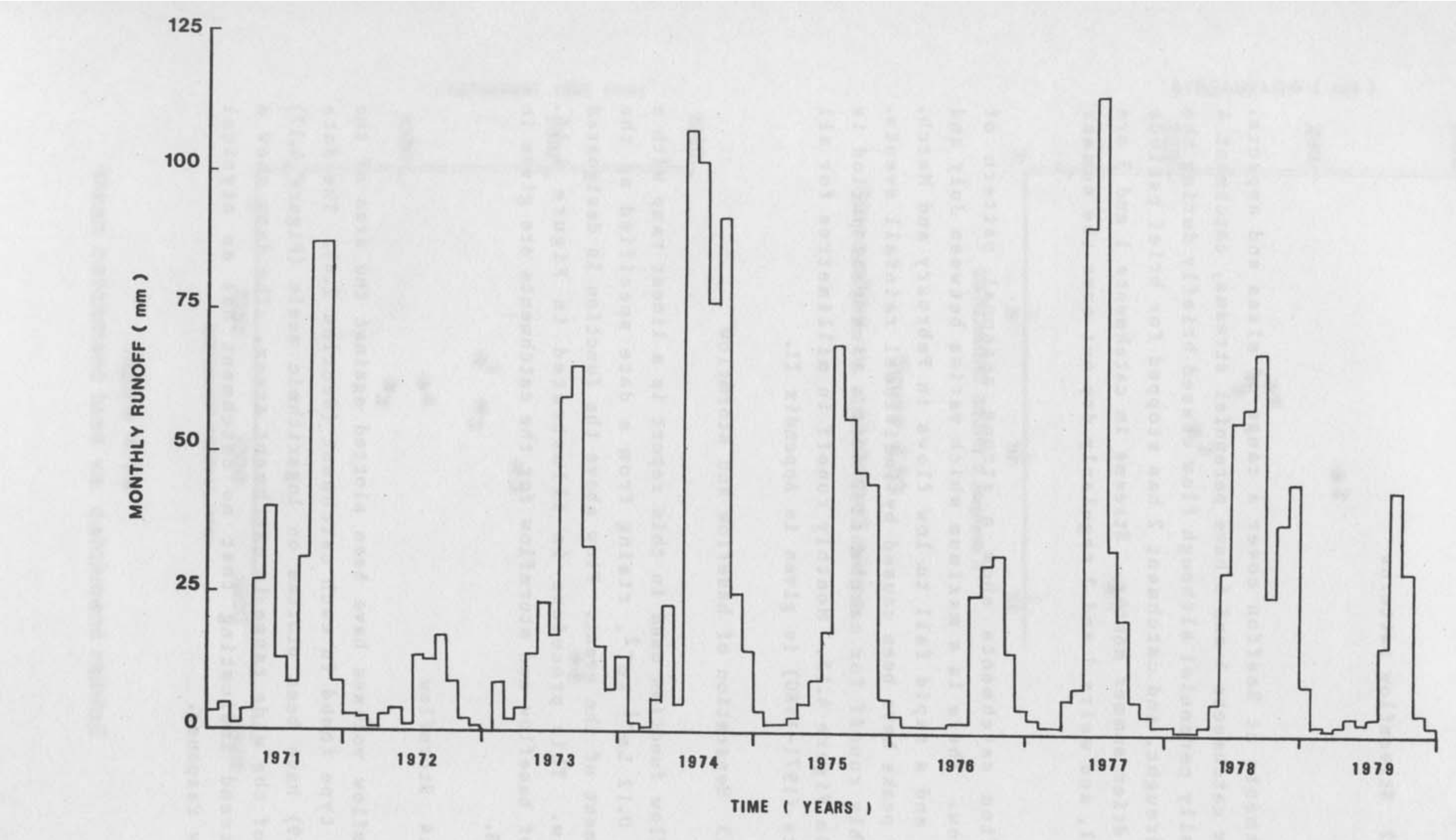


Figure 4. 15 - Monthly runoff for Reefton catchment 2 between 1971 and 1979

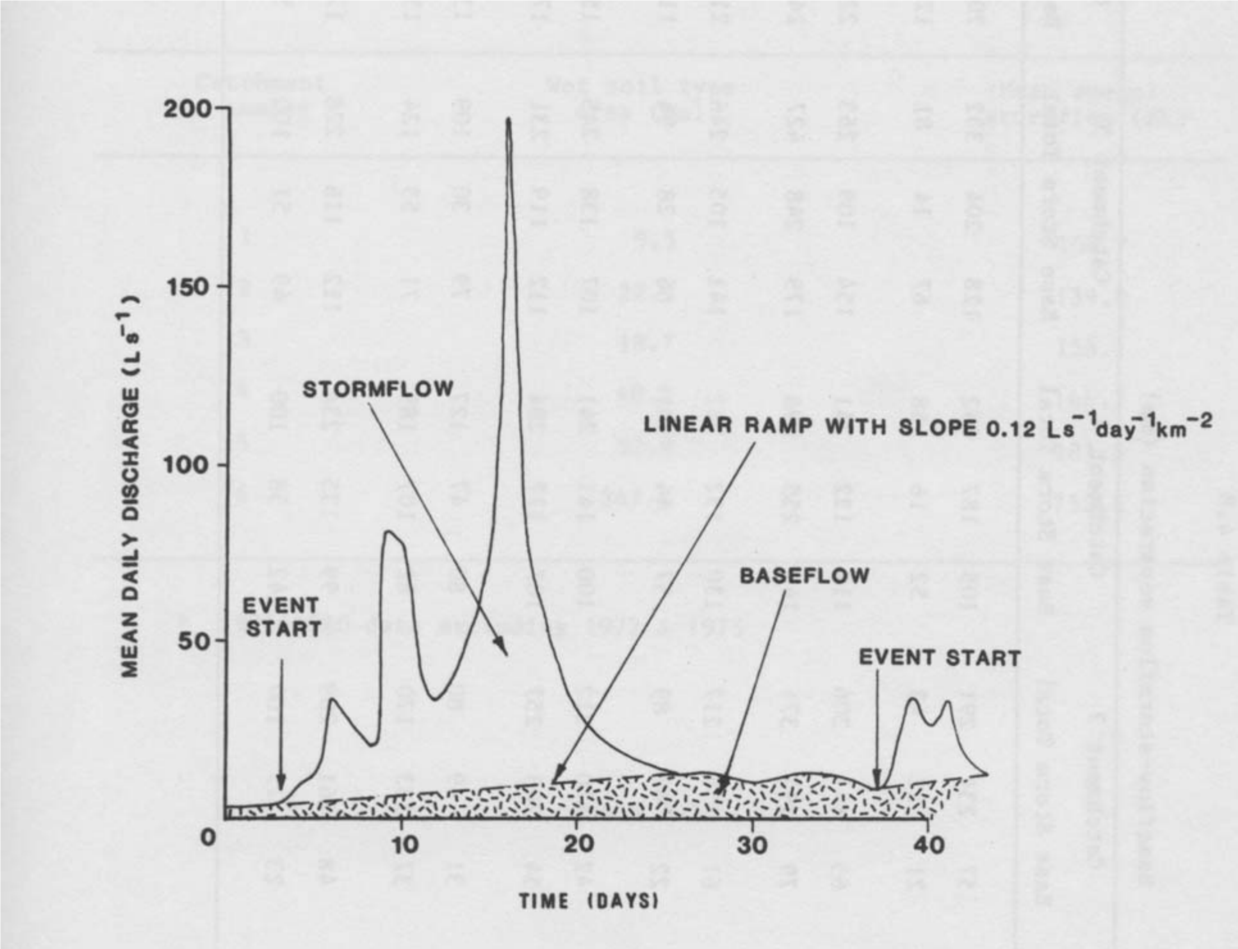


Figure 4.16 - Procedure to separate stormflow and baseflow

Table 4.8 - Baseflow-stormflow separation (mm)

	Catchment 1			Catchment 2			Catchment 3			Catchment 4			Catchment 5			Catchment 6		
	Base	**Storm**	**Total**	**Base**	**Storm**	**Total**	**Base**	**Storm**	**Total**	**Base**	**Storm**	**Total**	**Base**	**Storm**	**Total**	**Base**	**Storm**	**Total**
1971	40	195	235	79	237	316	57	234	291	105	187	292	128	204	332	206	194	400
1972	NA	NA	NA	37	31	68	1	22	43	52	16	68	67	14	81	127	15	142
1973	51	107	158	98	152	250	65	141	206	119	122	241	154	109	263	229	129	358
1974	60	271	331	122	343	465	79	292	371	143	255	398	179	248	427	241	314	555
1975	NA	NA	NA	105	157	262	61	156	217	130	132	262	141	105	246	214	146	360
1976	18	55	73	41	73	114	22	67	89	57	44	101	66	28	94	113	37	150
1977	41	171	212	69	205	274	42	170	212	100	141	241	107	138	245	154	159	313
1978	40	199	239	91	235	326	54	203	257	107	177	284	112	119	231	171	150	321
1979	18	35	53	47	67	114	31	49	80	80	47	127	79	30	109	138	58	196
1980	32	110	142	58	149	207	37	133	170	82	107	189	71	53	124	137	114	251
Mean* (mm)	37	143	180	75	183	258	48	161	209	99	135	234	112	116	228	174	144	318
(%)	21	79	100	29	71	100	23	77	100	42	58	100	49	51	100	55	45	100

* Years 1972 & 1975 excluded
NA data not available

Table 4.9 - Stormflow volumes and area of wet soil type for each catchment

Catchment number	Wet soil type area (ha)	Mean annual stormflow (ML)
1	9.5	100.7
2	22.9	139.0
3	18.7	153.1
4	40.2	144.7
5	52.9	181.5
6	247.8	752.8

* 1971-1980 data excluding 1972 & 1975

Table 4.10 - Catchment rainfall minus stormflow for each catchment

Catchment number	Area (ha)	Catchment rainfall minus stormflow (mm)
1	70.4	1091
2	76.1	1067
3	95.1	1104
4	107.2	1113
5	156.2	1192
6	521.2	1297

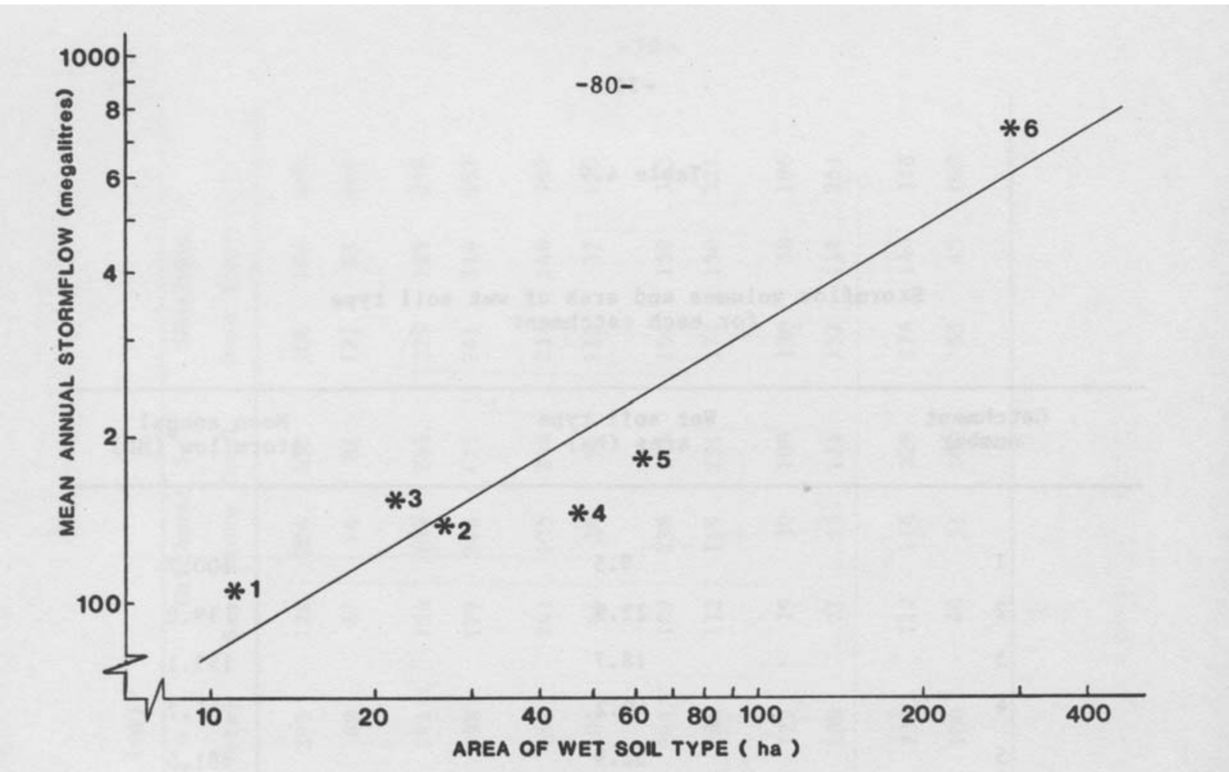


Figure 4.17 - Relation of area of wet soil type in each catchment and mean annual stormflow

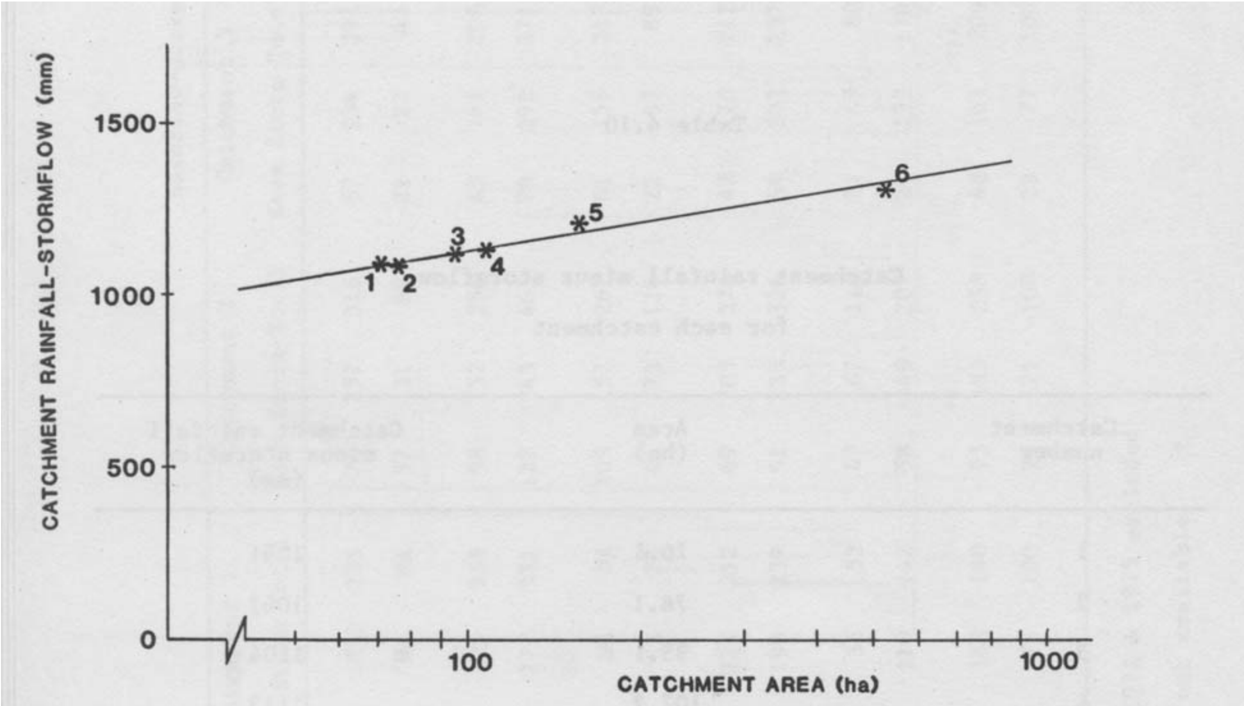


Figure 4.18 - Relation of catchment rainfall minus stormflow and catchment area

4.2.5 Catchment rainfall minus stormflow

A test for possible catchment leakage is to subtract catchment stormflow from catchment rainfall (leaving baseflow as the major term) and check for uniformity, assuming that interception and evapotranspiration are approximately uniform for all six catchments. These data are entered in Table 4.10, and are plotted against catchment area in Figure 4.18. The data lie very close to a straight line, and it is concluded that all six catchments are responding uniformly.

4.2.6 Flow duration curves

A flow duration curve is a plot of daily discharge against the percentage of time that the discharge is equaled or exceeded. This can provide information on the percentage of time that discharge is within a given section of the compound weir plates. Flow duration curves have been determined for the Reefton weirs for the period 1971-1980 inclusive. (Note that weir 1 was inoperative for 1972 and 1975). These curves have been plotted in Figures 4.19 (weirs 1-4) and 4.20 (weirs 4-6). The curves indicate low baseflow due to the shallow soils, and high storm -flow due to high rainfall in the Experimental Area. Any change in catchment response resulting from treatment will, inter alia, show in a change in the flow duration curves. Whether a change is detected depends on the precision of streamflow measurement. Table 4.11 lists the proportion of time that flow through the weir pond is within one of the four stages shown in Figure 3.3. With the exception of catchment 6, a high proportion of flow is confined to stage 1 where precision of measurement is highest.

4.2.7 Calibration of catchment runoff

The broad philosophy of paired catchment calibration and detection of significant change has been studied by Wilm (1949), Kovner and Evans (1954) and Reinhart (1958, 1967). Standard regression techniques as derived in Davies (1961) and Snedecor and Cochran (1978) have been used to analyse the data from the

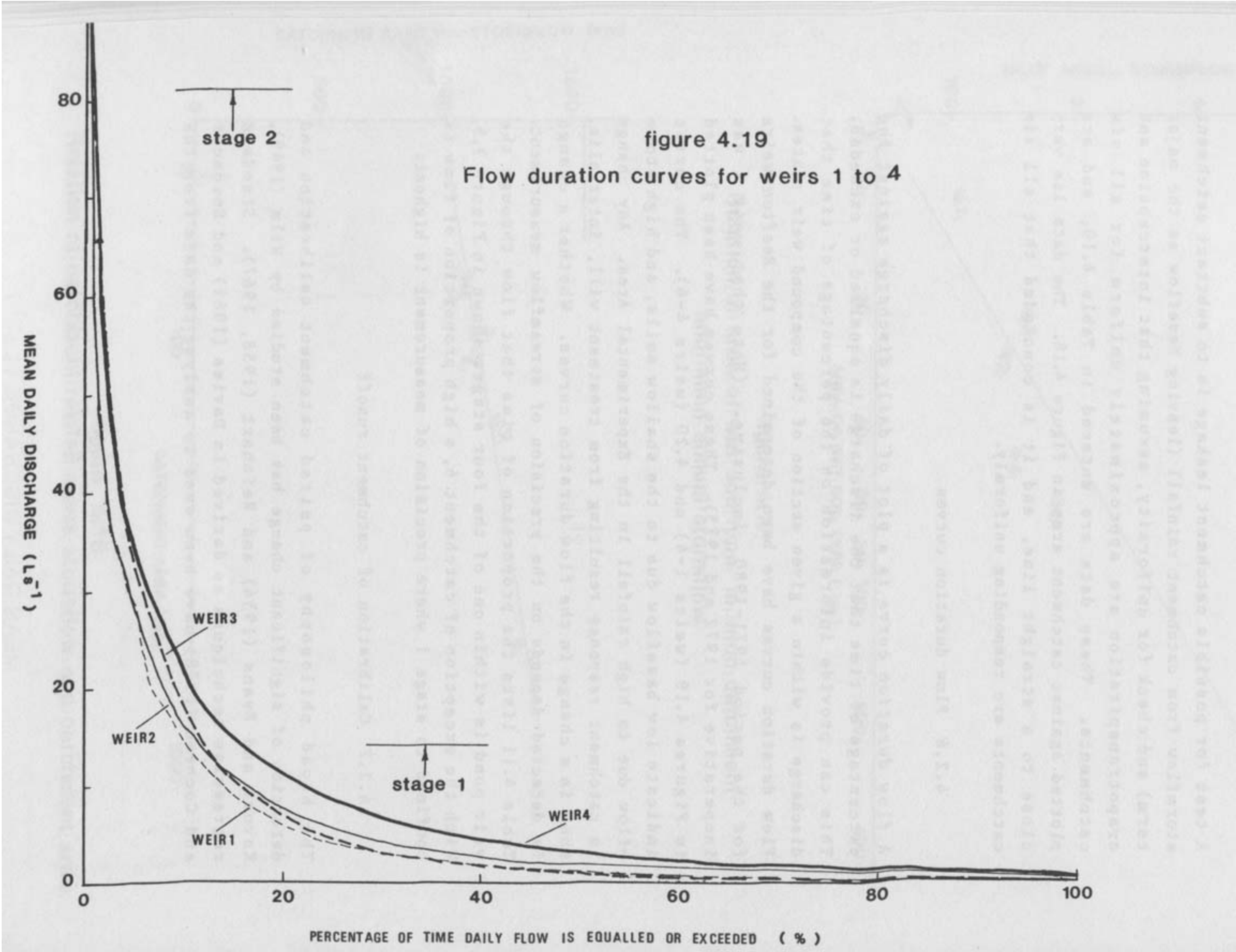


Figure 4.19 – Flow duration curves for weirs 1 to 4

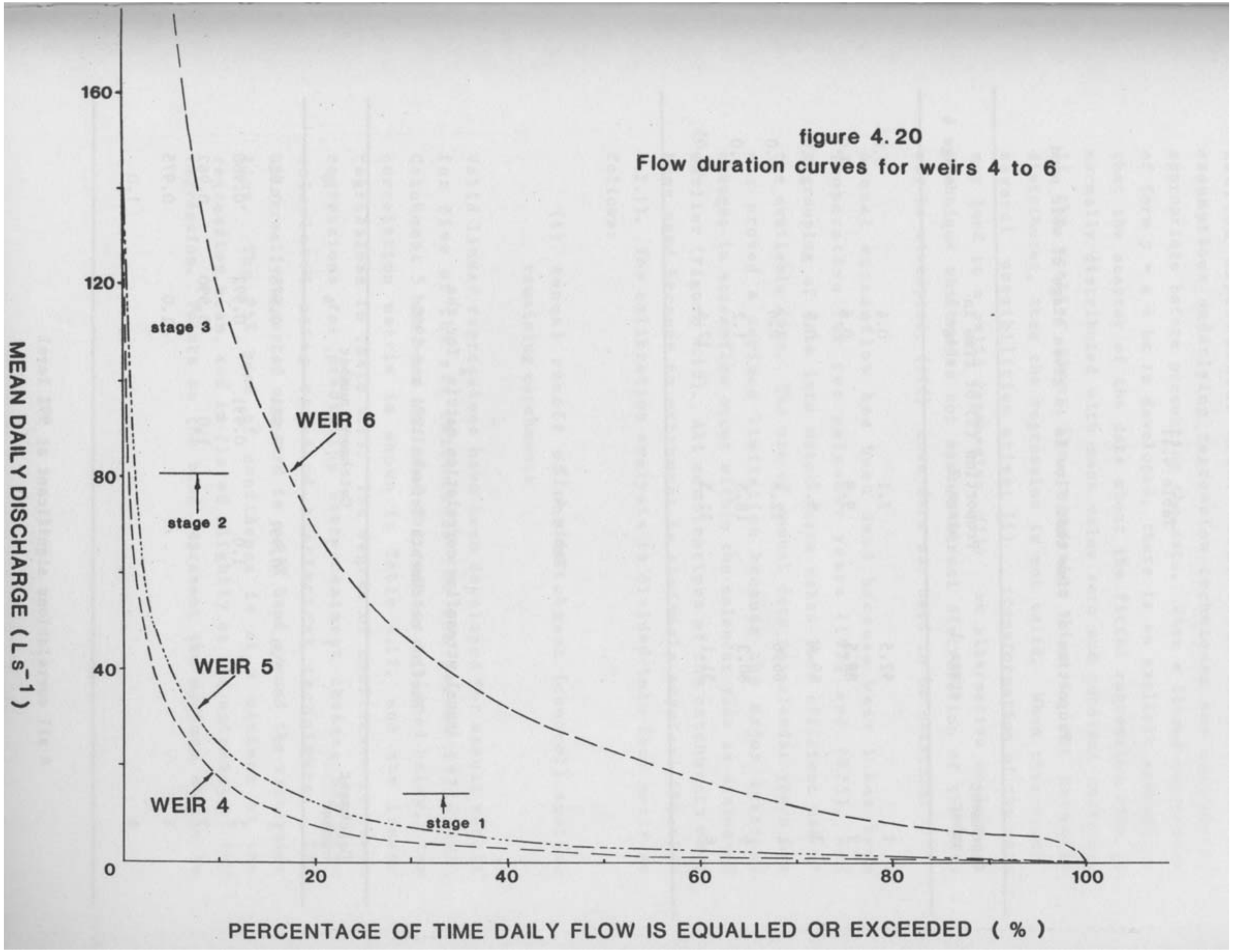


Figure 4.20 – Flow duration curves for weirs 4 to 6

Table 4.11 - Proportion of time that flow is in given stage of weir pond

Catchment number	Proportion (%) of time in Stage 1	stage 2	stage 3	stage 4
1	92.5	7.1	0.4	0.0
2	89.5	9.9	0.6	0.0
3	89.4	9.7	0.9	0.0
4	86.6	12.8	0.6	0.0
5	80.3	18.5	1.2	0.0
6	31.1	51.5	17.4	<0.05

Table 4.12 - Annual streamflow correlation matrix* for the Reefton catchments between 1971 and 1980

Catchment number	Catchment number 1	2	3	4	6
1	1.0	0.991	0.984	0.978	0.920
2		1.0	0.991	0.992	0.960
3			1.0	0.990	0.962
4				1.0	0.975
6					1.0

* all correlations significant at 99% level

Reefton Experimental Area. Some brief comments on the assumptions underlying regression techniques are considered appropriate before presenting the data. When a linear regression of form y = a + bx is developed, there is an explicit assumption that the scatter of the data about the fitted regression line is normally distributed with mean value zero and constant variance. If the scatter about the regression line is not normally distributed, then the regression is not valid. When this occurs several possibilities arise: (i) transformation of the data may lead to a valid regression, (ii) an alternative analytical technique which does not assume normal distribution of the data may be attempted, (iii) more data may need to be obtained.

Annual streamflow has been used because weir. 1 has been inoperative for two calendar years (1972 and 1975), and regrouping of data into water years makes less efficient use of the available data. The use of annual data in calendar years has not proved a serious limitation because the major seasonal changes in streamflow occur within the calendar year as discussed earlier (Figure 4.15). All combinations of the catchments have been used because no catchment is obviously atypical (Section 4.2.1). The calibration analysis is divided into four parts as follows:

(i) Annual runoff of one catchment (control) against remaining catchments

Valid linear regressions have been developed for annual runoff for five of the six catchments for the period 1971-1980. Catchment 5 has been excluded for reasons outlined below. The correlation matrix is shown in Table 4.12, and the linear regressions in Table 4.13. The degree of confidence in these regressions for predicting post-treatment changes has been calculated using standard statistical techniques. The universally accepted standard is a 95% band around the regression line. The 95% band of confidence is at a minimum at the regression mean, and is flared slightly at the extremes of the regression. Points on the band represent the minimum change in runoff which can be detected with 95% confidence in the first year post-treatment. The value corresponding to the pretreatment mean is entered in Table 4.13. This change in annual runoff is detectable (with 95% confidence) in the first year post-treatment mean. The detectable change is increased slightly if the annual runoff is far from the pre-treatment mean. A typical example is illustrated in Figure 4.21.

Valid linear regressions of the form $y = a + bx$ could not be obtained for runoff from catchment 5 relative to the other catchments. The residuals (i.e. the scatter about the regression) typically show both a drift with time and an increase of variance with time. An example of this for catchment 5 against 4 is shown in Figure 4.22.

Valid regression have been established by logarithmic-transformation of the data, and by the introduction of a time term. Valid regressions are of the form:

$$\text{Log}(Qcat) = a + b \log(Q5) + c \log(T)$$

where Qcat = runoff from test catchment,

Q5 = runoff from catchment 5,

T = time in years

The parameters of regression lines for each of the five test catchments are given in Table 4.14. It is noted that data transformation and addition of a time term has improved the accuracy of the calibration of the volumes of Table 4.13. However, simple linear regression is the preferred analytical technique.

The reasons for the difference in catchment 5 compared to the other catchments is under investigation. Although some of the runoff data have been estimated, the uncertainties in the data do not explain the trends in the residuals of Figure 4.22.

Table 4.13 - Regressions of annual runoff from a 'control' catchment against runoff from remaining catchments for the period 1971-1980

Control catchment number	Test catchment number	Regression equation		Correlation coefficient	Number of observations	95% confidence limit at pre-treatment mean	
		Intercept	Slope			(mm)	(%)
1	2	33.440	1.247	0.991	8	44	17
	3	20.593	1.047	0.984	8	49	24
	4	52.204	1.009	0.978	8	56	24
	6	91.194	1.259	0.920	8	139	44
2	1	-23.039	0.787	0.991	8	35	19
	3	- 9.502	0.846	0.991	10	34	18
	4	20.534	0.834	0.992	10	32	15
	6	67.175	1.016	0.960	10	91	30
3	1	-13.260	0.924	0.984	8	46	26
	2	15.088	1.161	0.991	10	40	17
	4	31.874	0.974	0.990	10	36	16
	6	74.036	1.193	0.962	10	88	29
4	1	-41.639	0.948	0.978	8	54	30
	2	-20.508	1.181	0.992	10	38	16
	3	-28.328	1.007	0.990	10	36	19
	6	33.993	1.229	0.975	10	72	24
6	1	-33.745	0.673	0.920	8	102	56
	2	-36.624	0.907	0.960	10	86	36
	3	-43.055	0.776	0.962	10	71	37
	4	-15.518	0.774	0.975	10	57	26

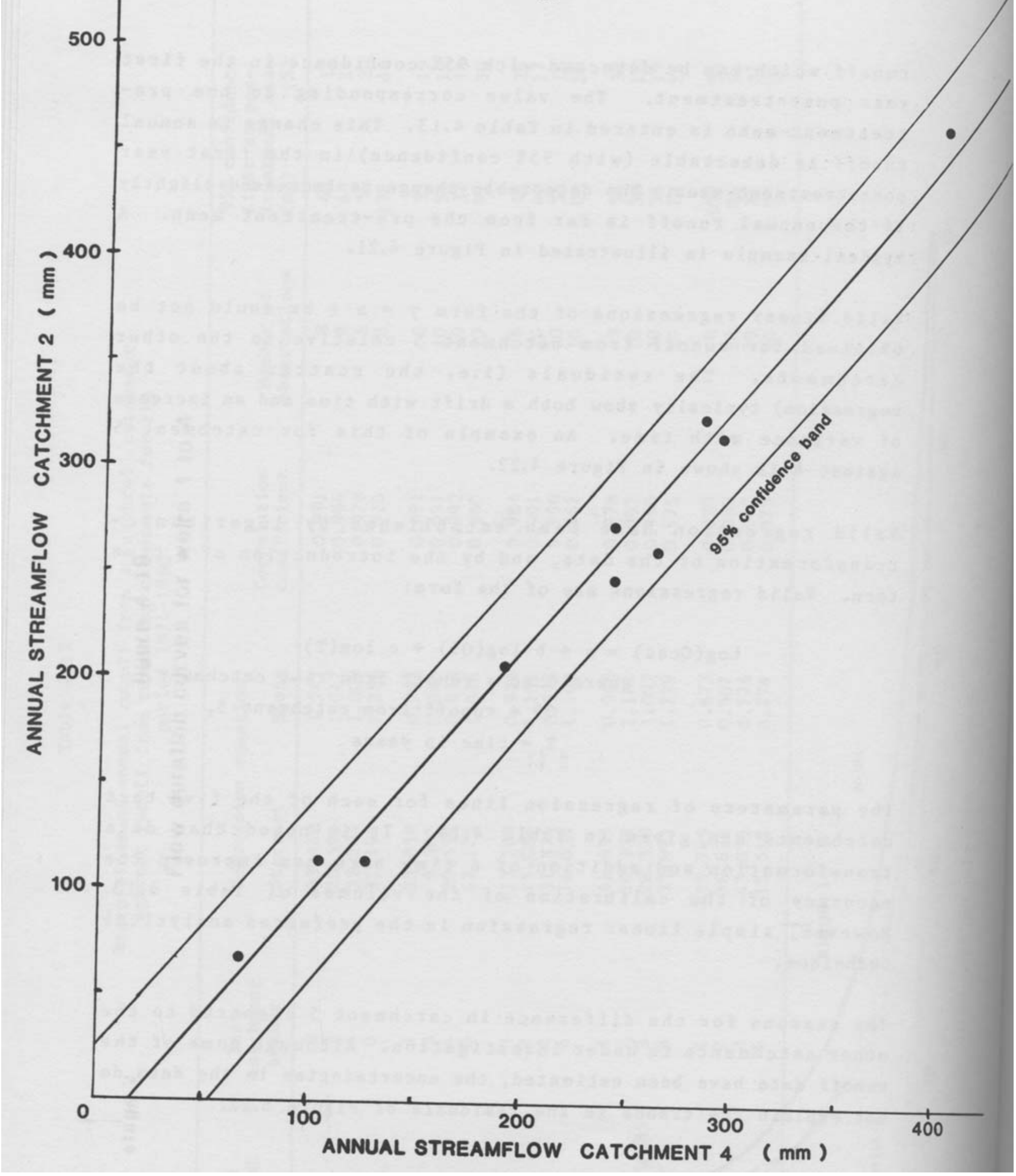


Figure 4. 21 - Linear regression for annual streamflow of catchment 2 on catchment 4

(ii) Relationship between annual runoff and rainfall

The aim here has been to obtain a reliable relationship between annual runoff and rainfall, using the minimum number of rainfall parameters from the Reefton Meteorological Station. Multiple regression techniques have been used for various combinations of rainfall periods. The correlation coefficients are shown in Figure 4.23.

The most consistent set of correlations for catchments 1, 2 and 3 has been obtained from a simple linear regression of annual runoff against rainfall over the period April to November inclusive (>0.920). The highest correlations for the larger catchments 4, 5 and 6 have been obtained for the 12 month rainfall period November to November. These relations are consistent with the seasonal runoff pattern for the catchments (Figure 4.14). Addition of extra rainfall parameters has not significantly improved the correlations.

Corresponding regression equations are shown in Table 4.15.

(iii) Monthly runoff of one catchment (control) against remaining catchments

Linear regressions have been calculated for monthly runoff from one catchment against the others. The correlation matrix is shown in Table 4.16. Log-transformation of the data has not removed time dependence of regression residuals (of Section 4.2.7). Further analysis of these data is in progress.

(iv) Calibration of a mathematical model

A soil dryness index (SDI) model has been developed by Mount (1972) as an aid to forest management, and the model has since been modified by Langford et al. (1978). The Reefton catchments are being studied with the SDI model. Initial findings are:

(a) Runoff is modeled optimally without the soil moisture overflow store for the four smaller Reefton catchments.

(b) The baseflow function is of the general form: Baseflow = (50 - SDI)/40. This is markedly different from the baseflow function published for the North Maroondah catchments (Langford and O'Shaughnessy 1979).

(c) The evapotranspiration values for Reefton catchments are approximately half those from the North Maroondah catchments (Langford and O'Shaughnessy (1979). The Reefton values have their major change in the 0-100 range of SDI.

These findings are tentative because the investigation is still in its initial stages. The shallow soils and type of vegetation in the Reefton catchments appear to have strongly influenced results obtained from the model.

Table 4.14 - Regressions of annual runoff from catchment 5 against runoff from remaining catchments for the period 1971-1980

Control catchment number	Test catchment number	Regression equation* Intercept	Slope (log Q5 term)	Slope (log T term)	Coefficient of determination	Number of observations	95% confidence limits at pre-treatment log (mm)	mean (%)
	1	- 0.676	1.187	0.190	0.839	8	0.391	17
5	2	- 0206	1.050	0.212	0.949	10	0.175	7
	3	- 0.590	1.172	0.211	0.918	10	0.253	11
	4	- 0.036	0.969	0.193	0.962	10	0.138	6
	6	0.653	0.772	0.059	0.964	10	0.109	4

* Regression equation is of the form:
log (test catchment runoff) = a + b log (catchment 5 runoff) + c log (time)

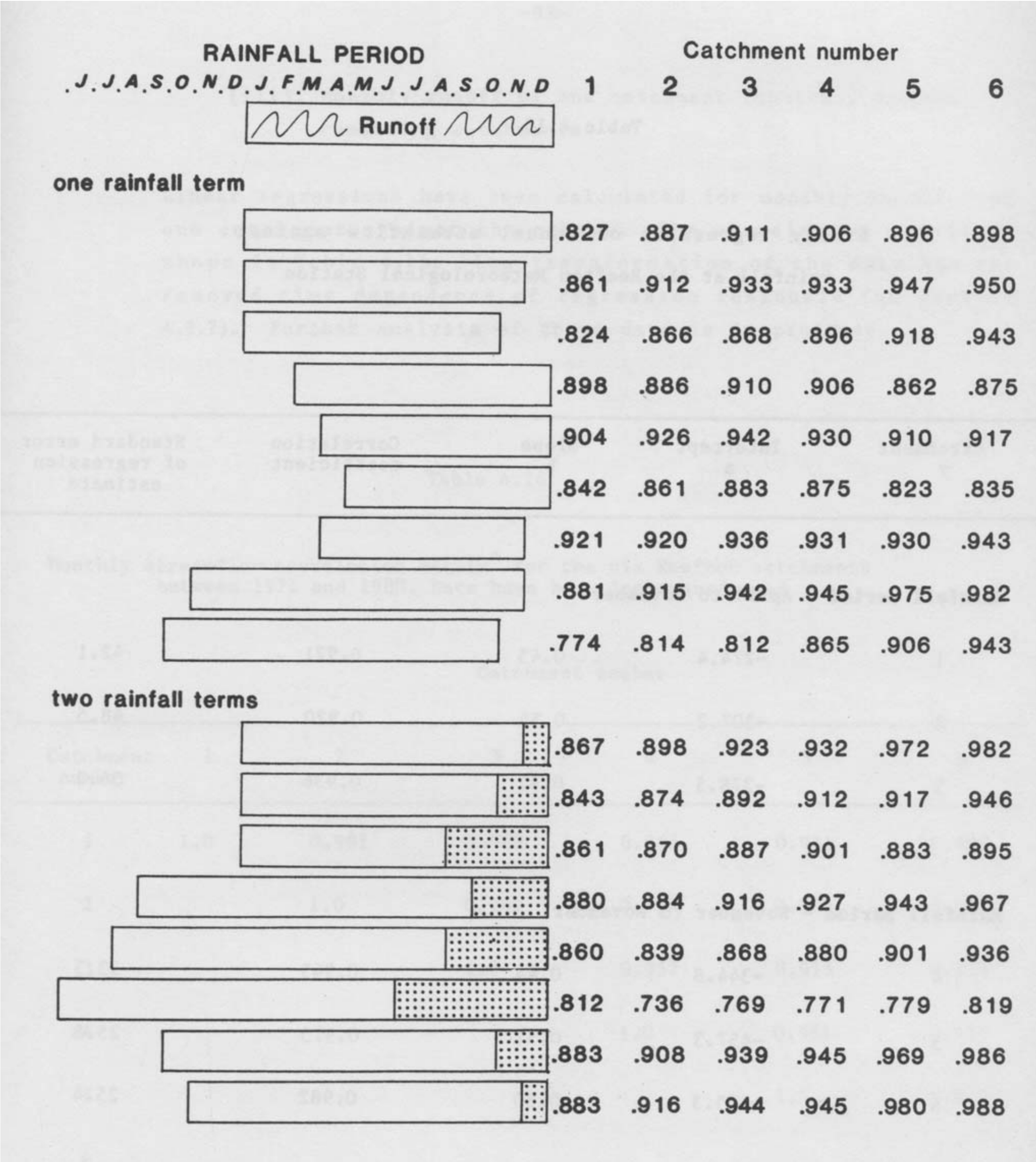


Figure 4.23 -Correlation of annual catchment runoff and various rainfall periods

Table 4.15 - Linear regression of annual streamflow against rainfall at the Reefton Meteorological Station

Catchment number	Intercept a	Slope b	Correlation coefficient	Standard error of regression estimate
Rainfall period- April to November				
1	-274.4	0.45	0.921	42.1
2	-307.2	0.55	0.920	48.5
3	-278.5	0.47	0.936	36.9
Rainfall period- November to November				
4	-344.8	0.44	0.945	33.3
5	-457.3	0.52	0.975	25.8
6	-475.3	0.60	0.982	25.4

Table 4.16 - Monthly streamflow correlation matrix* for the six Reefton catchments between 1971 and 1980. Data have been log-transformed Catchment number

Catchment number	1	2	3	4	5	6
1	1.0	0.981	0.980	0.964	0.931	0.892
2		1.0	0.980	0.977	0.940	0.904
3			1.0	0.957	0.915	0.874
4				1.0	0.961	0.935
5					1.0	0.973
6						1.0

* all values significant at 99% level

It is concluded from the data presented in Section 4.2.7 that annual runoff during the period 1971-1980 can be used to satisfactorily calibrate the catchments in their pre-treatment condition. Table 4.13 shows that correlation coefficients are relatively high, and that the precision in detecting changes in mean annual runoff is acceptable depending on the catchment selected to act as a control. As will be noted in Section 5 however, the choice of a control catchment is only partly dictated by the precision of the calibration relationships.

4.3 Water Quality

The classical methods of regression analysis cannot be readily applied to water quality data, due in part to non-normal distribution of the data. However, some statistical analysis is possible following data transformation.

Although the available record of water quality data stretches back 15 years, a smaller sample of five years has been chosen for analysis of the pre-treatment calibration of water quality. The period January 1971 to January 1976 has been selected, plus recent (1981 and 1982) water quality data. The reasons for choosing this period are that good quality records are available, and that compatible streamflow data (at the time of streamwater sampling) are generally accessible.

The approach in this Section has been to study the water quality and its variation in each catchment, investigate intra-catchment relationships between parameters (especially streamflow, as most physicochemical parameters are flow-dependent) and then examine inter-catchment relationships. A preliminary analysis has been made by Geary (1982).

4.3.1 Analysis of water quality data

The five year water quality record for Reefton catchment has been analysed statistically using Hewlett-Packard 9845B computer. In order to minimise the skewness, most of the data has been transformed into logarithms before analysis. Basic statistics for each parameter have been calculated. For the period 4 January 1971 to 19 January 1976, the data subset ranges from a minimum of 166 observations in catchment 1 to a maximum of 263 in the other catchments. The mean, maximum, minimum, standard deviation and median of water quality observation for each catchment are presented in Table 4.17.

The data indicate that the observed water quality in the Experimental Area is of good quality and most suitable as a potable water source. The largely undisturbed forested catchments provide waters of good pH, generally low colour, low electrical conductivity and variable, yet acceptable, turbidity and suspended solids.

The basic statistics presented in Table 4.17 require some comment. In water quality studies, the median is often cited as a more appropriate measure of central tendency than the mean because of skewness in the data resulting from high flow concentrations of parameters. This is clearly the case with the Reefton data because the median value is in most cases less than the mean value. Within the five year data subset, the highest flows on record have been recorded and these are most likely responsible for the large range in concentration for several parameters. The median values for each parameter in each catchment have been plotted comparatively in Figure 4.24.

The physicochemical characteristics of streamwater from catchment 1 appear to be much higher than in any other catchment at Reefton. The water is more highly coloured and contains more suspended material, even though flow on the day of sampling is lower. This may be related to the high proportion of dry soil in catchment 1 (Table 2.3). Electrical conductivity is low and fairly similar for all catchments, with catchment 3 having the highest concentration of dissolved material and catchment 6 the lowest. The pH of water from each catchment is also similar and shows the least variation with flow. From this preliminary observation of data, it appears that water quality in catchment 1 is of lowest quality and quite different to the others, with water from catchment 2 being more like catchment 3, water from catchment 4 being similar to catchment 5 and water from catchment 6 being of the highest quality. This broadly agrees with the variation in catchment soils and vegetation moving south from the most northerly catchment 6 to catchment 1.

Table 4.17 - Basic statistics of Reefton water quality

Parameter	Catchment	Number of observations	Mean	Maximum	Minimum	Median	Standard deviation
Colour (Pt/Co)	1	186	87	540	5	75	47
	2	260	26	150	0	20	21
	3	239	38	160	5	30	25
	4	263	26	150	0	20	18
	5	260	27	80	5	30	16
	6	261	16	75	0	15	12
pH	1	185	6.71	8.60	5.00	6.71	0.35
	2	260	6.89	7.95	5.67	6.83	0.02
	3	237	6.86	7.91	5.80	6.86	0.39
	4	263	6.91	7.80	6.25	6.88	0.31
	5	259	6.90	7.62	6.02	6.89	0.32
	6	261	6.85	7.70	6.09	6.83	0.33
Electrical conductivity 25o (FS m)	1	186	7032	12000	4010	6870	1357
	2	260	7648	12520	4750	7440	102
	3	238	8064	11630	1680	7925	1484
	4	263	7564	10100	4930	7820	1090
	5	260	6884	8750	5120	7000	732
	6	261	5468	9620	3460	5460	700
Turbidity (NTU)	1	185	25	300	0.3	12.0	45
	2	257	9.8	260	0.3	5.5	23
	3	236	10.0	120	0.3	7.0	15
	4	260	5.3	120	0.0	2.7	11
	5	257	4.9	150	0.3	2.3	13
	6	258	3.2	44	0.0	1.9	4.2
Suspended solids (mg 1.71)	1	186	31.6	380	1	22.0	43
	2	257	24.5	2250	<1	7.6	153
	3	235	14.2	300	<1	8.4	30
	4	259	14.3	810	<1	4.8	60
	5	255	19.6	1180	<1	5.5	90
	6	258	11.5	310	<1	5.6	26
Flow on day of sampling (L s)	1	166	6.78	248	0.00	0.91	23
	2	263	8.36	437	0.00	1.90	31
	3	263	14.15	471	0.00	1.29	35
	4	263	14.34	348	0.13	3.13	27
	5	263	14.82	465	1.27	5.16	35
	6	263	63.55	1318	6.52	30.50	107

4.3.2 Intra-catchment calibration

The data from Section 4.3.1 has been analysed at the intra-catchment level using correlation and regression techniques. The matrix of correlation coefficients for each parameter in the six catchments is presented in Table 4.18.

The large number of observations in each catchment results in considerable scatter in many of the relationships. However, most of the correlation coefficients are significant at the 95% level. The correlation coefficients are generally highest between streamflow and electrical conductivity (Table 4.18). The values for turbidity and suspended solids indicate that these parameters are flow dependent, although marked variation in concentration is often measured during high flow periods. The negative coefficient between pH and streamflow indicates that a relationship does exist but the correlation is low. The values for colour are variable; positive for catchments 2 and 3, low positive for catchments 1 and 4, and negative but not significant for catchments 5 and 6 (Table 4.18).

Table 4.19 shows intra-catchment regressions for electrical conductivity and suspended solids against streamflow. All correlations are significant at the 99% level. These regression equations are reported as preliminary findings only. Further analysis is required on a seasonal basis to ensure random residuals about the regression line.

4.3.3 Inter-catchment calibration

Water quality data for the period 1971-1976 have been used to establish pre-treatment regressions and correlations with catchment 4 selected as the control (see Section 5). Linear regressions have been developed for all water quality data (colour, pH, electrical conductivity, turbidity, suspended solids and streamflow on the day of sampling) between control catchment 4 and the other five experimental catchments. Data are paired according to sampling date, with missing observations and the other half of the data pair being deleted. The results of this calibration are presented in Table 4.20.

For most water quality parameters, the correlation coefficients are generally low (Table 4.20), though they are all significant at the 997 level. The standard error of the estimate is often very large, but this is not surprising in view of the large number of scattered observations. This data requires further analysis on a seasonal basis to ensure random residuals about the regression lines.

In an effort to improve the Reefton water quality calibrations, data for the six catchments have been summed and annual means calculated. Correlations and regressions have been calculated for annual water quality means between catchments, again using catchment 4 as the control. The use of annual means in the calibrations results in a marked increase in correlation coefficients and a reduction in the standard error of the estimates. The regression coefficients, correlation coefficients and standard error of estimates, are given in Table 4.21. All correlations for pH are significant; correlations for electrical conductivity are significant for catchments 1, 3, 5 and 6 vs. catchment 4. The only significant correlations for suspended solids are for catchments 3 and 5 vs. catchment 4; for colour only catchment 5 correlation is significant. It is apparent that, in terms of the calibration, water quality in catchment 1 is quite distinct from the remaining catchments. The concentration of the physical parameters of colour, suspended solids and turbidity vary greatly in relation to flow in this catchment and consequently difficulties have been experienced in the calibration. In contrast, water quality variations in catchment 5 calibrate well with the control catchment and catchment 2, 3 and 6 fall somewhere in between the range of catchments 1 and 5.

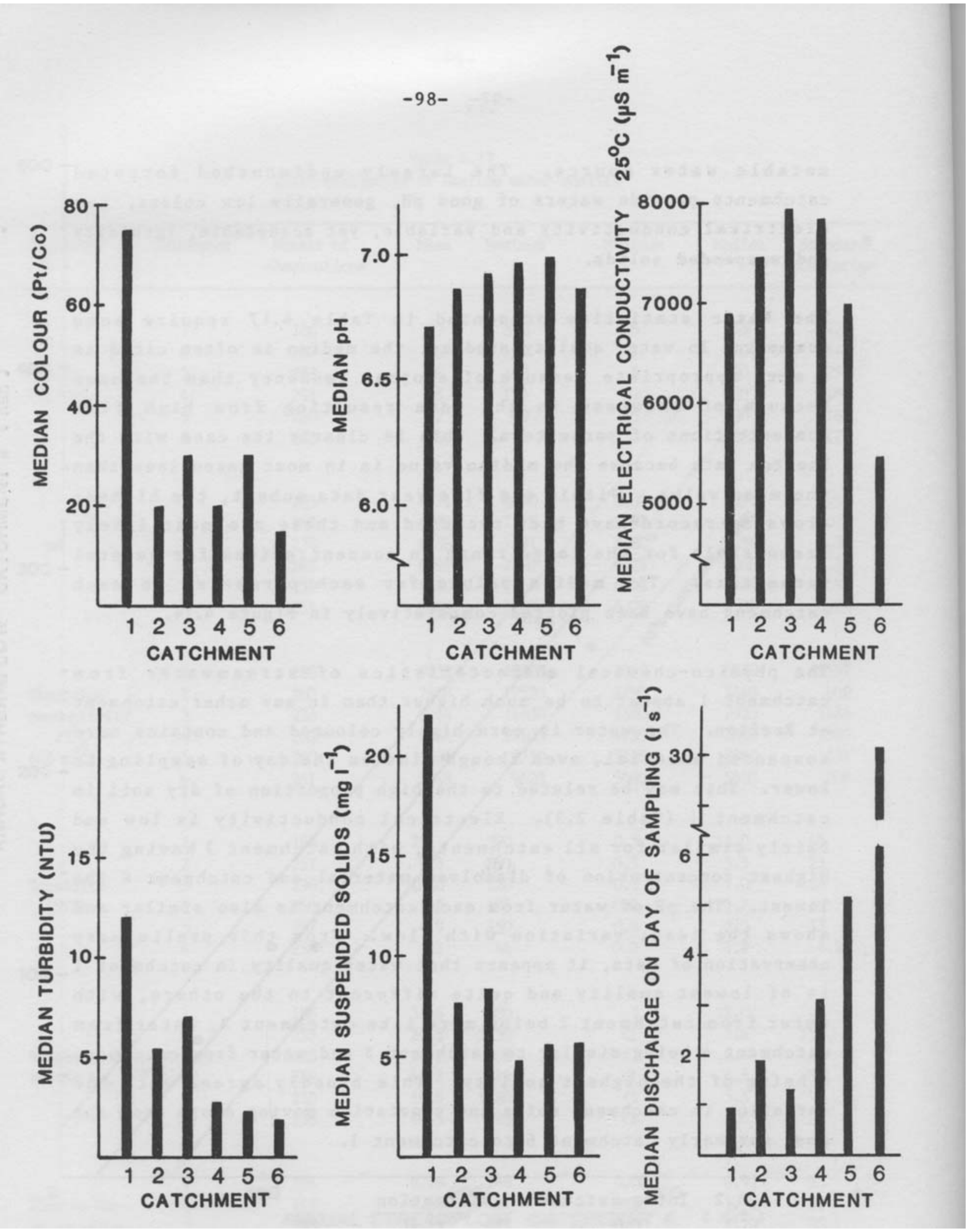


Figure 4.24 - Median values for water quality parameters and streamflow between 1971 and 1976

Table 4.18 - Correlation matrices relating water quality parameters with each catchment

Catchment 1	**log(pH**	**log(EC)**	**log(Turb)**	**log(SS)**	**log(l+flow)**
log Col) log pH) log EC) log Turb) log SS)	-0.1717	-0.2681** .2109*	0.415C** 0.0045 -0.1883	0.5120** -0.0236 -0.3298** 0.3820**	0.2665** -0.1745 -0.7668** 0.0948 0.4581**
Catchment 2	**pH**	**log(EC)**	**log(Turb)**	**log(SS)**	**log(l+flow)**
log(1+col) pH log EC) log Turb) log SS)	-0.2552**	-0.5857** 0.2918**	0.5656** -0.0173 -0.4464**	0.4645** -0.2444* -0.3314** 0.4420**	0.5848** -0.2944** -0.8144** 0.4716** 0 .4371**
Catchment 3	**PH**	**EC**	**log(Turb)**	**log(SS)**	**log(l+flow)**
log(Col) pH EC log(Tub) log(SS)	-0.1167	-0.5669**	0.3328** 0.3328** 0.5653** 0.0366	0.4685** -0.1275 -0.3303** 0.2898**	0.6024** -0.1740 -0.6933** 0.5393** 0.4834**
Catchment 4	**pH**	**EC**	**log(l+Turb)**	**log(1+SS)**	**log(flow)**
log(l+Col) pH EC log (Turb) log(SS)	-0.1029	-0.1184 0.2931	0.4036** -0.0954 -0.3267**	0.3941** -0.3017** -0.3885** 0.5007**	0.2864** -0.2743** -0.8019** 0.4747** 0.5173**
Catchment 5	**pH**	**EC**	**log(Turb)**	**log(SS)**	**log(flow)**
log(Col) pH EC log(Turb) log(SS)	-0.0991	0.0642 0.3923**	0.3990** -0.1194 -0.1748	0.2684** -0.2684** -0.3154** 0.4714**	0.0185 -0.3028** -0.7437** 0.4027** 0.4773**
Catchment 6	**pH**	**log(EC)**	**log(1+Thrb)**	**log(SS)**	**log(flow)**
log(1+Col) pH log(EC) log (1+Turb) log SS)	-0.1237	0.0960 0.3833**	0.2804** -0.0720 -0.0016	0.2299* -0.1720 -0.0620 0.5618**	-0.0788 -0.2783** -0.6181** 0.2294* 0.3327**

Code: Col - colour
EC - electrical conductivity
Turb - turbidity
SS - suspended soils

* significant at 95% level
** significant at 99% level

Table 4.19 - Intra-catchment calibration for electrical conductivity and suspended solids against streamflow. Regression equations are of the form y = a + bx

Catchment Number	x	y	Intercep t (a)	Slope (b)	Number of observations	Correlation coefficient*	Standard error
Electrical conductivity (EC)							
1	log(14flow)	log(EC)	-1.893	-0.104	125	-0.767	0.044
2	log(14flow)	log(EC)	1.965	-0.160	260	-0.814	0.054
3	log(l+flow)	EC	91.836	-20.497	238	-0.693	10.718
4	log(flow)	EC	85.082	-16.459	263	-0.802	6.523
5	log(flow)	EC	78.304	-11.368	260	-0.744	4.904
6	log(flow)	log(EC)	1.851	-0.075	261	-0.618	0.042
Suspended solids (SS)							
1	log(l+flow)	log(SS)	1.225	0.309	125	0.458	0.299
2	log(1+flow)	log(SS)	0.634	0.433	257	0.437	0.422
3	log(1+flow)	log(SS)	0.678	0.432	235	0.539	0.338
4	log(1+flow)	log(SS)	0.578	0.403	259	0.517	0.357
log(1+SS)	log(flow)	log(SS)	0.37	0.484	255	0.477	0.427
6	log(flow)	log(SS)	0.297	0.322	258	0.333	0.396

* all correlations significant at 99% level

Table 4.20 - Inter-catchment calibration of water quality data (Individual values) using catchment 4 as the control. Regression equations are of the form y (test catchment) = a + bx (control catchment)

Parameter	x	y	Intercept (a)	Slope (b)	Number of observations	Correlation coefficient	Standard error
Colour	4	1*	1.426	0.337	186	0.453	0.196
		2*	0.249	0.792	260	0.659	0.264
		3*	0.592	0.661	239	0.633	0.234
		5*	0.312	0.773	260	0.786	0.179
		6*	0.197	0.695	261	0.658	0.234
pH	4	1*	0.510	0.046	185	0.641	0.017
		2	0.776	0.885	260	0.735	0.254
		3	0.808	0.876	237	0.712	0.272
		5	1.455	0.789	259	0.757	0.213
		6	1.455	0.780	261	0.737	0.223
Electrical conductivity	4	1*	1.374	0.006	186	0.820	0.047
		2*	1.391	0.006	260	0.755	0.061
		3	3.225	1.032	238	0.754	9.764
		5	27.749	0.544	260	0.813	4.274
		6	1.483	0.003	261	0.690	0.038
Turbidity	4	1*	0.789	0.480	185	0.352	0.444
		2*	0.206	0.782	257	0.564	0.380
		3*	0.394	0.652	236	0.565	0.323
		5*	-0.105	0.792	257	0.617	0.337
		6*	0.301	0.346	258	0.426	0.244
Suspended solids	4	1	1.108	0.274	186	0.341	0.330
		2	0.423	0.576	256	0.511	0.402
		3	0.462	0.555	234	0.584	0.326
		5	0.190	0.734	254	0.627	0.379
		6	0.418	0.472	257	0.470	0.369

* data has been log-transformed
all correlations significant at 99% level

4.4 Bedload

All statistical analyses on bedload data have been made on a HP 9845 computer. A block diagram of available information is shown in Figure 4.25. Transformation of some data has been necessary to normalise the distribution.

Table 4.21- Inter-catchment calibration of water quality data (annual means) using catchment 4 as control. Regression equations are of the form y (test catchment) = a + bx (control catchment)

Parameter	x	y	Intercept (a)	Slope (b)	Number of observations	Correlation coefficient	Standard error
Colour	4	1	0.791	0.810	5	0.659	0.081
		2	-0.315	1.210	5	0.844	0.067
		3	0.073	1.160	5	0.691	0.106
		5	-0.442	1.332	5	0.942	0.041
		6	-0.328	1.084	5	0.760	0.081
pH	4	1	0.511	0.046	5	0.946*	0.004
		2	-0.343	1.047	5	0.998**	0.018
		3	-1.152	1.159	5	0.977**	0.072
		5	0.100	0.985	5	0.999**	0.007
		6	0.282	0.950	5	0.998**	0.019
Electrical conductivity	4	1	0.981	0.011	5	0.917*	0.020
		2	1.514	0.005	5	0.821	0.014
		3	-61.106	1.870	5	0.896*	3.794
		5	14.453	0.719	5	0.971**	0.727
		6	1.309	0.006	5	0.968**	0.006
Turbidity	4	1	0.153	1.531	5	0.689	0.192
		2	- 0.260	1.543	5	0.739	0.168
		3	- 0.249	1.700	5	0.877	0.111
		5	-0.485	1.405	5	0.807	0.123
		6	0.126	0.633	5	0.589	0.104
Suspended solids	4	1	1.100	0.291	5	0.493	0.111
		2	0.557	0.406	5	0.639	0.105
		3	0.321	0.739	5	0.890*	0.082
		5	-0.044	1.017	5	0.941*	0.079
		6	0.309	0.605	5	0.698	0.134

* significant at 95% level
** significant at 99% level
data has been log-transformed

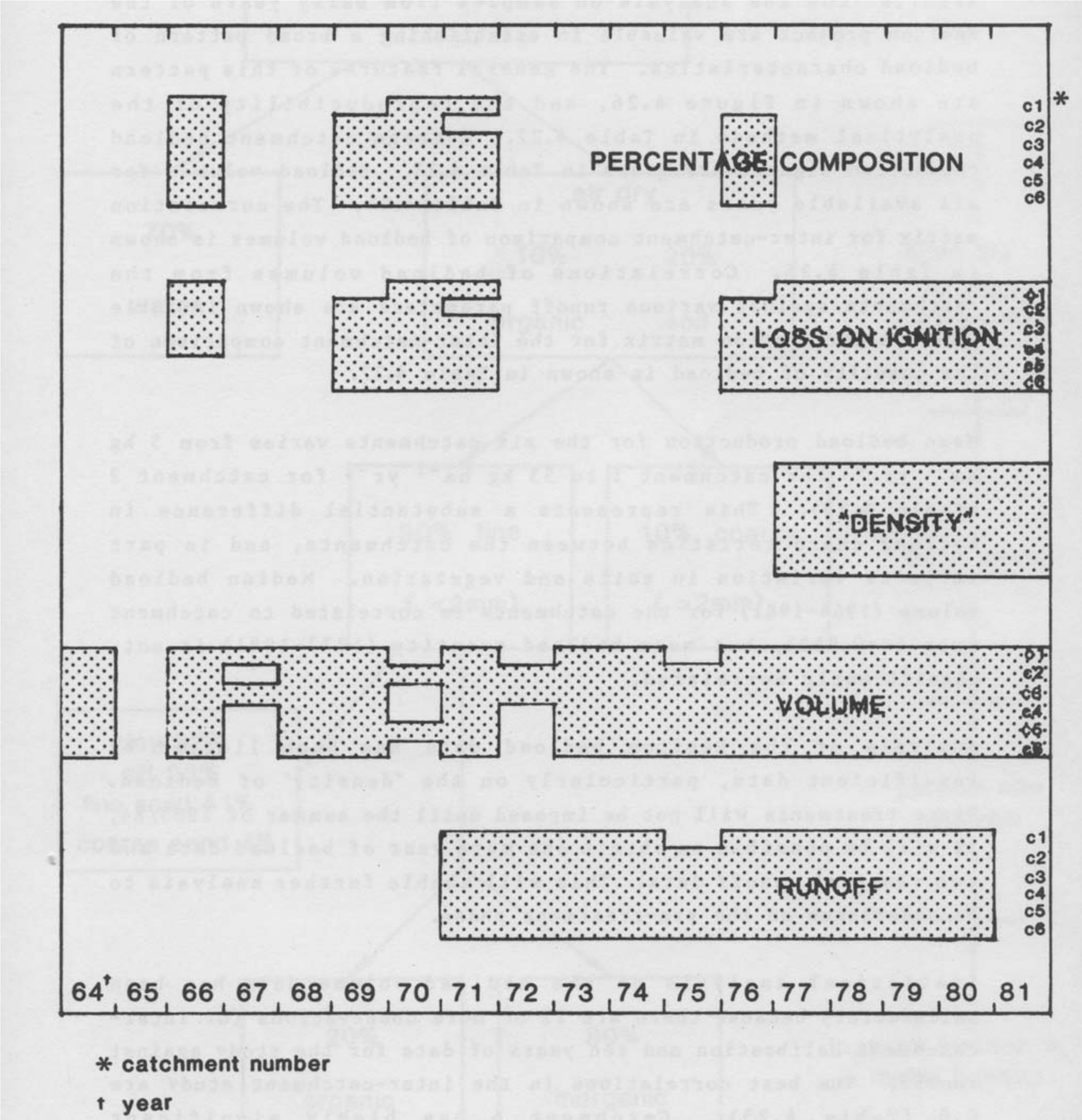


Figure 4.25 - Block diagram of available bedload information

Results from the analysis on samples from early years of the Reefton project are valuable in establishing a broad pattern of bedload characteristics. The general features of this pattern are shown in Figure 4.26, and the reproducibility of the analytical methods in Table 4.22. Average catchment bedload production figures are given in Table 4.23. Bedload volumes for all available years are shown in Table 4.24. The correlation matrix for inter-catchment comparison of bedload volumes is shown in Table 4.25. Correlations of bedload volumes from the catchments against various runoff parameters are shown in Table 4.26. A correlation matrix for the inter-catchment comparison of the quantity of bedload is shown in Table 4.27.

Mean bedload production for the six catchments varies from 5 kg ha-1 yr -1 for catchment 1 to 53 kg ha-1 yr-1 for catchment 2 (Table 4.23). This represents a substantial difference in bedload characteristics between the catchments, and in part reflects variation in soils and vegetation. Median bedload volume (1964-1981) for the catchments is correlated to catchment area (r=0.842), but mean bedload quantity (1977-1981) is not significantly correlated.

Analysis of the Reefton bedload data has been limited by insufficient data, particularly on the 'density' of bedload. Since treatments will not be imposed until the summer of 1983/84, it will be possible to obtain one more year of bedload data and two years of runoff data. This will enable further analysis to be undertaken on the pre-treatment phase.

Statistical analysis on the bedload volume data has been satisfactory because there are 12 or more observations for inter-catchment calibration and ten years of data for the study against runoff. The best correlations in the inter-catchment study are 0.8 (Table 4.25). Catchment 6 has highly significant correlations (>0.84) of bedload volume with all runoff parameters (Table 4.26). Catchment correlations are above 0.89 except the value for baseflow. Catchments 2 and 3 have good correlations with annual runoff, annual stormflow and storm runoff - peak stormflow product, while catchment 4 data shows good correlation with the storm runoff - peak stormflow product. The other correlations of bedload volume and various runoff parameters are not highly significant. Catchment 5 has very low correlations for all statistics on volumes. These results indicate that there is no simple relation for annual bedload volume and various runoff parameters which applies to all six catchments with the existing data.

There is a temptation to extend the record of quantity of bedload by applying the five years of 'density' data to the 13 years of bedload volume data. Possibilities are (i) to apply average 'density' figures to all earlier data, (ii) to utilise the trend of 'density' and annual runoff (r=0.851) from existing data to predict 1971-1980 values. Both proposals have been rejected, the first because it ignores the trends in the data, the second because it builds correlations into the subsequent analysis. Further analysis will be made when more data become available.

It is concluded that any marked changes in bedload characteristics as a result of treatment should be detectable statistically. Further analysis is needed with more pre-treatment data to see if minor changes can be detected.

Table 4.22 Reproducibility of analytical methods

Method	Number of duplicate determinations	Maximum spread
loss on ignition	17	± 6% _
$\frac{\text{(dry mass)}}{\text{saturated volume}}$ sediment	15	± 0.05 g cm-3 _
$\frac{\text{(dry mass)}}{\text{saturated volume}}$ gravel	2	± 0.2 g cm-3 _

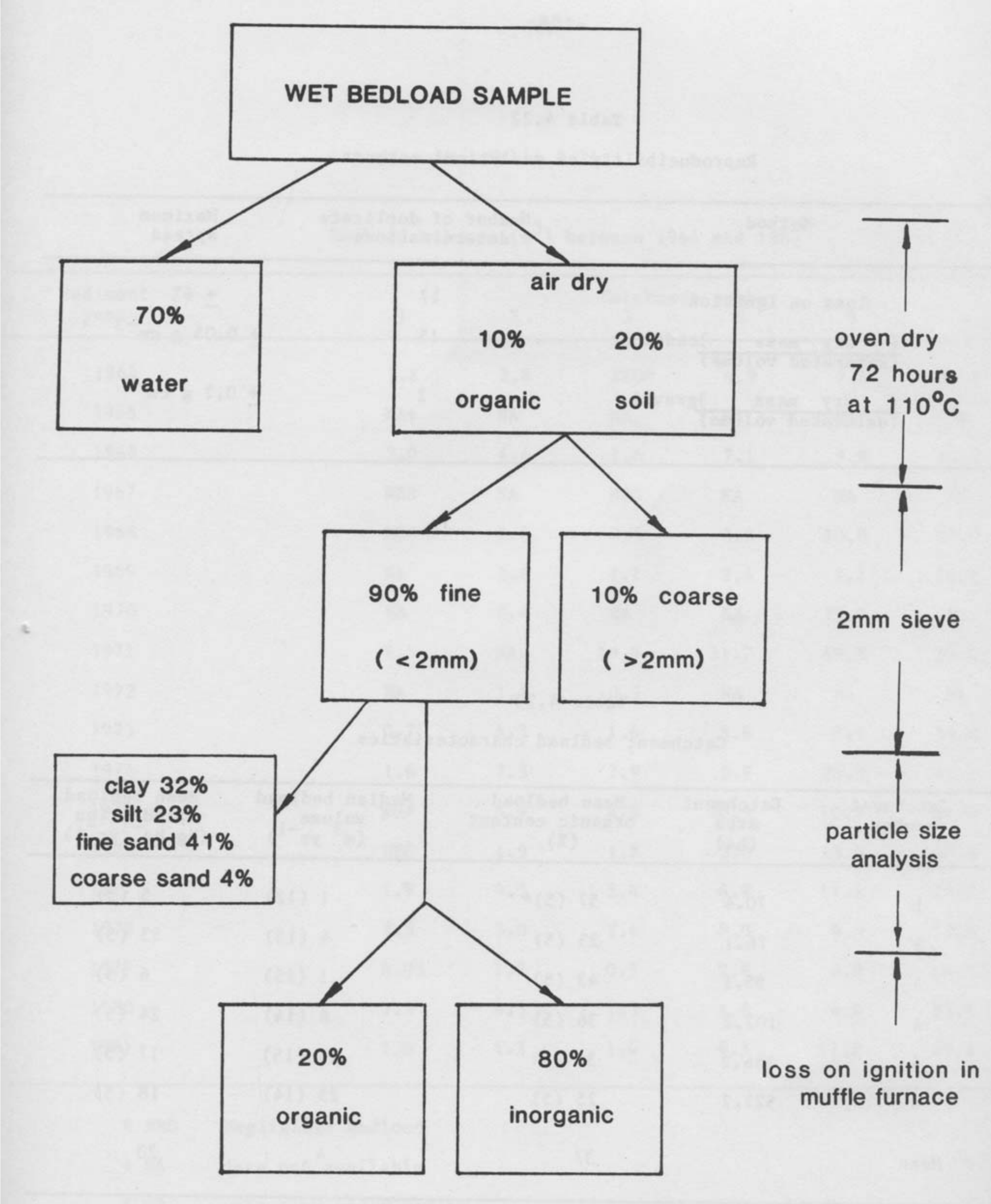


Figure 4.26 - General characteristics of Reefton bedload

Table 4.23 - Catchment bedload characteristics

Catchment number	Catchment area (ha)	Mean bedload organic content (%)	Median bedload volume (m^3 yr^{-1})	Mean bedload production (kg ha^{-1} yr^{-1})
1	70.4	57 (5)*	1 (12)	5 (5)
2	7production	23 (5)	4 (15)	53 (5)
1	95.1	43 (5)	1 (15)	6 (5)
4	107.2	36 (5)	6 (14)	24 (5)
5	156.2	36 (5)	11 (15)	17 (5)
6	521.2	25 (5)	25 (14)	18 (5)
Mean		37	4	20

* figures in brackets are number of yearly observations

Table 4.24 - Bedload volumes (m3) between 1964 and 1981

Sediment year	Catchment number					
	1	2	3	4	5	6
1964	1.2	2.8	NEG*	4.9	7.6	26.
1965	NA+	NA	NA	NA	NA	NA
1966	2.0	4.6	1.6	7.1	9.8	24.
1967	NFG	NA	NEG	NA	NA	NA
1968	NEG	2.6	0.6	3.8	10.0	27.(
1969	NA	2.1	1.1	2.4	7.1	
1970	NA	6.6	NA	NA	13.8	NA
1971	5.5	NA	19.9	31.7	49.5	39.
1972	NA	1.1	0.7	NA	NA	NA
1973	0.7	4.3	1.6	5.8	8.1	34.
1974	1.6	7.5	7.9	9.9	25.5	43.1
1975	WR#	5.9	4.3	10.3	10.1	31.
1976	NEG	1.9	1.2	3.0	15.4	10.
1977	1.9	9.3	3.4	6.9	11.1	29.
1978	2.5	3.0	2.4	8.0	9.9	19.
1979	0.03	1.2	0.3	2.8	4.8	
1980	1.3	4.5	1.3	4.6	6.8	23.
1981	1.6	4.3	1.4	4.5	11.8	29.

* NEG Negligible bedload
\+ NA data not available
1 WR weir pond under repair

Table 4.25 - Bedload volume correlation matrix for the six catchments between 1964 and 1981.

Data for catchments 1 and 3 have been transformed to log (1 + volume), and for the remaining catchments to log (volume)

Catchment number	**Catchment number**					
	1	**2**	**3**	**4**	**5**	**6**
1	1.0	0.729**	0.400	0.735**	0.354	0.642*
2		1.0	0.558*	0.802**	0.546*	0.773**
3			1.0	0.664**	0.691**	0.382
4				1.0	0.766**	0.703**
5					1.0	0.435
6						1.0

* significant at 95% level
** significant at 99% level

Table 4.26 - Correlation coefficients of bedload volume and various runoff parameters (1971-1980). All data are log-transformed.

Runoff parameter in catchment		**Bedload volume in catchment number**					
parameter	**catchment**	**1**	**2**	**3**	**4**	**5**	**6**
Annual runoff	same	0.902**	0.864**	0.805**	0.769*	0.589	0.932**
	4	0.891**	0.845**	0.752*	0.769*	0.456	0.884**
Annual stormflow	same	0.897**	0.862**	0.798**	0.788*	0.623	0.915**
	4	0.926**	0.853**	0.754*	0.788*	0.520	0.845**
Annual baseflow	same	0.832*	0.773*	0.697*	0.628	0.415	0.884**
	4	0.749*	0.780*	0.636*	0.628	0.249	0.885**
Product of storm volume and peak stormflow	same	0.940**	0.830**	0.762*	0.879**	0.760*	0.937**
	4	0.969**	0.844**	0.846**	0.879**	0.591	0.815**

* significant at 95% level
** significant at 99% level

Table 4.27 - Correlation matrix for inter-catchment comparisons (1977-1981) of bedload quantity (tonnes)

Catchment number	Catchment number					
	1	**2**	**3**	**4**	**5**	**6**
1	1.0	0.198	0.870	0.822	0.795	0.477
2		1.0	0.608	0.536	0.695	0.934*
3			1.0	0.945*	0.976**	0.762
4				1.0	0.861	0.610
5					1.0	0.860
6						1.0

* significant at 95% level
** significant at 99% level