Land Protection Division

Research Report No. 4

Logging Alpine Ash
in the
East Kiewa River Catchment

Part I:

Effects on Stream Sediment Levels

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This study is in two parts published in separate volumes.

Part I covers the analysis of flow and sediment concentration over the calibration and treatment periods for the experimental catchments.

Part II deals with estimation of sediment yield and extrapolation of these findings to the proposed logging area in the East Kiewa River Catchment.

EXECUTIVE SUMMARY

This study was established to determine the effects on stream sediment levels of logging alpine ash (Eucalyptus delegatensis).

Continuous record of flow and discrete samples of suspended solids were collected from May 1978 until December 1987.

Data was analysed both monthly and as daily events to ensure validity of the findings.

In the calibration period, both catchments were well-behaved. There was a relative change in Springs Creek during the wet period in the latter half of 1981. Relative flow and sediment concentration increased temporarily, but then returned fairly close to the calibration values. Only small positive changes in flow (<7%) were observed in the roading and third harvest periods. Sediment concentrations were elevated for all phases of the treatment period. The maximum increase of the median value of sediment concentration was +206% in the second harvest period. This increase persisted into the recovery period; it was still +118% when the experiment was stopped in 1987.

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1. INTRODUCTION

The background to the East Kiewa hydrological study and the experimental approach taken have been previously described by Leitch (1981). Briefly, the experiment was established in 1978 with an objective to determine the effects on stream sediment levels of logging alpine ash (*Eucalyptus delegatensis*). The treatment commenced in 1982 and experimental measurements continued until the end of 1987. The key question to be answered is whether forestry operations in the A17 area would add significantly to sediment loads in the East Kiewa River and particularly to the supply reserves of the State Electricity Commission's (SEC) hydroelectric generators.

As part of the restructure of the former Department of Conservation, Forests and Lands the functions and responsibilities of the Forest Hydrology Branch of Research Division, Forest Commission Victoria (FCV), were transferred to the Hydrology Section of the Land Protection Division. This report describes the analysis of hydrological data carried out after the transfer and presents the results of that analysis.

The 'paired catchment' approach was adopted in the experiment with the underlying assumption that adjacent areas respond to natural processes in a similar manner. More specifically, adjacent experimental catchments are assumed to have similar climate, soils and geology. In this experiment, raingauges, stream gauges and sediment samplers were installed to establish inter-catchment relationships. Once a satisfactory relationship was established, the land use on one catchment only was changed and measurements continued. Assuming that the control catchment has not changed, the inter-catchment relationships can predict what would have been measured without treatment. Predicted values were compared to observed values to detect changes due to treatment.

The paired catchments were Slippery Rock Creek and Springs Creek as described by Leitch (1981). The original Land Conservation Council (LCC) recommendations were that Slippery Rock Creek catchment would be treated. During the calibration period, it was realized that logging roads in Slippery Rock Creek catchment would require access roads through Springs Creek catchment. This would have changed the control catchment, and complicated the analysis. Treatment of Springs Creek catchment did not require any roads through the control catchment, and so this catchment was treated.

Another point to note relates to the final Land Conservation Council recommendations 1983. Reference was made to 'determine the effects of logging on sediment bedloads and turbidity in the Slippery Rock Creek and Springs Creek catchments'. At the start of the experimental phase a decision was made to dispense with the measurement of turbidity and substitute the measurement of suspended solids. Also, because of site difficulty, bed load was only measured at Slippery Rock Creek and then only for two years.

2. ANALYSIS OF THE DATA SET

The data set consisted of continuous records of rainfall and water level, and discrete suspended sediment concentrations for both experimental catchments. Initially, suspended sediment was sampled at four-hourly intervals during events and twice a week between events. After a review in March 1979, hourly suspended sediment was sampled during events. Rainfall and water levels were digitized at 6 - minute intervals. Full details of instrumentation are given in Appendix B.

It has been well documented that classical regression analysis, which minimizes the squares of deviations from the calculated line, is very sensitive to extreme data values. (Mosteller and Tukey (1977) and Hampel *et al* (1986) are two examples from the list of references). Although least squares (IS) analysis has been used extensively throughout this report, the findings have been checked using resistant and non-parametric techniques. Exploratory techniques such as boxplots have been used to illustrate general patterns.

A glossary of some mathematical/statistical terms used is included in Appendix J.

2.1 Transfer of Data

The transfer of data collected by the former Forests Commission to the Land Protection Division was not straightforward, essentially because of the incompatibility of the mainframe GCS Burroughs computer and the desk top HP9845B computer.

2.1.1 Storage/Processing on GCS Burroughs

Field data were recorded on the one A35 recorder chart. Three sets of data, rainfall, water level and time of sediment sampling were digitized by MMBW and transferred by magnetic tape to the GCS Burroughs computer system. A suite of programs was developed by the former FCV to condense the water level readings. Rainfall and streamflow were stored in this format. Time of sampling with a sample code was matched with the corresponding sediment concentration following analysis. Within the GCS Burroughs system, there are a number of programs to collate, edit, and make statistical tests on the data.

Note that the value of a given sediment concentration was assumed to apply over a time interval extending half-way to the next sample.

A summary of the analysis by Forest Research to December 1980 was presented by C. Leitch at the First National Symposium on Forest Hydrology, Melbourne, 1982.

2.1.2 Amount of missing data

The amount of missing data is shown in Figure 1.1 for pre-treatment and Figure 1.2 for treatment periods. No data corresponds to days of low flow when no sediment samples were taken. Missing data occurs when samples were attempted but faults occurred in the equipment.

The raingauges in both catchments were not installed at the start of the experiment. The 10% missing rainfall in the post-treatment period is due to two charts which were lost after being digitized. The water level data are available, but the rainfall data are not.

Missing data for sediment in the pre-treatment period was due to the sediment samplers becoming blocked during the larger events. These problems were largely overcome in the treatment period.

2.1.3 Estimation of missing data by Forests Research, FCV

Missing water levels were estimated from corresponding values in the other creek. This was done during routine processing by MMBW.

Each water year, a linear regression was established from the logarithms of sediment concentrations for both catchments (Figure 13). The two lines are the regressions of y on; and x on y. Some outliers were excluded from the main population before determining the regressions. Each regression was used to estimate missing sediment data in the other catchment, as described by Leitch (1981):-.

> "Where sediment concentrations were to be estimated for both creeks, sediment concentrations of Springs Creek were estimated (by examining sediment concentration data from similar past events), then the corresponding sediment concentrations of Slippery Rock Creek were calculated to be 1.22 times these estimates".

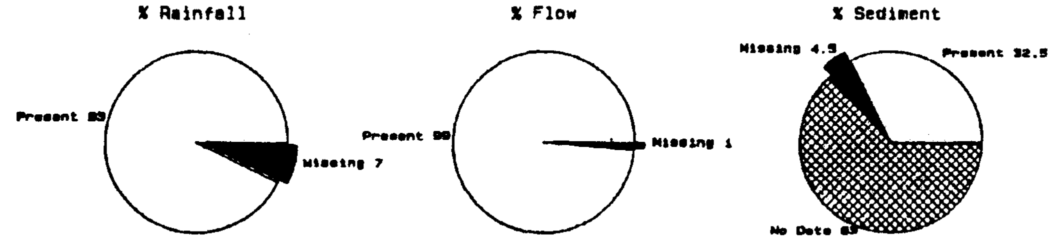
2.1.4 Rainfall

Rainfall charts were digitized by MMBW only to 1983. Although the raw data was stored in condensed/compressed format, the daily rainfall data was only available as 9am -to- 9am totals. This format is used by the Bureau of Meteorology.

All analysis within LPD Hydrology has been done on a midnight-to-midnight basis. There was a program on the GCS Burroughs to convert the rainfall data to midnight-to-midnight values. However, this was a rather lengthy procedure and was not completely satisfactory. The most direct solution was to enter the daily rainfall values manually into the HP 9845B computer.

Figure 1.1 Percentage of missing data - pre-treatment period

Springs Creek



Slippery Rock Creek

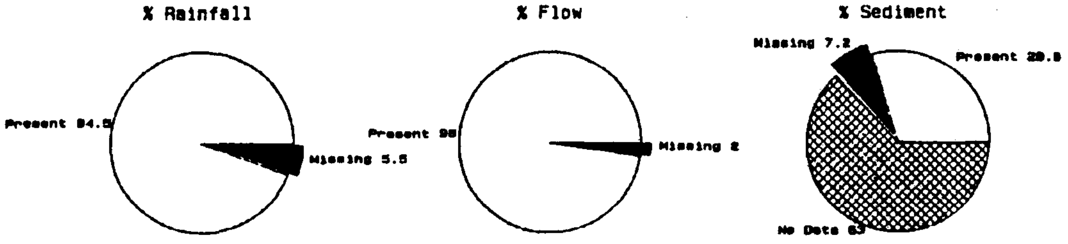
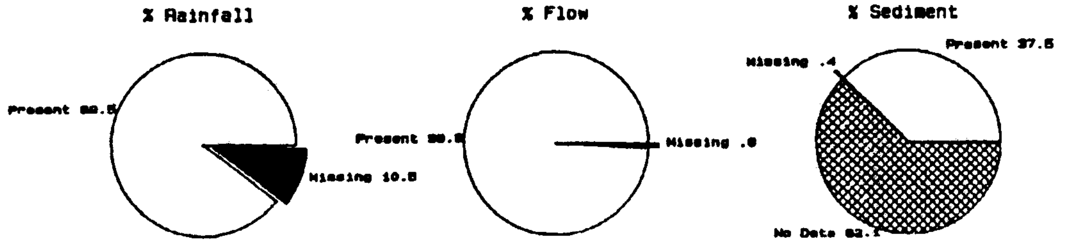


Figure 1.2 Percentage of missing data - treatment period

Springs Creek



Slippery Rock Creek

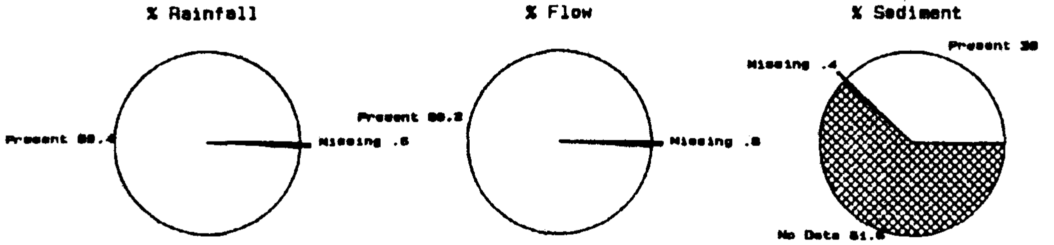
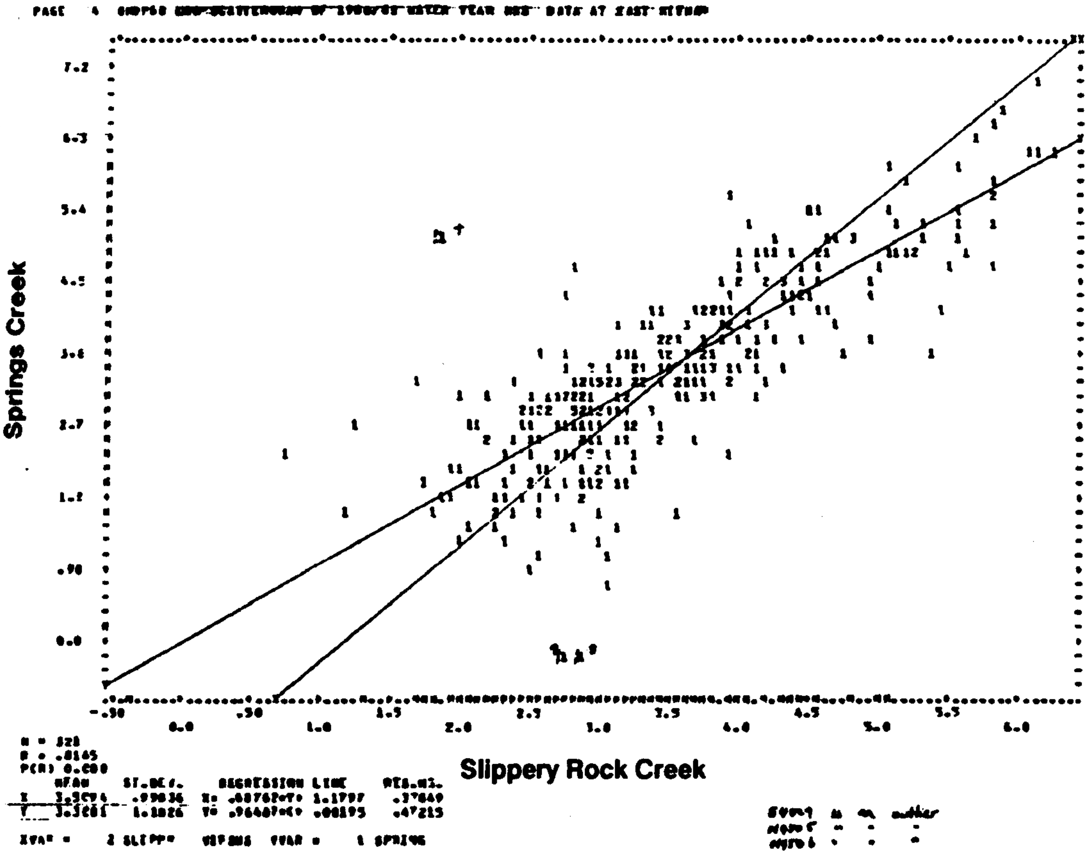


Figure 1.3 FCV estimation of missing sediment concentration using linear regression with removal of outliers



2.1.5 Streamflow

There were a number of problems in getting the A35 charts processed by MMBW. These include fitting in with MMBW priority system, change in the MMBW computing system, failure of the MMBW digitizer and MMBW staff cutbacks.

It was decided to digitize the 1987 data within LPD directly onto the HP 9845B computer. Earlier data at daily level was entered manually into the HP 9845B computer.

2.1.6 Sediment

The whole data set of sediment concentration value and its time of sampling for each creek was entered manually into the HP 9845B computer.

2.1.7 Checking the data set

Extensive checking and editing was then done to ensure that:

(i) all three data sets were synchronised,
(ii) estimated data in the original data set was suitably identified,
(iii) sediment concentration values not fitting the general pattern were analysed separately (Section 2.4.9).

2.2 Rainfall

Long term rainfall records are available for Bogong Village, which is situated 1.5km south of the experimental catchments. Annual rainfall since 1939 has been plotted against the order statistic m/(N + 1) where m is the rank and N is the number of observations. (Figure 2.1) (Yevjevich, 1972, page 90).

The initial analysis (1978-1980) was made in a period of near average annual rainfall. Results of this analysis have been reported by Leitch (1982).

The final year of calibration was the wettest in the study period, and was followed by the 1982 drought - the second driest year in the 49-year record at Bogong Village (Figure 2.1).

The succeeding years fell within the low to medium range with 1986 being wetter than average.

Annual totals of Bogong Village rainfall are shown in Table 2.1.

Figure 2.1 Long term probability plot of Bogong Village rainfall (1942-1987)

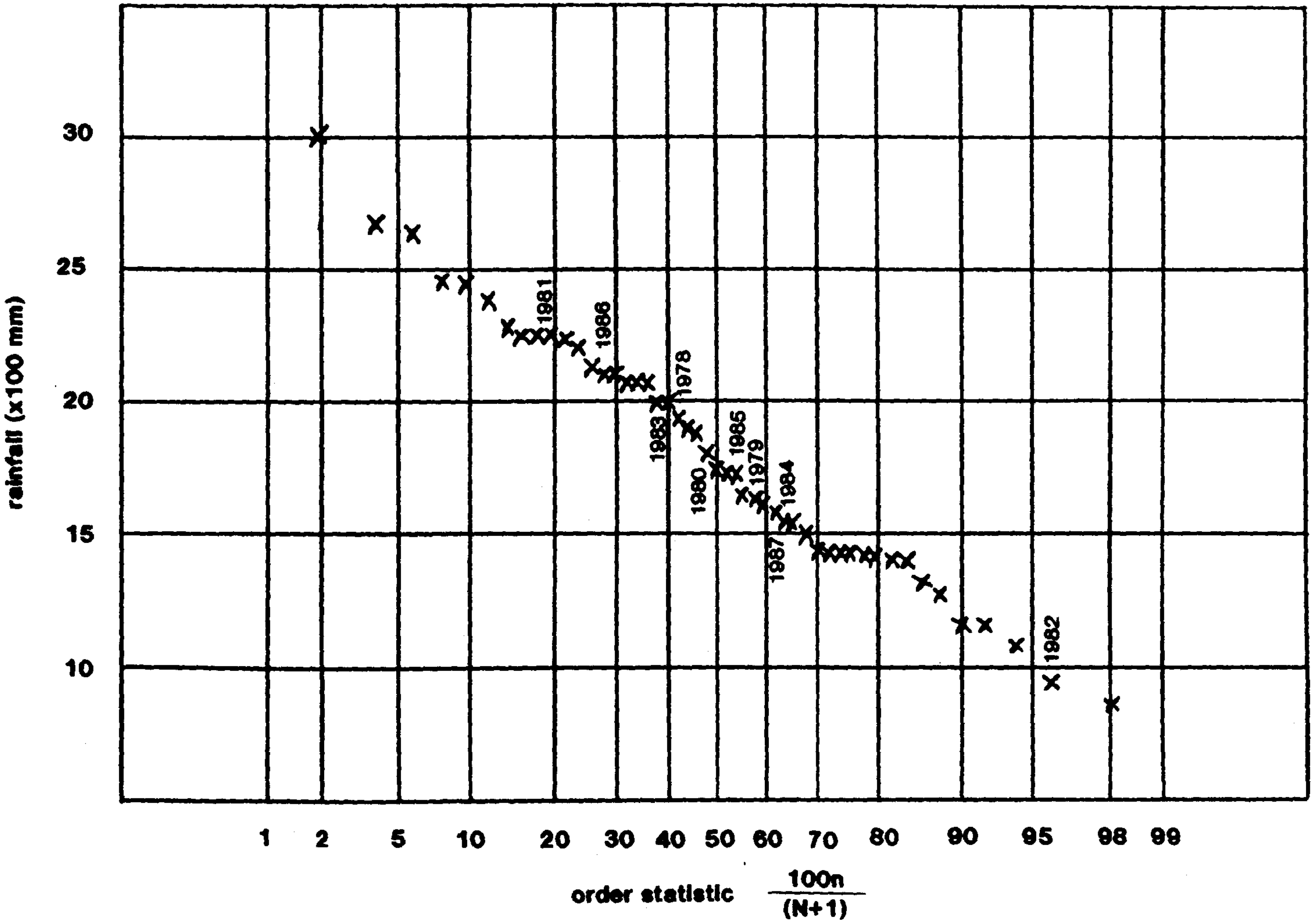


Table 2.1 - Annual rainfall totals at Bogong Village for the period of the study

Year	Annual Rainfall (mm)
1978	1940.8
1979	1611.9
1980	17553
1981	2246.5
1982	938.8
1983	1998.6
1984	1564.1
1985	1725.9
1986	2104.5
1987	1585.5

Annual distribution of daily rainfall at Bogong Village is exhibited in Table 2.2. The figures estimate the number of rain days and the rainfall intensity in the two catchments.

Annual water year totals (mm), (Table 23), directly compare the amount of rainfall that fell at Bogong Village and the experimental catchments. There is a decrease in the rainfall recorded at Slippery Rock Creek compared to the other gauges over the study period. This may be due to inadequate exposure of the raingauge, with some sheltering by overhanging branches.

The raingauges in the experimental catchments were located at low elevations near the catchment outlets, and may not be representative of catchment rainfall.

Daily graphs of Slippery Rock Creek rainfall are shown in Figures 2.2 and 2.3.

Table 2.3 - Annual water year rainfall totals (mm) for Bogong Village, Slippery Rock Creek and Springs Creek.

Year	Bogong Village	Slippery Rock Creek	Springs Creek
1978/79	17483	-	-
1979/80	1626.7	1799.7	1755.1
1980/81	1848.3	2061.1	1943.6
1981/82	2240.5	2566.4	2613.1
1982/83	1068.8	1194.3	1124.6
1983/84	1967.1	2039.8	2190.2
1984/85	1467.7	1457.6	1176.6*
1985/86	1487.9	14243	-
1986/87	2275.4	2119.0	2308.7 - missing data * incomplete year

Table 2.2 - Annual Distribution (number of days) of daily rainfall at Bogong Village

Daily Rainfall (mm)	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
0	191	224	223	203	247	198	206	215	191	221
0.1-15.0	125	103	103	107	106	118	129	102	98	111
15.1-25.0	29	21	17	24	11	24	17	19	15	13
25.1-50.0	15	16	17	23	0	18	9	17	26	13
50.1-75.0	5	1	5	8	1	5	3	2	4	6
75.1-100.0	0	0	1	0	0	2	2	1	1	0

1985 missing 9 days
1986 missing 29 days
1987 missing 1 day

Figure 2.2 Slippery Rock Creek daily rainfall (mm): May 1978 - January 1982

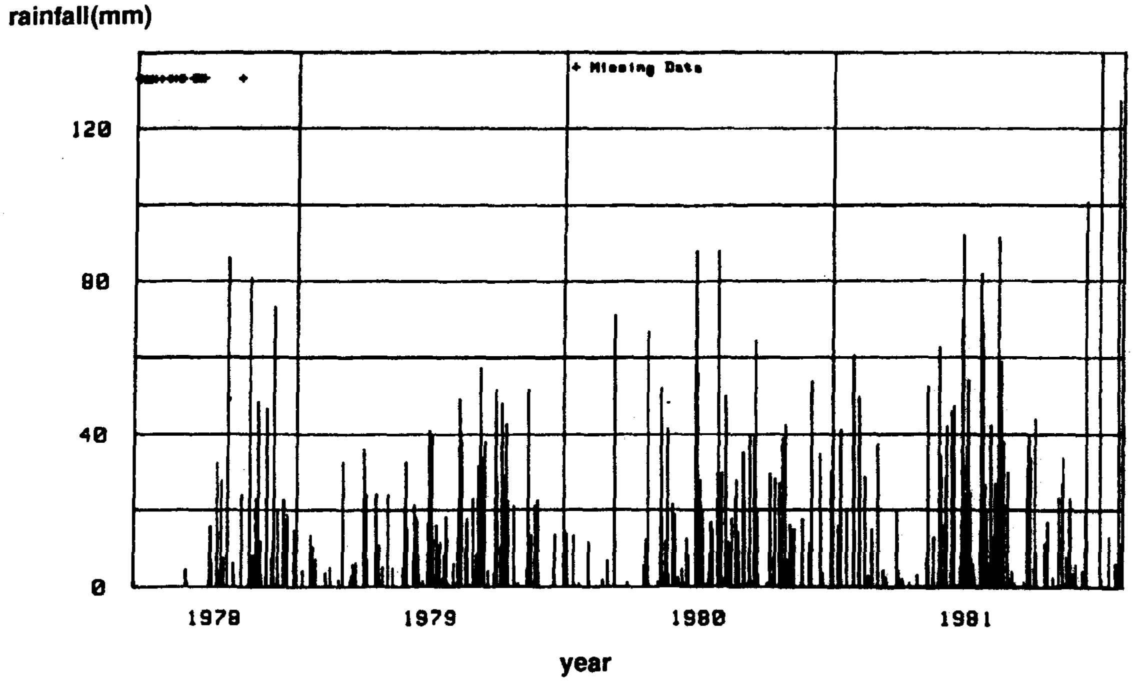
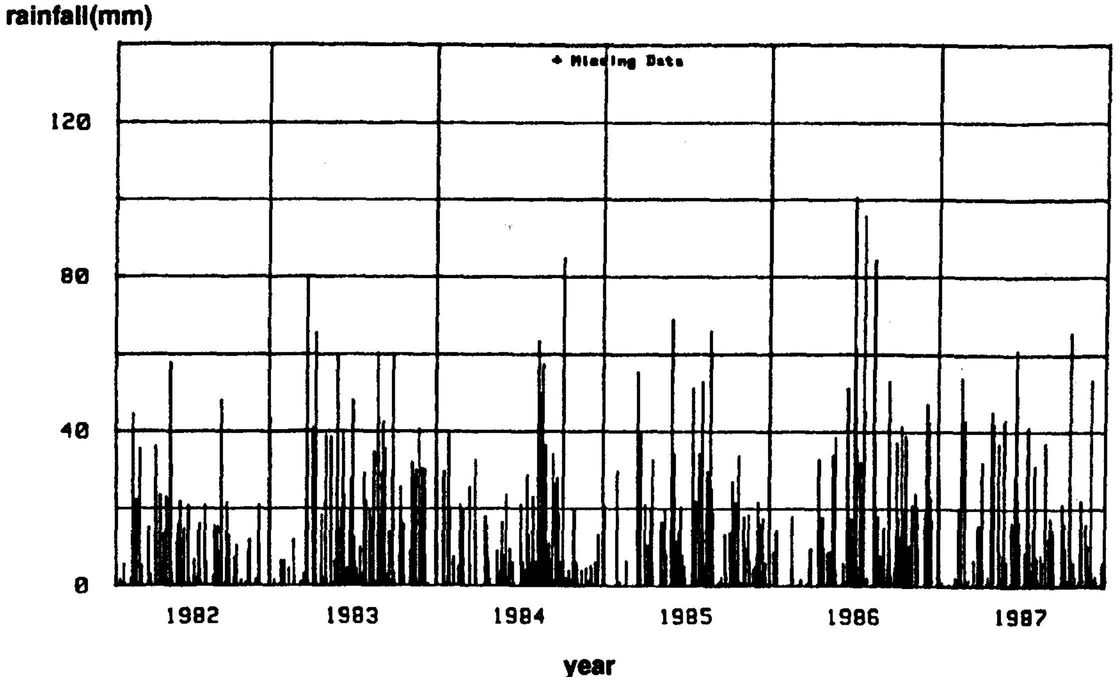


Figure 2.3 Slippery Rock Creek daily rainfall (mm): February 1982 - December 1987



2.2.1 Rainfall consistency over time and space

Double mass plots were used to establish the reliability of the rainfall data of Springs Creek and Slippery Rock Creek catchments over time and space. This procedure is described in various reports (Langford and O'Shaughnessy 1977, 1980) (Wu *et al*, 1984).

There are three raingauges to be tested. Slippery Rock Creek and Springs Creek raingauges indicate rainfall in the lower portions of the experimental catchments. Bogong Village raingauge is 1.5 km from the area and has a long term record. This data was used in early analysis (Leitch, 1981).

The reliability was established by first checking some nearby raingauges against the Melbourne Regional Office raingauge, and then testing the individual raingauges. Averaging makes the data set more homogeneous.

The four stations selected for initial comparison were Harrietville, Tawonga, Mt Beauty and Rocky Valley. Annual double mass data from these stations were compared individually to the Melbourne Regional Office raingauge. Results are shown in Figure 2.4. Gauges at Mt Beauty, Tawonga and Harrietville showed no significant departure from a straight line and were judged consistent. Rocky Valley raingauge was excluded because of extensive missing data.

Next, a double mass curve was plotted of Bogong Village raingauge data against the average of the three consistent raingauges (Figure 2.5). There were discontinuities corresponding to the missing data, but the slopes of the segments were equal. This indicated that there was no change in Bogong Village raingauge relative to the 3-station mean. Therefore, Bogong Village raingauge is consistent.

The Slippery Rock Creek raingauge was tested at a monthly level because of the short duration of record. In this case the double mass plot (Figure 2.6) showed a change in slope at approximately (6000, 8000). This meant that the Slippery Rock Creek raingauge had changed mid-1983 relative to the 3-station mean. This may have been due to equipment malfunction and/or interference from vegetation. Therefore, Slippery Rock Creek raingauge is not consistent.

The process was repeated with Springs Creek raingauge data (Figure 2.7). There were discontinuities due to missing data, and a change in slope in 1981 (corresponding to (4000, 4000)), but the overall slope was uniform. Therefore, Springs Creek data appears consistent, but the missing data limits its value in subsequent statistical analysis.

The overall conclusion is that the Bogong Village raingauge provides the only consistent long-term rainfall record. However, this raingauge is not optimally located for estimating catchment rainfall.

Figure 2.4 Double mass plot of annual rainfall (1961-1987): Melbourne Regional Office versus four stations

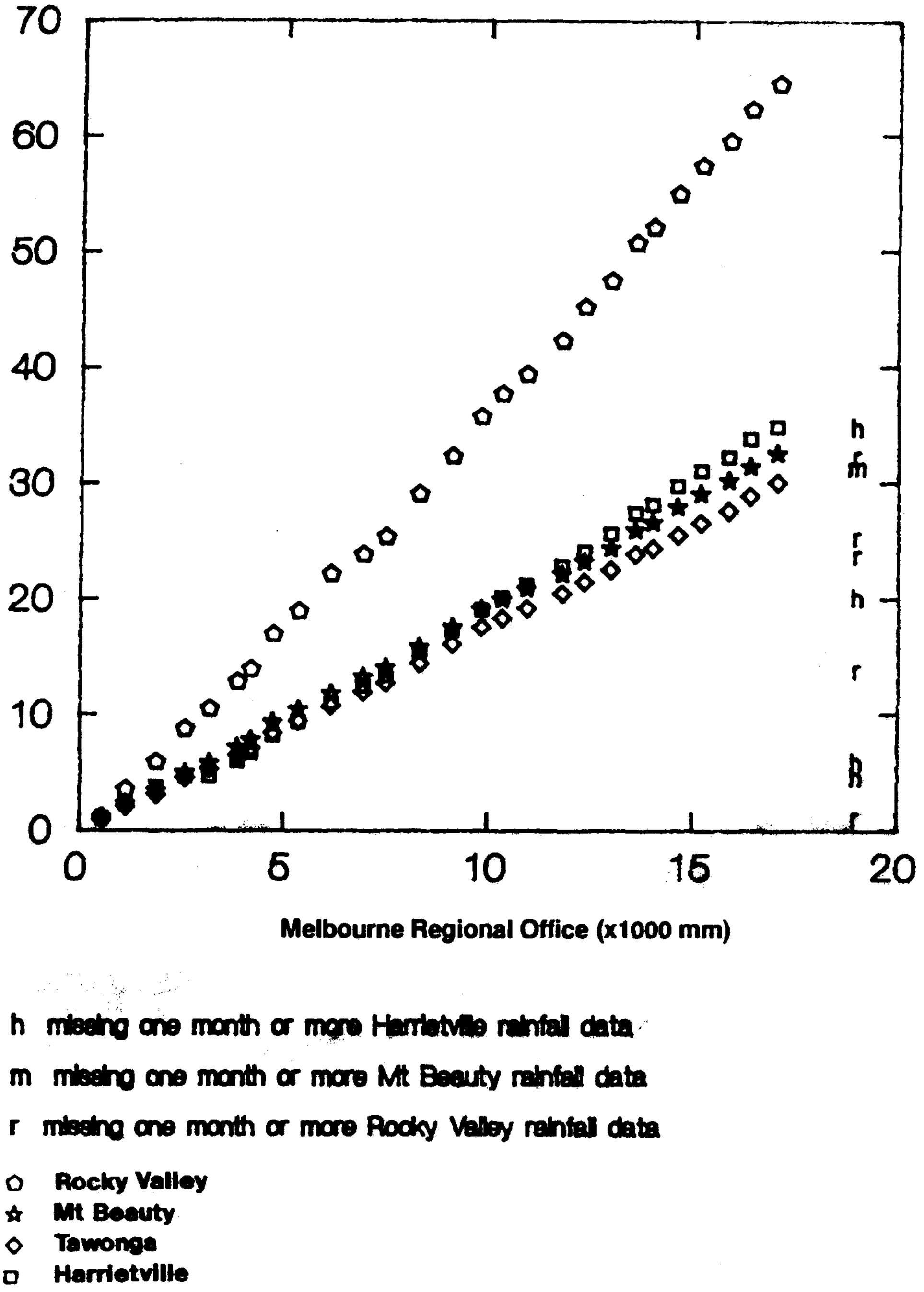


Figure 2.5 Double mass plot of annual rainfall (1961-1987): Bogong Village versus three station mean

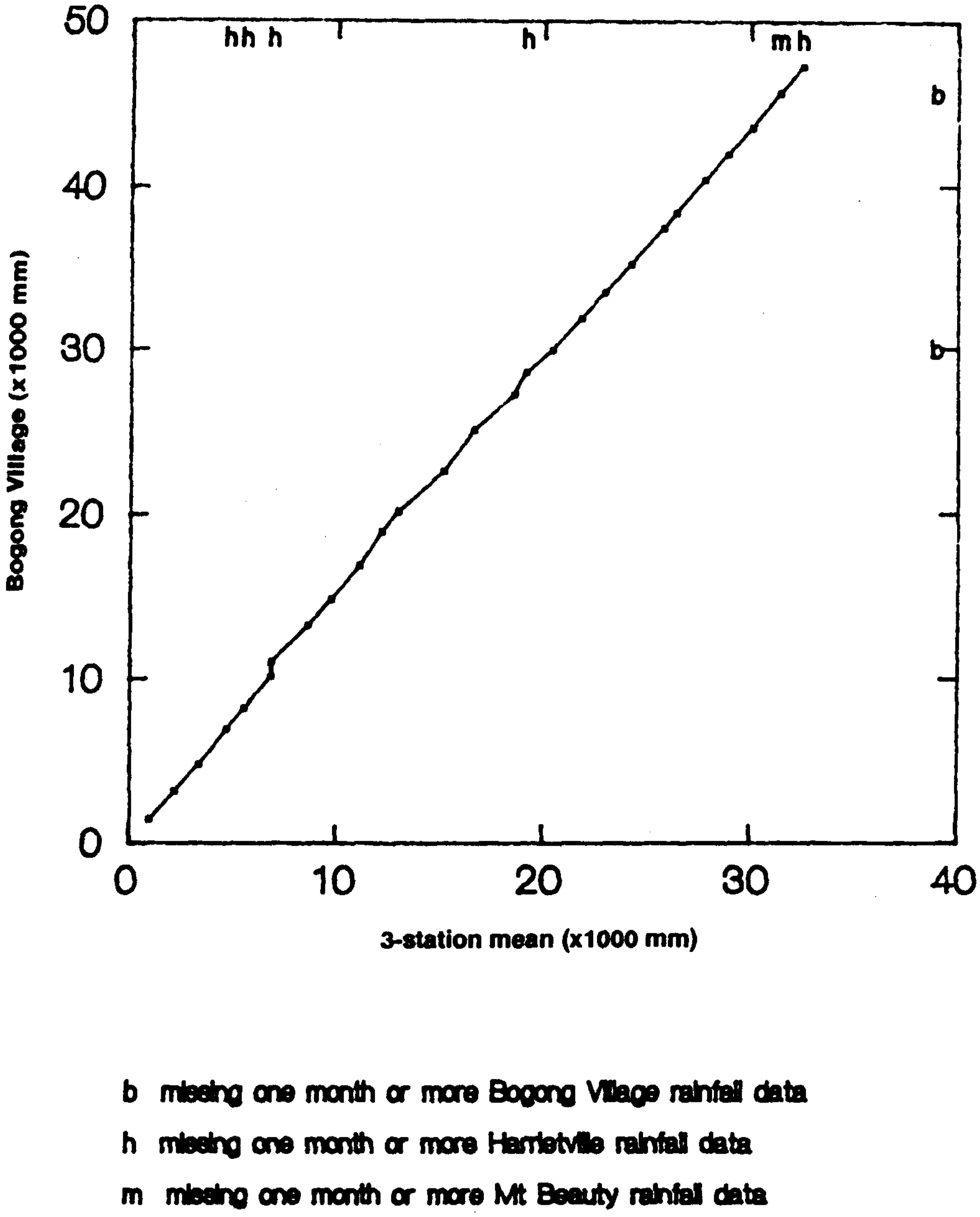
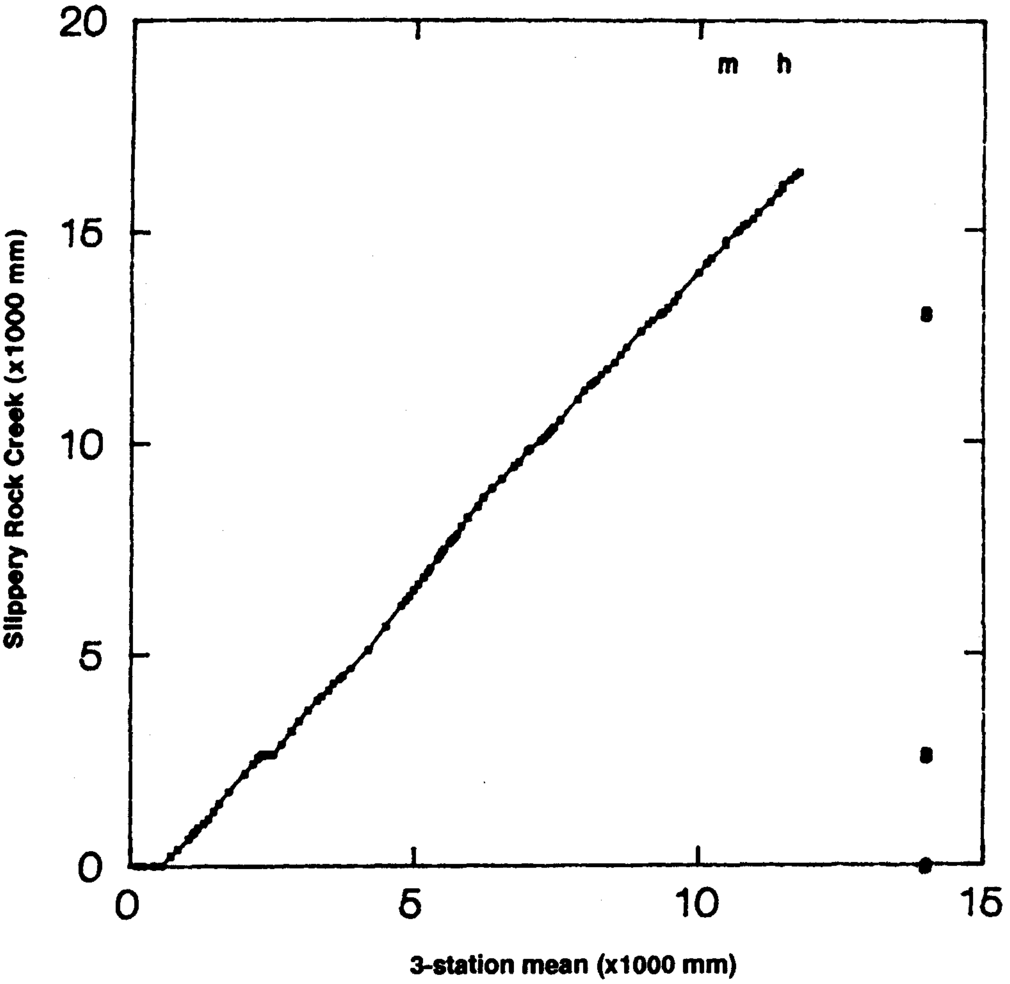


Figure 2.6 Double mass plot of monthly rainfall (1978-1987): Slippery Rock Creek versus three station mean

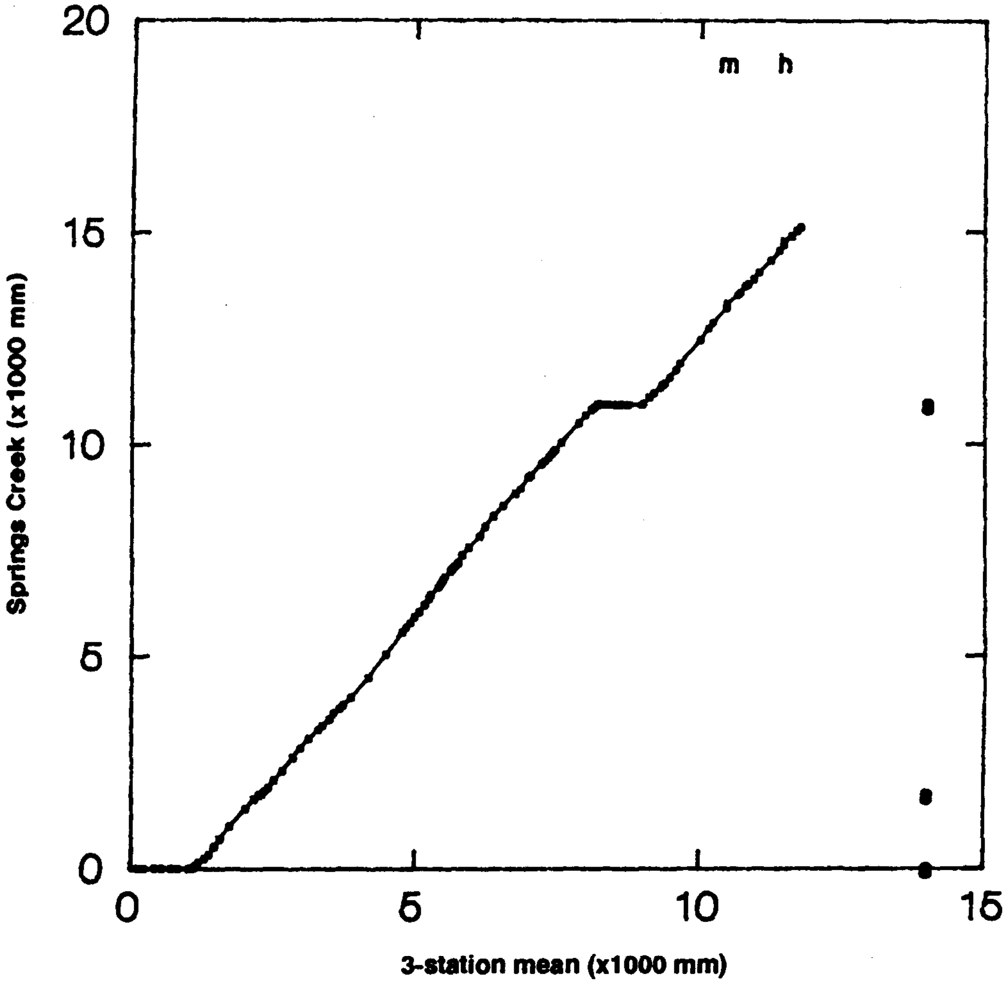


s missing one month or more Slippery Rock creek rainfall data

h missing one month or more Harrietville rainfall data

m missing one month or more Mt Beauty rainfall data

Figure 2.7 Double mass plot of monthly rainfall (1978-1987): Springs Creek versus three station mean



s missing one month or more Springs creek rainfall data

h missing one month or more Harrietville rainfall data

m missing one month or more Mt Beauty rainfall data

2.3 Streamflow

Plots of mean daily flow for pre-treatment and treatment periods of the study are shown in Figures 2.8 and 2.9 respectively. The plots highlight the effect on flow of the 1981/82 high rainfall year (2240 mm at Bogong) and the very low rainfall year, 1982/83 (1069 mm Bogong). In June, July and August 1981, Bogong Village received approximately 60% of its annual rainfall. These high rainfall months resulted in a build-up in the baseflow level and events that are a lot higher than average. This did not occur in the wetter year (1986/87) because rainfall is spread more evenly over the year (Figures 2.10).

The low level of streamflow in 1982/83 contrasts strongly with the streamflow of 1981/82. There is very little build up in baseflow in the winter months (Figure 2.9 & 2.10).

2.3.1 Double mass plots of flow

Accumulated flows for each catchment plotted against time (Figure 2.11) and against each other (Figure 2.12) show no significant departures from the lines. In Figure 2.11 the cyclic nature of the flow is apparent. The steep increases correspond to a build-up in baseflow and an increasing number of events during the wetter months. The flat sections correspond to the drier months. The anomolousness of 1981/82 and 1982/83 streamflow is prominent, with the very steep increase occurring in mid 1981 and the absence of the wet-dry cycle in 1982.

Total amount of flow is greater at Springs Creek. Approximately 70 000 *l*/s accumulated flow passed through the weir at Springs Creek compared to 55 000 *l*/s at Slippery Rock Creek during the pre-treatment period. The corresponding values were 90 000 *l*/s and 75 000 *l*/s respectively during the treatment period.

The double mass plot (Figure 2.12) shows two slight deviation from a straight line. The first corresponds to the 1982/83 dry year at 68 0001/s, and the other to 1985 at 105 000 *l*/s.

2.3.2 Flow duration curves

Comparison of flow duration curves of mean daily flow in the pre-treatment (Figure 2.13) and treatment (Figure 2.14) periods indicated that there was a substantial change in flow above the 50 *l*/s mark, i.e. event flow, in both creeks. The pre-treatment period had a higher percentage of events greater than 50 *l*/s compared to the treatment period. With the removal of daily flow observations from June 1981 to January 1982 (corresponding to the high rainfall period from the pre-treatment data set), the resulting flow duration curve (Figure 2.15) was almost identical to that of the treatment duration curve (Figure 2.14).

It appears from these graphs that there has not been a major change in the distribution of flow from the catchments.

Figure 2.8 Mean daily streamflow (l/s): May 1978 - January 1982

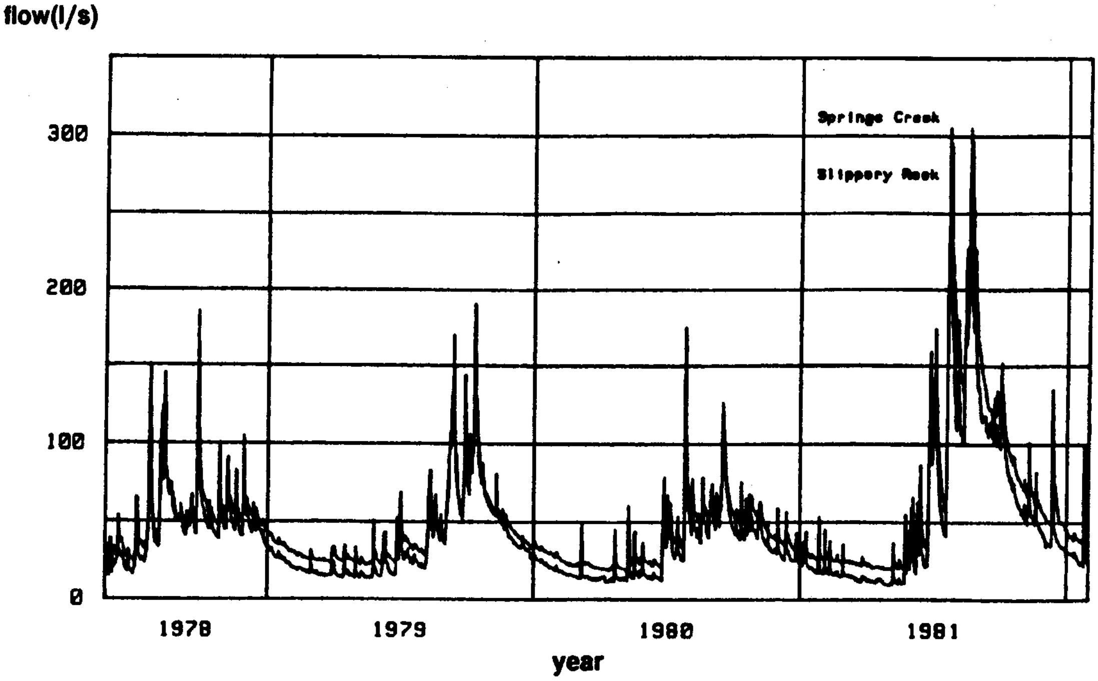


Figure 2.9 Mean daily streamflow (I/s): February 1982 - December 1987

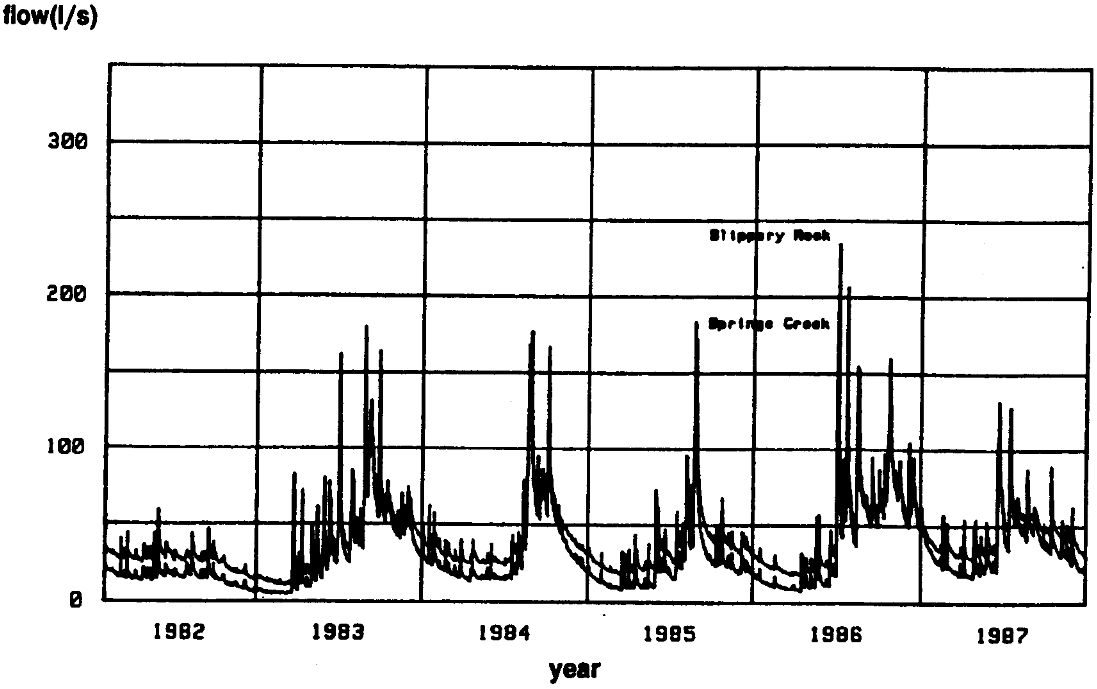


Figure 2.10 A comparison of monthly rainfall (mm) total against monthly streamflow (l/s)

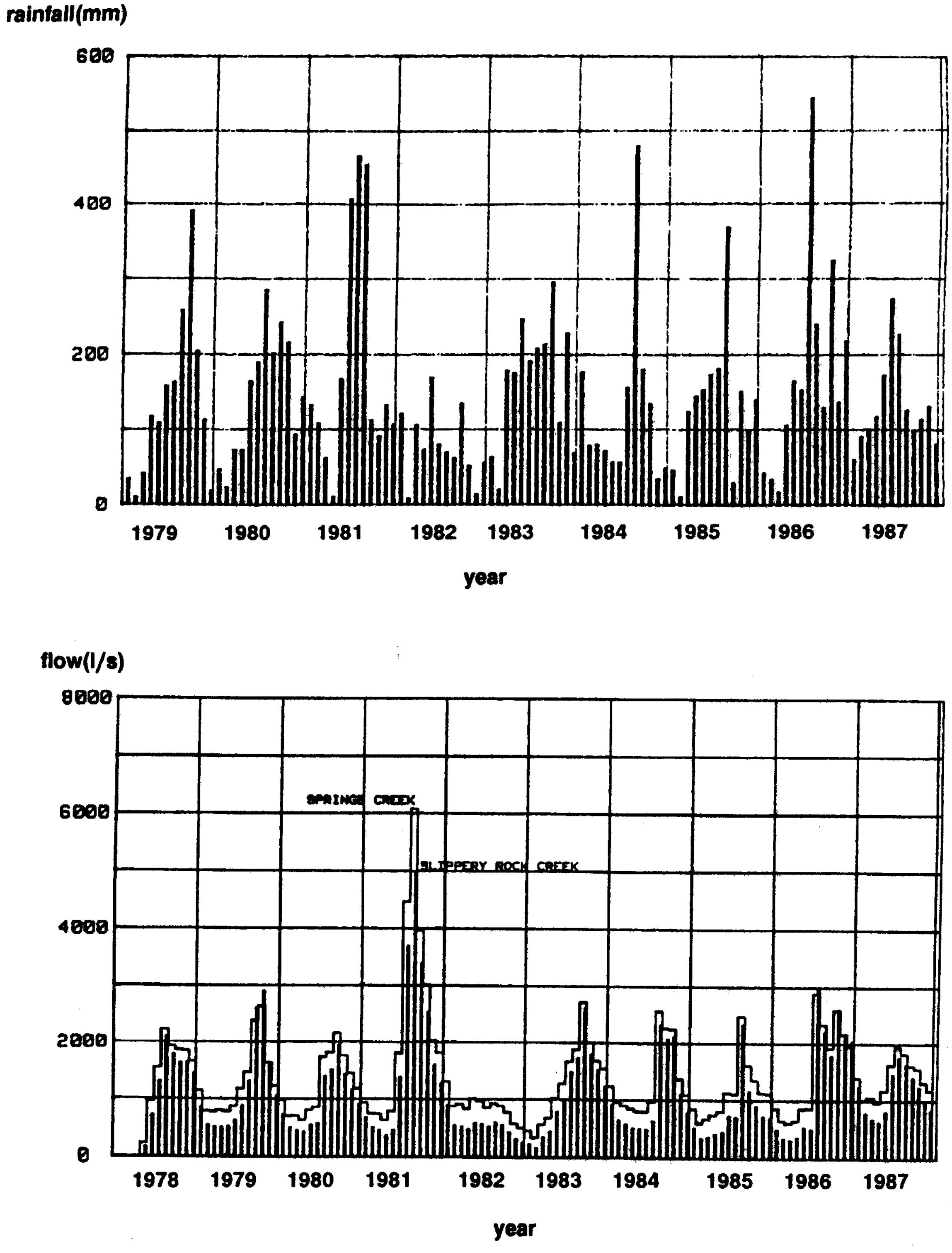


Figure 2.11 Accumulated mean daily streamflow (l/s): Springs Creek versus Slippery Rock Creek

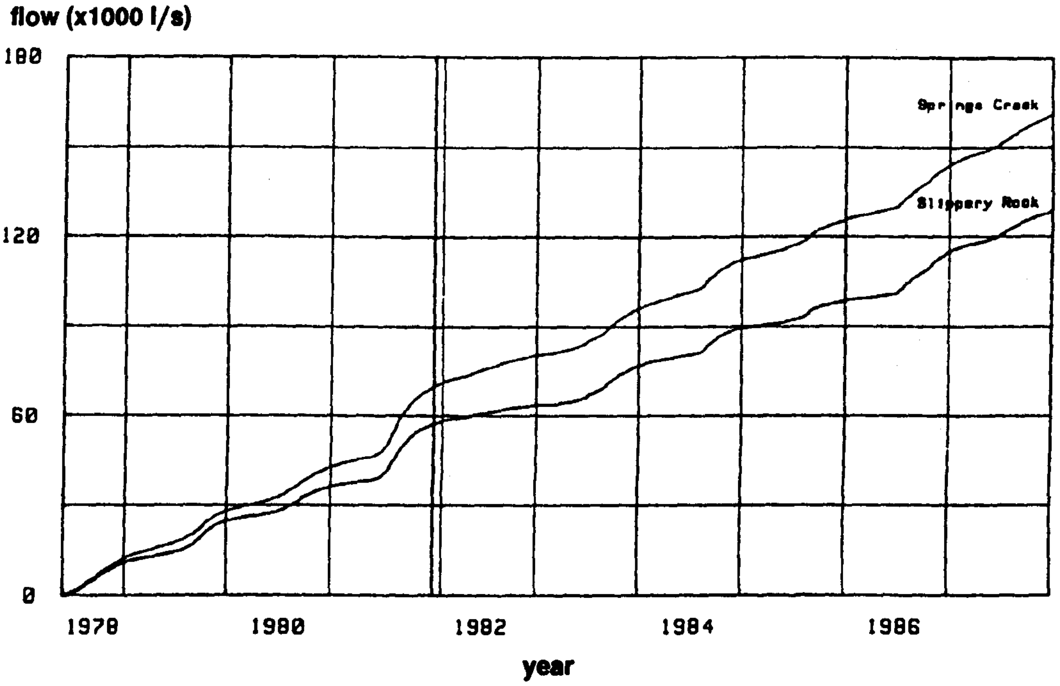


Figure 2.12 Double mass plot of mean daily streamflow (x1000 l/s) of Springs Creek versus Slippery Rock Creek

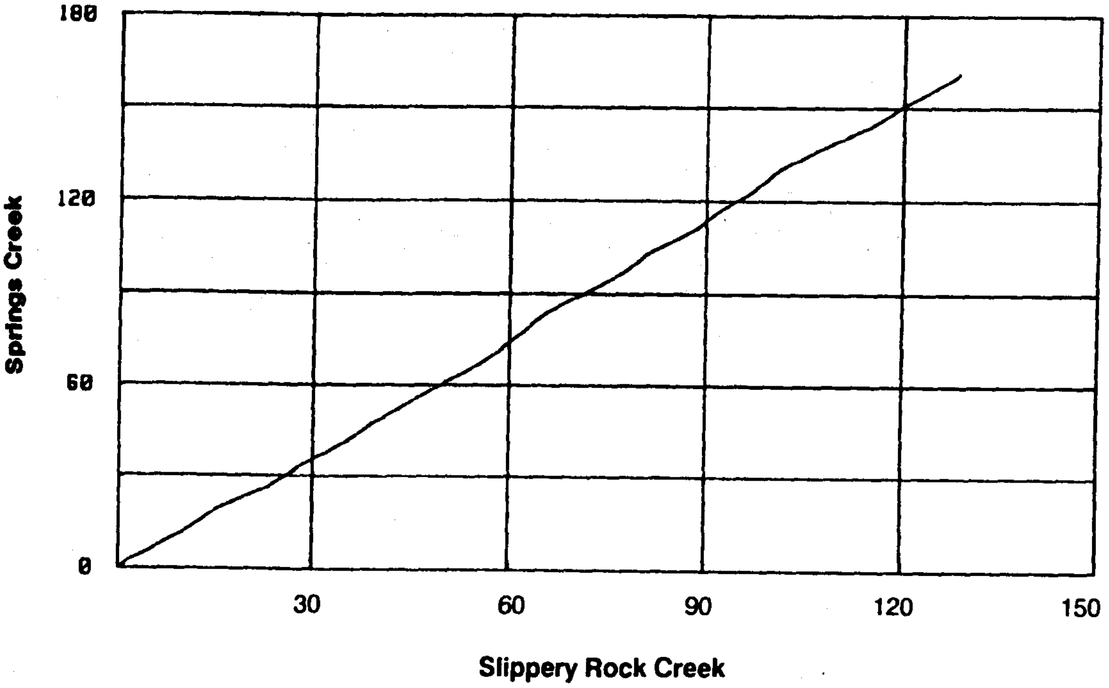


Figure 2.13 Flow duration curves of pre-treatment mean daily streamflow (l/s)

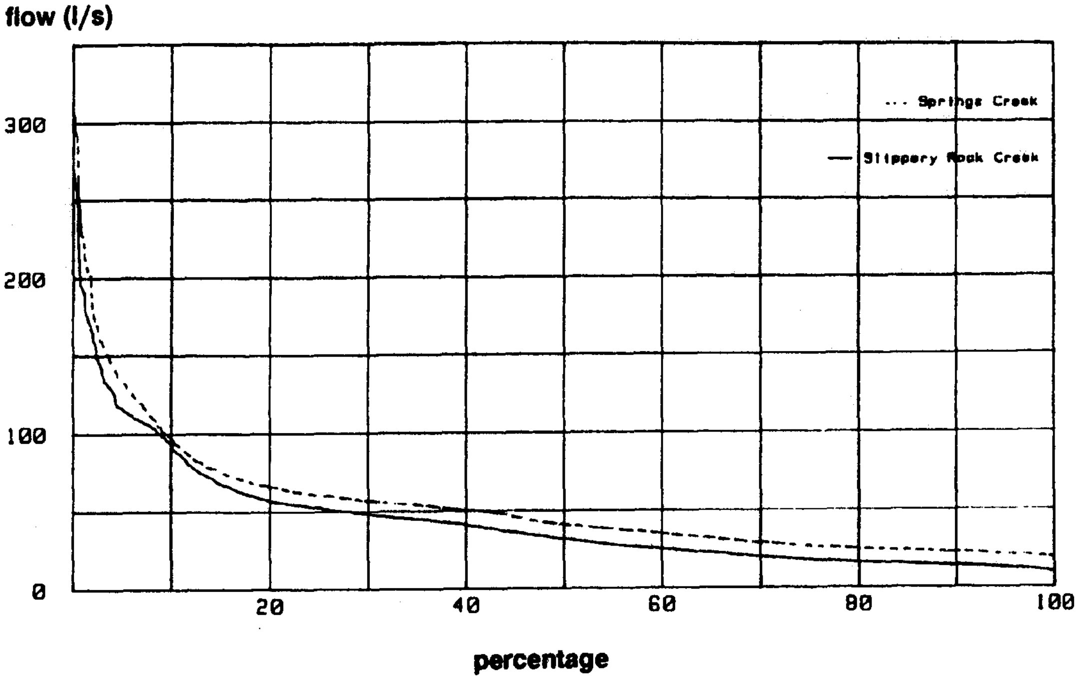


Figure 2.14 Flow duration curves of treatment mean daily streamflow (l/s)

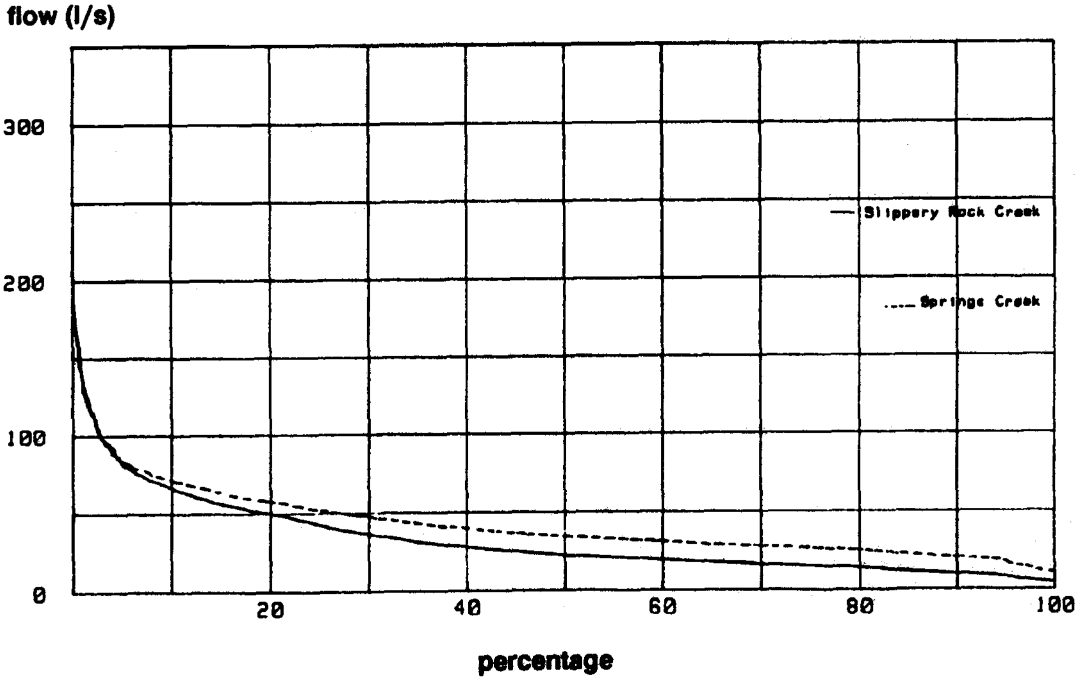
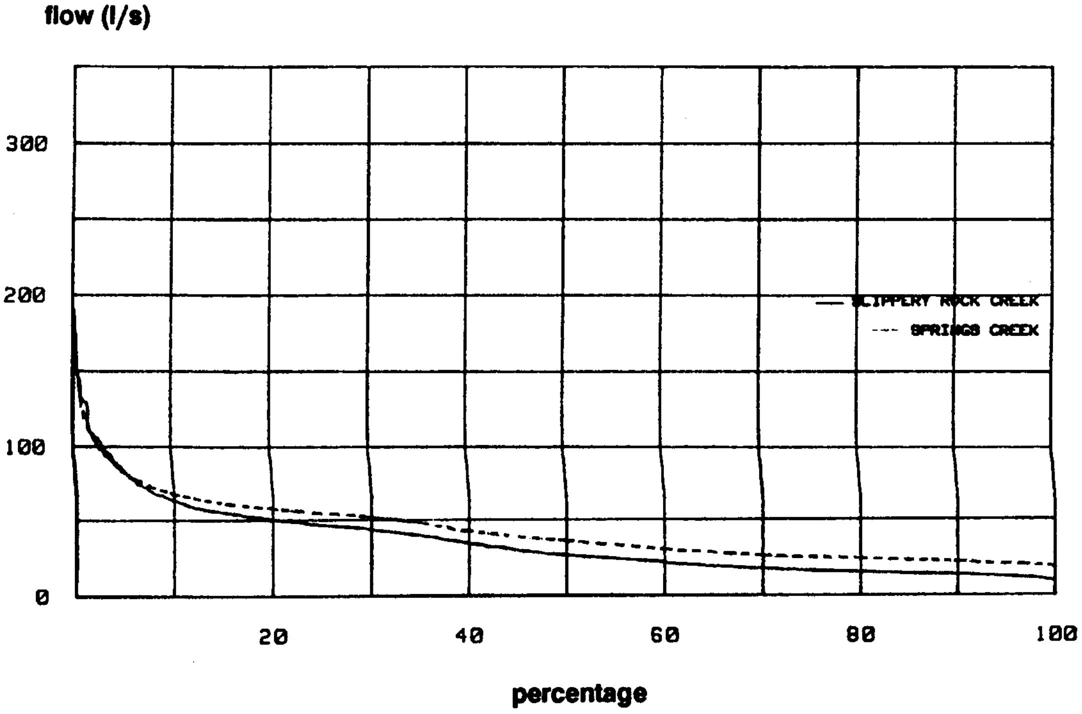


Figure 2.15 Flow duration curves of pre-treatment mean daily streamflow (l/s) with June 1981 to February 1982 removed



2.3.3 Base/event separation

In this study two components of flow were considered:- baseflow from moisture in the soil, and stormflow from the saturated region near the stream itself. A linear ramp was chosen which (i) was steep enough to separate events, (ii) was shallow enough to fit continuously under the flow plot, and (iii) allowed for recession in discharge to be registered as baseflow. Using these criteria, the slope of the rising ramp for each catchment was 1.5 litres/second/day. Details of baseflow and stormflow are given in Table G2, (Appendix G). Baseflow is in the range 81 - 88% of total flow. There are no detectable changes in baseflow associated with the treatment.

2.3.4 Baseflow recession

A baseflow recession coefficient was obtained following the method outlined by Duncan (1980). Baseflows at the start of each month for both creeks were found by drawing baseflow curves on annual graphs of daily flow. For each annual recession, baseflow at the start of each month was plotted against time on log-linear graph paper. A straight line was drawn through the steepest part of each recession, and the gradient calculated. Values for the annual recessions are given in Table G2. There were no detectable trends in the recession coefficients in either creek. The mean of the gradients was used to find the recession coefficients for both catchments. The coefficients are shown in Table 2.4.

Table 2.4 - Baseflow recession coefficients

Catchment	Recession Coefficient	95% limits on coefficient
Slippery Rock Creek	0.81	± 0.17
Springs Creek pre-treatment 1978/79-1980/81	0.77	± 0.15
treatment 1981/82-1986/87	0.67	± 0.12

2.3.5 Exploratory and non-parametric analysis

The motivation here is to use resistant techniques to look at the data in batches and reach broad conclusions, before proceeding with the more detailed analysis. A description of the techniques is given in the Glossary (Appendix J).

Boxplots are intended to summarise the broad characteristics of the creeks. Flow data has been transformed by taking logarithms to make the distributions more symmetrical.

The boxplots for the flow are shown in Figure 2.16 on a common scale.

The overall distributions of both data sets are similar in the pre-treatment and treatment periods. The median for Slippery Rock Creek is lower in the treatment period.

The Mann-Whitney test is applied to raw data to test for possible differences in flow in pre-treatment and post-treatment periods. Results are shown in Table 2.5.

The boxplots show that Slippery Rock Creek data is low in the treatment period compared to the pre-treatment period. The Mann-Whitney test is close to significance for this period. Both tests indicate that further investigations are necessary to verify stability of the control catchment.

Monthly streamflows from both catchments were tested against monthly rainfall from Bogong Village. Bogong Village rainfall is in Appendix G. Both sets of data were transformed to make their distributions symmetrical - logarithmic for streamflow, and square root for rainfall. Simple linear regressions were established of the form:-

Y = a + bx

where x is Bogong Village rainfall
y is catchment streamflow
a, b are constants

Autocorrelation in the error terms was incorporated in the model as discussed in Appendix K1. In this case, catchment streamflow was lagged one term and rainfall was lagged two terms in achieving the transformation. Results are shown in Table 2.6.

The results are shown below:-

Table 2.6 - LS regression of streamflow versus Bogong Village rainfall

Dependent Variable	Period	n	a	b	d.f. (b)	R^2 (%)	DW
Springs Creek	Pre-treatment June '78-Jan '82	43	.0042	.0189	.003	56.8	1.61
	Treatment Feb '82-Dec '87	69	-.0004	.0189	.002	49.5	2.31
Slippery Rock Creek	Pre-treatment June '78-Jan '82	43	.0037	.0236	.003	57.0	1.46
	Treatment Feb '82-Dec '87	69	.0002	.0258	.003	45.7	233

Figure 2.16 Boxplots of monthly streamflow log (*l*/s): pre-treatment period June 78-Jan 82, treatment Feb 82-Dec 87

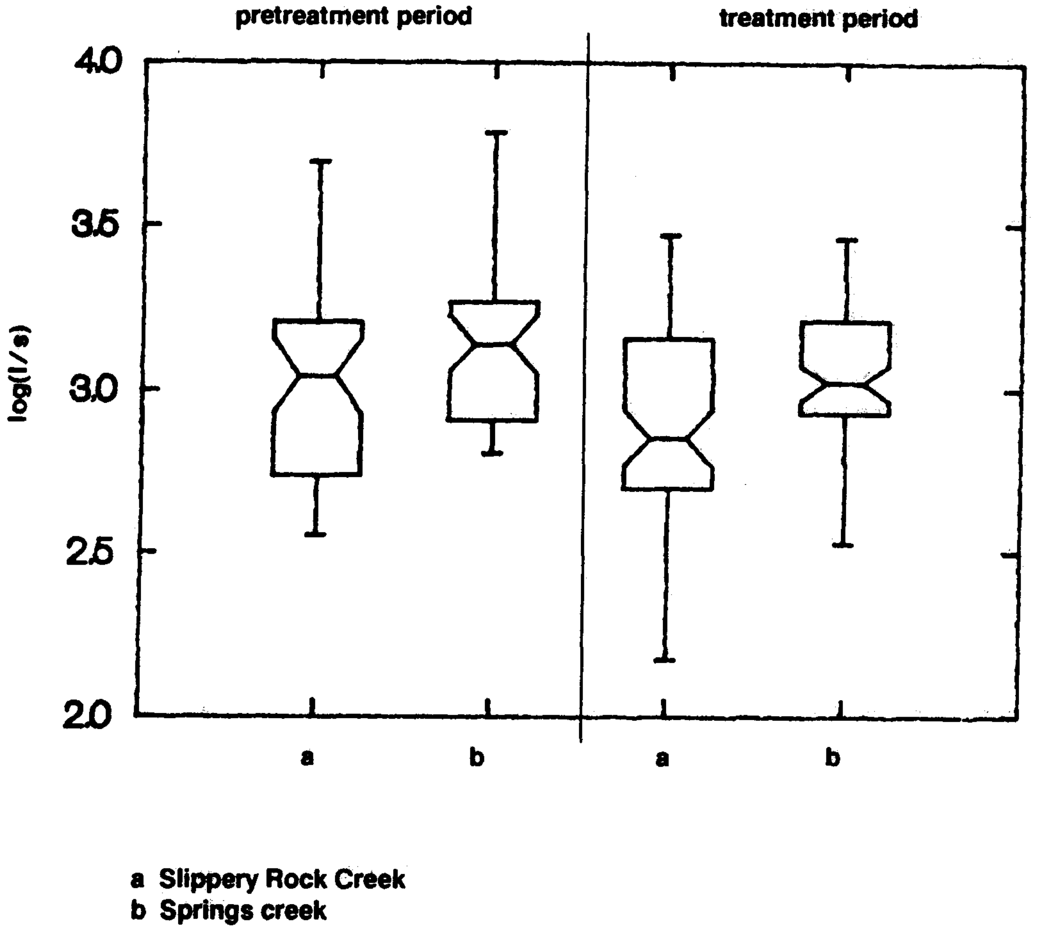


Table 2.5 - Monthly Streamflow: Mann-Whitney Test

	Period	n	median	Point Estimate	95% CI Point estimate	W	Probability Level
Springs Creek	Pre-treatment June ,718-Jan '82	44	1379.4	166.5	-60.5, 443.4	8-Jan	NS
	Treatment Feb '82-Dec '87	71	1046				
Slippery Rock Creek	Pre-treatment June 18-Jan '82	44	1099.7	193.8	-7.8, 480	2882	NS[1]
	Treatment Feb '82-Dec '87	71	709				

S Not Significant

[1] Significant at 0.0579

The findings of this analysis are:-

i) although the R^2 values are low, the regression lines are significant.
ii) for each creek, the slopes of regression lines are not significantly different in the pre-treatment and treatment periods.

The conclusion is that the streamflow from both catchments is consistent with the catchment rainfall.

2.3.6 Resistant analysis of monthly streamflow

A description of terms used is given in Appendix J. As an initial step in analysis, logarithms of monthly streamflow were taken to make the distribution of data more symmetrical. The data are in Appendix G.

Simple linear regressions were determined using the formula

$y = B_o + B_1 x$

where y = Springs Creek monthly streamflow
x = Slippery Rock Creek monthly streamflow
B_0, B_1 are constants

The ordinary LS regression for the pre-treatment period (May 1978 to February 1982) has a high coefficient of determination ($R^2 = 0.974$). A plot of the residuals shows two interesting features (Figure 2.17).

Firstly, the residuals from June 1981 to January 1982 (observations 38 to 44) are consistently high, which indicates that this period should be considered separately. The data has been split into three sections, an initial period (May 1978 to May 1981), a wet period still within the pre-treatment period (June 1981 to January 1982), and the treatment period (February 1982 to December 1987).

Secondly, there is serial correlation in the residuals. The structure of the regression model is transformed to incorporate serial correlation in the error terms. (This is explained more fully in Appendix J). A resistant line has been calculated as a check on the LS regression.

The results of this analysis are shown in Table 2.7. Note that within each period the slopes of the lines have not changed significantly before and after transformation. This verifies the findings in Appendix K (equation K-5 and K-6). There is no evidence of serial correlation in the residuals of the transformed model.

Figure 2.17 Monthly streamflow log (*l*/s) standardized residuals

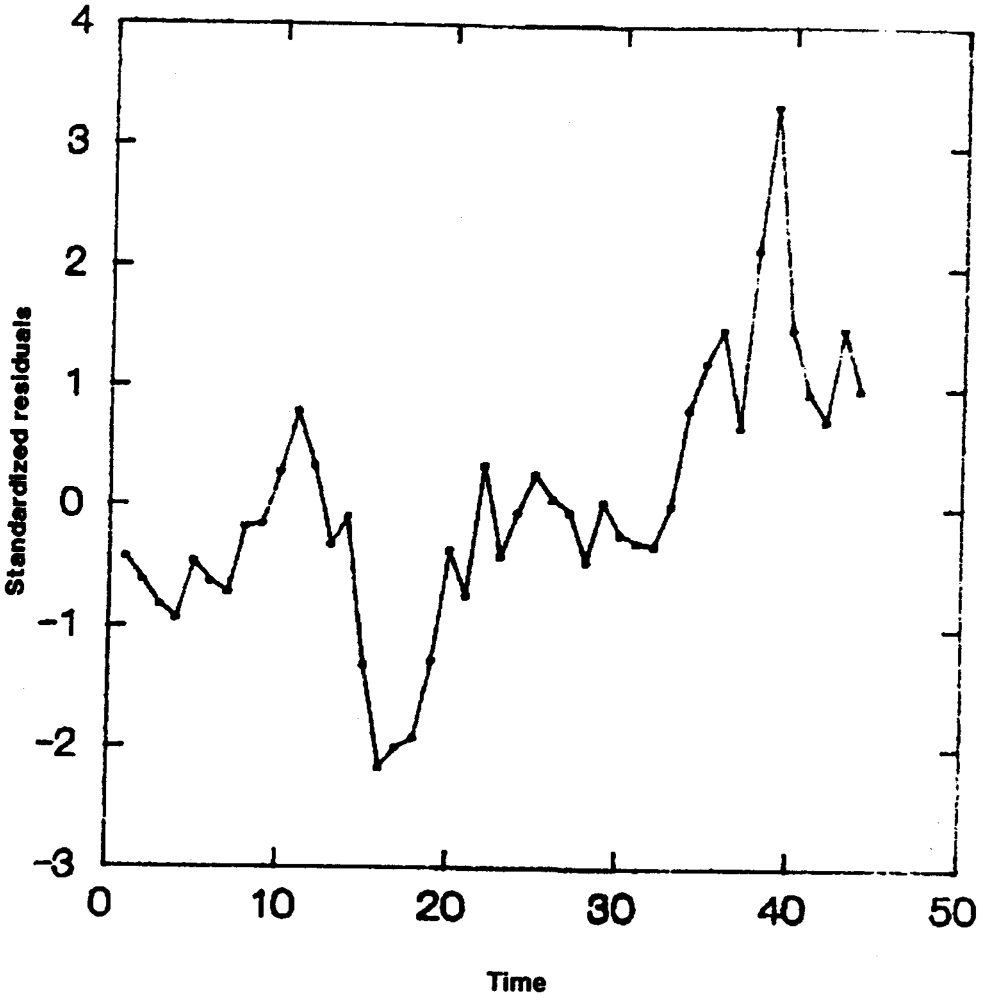


Table 2.7 - Regression and resistant analysis of monthly streamflow (log *l*/s)

analysis	df	b_o	b_1	R^2	Durbin-Watson
Calibration Period May 1978 to May 1981					
OLS	35	0.939	0.722	98.8%	
TRANSF	34	0.459	0.730	983%	0.76
RLINE	NR	0.468	0.725	NR	1.80 NR
Wet Period June 1981 to January 1982					
OLS	7	0.503	0.881	93.3%	
TRANSF	6	0.177	0.902	98.8%	1.57 1.86
RLINE	Insufficient Points To Calculate				
Treatment Period February 1982 To December 1987					
OLS	70	1.07	0.684	98.8%	
TRANSF	69	0.421	0.691	98.4%	0.66 1.89
RLINE	NR	0.442	0.674	NR	NR

Note:	Full explanation is given in appendix J.
OLS	Ordinary least squares regression
TRANSF	LS regression following transformation of the model to incorporate serial correlation in the error term
RUNE	Resistant line as a check on the transformed model

Changes in slope of the regression lines were tested for significance as described in Appendix K2.

The slope of the regression line increases significantly from 0.73 in the initial period to 0.90 in the wet months of the pre-treatment period, and then comes back to 0.69 in the treatment period. The slopes 0.73 and 0.69 are not significantly different according to the test in Appendix K2.

Having verified that Slippery Rock Creek is behaving consistently as a control catchment (Section 2.3.5), then Springs Creek produces approximately 20% more streamflow over the wet period (June 1981 to January 1982) than over the initial period May 1978 to May 1981. This does not persist; the relationship of the two catchments in the treatment period (February 1982 to December 1987) is the same as in the initial period.

2.3.7 LS Regression analysis of mean daily streamflow

A polynomial regression was used to determine effects of treatment on mean daily streamflow. The data for both creeks had high coefficients of skewness; these were removed by taking logarithms of the data. The mean daily flow from May 1978 to May 1981 was used for calibration. Flow from June 1981 to December 1981 has been considered separately because this period had heavy rainfall.

A scattergram of the calibration Springs Creek versus Slippery Rock Creek data (log l/s) is shown in Figure 2.18. The data depicts a slight curve, possibly because while the baseflow is lower at Slippery Rock Creek, eventflow at Slippery Rock Creek tends to catch up or is greater than that of Springs Creek.

The equation for the calibration data is:

$$MDF_{SP} = 0.08\ MDF^2_{SRK} + 0.48\ MDF_{SRK} + 0.70 \qquad (R^2 = 0.99)$$

where MDF is log (mean daily flow)
SP refers to Springs Creek
SRK refers to Slippery Rock Creek

Statistics related to the regression are shown in Figure 2.19. Figure 2.20 is a plot of the residuals against time. The residual pattern indicates serial correlation. Therefore the confidence intervals may not be very accurate.

A plot of predicted and actual mean daily flow, Figures 2.21 and 2.22, shows how the regression line predicts the mean daily flow at Springs Creek. However, flow is underpredicted in the wetter years (i.e. 1978 and 1980), and overpredicted in the drier year (1979). The discrepancies in the 1979 baseflow recession period may be due to estimates in the original data.

Figure 2.18 Scattergram of mean daily streamflow (l/s) calibration period (May 1978 - May 1981)

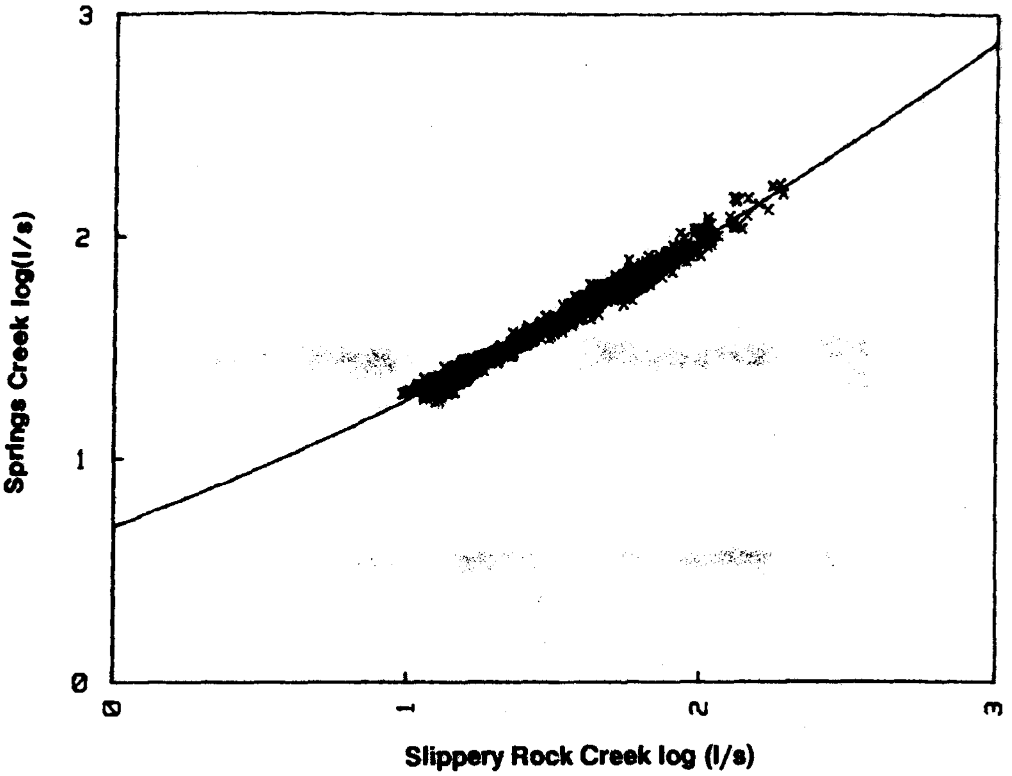


Figure 2.19 Details of regression analysis of calibration mean daily streamflow log (l/s)

Source	df	Sum of Squares	Mean Square	F-value
Total	1095	43.44		
Regression	2	42.66	21.33	30117
x'1	1	42.62	42.62	60171
x"2	1	0.04	0.046	64
Residual	1093	0.77	0.0007	

			95% confidence interval	
Variable	Regression Coefficient	Standard error	lower limit	upper limit
`constant'	0.70	0.023	0.65	0.74
x^1	0.48	0.30	0.42	0.54
x^2	0.08	0.01	0.06	0.10

Figure 2.20 Standardized residuals of regression analysis of calibration mean daily streamflow (l/s)

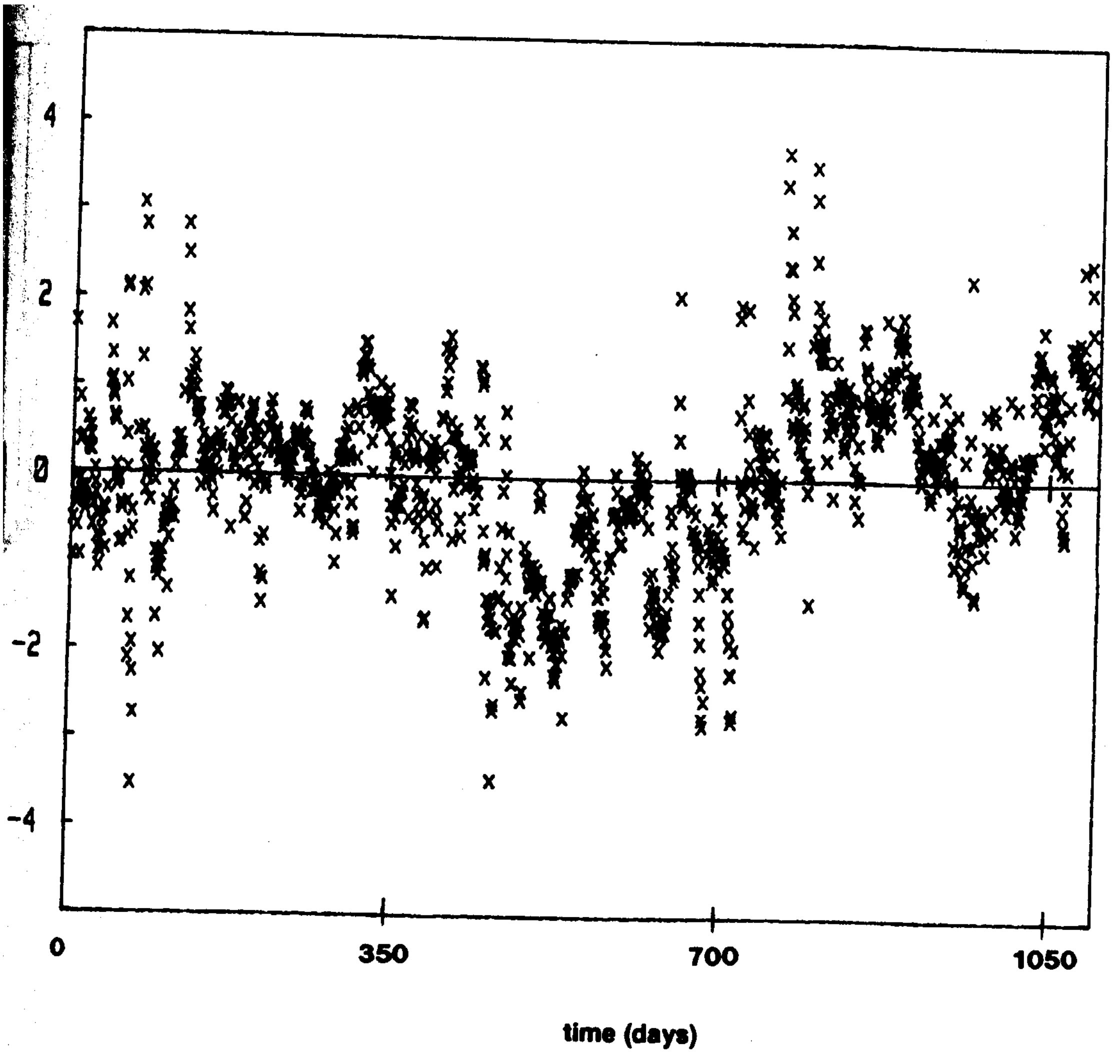


Figure 2.21 Springs Creek pre-treatment predicted and actual mean daily streamflow (l/s)

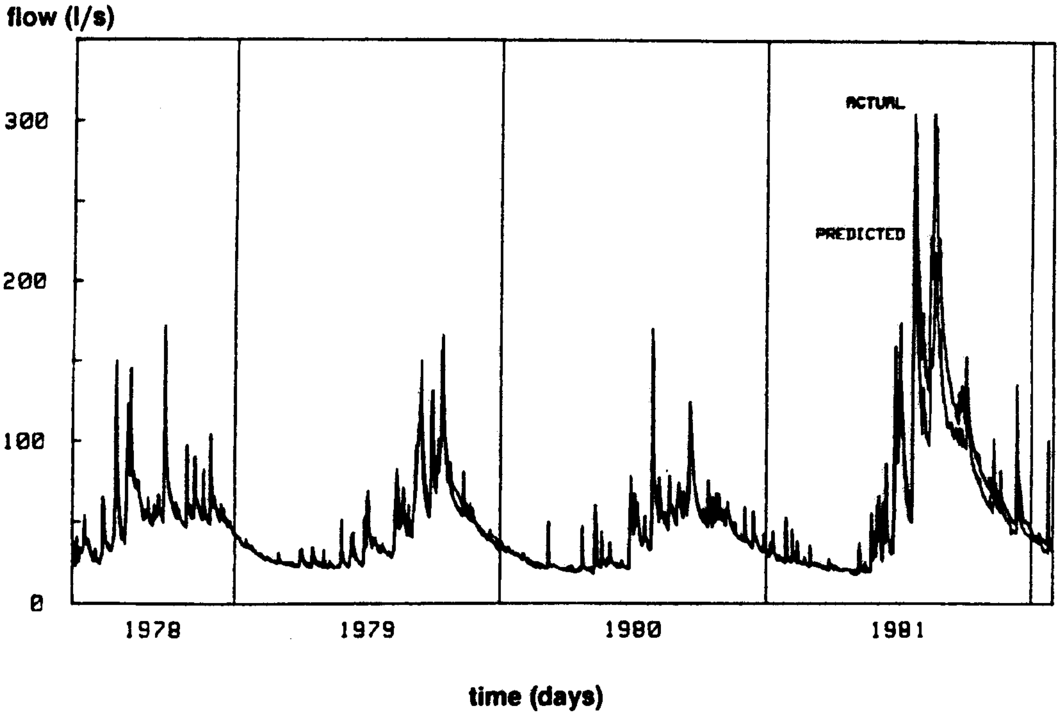
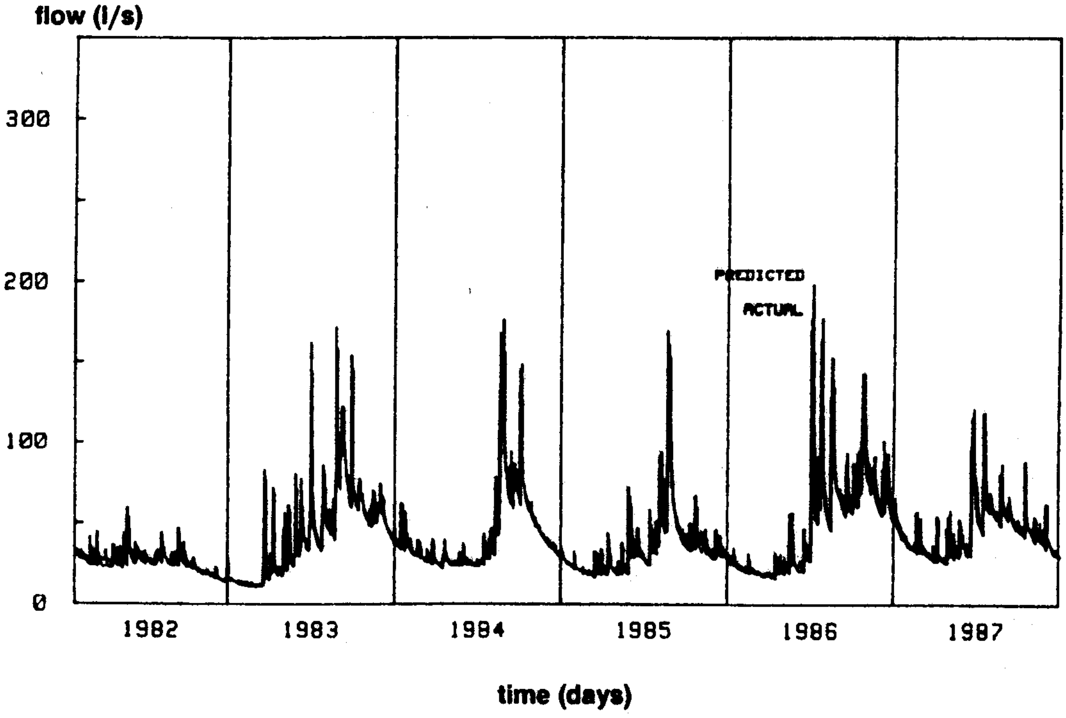


Figure 2.22 Springs Creek treatment predicted and actual mean daily streamflow (l/s)



Flow was predicted using the regression equation for the remaining pre-treatment data and the treatment data. It can be seen from Figures 221 and 2.22 the only large discrepancies between actual and predicted data occurred in the pre-treatment period June 1981 to January 1982.

The residuals, Figures 2.23 and 2.24, show a change in the cyclic pattern from 1985. The residuals continue to increase until April; they drop in mid 1986.

2.3.8 LS Regression of mean daily event flow

In this section, the effect of treatment on mean daily event flow is considered. Baseflow is removed from total flow as described in Section 2.3.3. The data set has been transformed (logarithms) to minimise coefficients of skewness. In this analysis, only events with greater than 7 litres/second flow increase in both creeks are considered.

A LS regression has been determined for the period May 1978 to May 1981:

$$y = 0.5 + 0.743x \qquad (R^2 = 0.946)$$

where y = Springs Creek mean daily event flow
x = Slippery Rock Creek mean daily event flow

The statistical derivation is given in Appendix E.

The remaining time in the experiment has been partitioned as follows:-

The wet period in 1981 (in the pre-treatment period), the roading period, three partitions corresponding to the logging in each coupe, the regeneration burn and the recovery period. For each partition, the daily event flow for the control catchment has been substituted into the above calibration equation and summed to predict event flow in Springs Creek without treatment. Predicted flows have been plotted against observed flows for each partition (Figures 2.32 to 2.39 top half). Least square regressions have been determined for observed and predicted flows. Parameters of these regressions are in Table 2.8.

The question raised at this point is - are there significant flow differences in these periods?

This was addressed as follows. The difference (observed flow minus predicted flow) was tested for significant change from zero using the Wilcoxon signed - rank test. If there was a significant change in flow, a one sample Wilcoxon rank estimate and confidence interval were obtained. Results are shown in Table 2.9.

Figure 2.23 Residuals mean daily streamflow (l/s): pre-treatment period

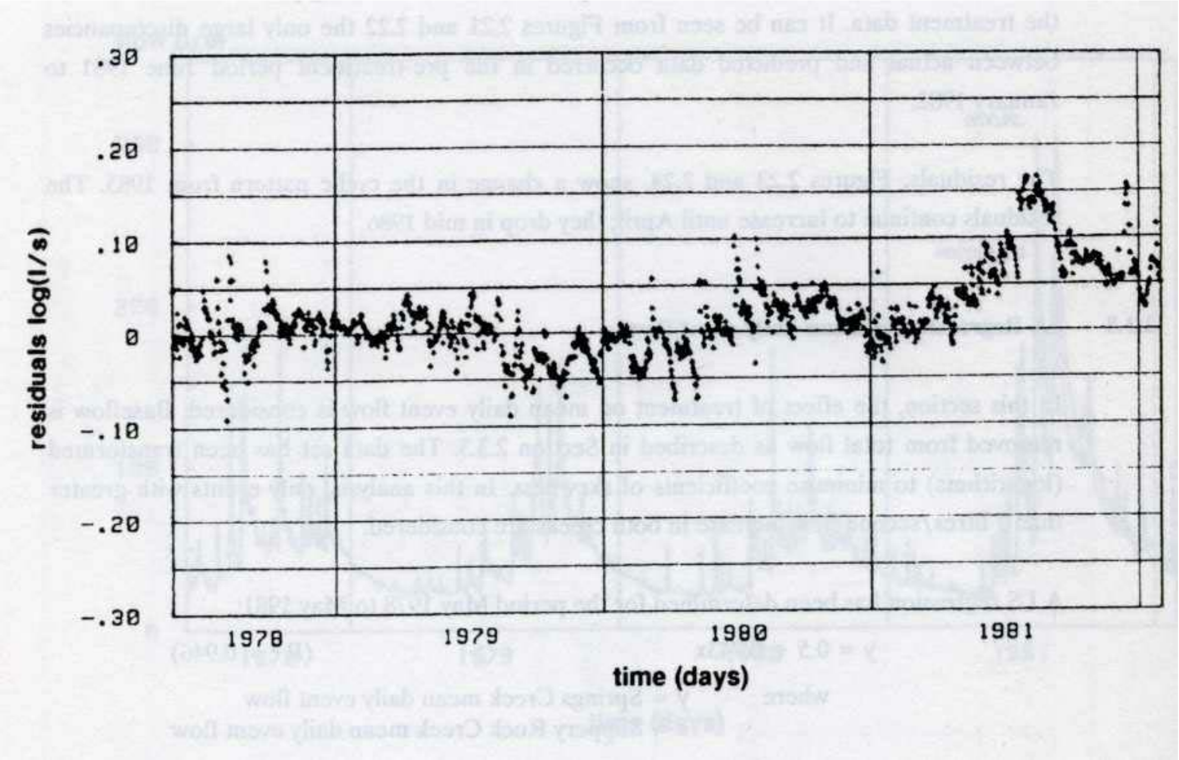


Figure 2.24 Residuals mean daily streamflow (l/s): treatment period

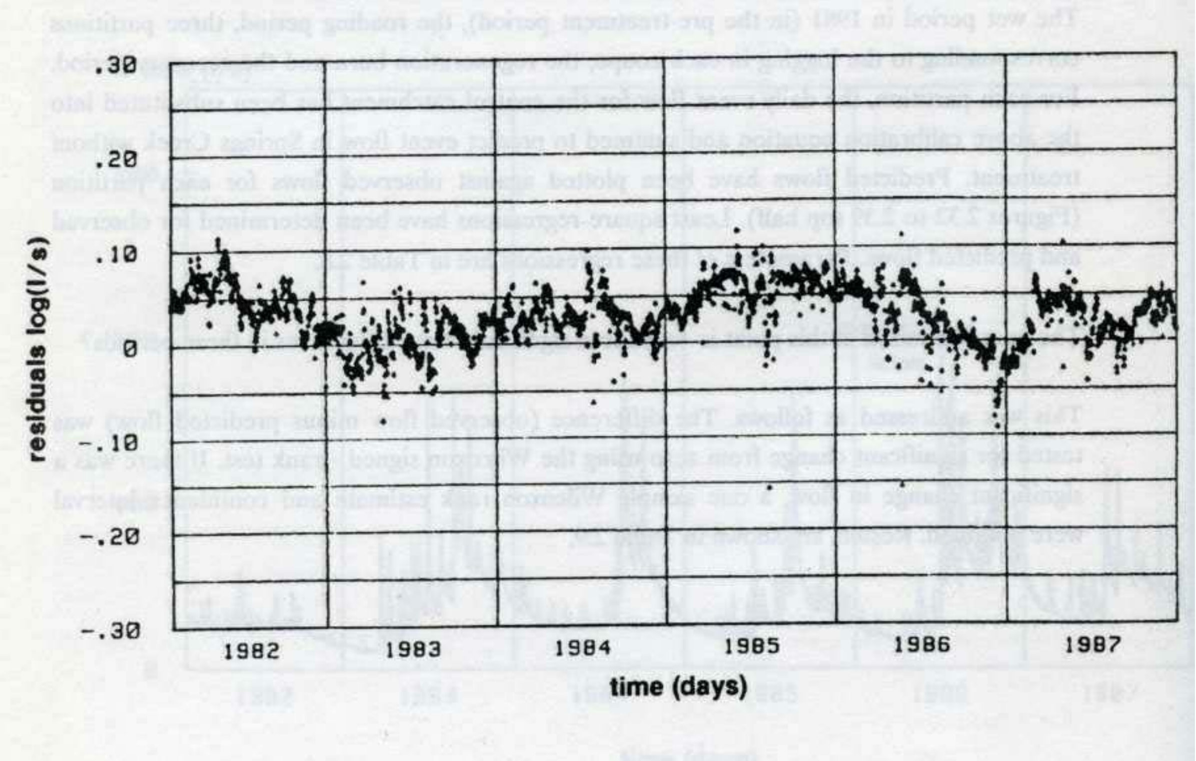


Table 2.8 - LS regression of mean daily eventflow: observed against predicted Values

Period	**LS regression PRED = $b_0 + b_1$ OBS**		**R^2**	**Matching figure**
	b_0	**b_1**		
1978	-0.196	1.10	0.980	232
1979	0.112	0.93	0.974	232
1980	-0.056	1.04	0.983	232
1981	-0.411	1.26	0.993	2.33
1982	0.307	0.84	0.886	2.34
1983	-0.273	1.14	0.976	2.35
1984	-0.105	1.06	0.972	2.36
1985	0.092	0.969	0.988	2.37
1986	-0.0041	0.997	0.983	238
1987	0.74	0.954	0.983	239

Table 2.9 - Nonparametric test for change in flow

Period	**One sample Wilcoxon Rang estimate and confidence interval (CI)**		**CI**	**p-value**
	Estimate	**% confidence**		
Wet	0.11	94.9	(0.09, 0.13)	<.001`
Road	0.05	94.8	(0.02, 0.07)	0.035*
Harvest 1	-0.001	95.0	(-.02, 0.02)	0.979
Harvest 2	0.009	95.1	(-.01, 0.02)	0.345
Harvest 3	0.04	94.9	(0.03, 0.05)	<.001*
Burn	-0.01	95.0	(-0.03, 0.01)	0.216
Post-treatment	-0.01	94.8	(-0.02, 0.002).	0.108

• estimates are significantly differ from zero. All others are not significant.

These findings show that there were significant increases in flow in the wet period (June 1981 to January 1982), the roading period (February 1982 to September 1982), and the third harvest period (November 1984 to December 1985). These are also apparent on the time series plots of eventflow differences (top of figures 2.40 and 2.41).

Although there was a significant increase in eventflow in the roading period, the magnitude is small. There were only 7 events because roading occurred during a drought period. There was minimal groundwater recharge over the period (see Figures 2.8 and 2.9).

These findings have been summarised graphically and related to sediment concentrations. This has been done as follows:-

The global median flow for Slippery Rock Creek is 58.81/s. For each block, this median flow has been substituted in its respective regression equation (Table 2.8) to give a Springs Creek flow value. Then, a common number has been subtracted from all flow values to bring the pre-treatment values close to zero. Results have been plotted in the top half of Figure 2.44.

An increase of 12 *l*/s occurs in the wet year due to the change in the flow relationship between the catchments. There is an increase of 32 *l*/s in the roading period and of 4.0 *l*/s in the third harvest period. Both these changes are small relative to the global median (58.8 *l*/s).

2.4 Sediment

In this section, some limitations in the initial calculation of sediment yield are considered (Section 2.4.2). This method was discarded. Then, an alternative method of analysis which overcomes these limitations is developed (Section 2.4.3). General characteristics of sediment concentration are extensively analysed using LS regressions, resistant lines and EDA techniques independently. Finally, in Section 2.4.9, the transient sediment values are discussed separately.

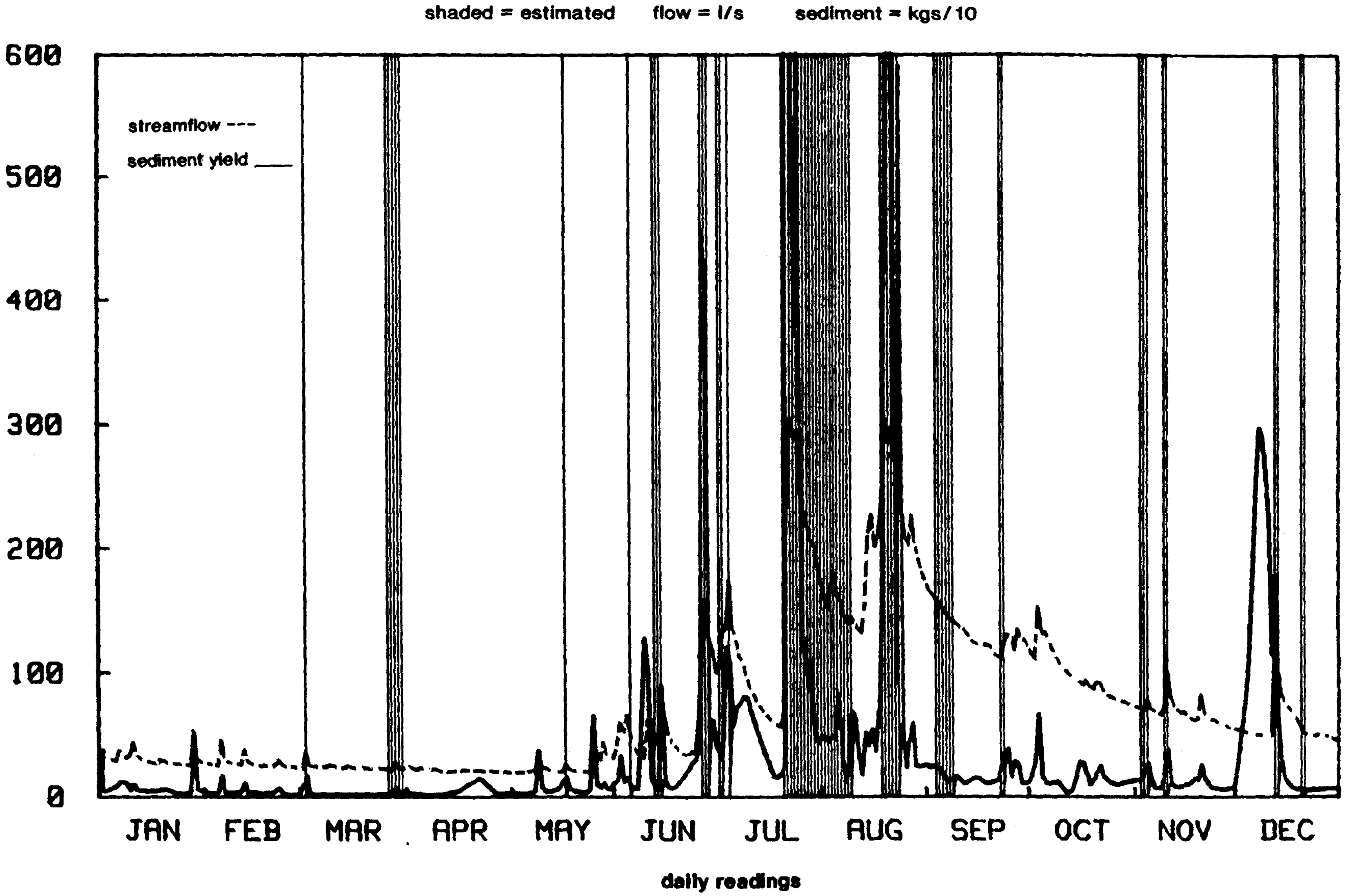
2.4.1 Initial calculation of sediment yield

Single sediment samples were taken on days of low flow; events were sampled at hourly intervals. Values in the period between samples were obtained by interpolation. Both flow and sediment concentration were reduced to thirty-minute totals and multiplied to give daily sediment yield in kilograms. Missing data were estimated using linear regression as described in Section 2.1.3.

2.4.2 Limitations of the above method of yield calculation

The main limitations of the above method (Section 2.4.1) are illustrated in Figure 2.25. The broken trace shows flow in Springs Creek in 1981; the solid tract shows daily sediment yield calculated as described in Section 2.4.1. Vertical lines indicate days with estimated data. 1981 was chosen because it had the major events in the pre-treatment period.

Figure 2.25 Springs Creek streamflow and sediment yield 1981 showing limitations of initial yield calculation. See text for discussion



The major limitations are:-

If there is a long interval between samples, particles tend to collect in the sampler suction tube. This tube is flushed before sampling, but occasionally the flush is insufficient to clear out the tube, and a biased sample is collected. Thus, one isolated sample may have undue influence over a long period of time. An example is shown in December 1981 in Figure 2.25. During a flow recession period one high sediment sample has produced a large spike in the graph.

Another limitation occurs when interpolation is made between a low value prior to an event and the first sediment sample of the event. The event sample is correctly high, but it is only representative of a one-hour period. The yield data shows a rising ramp into the event while the flow is receding. This is illustrated in June 1981 in Figure 2.25.

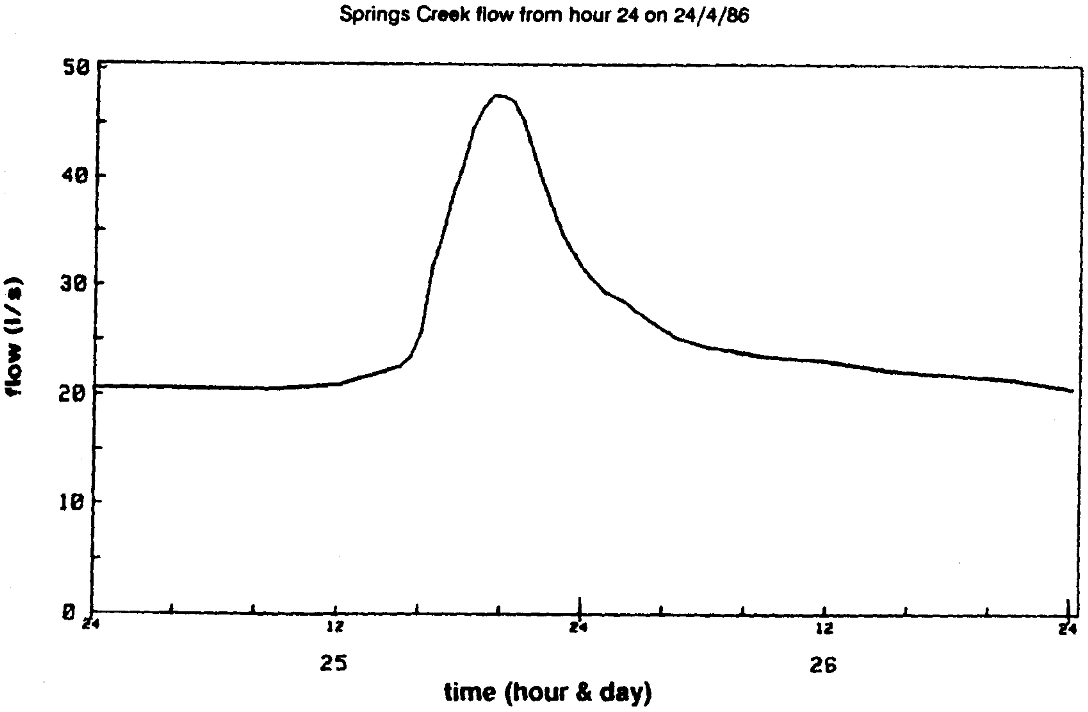
A third limitation arises when streamflow is multiplied by sediment concentration to give sediment yield. The high correlation of flow between the creeks ($r = 0.99$) strongly influences the sediment yield between the creeks. Therefore, sediment yield from one creek should not be used to predict sediment yield in the other creek. Missing sediment yield values at stormflow peaks in July and August 1981 should not be estimated using this method.

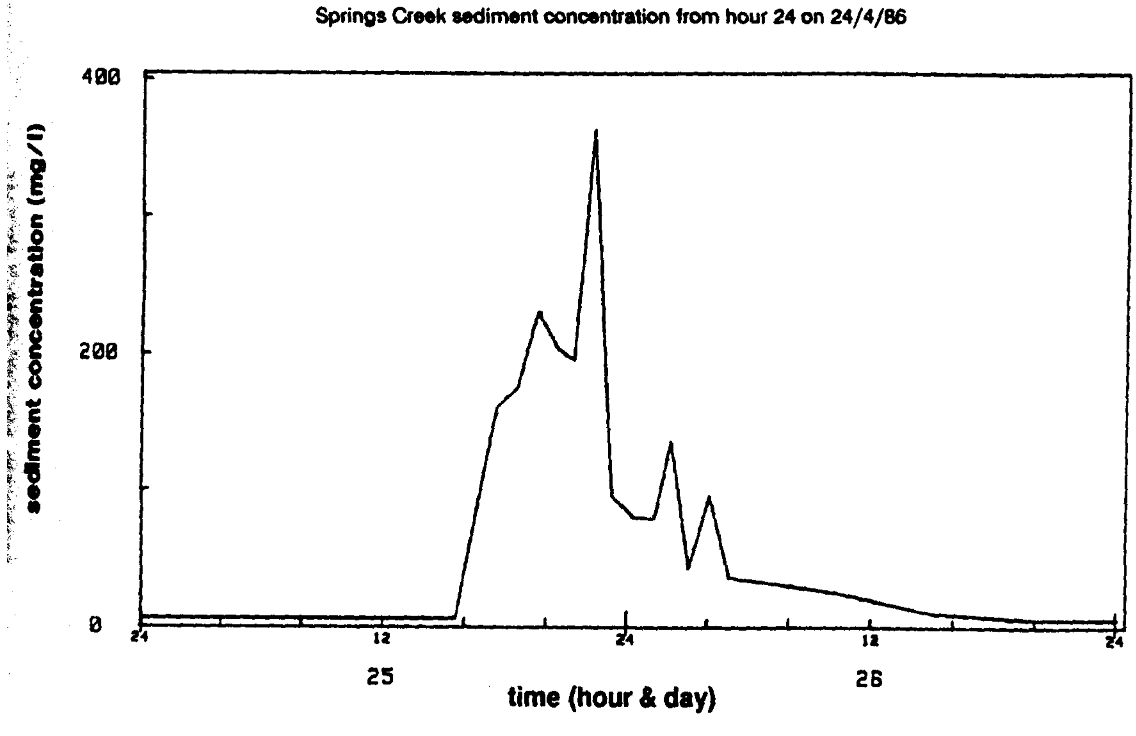
2.4.3 Alternative sediment analysis technique

To avoid the limitations of Section 2.4.2, it was decided (i) to analyse sediment concentration from both creeks, because they are independent data sets, and (ii) not to include any estimated data. A computer program used to digitize flow was adapted to analyse sediment values. The following method was developed to accurately represent the sediment data. Each event was digitized using a time and sediment value. A prior low value was used as a starting point of the 24-hour period in which the event commenced. This value was used until one hour before the first event sample. The hourly sediment values of the event were representative of that period of time. The day on which the event finished was completed at a low sediment value. The data were averaged into mean daily sediment concentration. Rainfall, streamflow and sediment concentration data were then cross referenced to check for timing errors.

At this stage of the analysis there were still some large transient values in the data set. Figure 2.26 shows three such values. The classic mechanism for sediment transport during storms indicates that high sediment values occur on the rising limb of the hydrograph. Sporadic high sediment values on the descending limb of the hydrograph are aberrant. In the case illustrated in Figure 2.26, the latter two 'spikes' have little effect over a 24-hour period. The daily value for 26 April 1986 does not appear excessively high. However, the first 'spike' raises the concentration of 25 April; this value is used in the analysis.

Figure 2.26 Hydrograph and corresponding sediment concentration indicating three transient points





These data are included on the assumption that outliers have a reasonable distribution throughout the data set. The measuring techniques determine that they are positive outliers, probably due to the position of the intake in a turbulent part of the stream. Both these points will be discussed in Section 2.4.8.

2.4.4 Sediment duration curves

The percentage of time when a mean daily sediment concentration value is greater than a given sediment value is shown in Figure 2.27 for pre-treatment period, and Figure 2.28 for the treatment period.

The graphs for Slippery Rock Creek for both pre-treatment and treatment periods are similar. The pre-treatment graph for Springs Creek catchment is an underestimate, due to large missing values in the wet year 1981. However, it still appears that there is a definite increase in the sediment values at high flows.

2.4.5 Double mass plots of sediment data

Cumulative sediment concentrations have been plotted against time in Figure 2.29 and against the control catchment in Figure 2.30.

Missing data from either catchment was omitted from the plot.

The cumulative plot against time shows increasing divergence associated with the treatment. This is verified in the plot against the control catchment.

2.4.6 Exploratory and non-parametric analysis

The motivation here is similar to that noted in Section 23.5, and the same general remarks apply here.

The parameter for analysis is the pair of matching maximum sediment concentration values occurring during each month. This has been chosen because (i) it is an extreme indication of sediment transport, (ii) it is independent of and complementary to the analysis in other sections. If the sediment values for the maximum event in a given month are missing in one catchment, then the next matching pair for the next largest event arc obtained. Note that major events in July and August 1981 are incomplete, so that the data set may underestimate the population in the pre-treatment period. Data are listed in Appendix Hl. Months without major events are omitted from the record.

There are limitations in estimating maximum sediment concentration in a given event. **Firstly**, the probability is low that the true maximum sediment concentration in any event occurs at the time of sampling. Therefore, the maximum measured value is an **underestimate** of the true value. No interpolation has been made to attempt an improved estimate of the maximum value. Secondly, measurement errors are more important at lower sediment concentrations. For example, one grain of sand on the filter paper has a large influence at low sediment concentrations, but only a low influence at high sediment concentrations. Effects of measurement error could be incorporated into the model by weighting the sediment concentration values according to their accuracy, but this was not investigated.

Figure 2.27 Pre-treatment sediment duration curves

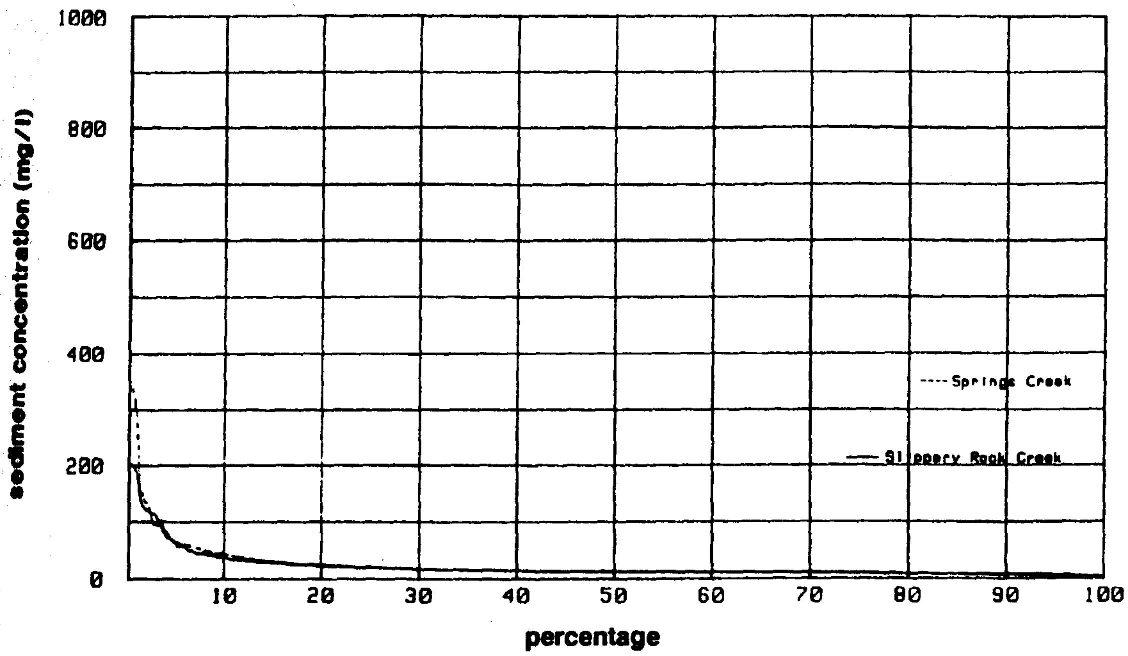


Figure 2.28 Treatment sediment duration curves

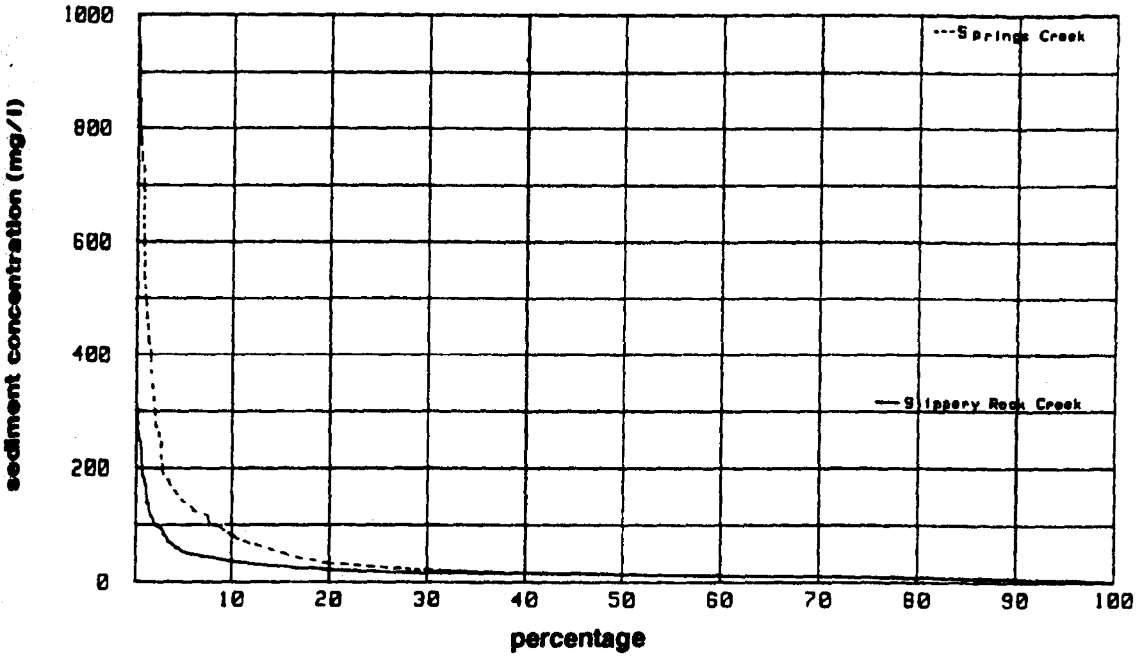


Figure 2.29 Accumulated mean daily sediment concentration (mg/l) against time

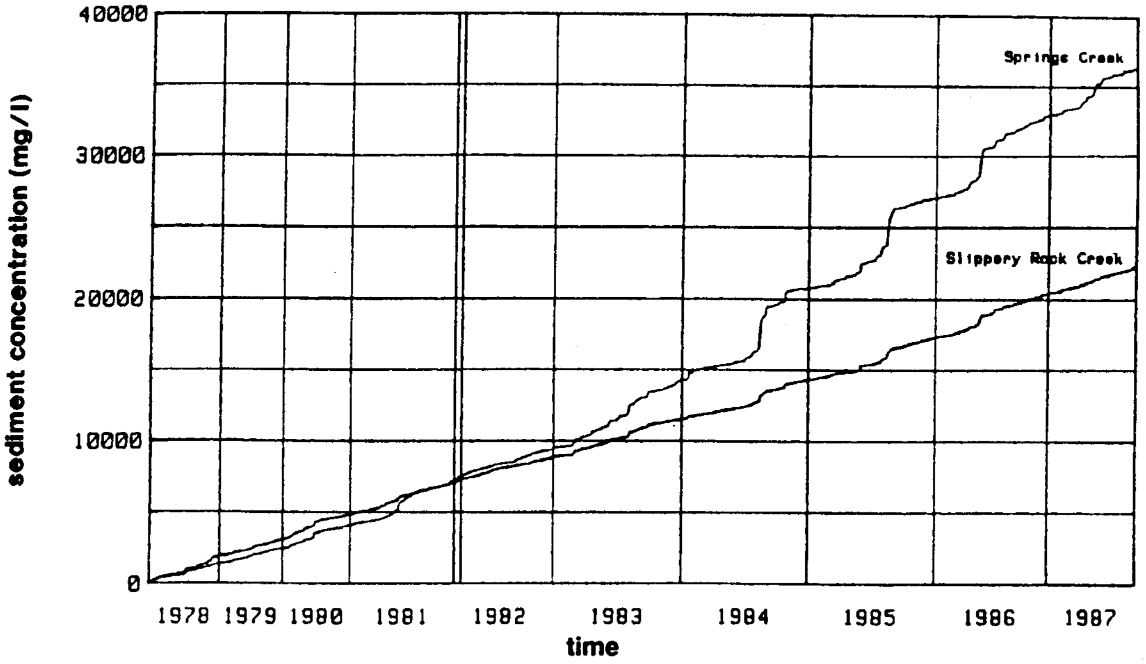
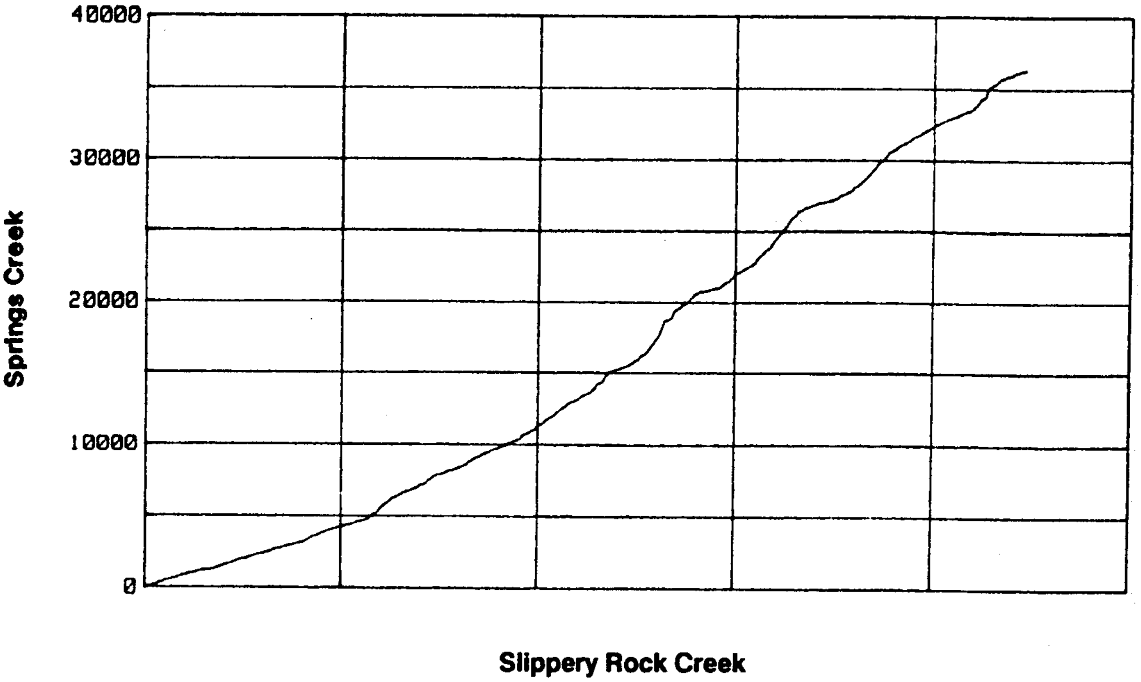


Figure 2.30 Double mass plot of mean daily sediment concentration (mg/l) Springs Creek versus Slippery Rock Creek



Boxplots and the Mann-Whitney test are explained in the Glossary.

Boxplots for the pre-treatment and treatment periods are shown in Figure 2.31.

The boxplots are on transformed data (logarithm) to make the distributions reasonably symmetrical.

Boxplots for both catchments in the pre-treatment period and Slippery Rock Creek in the treatment period appear very similar. The medians and their confidence intervals overlap, and the 'boxes' are of similar dimensions and are located in similar positions. The pre-treatment distribution for Springs Creek has heavier tails than the control catchment.

However, the boxplot for Springs Creek looks very different in the treatment period. The median and its confidence interval are significantly above the corresponding pre-treatment value, and the 'box' extends to greater value.

Raw data is used for the Mann-Whitney test. Results are shown in Table 2.10. There is no significant change in maximum sediment concentration for the control catchment over the experiment.

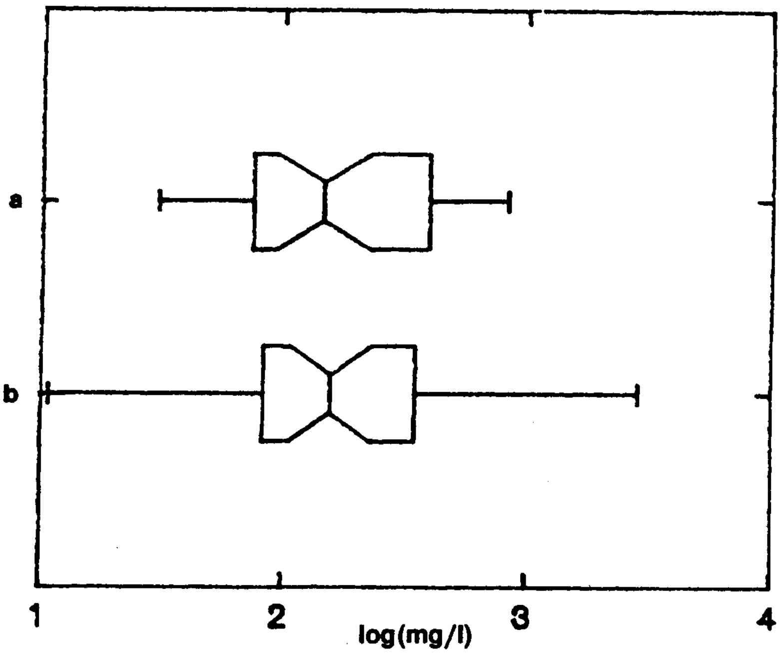
For Springs Creek, the median of the difference is 142.5mg/*l*, with 95% confidence interval (19.5, 302.5), when zero is expected for no treatment effect. The probability of observing medians are separated as these from the same population is 0.0128 (Table 2.10).

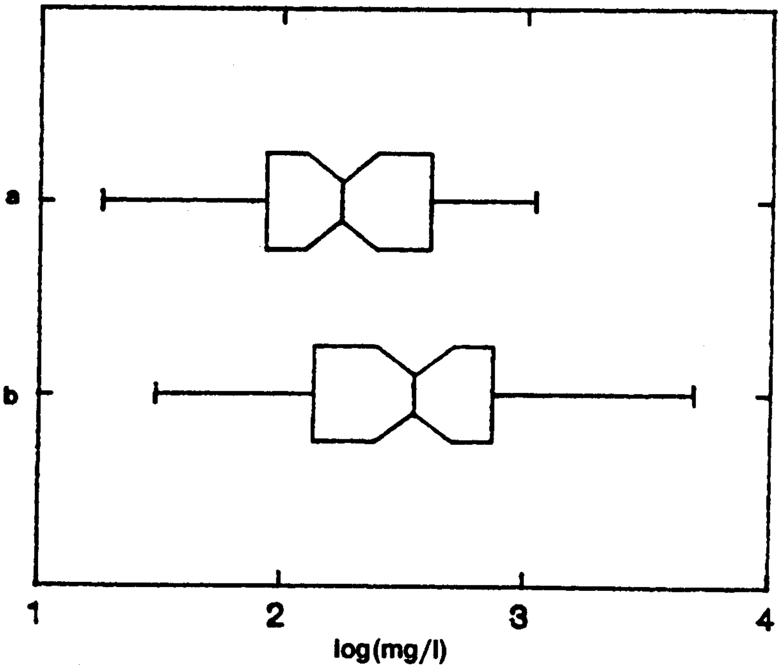
The conclusion from both boxplots and the Mann-Whitney test is that the maximum sediment concentration has increased significantly in the treatment period.

2.4.7 Resistant analysis of sediment concentration (maximum values)

The analysis in this section is an extension of that in Section 2.4.6, where here the structure of the blocks of data is being inspected. Note that the limitations described in Section 2.4.6 also apply here.

Figure 2.31 Boxplots of maximum sediment concentration log (mg/l)


pretreatment period (June 78-Jan 82)


treatment period (Feb 82-Dec 87)

a Slippery Rock Creek
b Springs Creek

Table 2.10 Maximum Sediment Concentration: Mann-Whitney Test

	Period	n	median	Point Estimate	95% CI Point estimate	W	Probability Level
Springs	Pre-treatment '78-Jan '82	35	155.8	-142.5	-302.5, -19.5	1265	0.0128* $p<0.05$
Creek	Treatment Feb '82-Dec '87	53	352.2				
Slippery Rock	Pre-treatment June '78-Jan '82	35	145.3	-10.2	-80.5, 47.5	1504	NS
Creek	Treatment Feb '82-Dec '87	53	190.5				

*	Significant
NS	Not Significant

Parameters of the LS regression are given in Table 2.11. As observed in sections on flow analysis, there is significant serial correlation in the linear regression residuals. The results of incorporating the serial correlation of error terms into the regression model are listed in Table 2.11. A resistant line has also been calculated as a check on this model.

Table 2.11 - Regression and resistant analysis of maximum instantaneous sediment concentration (log mg/*l*): data in two groups

Pre-treatment Period May 1978 to January 1982

Analysis	df	b_o	b_1	R^2	Durbin-Watson
OLS	34	0.134	0.940	51.6%	1.19
TRANSF	33	0.136	0.912	523%	2.04
RLINE	NR	0.315	0.759	NR	NR

Treatment Period February 1982 to December 1987

Analysis	df	b_o	b_1	R^2	Durbin-Watson
OLS	52	0.537	0.879	53.7%	1.60
TRANSF	51	0.521	0.835	553%	1.94
RLINE	NR	0.357	0.932	NR	NR

Note:	Full explanation of terms is given in appendix J
OLS	ordinary least squares regression
TRANSF	least squares regression following transformation of the model
RLINE	resistant line as a check on the transformed model
NR	indicates not relevant

Only 52-56% of the total variation in the data is explained by the regression model, because the mechanism for sediment transport is fairly complicated.

Note that the parameters of the resistant line and regression model do not agree well because of the scatter and heterogeneity in the data.

Tentative findings are that the regression slopes are equal, but that the intercept in the treatment period is significantly greater than zero. However, there is no significant difference in the intercepts in the two periods.

The data has been split into four groups to analyse the heterogeneity in the data. Details of the groups and the analysis are in Table 2.12.

Table 2.12 - Regression and resistant analysis of maximum instantaneous sediment concentration (log mg/l data separated into four groups

analysis	df	b_o	B_1	R^2	Durbin-Watson	half-slope ratio
Calibration Period May 1978 to May 1981						
OLS	27	0.134	0.890	59.1%	1.82	NR
RLINE	NR	0375	0.786	NR	NR	125
Wet Period June 1981 to January 1982						
OLS	6	-0.359	1.367	85.7%	1.85	NR
RLINE	NR	-0.385	1371	NR	NR	1.44
Operations Period February 1982 to December 1985						
OLS	34	0.456	0.934	54.4%	1.58	NR
RUNE	NR	0.0305	1.120	NR	NR	1.38
Post-operations January 1986 to December 1987						
OLS	17	0.771	0.743	49.3%	2.18	NR
RUNE	NR	0.743	0.759	NR	NR	0.11

Note:	Full explanation of terms is given in Appendix J
OLS	Ordinary least squares regression
RLINE	Resistant line as a check on the transformed model
NR	Indicates not relevant

The half-slope ratios of the resistant lines are not close to unity in calibration and post-operations groups. This indicates that the data in these groups are not scattered about a straight line.

There is no evidence of serial correlation in the residuals of the LS regression.

Slopes of the regression lines in the calibration, operation and post-operations groups are not significantly different. But, the slope of the regression line in the wet period is significantly raised.

The intercepts are not significantly different from zero. This is consistent with the smaller numbers of observations and noisy data.

In conclusion, analysis of the data in four groups reveals a temporary change in the relative response in the wet period. This restores to the calibration value in the following period. There is no significant difference in the intercepts due to noise in the data.

2.4.8 LS Regression analysis of mean daily event sediment concentration

As an initial step, all sediment concentration values were transformed by taking logarithms to give symmetrical distributions.

The following regression line was developed for the period May 1978 to May 1981:

$y = 0.891\,x + 0.106$ $R^2 = 0.805$ s.e.e. = 0.148

where y = Springs Creek sediment concentration
x = Slippery Rock Creek sediment concentration

The statistical derivation is given in Appendix E.

The remaining time in the experiment has been subdivided into blocks; viz, the wet period in 1981 (still within the pre-treatment period), roading, logging of each coupe, the regeneration burn and recovery period. For each block, the daily event sediment concentration for Slippery Rock Creek has been substituted into the above calibration equation and summed to predict sediment concentration for the whole event in Springs Creek without treatment. These predicted event values have been plotted against the observed event Springs Creek values for each block. (Figures 232 to 239).

Similar to the analysis in Section 2.3.8, least squares regressions have been determined for observed and predicted sediment concentrations. Parameters of these regressions are in Table 2.13.

Figure 2.32 Comparison of observed and predicted event values: May 1978 - May 1981 (a) streamflow log (l/s), (b) sediment concentration log (mg/l)

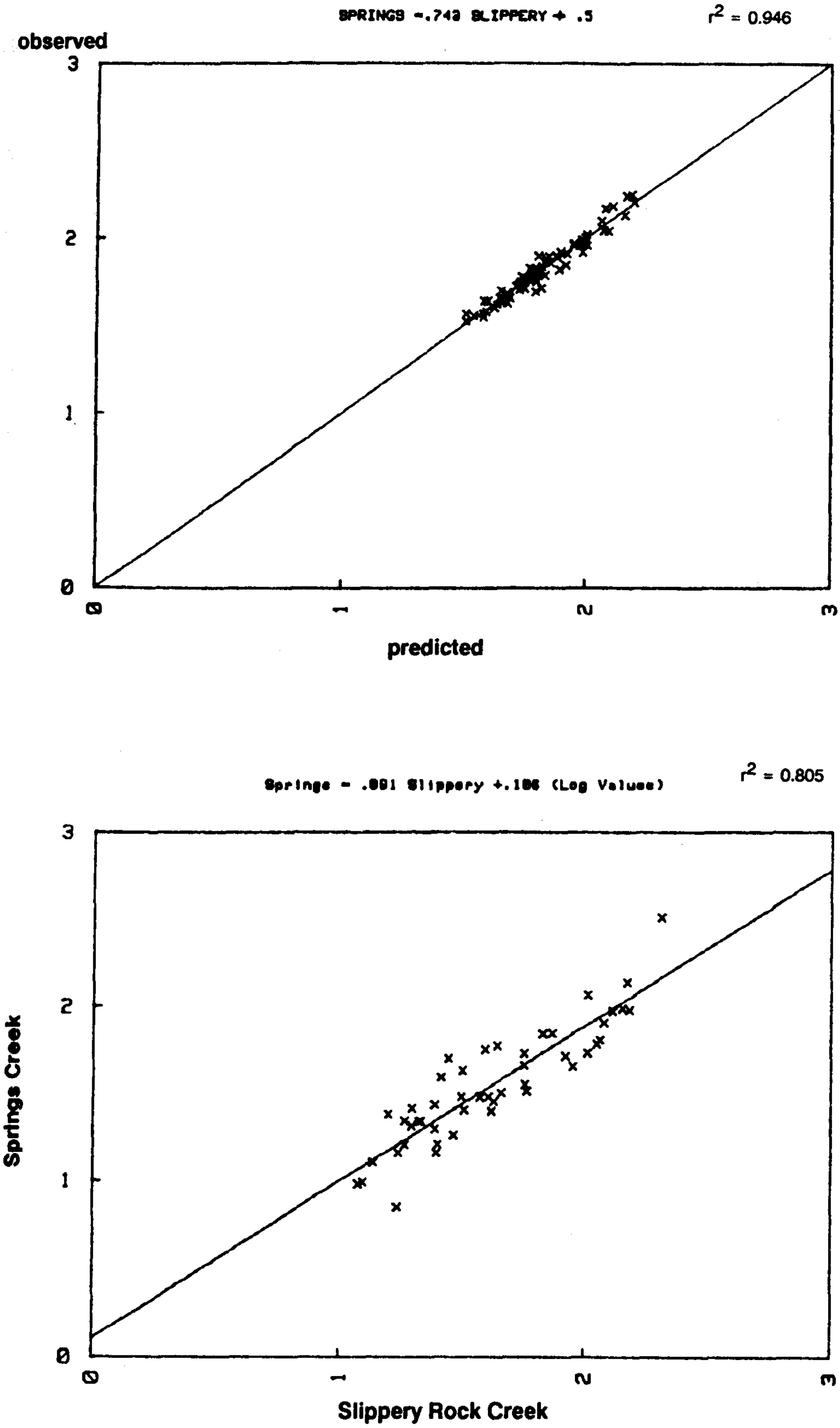


Figure 2.33 Comparison of observed and predicted event values: June 1981 - January 1982 (a) streamflow log (l/s), (b) sediment concentration log (mg/l)

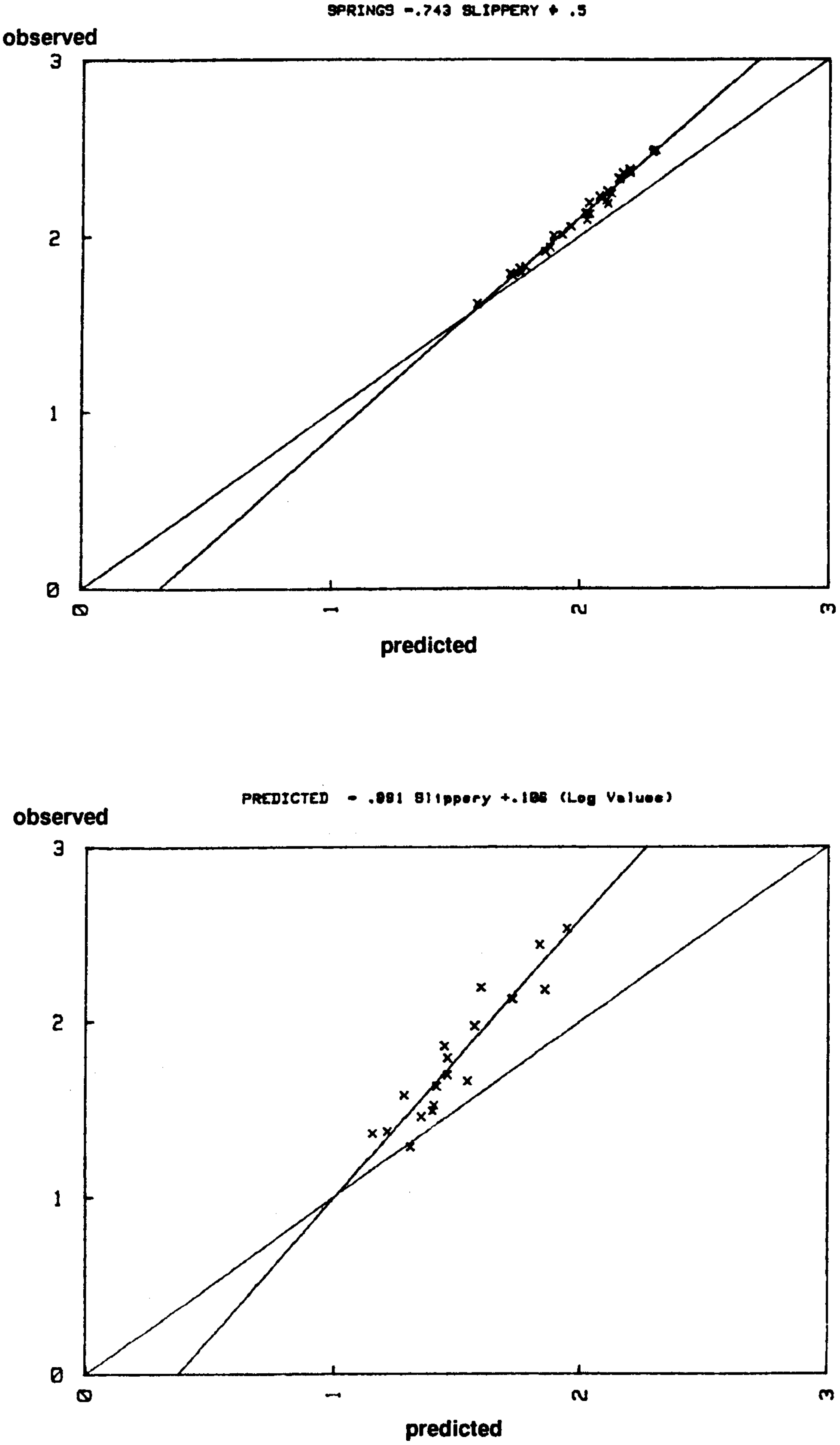


Figure 2.34 Comparison of observed and predicted event values: February 1982 - September 1982 (a) streamflow log (l/s), (b) sediment concentration log (mg/l)

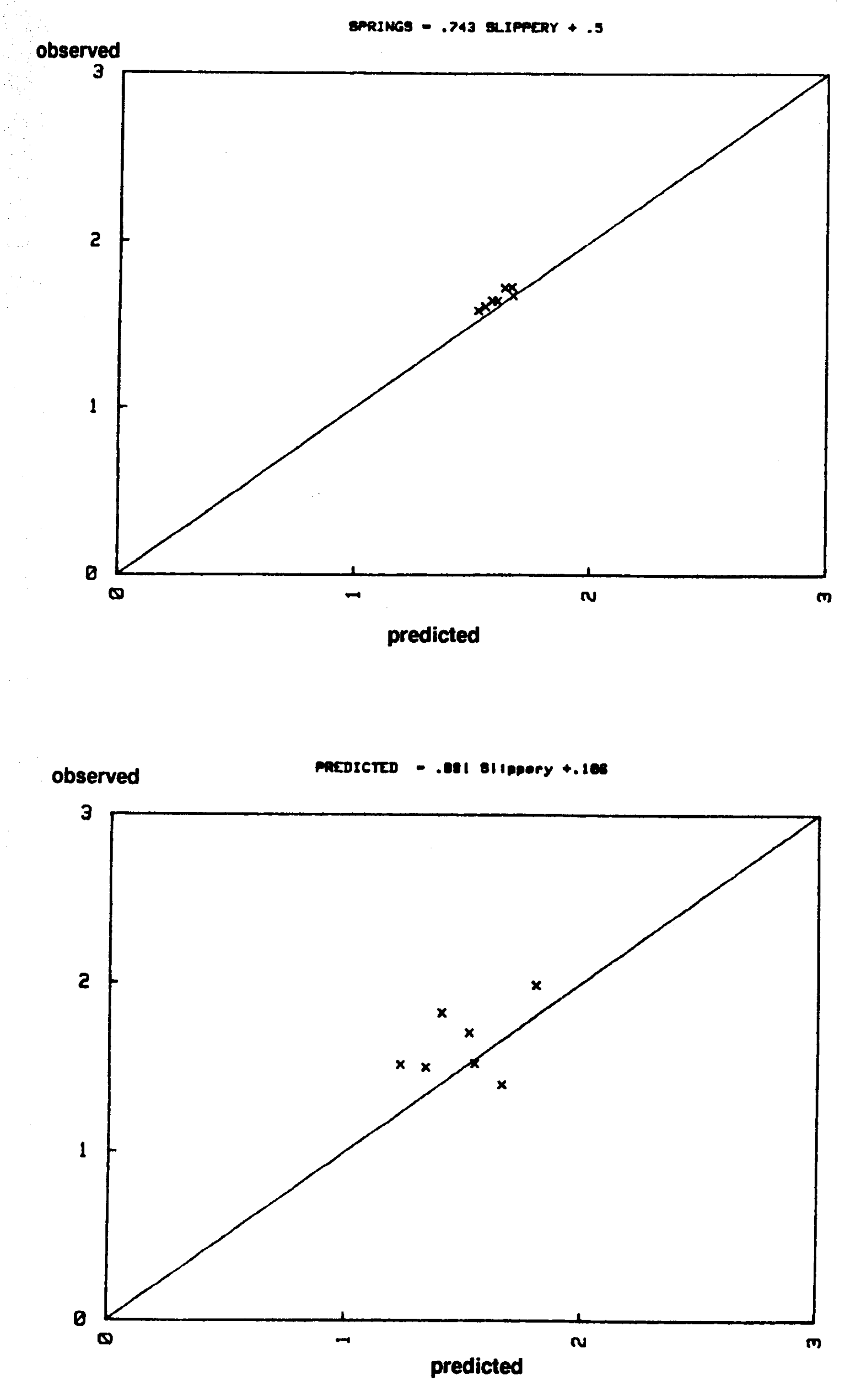


Figure 2.35 Comparison of observed and predicted event values: October 1982 - September 1983 (a) streamflow log (l/s), (b) sediment concentration log (mg/l)

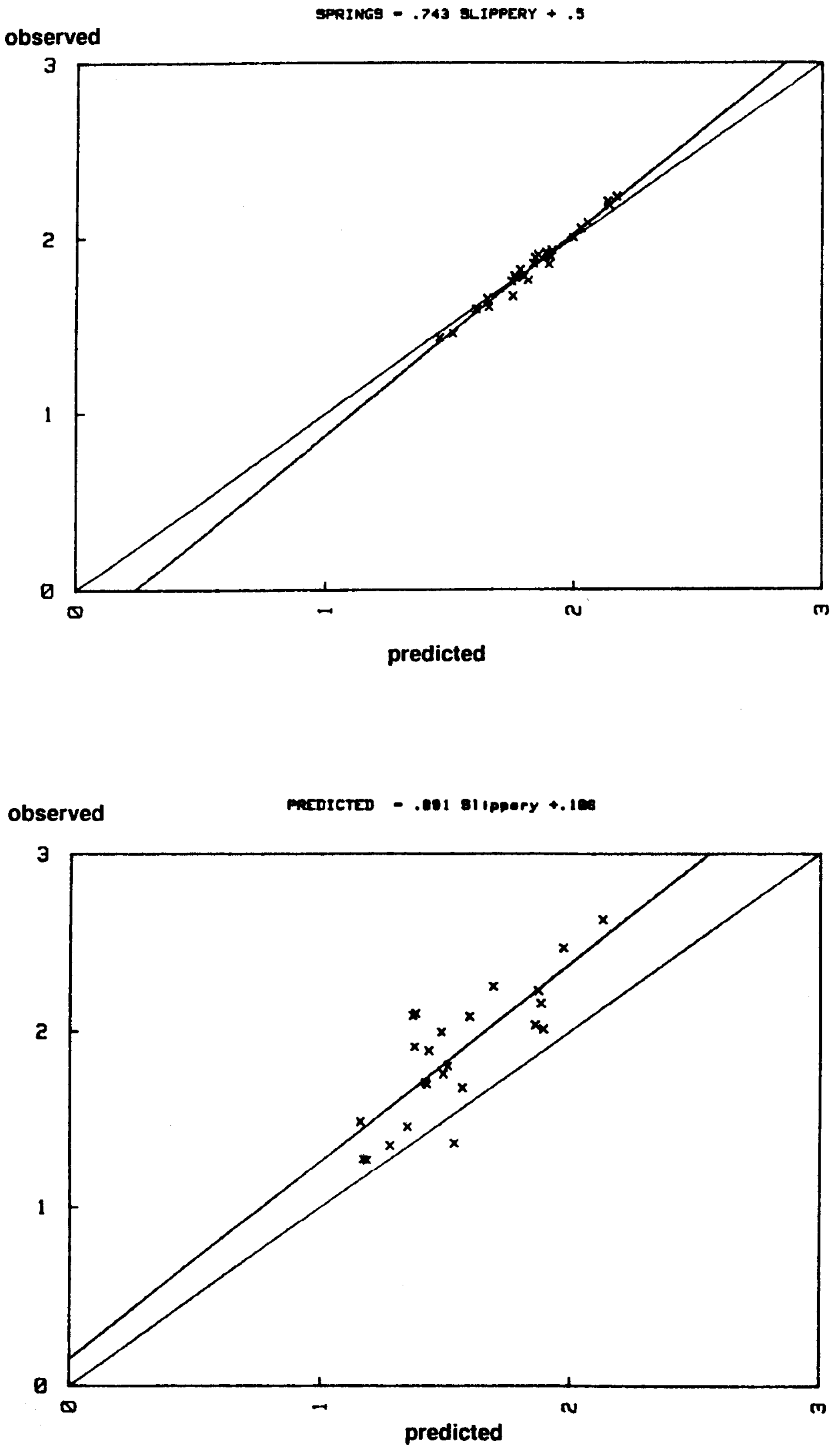


Figure 2.36 Comparison of observed and predicted event values: October 1983 - October 1984 (a) streamflow log (l/s), (b) sediment concentration log (mg/l)

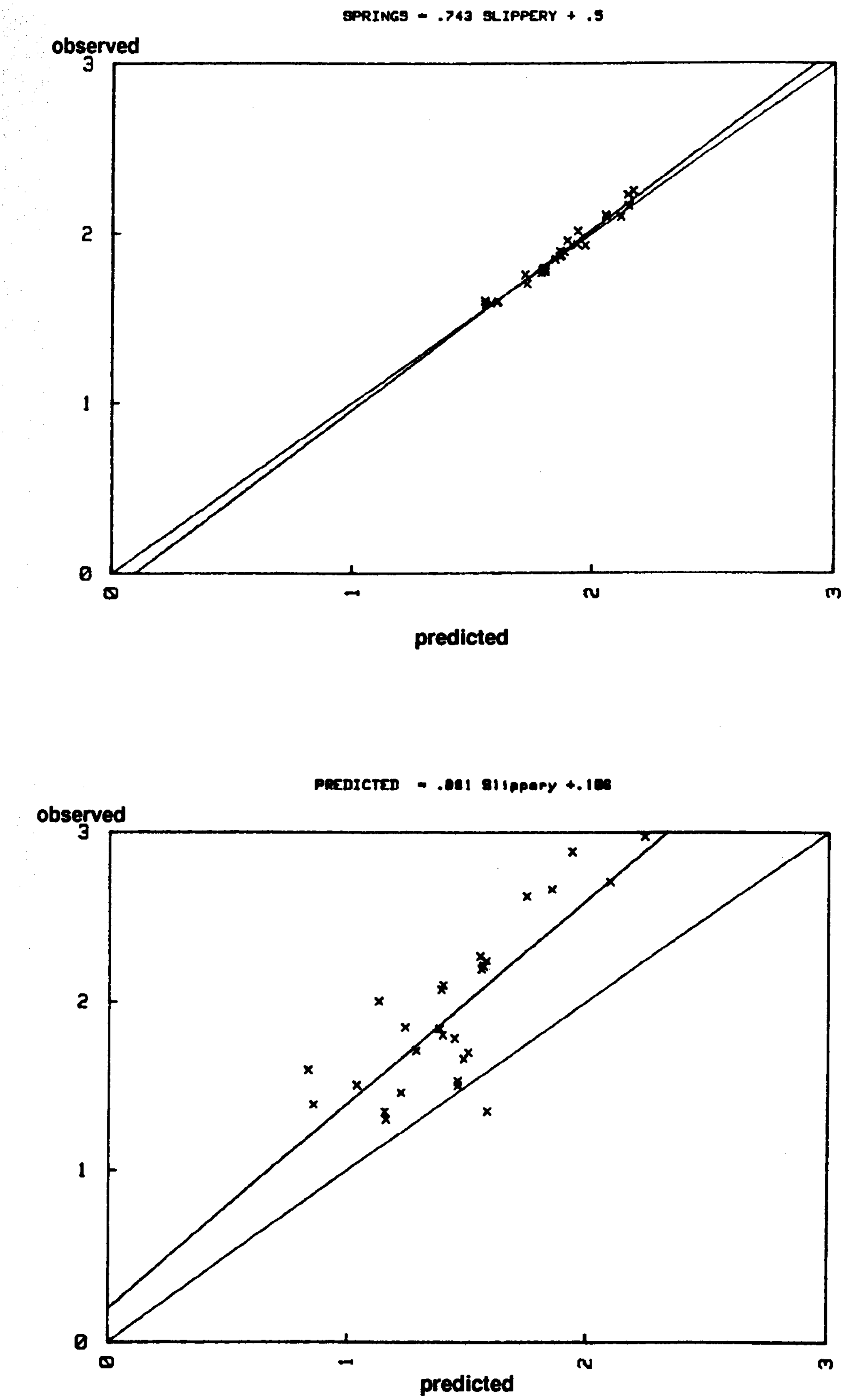


Figure 2.37 Comparison of observed and predicted event values: November 1984 - December 1985 (a) streamflow log (l/s), (b) sediment concentration log (mg/l)

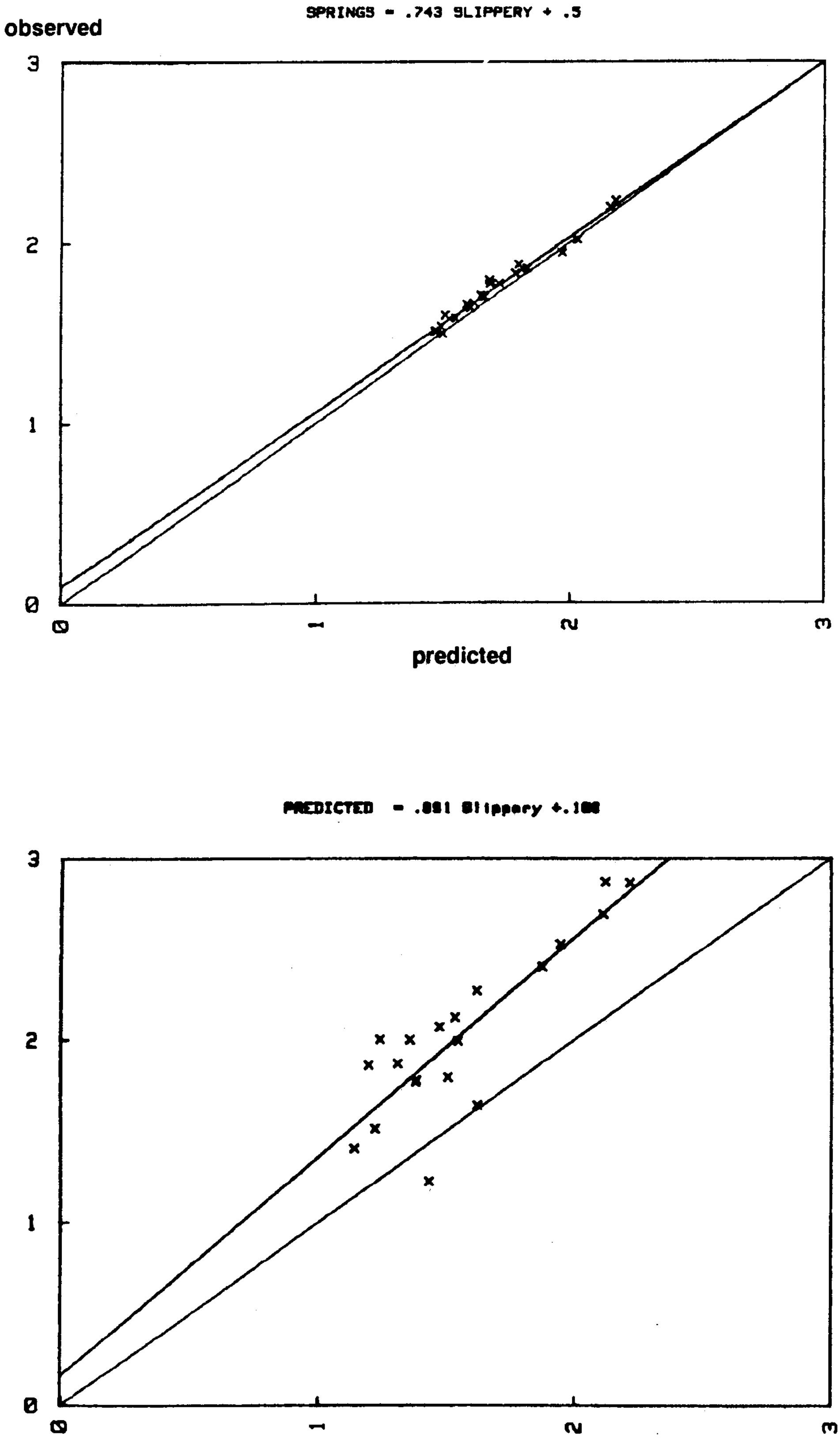


Figure 2.38 Comparison of observed and predicted event values: January 1986 - December 1986 (a) streamflow log (l/s), (b) sediment concentration log (mg/l)

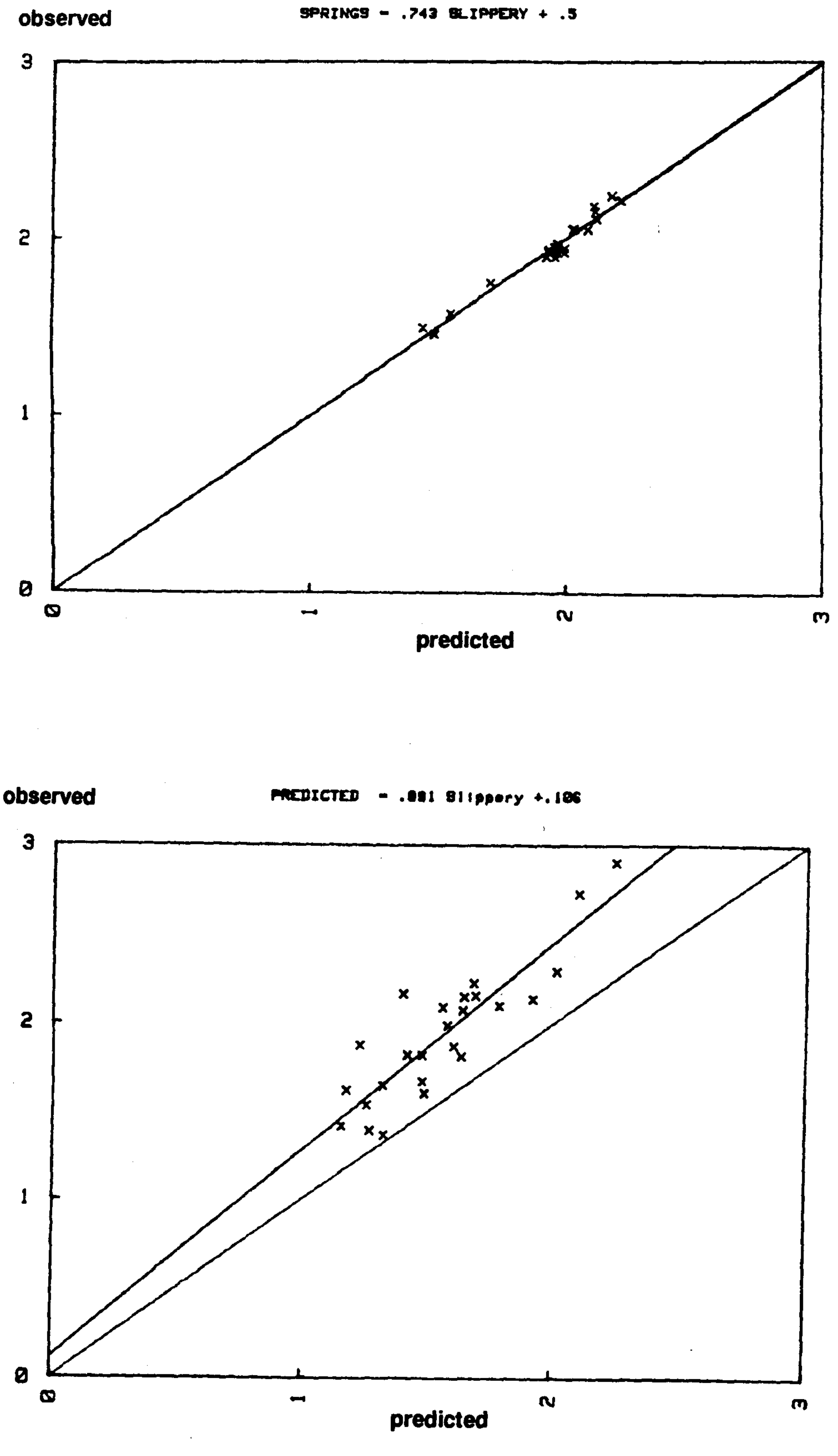
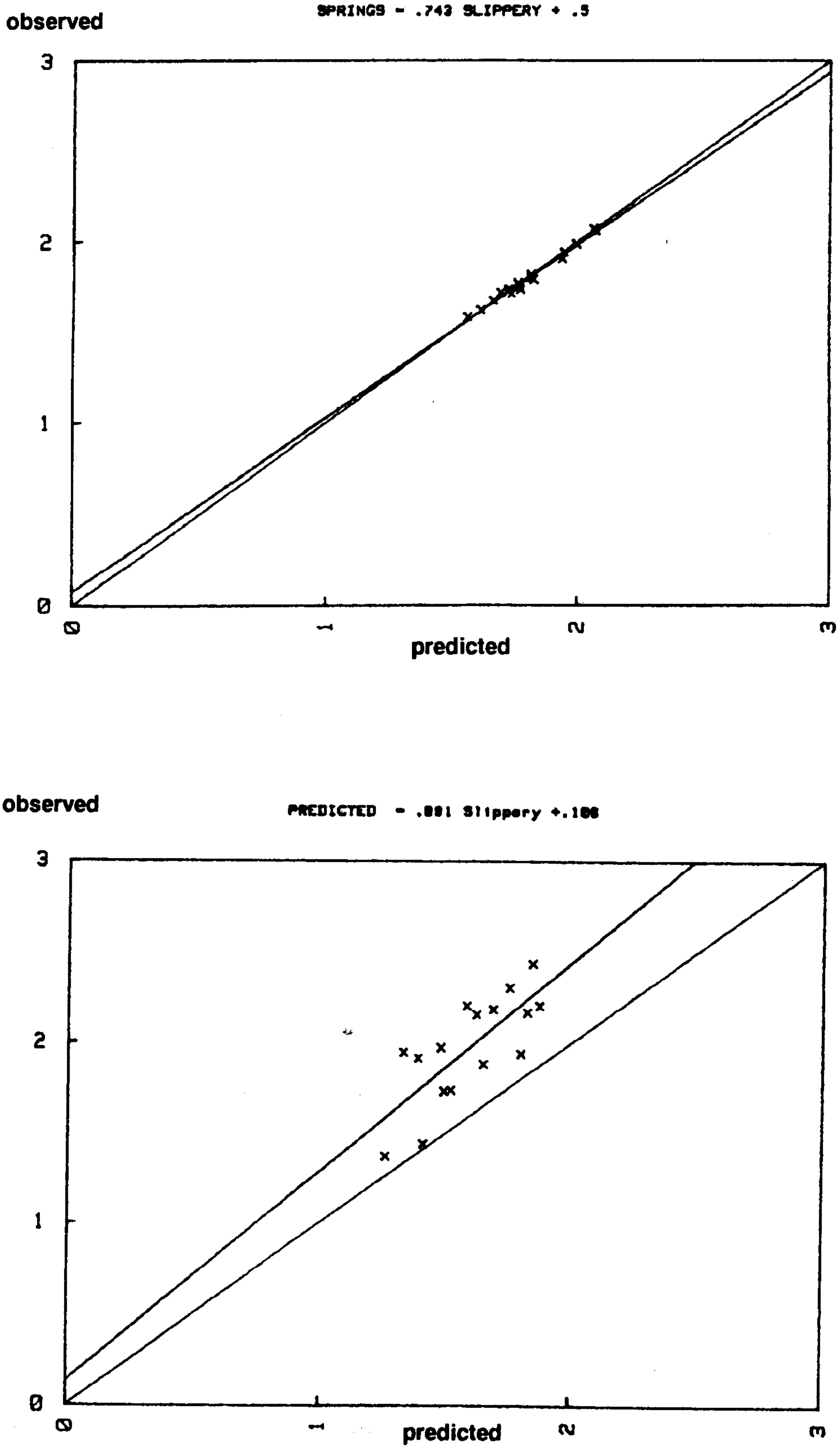


Figure 2.39 Comparison of observed and predicted event values: January 1987 - December 1987 (a) streamflow log (l/s), (b) sediment concentration log (mg/l)



Only events with flow increase greater than 7 litres/second in both creeks have been considered in this analysis. In the absence of any treatment effect, the points will be close to but scattered around the 1:1 line. Increased sediment concentration due to treatment will lift the plotted points above the 1:1 line. The significance of the differences was tested using the nonparametric tests as described in Section 2.3.8. Results are shown in Table 2.14.

There are significant increases in sediment concentration in Springs Creek in all periods except the roading period. Note that roading occurred during a drought.

Table 2.13 - LS regression of mean daily event sediment concentration observed against predicted values

Period	LS Regression PRED = $b_0 + b_1$ OBS		R^2	Matching figure
	b_0	b_1		
1978	0.253	0.838	0.791	232
1979	-0.038	1.00	0.816	2.32
1980	-0.22	1.16	0.839	2.32
1981	-0.59	1.58	0.945	2.33
Roading	-0.072	1.06	0.170	2.34
Harvest 1	0.148	1.12	0.645	235
Harvest 2	0.19	1.20	0.651	2.36
Harvest 2	0.161	1.20	0.733	237
Burn	0.113	1.17	0.773	2.38
Post-treatment	0.133	1.15	0.567	239

Table 2.14 - Nonparametric test for change in sediment concentration

Period	One sample Wilcoxon Rank estimate and confidence interval CI		I	p-value
	Estimate	% confidence		
Wet	0.26	94.9	(0.16, 0.36)	<.001*
Road	0.17	94.8	(-0.05, 0.30)	0.205
Harvest 1	032	95.0	(0.22, 0.42)	<.001*
Harvest 2	0.50	95.1	(0.39, 0.63)	<.001*
Harvest 3	0.51	95.0	(0.38, 0.60)	<.001*
Burn	037	95.0	(0.29, 0.46)	<.001*
Post-treatment	0.38	94.8	(0.27, 0.51)	<.001*

* estimates are significantly different from zero. All others are not significant

The changes are also shown in time sequence in Figures 2.40 and 2.41.

These findings have been summarised graphically and related to the flow values using the method described in Section 2.3.8. The global median sediment concentration for Slippery Rock Creek is 33.9mg/l. The parameters of the regression equations for observed and predicted values are in Table 2.12. Results have been plotted in the bottom half of Figure 2.44.

Values of sediment concentration show an increase of 33 mg// in the wet year 1981. This corresponds to the increase in flow. There are few events in the drought year (1982). There are increases in median sediment concentration compared to pre-treatment values, associated with the combined roading and logging operations. The maximum increase is +200% in the second year of forestry operations. The increase in sediment concentration persists into the recovery period (it is still approximately + 100% in 1987). It is not possible to determine accurately how fast the catchment recovers from the operations because the experiment was terminated in December 1987.

2.4.9 Analysis of transients

The data set of raw sediment concentrations (Section 2.4.3) was inspected for very high values on the descending limb of the hydrograph, on occurrence without change in flow, or in absence of rain. Slightly less than 2% of data set was involved. The values were usually not in pairs; they are tabulated in Appendix H3. Their relative numbers are summarized in Table 2.15.

Table 2.15 - Summary of Sediment Concentration samples

Catchment	Springs Creek		Slippery Rock Creek	
Period	Pre-treatment	treatment	Pre-treatment	treatment
Samples taken throughout period	1921	3325	1964	3322
Samples classified as transient	32	60	23	43

Questions of interest at this point are whether there are significant differences in the numbers over the pre-treatment and treatment periods for each catchment, and whether there is an overall difference between catchments over the whole experiment.

Figure 2.40 Plot of regression residuals against time: pre-treatment period (a) streamflow log (l/s), (b) sediment concentration log (mg/l)

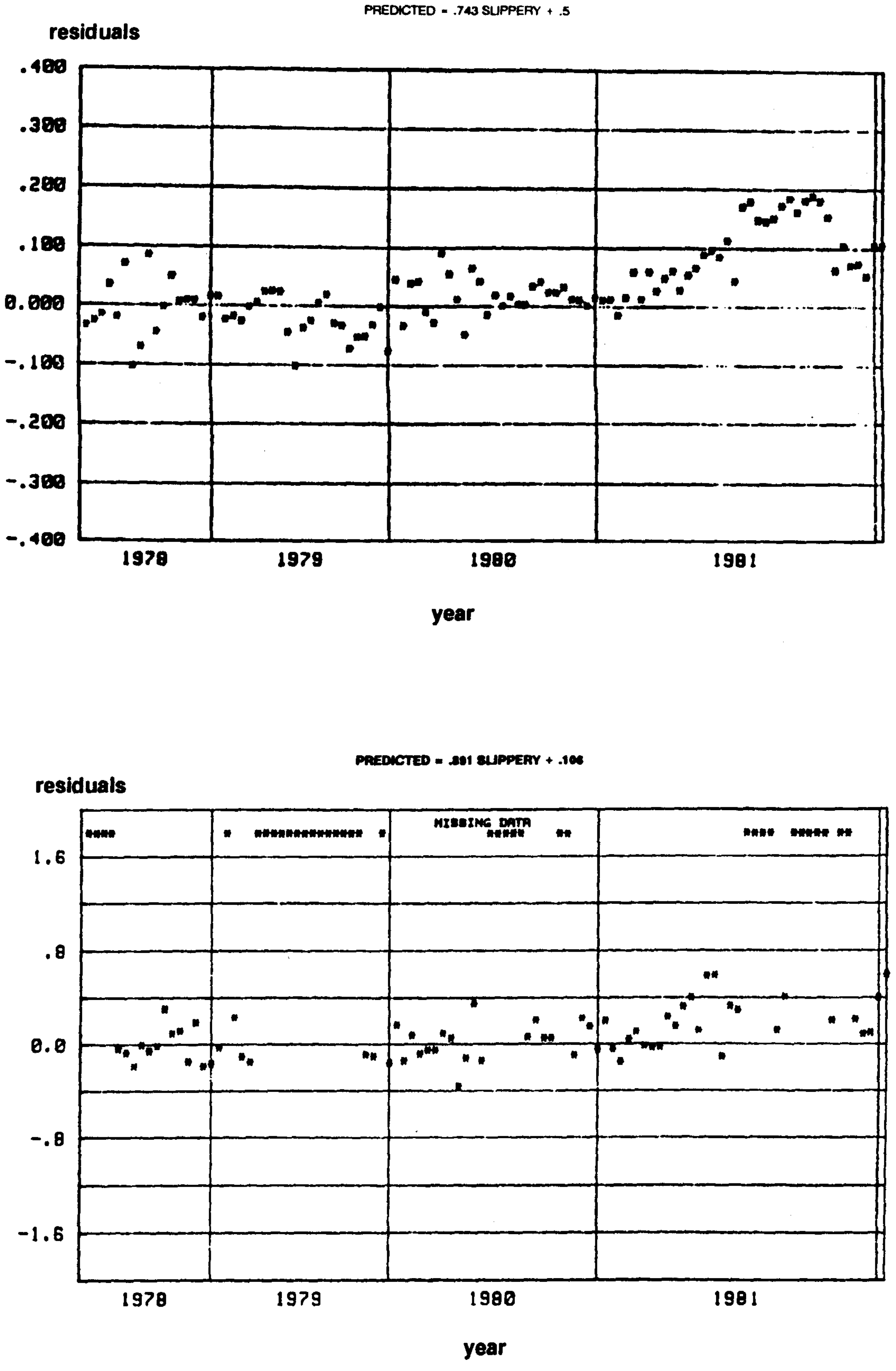
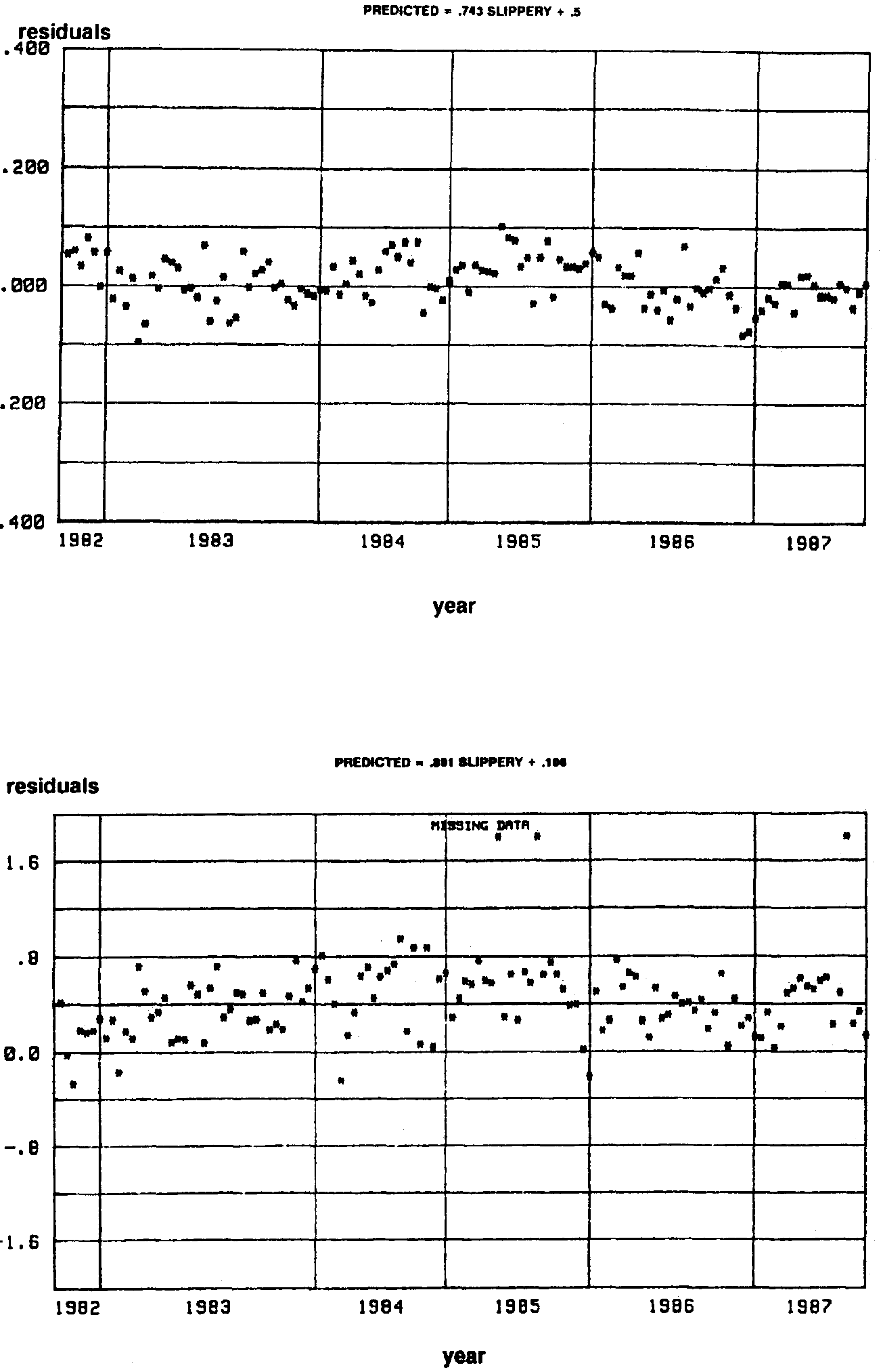


Figure 2.41 Plot of regression residuals against time: Treatment period (a) streamflow log (l/s), (b) sediment concentration log (mg/l)



Each question has been tested by two methods:-

a) By calculation of a confidence interval for the difference in proportion. Values are shown in Table 2.16. Results indicate that there is no difference between pre-treatment and treatment periods for either catchment, but that there is a difference between catchments over the whole experiment.
b) Using an EDA technique, data from both catchments were transformed to make the distributions more symmetrical. Boxplots of these distributions were then determined (Figure 2.42). These verify the above findings.

The conclusion here is that Springs Creek had significantly more transient values than Slippery Rock Creek. The mechanism may depend on characteristics of the catchments or streams, or on methodology and warrants further study.

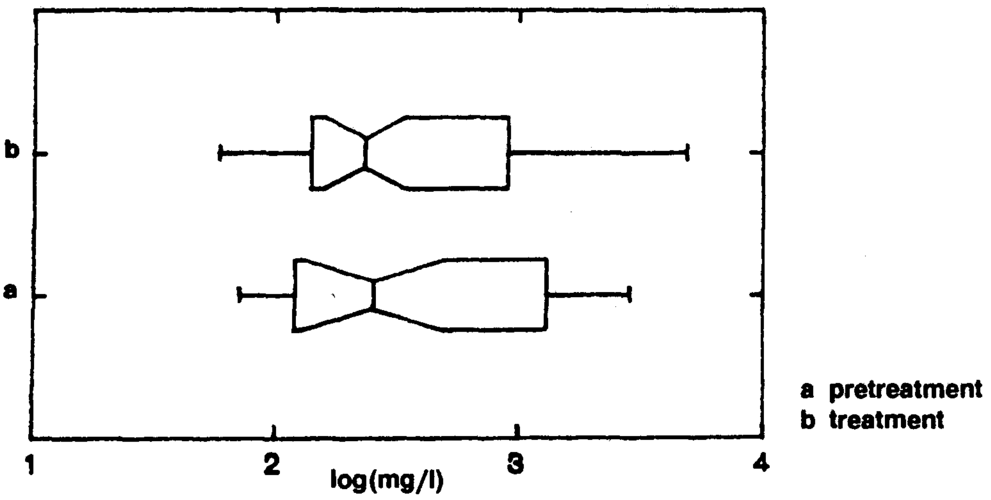
Table 2.16 - Analysis of transient numbers. Estimates and Confidence Interval (CI) for difference in proportion. (All numbers are x 10^{-3})

	Estimate	**95% CI**
between periods for each catchment		
Springs Creek	1.3	-0.6, 8.6
Slippery Rock Creek	4.9	-4.9, 73
between catchments for the whole experiment	5.1	0.4, 9.7

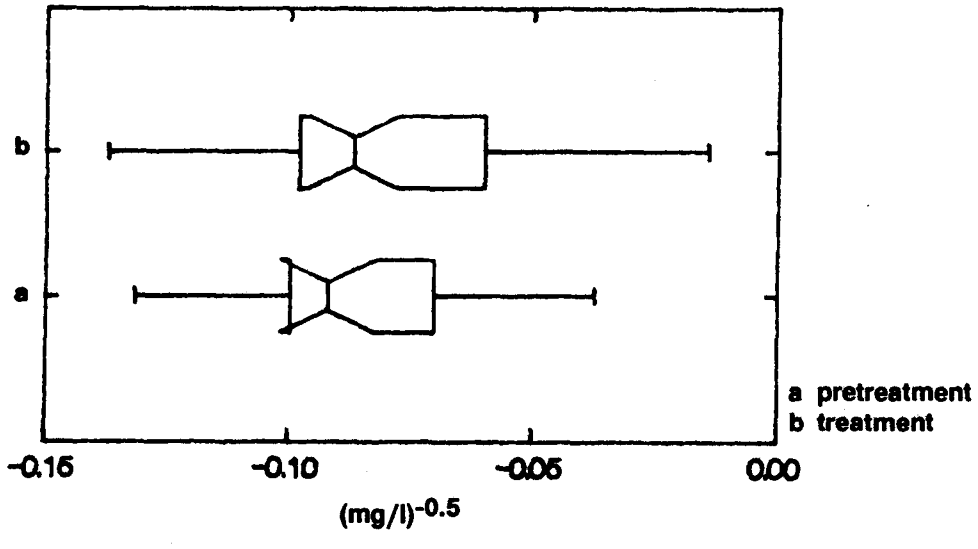
There has been some debate as to whether the automatic samplers collected suspended sediment, saltating bedload, or a combination of both. If increased flow in the stream raises turbulence at the sampling site, so that coarser material is picked up and subsequently sampled, then some dependence of transient sediment values on streamflow would be expected. Sediment concentration values are plotted against daily streamflow for each catchment in Figure 2.43. Both scatterplots show a slight increase in sediment concentration with increasing flow, but the coefficients of determination are low (13% for Springs Creek, 23% for Slippery Rock Creek). Both plots have high leverage points and outliers. A more definitive result may be obtained by using the streamflow at the time of sampling, when this is available.

Figure 2.42 Boxplots of transients: pre-treatment June 78-Jan 82, treatment Feb 82-Dec 87

Springs Creek



Slippery Rock Creek



Whole experiment

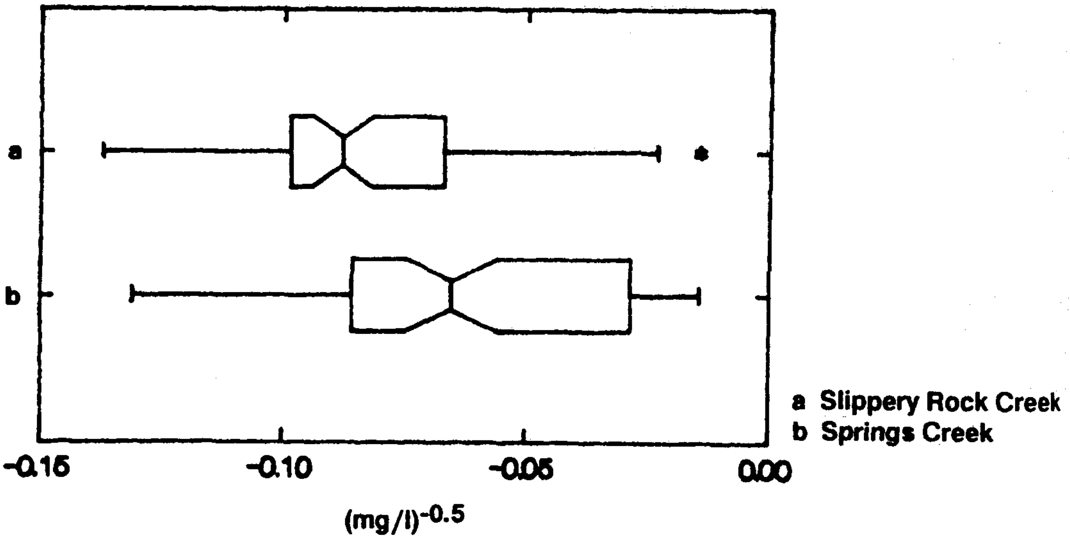
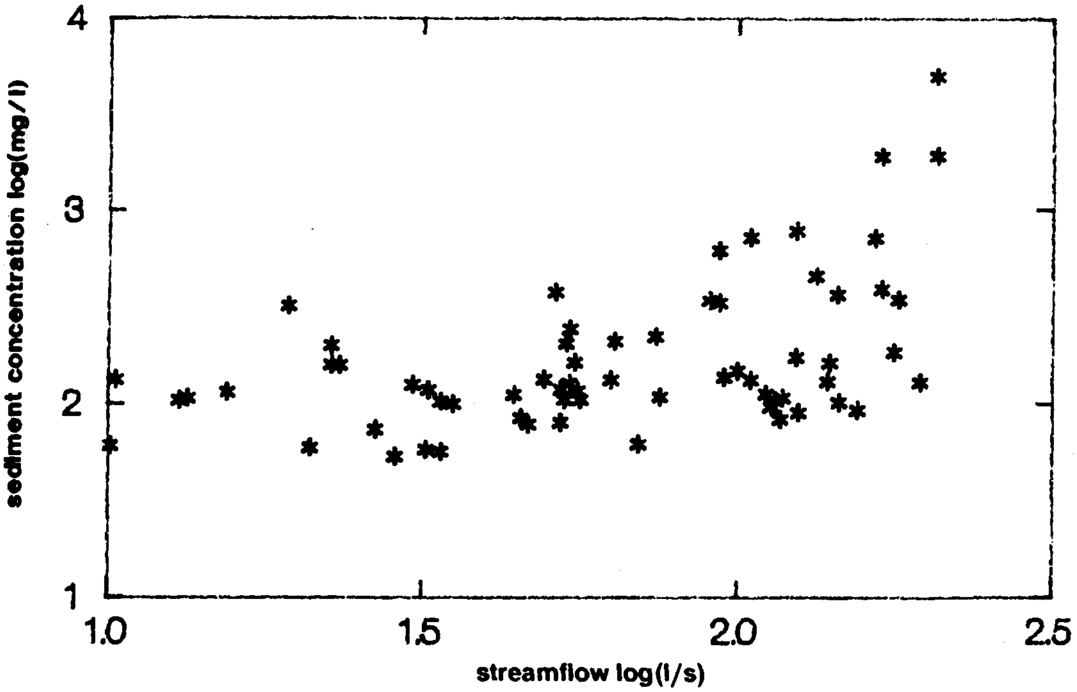
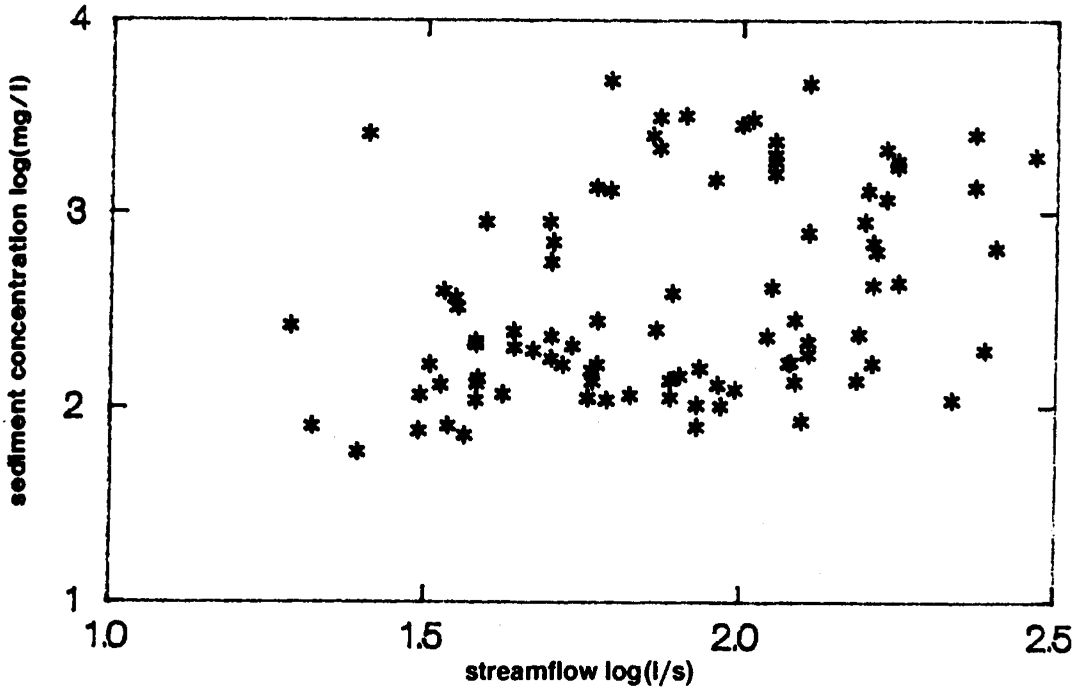


Figure 2.43 Transient sediment concentration values versus daily streamflow

Slippery Rock Creek



Springs Creek



2.5 Discussion and Summary

The **flow data** set has been looked at in different levels of detail.

At a fairly coarse level, tests show that both catchments are consistent in the calibration and treatment periods. This means that if there are changes in flow then they are either small in magnitude, or do not persist, or both.

At a monthly level, there is a significant change in the relationship between the two catchments during the wet period in 1981. The change is temporary; the catchments behave the same over the treatment period as they did over the calibration period. These findings are verified by analysis of flow at a daily level.

When mean daily event flow is considered, there are significant increases in flow:

i) in the wet period during the calibration. This occurred over the second half of 1981. The median value of the increase is +12*l*/s.

ii) in the roading period in 1982. The median of increase is +3.2*l*/s. Roading was done during the 1982-83 drought. Consequently, there are few events, and the magnitude of the increase is small.

iii) in the third harvest period in 1985. The median of increase is +4*l*/s. Although this increase is significant, it is small relative to the median flow over the duration of the experiment (58.8 *l*/s).

The **sediment concentration** data set has been considered in two ways.

Firstly, the maximum sediment concentration value for each month was obtained from each catchment. There are limitations of sampling the maximum value, both in magnitude and in timing. Also, there are large measurement inaccuracies at low sediment concentrations. For these reasons only broad conclusions are valid from analysis of maximum sediment concentration.

Two tests were applied to this data set. Despite the above limitations, a significant difference was found for Springs Creek catchment between calibration and treatment periods. The control catchment was well-behaved for the duration of the experiment.

Regression analysis was then used to analyse the data in greater detail. Regressions of Springs Creek values against Slippery Rock Creek values were similar in the calibration and treatment periods. However, the regression line showed a significant increase in slope during the wet period (1981). Details of the regressions are in Table 2.12.

These findings imply that there is a stable relationship (with respect to sediment concentration) between the two catchments throughout the calibration period. This relationship changes in the wet period in the latter half of 1981, and then restores close to the calibration value for 1982 to 1987. This is not definitive, because the coefficients of determination of the regressions are in the range 50 - 60%. Also, it should be noted that regressions of logarithmic data are being considered. Although the intercepts are not significantly different, they represent an offset of one order of magnitude.

In the second and more detailed analysis, the mean daily event sediment concentration was considered. The data set in this analysis does not have the limitations of the previous analysis. The findings are summarised in Figure 2.44. Significant increases in sediment concentration were observed in all periods except roading, which was done during a drought period with few events. Sediment concentration increased by a median value of 40 mg/l (+118%) in the first harvest period, by 70 mg/l (+206%) in the second harvest period, by 65 mg/l (+192%) in the third harvest period, and by 45 mg/l (+133%) in the burn period. The increase persists into the recovery period.

The experiment was terminated before an accurate indication could be made of the recovery of Springs Creek catchment.

There are 'strange' sediment concentration readings scattered through the data set. They are usually very high and appear at unexpected times, e.g., when there is no rain or no change in flow. A colleague suggested that they might be caused by the large lyre-birds in the catchments, but these were not surveyed.

These transient values (so-called because they are isolated readings) were analysed to search for an underlying mechanism.

The findings are that the transients are scattered more or less evenly through the sediment concentration values for both catchments, but that there are more from Springs Creek.

One possible cause was that the samplers may have been measuring saltating bedload as well as suspended sediment.

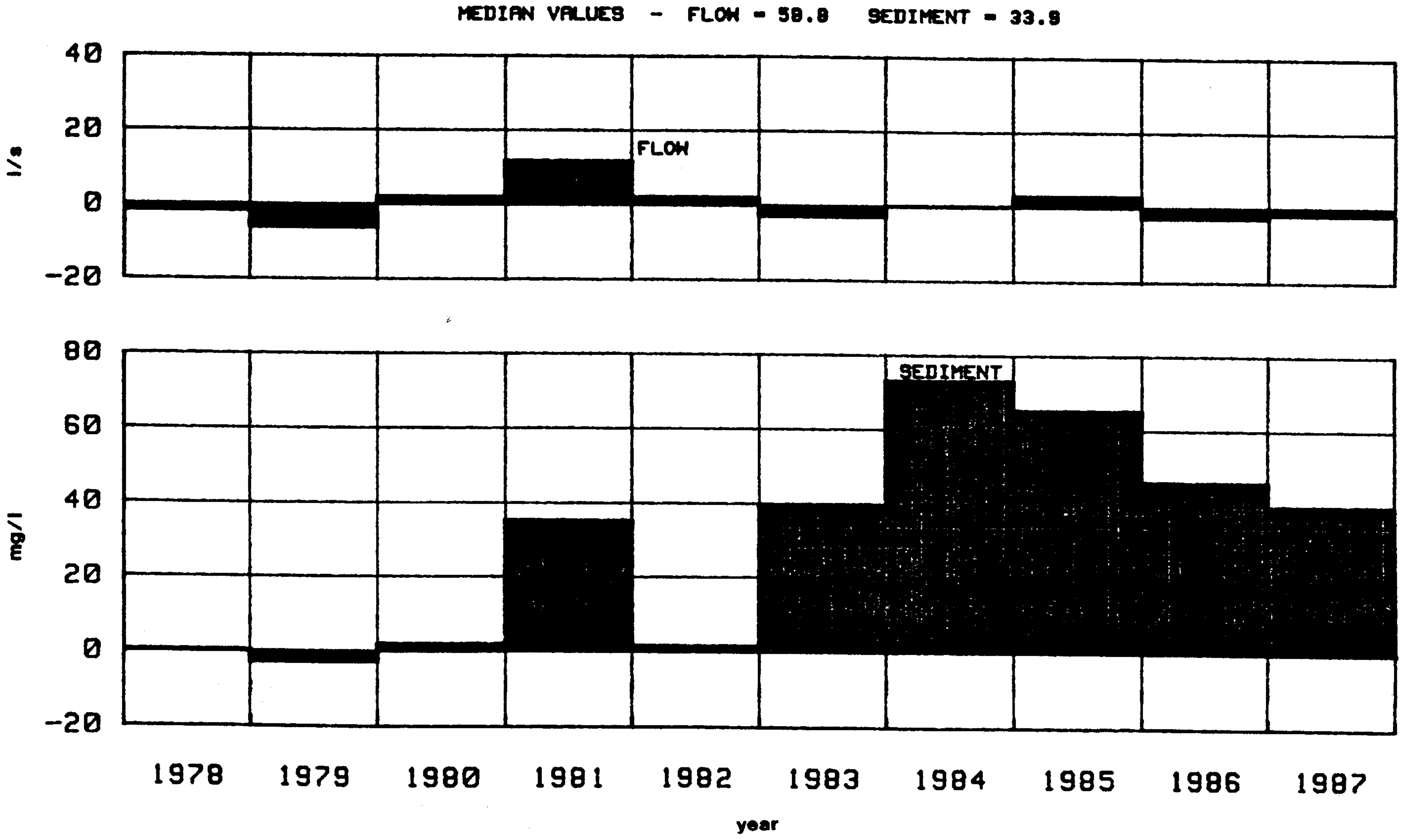
If this was happening, increased numbers of transient values would be expected at higher flows (i.e. at higher stream energy). However, only a slight dependence on flow (13 - 23%) was observed, so that this has not been resolved.

2.6 Conclusions

i) It has been established that there was a reasonably stable relationship between the experimental catchments both for flow and for sediment concentration.

ii) These relationships changed temporarily during the wet period in the latter part of 1981. Consequently, relative flow and sediment concentration increased over that period.

Figure 2.44 Annual summaries of (a) streamflow (b) sediment concentration. For details see text.



iii) After the wet period, the flow relationship came back fairly close to the calibration values. Only small positive changes in flow (<7%) were observed in the roading and third harvest periods.

iv) Roading operations were done during the 1982 drought period, when there were few events. Sediment concentrations were elevated for all phases of the treatment period. The maximum increase of median value of sediment concentration is +206% in the second harvest period. The increase persists into the recovery period; it was still +118% when the experiment was stopped in December 1987.

3. GUIDELINES FOR FUTURE PROJECTS

There have been some difficulties completing this study, both in the experiment itself and in the analysis. In this Section, some suggestions are made so that future studies of this type may benefit from the experience gained in this study.

As general comments, the optimal management of a project depends strongly on the available resources. There are definite advantages in having the same analytical team throughout the project.

Some specific suggestions relating to experimental design are as follows.

3.1 Rainfall

It is important that there is a network of 203 mm diameter reference raingauges in the experimental area. This gives valuable information on the rainfall distribution through the area. It also minimizes bias in measuring rainfall only at low elevations in the catchments. Positioning of pluviographs in clearings with adequate exposure is necessary to avoid spurious results from overhanging branches.

3.2 Streamflow

Flow measurements through a weir and a test flume require great care in setting up. It is difficult to guarantee that total flow through the test flume is measured, especially when it is upstream of the main weir structure. Possible alternatives are:

i) to fix a V-notch to the upstream face of the culvert. Suitable dimensions would need to be chosen to permit unrestricted flow. The philosophy behind this idea is that flow over a V-notch varies with water depth raised to the power of 2.5, where the corresponding power for a circular culvert is 2.0 (Bos, 1976). Flow can be measured much more accurately over a V-notch.

ii) to position the flume on the downstream side of the culvert. In this case, the road itself acts as a cutoff wall; and there is no flow restriction. However, there may be practical problems with siting the flume.

3.3 Sediment

Suspended sediment and bedload should be measured separately.

Bedload is measured by installing a settling pond in the stream. The pond dimensions are sufficiently large to ensure settling of sediment with large particle sizes. Quantity of bedload is determined by survey and sampling.

Suspended sediment is measured by automatic sampler. The sampling head is position in a well-mixed part of the stream at the outlet of the settling pond. This ensures that material not trapped as bedload is measured as suspended load.

Some possible causes of relative variability of sediment yield from these catchments have been discussed by Leitch (1982). In future studies of this type it will be valuable to measure basic information on the number of obstructions across streams as well as streambank characteristics. Detailed fauna surveys are needed to assess the degree of relevance of fauna as sources of sediments.

3.4 Roading

To accurately study the effect of roads on quantities of sediment, suitable instrumentation would need to include traffic counters, continuous and sampling water quality monitors, and suitable structures for detailed bedload measurements.

Existing data on the effects of roads is limited. From the literature, two of direct relevance are a study of the MMBW on the effects of a logging road on water quality; and a study by Bren and Leitch (1985) on the water quality from a length of forest road.

If a study of roading is desired, then there is an area available for detailed study. Long Corner Creek experimental area is one of the Department's hydrology experimental areas located near Myrtleford. There are 16 years of flow data and 6 years of bedload data from two instrumented catchments of 101 ha and 146 ha. These catchments could be made available for a roading study at short notice.

4. ACKNOWLEDGEMENTS

This experiment would not have been possible to undertake without the active participants of officers within the Department of Conservation, Forests and Lands, the State Electricity Commission of Victoria, and Melbourne and Metropolitan Board of Works.

Richard Hartland entered, edited and digitized data on the HP9845B computer. He extended the in-house statistical package; he did the LS analysis on streamflow and sediment; he developed the algorithms used in Section 3. Wayne Smith kept the field equipment operational and processed the bulk of the sediment samples. Peter Farrell set up the suite of programs on GCS Burroughs computer. Colin Leitch analysed the data prior to 1980. He was responsible for theproje4ct until the amalgamation. Raj Rajendrank extended the analysis of flow and sediment yield and provided valuable discussion. Peter Leerson calculated the catchment characteristics. Peter Clinnick provided the basis catchment information and valuable advice. Cath Cannon digitized the field charts for rainfall, flow and sediment times. John Woodward was also involved in the digitizing of charts, and gave valuable advice on the data set. Robin Adair, Max Howell, Ian Holden, Trevor Watson and David Panozza from the SECV kept the field equipment operational throughout the project.

In addition to these specific people, there are the officers who have provided information for the study, the operations personnel who recorded the logging details, and colleagues, who have helped with computing. The report has been typed by Roberta Carini and Pat Davies with much care.

Jim Bates, Graham Varcoe and Sooriyakumaran critically (positively) reviewed the manuscript. Professor Tom McMahon and Kien Gan review the final draft.

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Appendixes

A REGIONAL DESCRIPTION

Al Geology

Since the Upper Ordovician, approximately 435 million years b.p., North-east Victoria and East NSW have undergone several tectonic episodes, including the Benambran, Bowning and Tabberabberan Orogenesis, and the Kosciuskoan Uplift. These events resulted in a region of locally and regionally metamorphosed sediments, intrusive igneous rocks folded, faulted and jointed. Altogether this is known as the Omeo Metamorphic Complex (Laing 1981) and (Beavis 1962).

The three geological units found in the experimental catchments are part of this complex (refer to Figure Al):

1. Epi-Ordovician High Plains Gneiss, which occupies most of the lower elevations of both catchments and the higher elevations on the northern border of Springs catchment, was formed during the Benambran Orogeny and is the core of the metamorphic complex (Beavis, 1962).
2. High plains Gneiss has dark and light bands interbedded with a north-south trending foliation. Quartz, alkali feldspar plagioclase, biotite and muscovite are its main constituents. Zircon and apatite are accessory minerals (Laing, 1981).
3. Epi-Silurian Kiewa Granodiorite intruded into the Gneiss during the Bowning Orogeny. It is found in the lower southern portion of Slippery Rock Creek catchment. Beavis (1962) states that most of the contact is faulted, but (Laing 1981) found no evidence of this. Fine grained crystals predominantly light coloured but black speckled can be seen in hand specimen. The crystals are quartz, alkali feldspar, plagioclase, hornblende and biotite with accessory minerals of iron ore, apatite, zircon and sphene.
4. Epi-Mid Devonian Big Hill Quartz Diorite is intrusive into the Granodiorite and Gneiss. Beavis believes S, W & SE and part of N boundaries are faulted. Laing has found no evidence of this. However from air photographs he detected a fracture zone trending NE from Bald Hill along the contact of the Quartz Diorite and the High Plains Gneiss.

   The Quartz Diorite consists of quartz, plagioclase, alkali feldspar, hornblende and biotite with accessory minerals of iron oxide, apatite, zircon and sphene.

   There are a few rocky outcrops in the catchments at the water falls in Slippery Rock Creek, on ridges and in the stream bed (Laing 1981). Sandy alluvium is deposited in and adjacent to the creek beds. Springs Creek catchment has extensive outcrops of High Plains Gneiss and Big Hill Quartzdiorite. Laing (1981) took 16 sand samples. He found they were all of similar composition - quartz, feldspar, rock fragments, organic material and golden mica. The latter mineral being the distinctive feature of the sand.

There are a number of boulders, some of very great in size in the catchments. Laing (1981) noted that boulders of Big Hill Quartz Diorite were found at the hydrographic station in Springs Creek although the nearest outcrop is at the head of the Creek. Similarly, boulders of Kiewa Granodiorite were found in the lower section of Slippery Rock Creek indicating the streams have a considerable amount of force.

A2 Geohydrology

Beavis (1962) proposed that there is a basic structural control of the topography. This can be seen at Slippery Rock Creek catchment where the creek tends to follow the line of fractures. This is also true of Staff Camp Creek, to the south of Slippery Rock Creek catchment.

At each creek there were no distinct springs but flow increased in a fairly regular fashion from the headwaters indicating the stream is fed by ground water inflow.

Groundwater follows two paths: one through the soil mantle, the second within fractures of the rock (Laing 1981). Beavis reported "the majority of ground water discharges occurred along joints". "The results suggested that flow under these conditions was similar to that through a porous medium, the joints having, en masse, the role of pores".

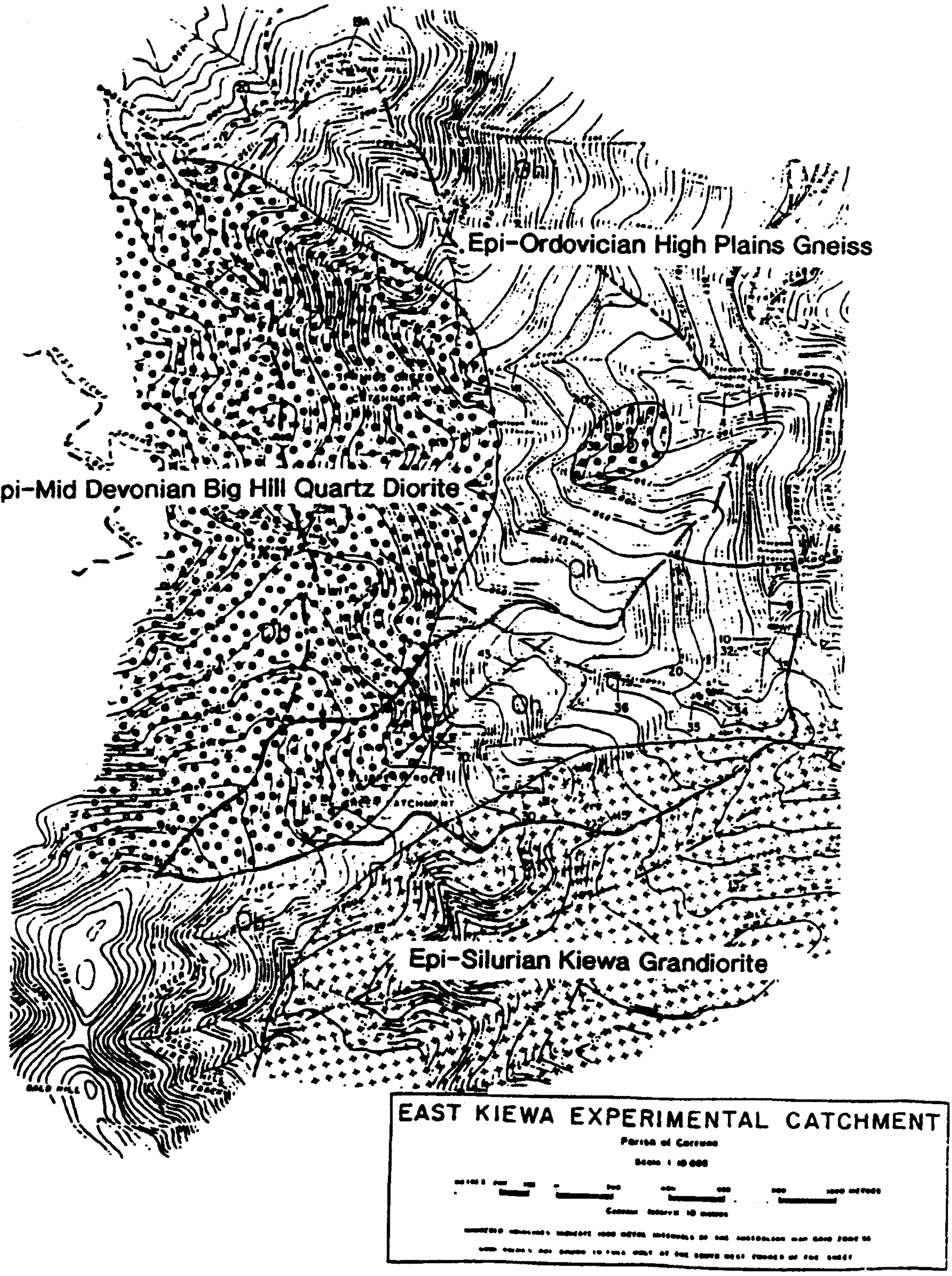
The Kiewa area is highly faulted; it harbours many joints and fractures along which groundwater travels. The geology of the experimental catchments extends beyond the catchment boundaries, as defined by surface topography. There is no guarantee that rainfall in one catchment (i) remains in that catchment, or (ii) leaves that catchment as streamflow. There is a possibility (i) that groundwater may leak away to an adjacent catchment, or (ii) that groundwater may be augmented by leakage from an adjacent catchment.

A3 Topography

The experimental catchments are found in the Darbalang sub-system of the Tawonga Land System (Rowe, 1972). The landform is that of a steep ridge and spur complex with 57% of the slopes in Springs Creek Catchment, and 55% of the slopes in Slippery Rock Creek catchment, being greater than 24° . Most slopes greater than 30° occur in the lower levels of the catchment.

Elevation Ranges from 620-1380 m in Springs Creek catchment; 660-1520 m in Slippery Rock Creek catchment.

Figure Al Geology of the experimental catchments



Springs Creek catchment (244 ha) has two main tributaries of approximately equal catchment area converging in the lower section of the catchment. Slippery Rock Creek catchment (136 ha) has one main water course. Perennial stream length of Springs Creek is 5600 m compared to the perennial stream length of 4100 m of Slippery Rock Creek.

Springs Creek catchment is broader with gentler valleys whereas Slippery Rock Creek is narrower. Beavis (1962) proposed that there is a basic structural control of the topography with drainage lines following the line of fractures. Bolger (1984) notes the drainage history is more complex south of the Tawonga fault with many examples of river piracy. Laing (1981) suggested that Slippery Rock Creek had captured one of Springs Creeks tributaries. This can be seen on the map as a sharp directional change of the watercourse on the northern side of the catchment.

A4 Soils

A general description of the soils of the Upper Kiewa catchment has been given by Rowe (1972). More detailed descriptions can be found in Clinnick and Patrick (1984) and Hough (1983).

The predominant nature of the soils in the catchments is that they are well drained, highly porous and deeply weathered (Rowe, 1972). These soils can become unstable if the top layer, generally an organic or clay loam, is removed (Leitch, 1979).

Friable brownish gradational soils are common to all of the mountainous high rainfall areas of north-eastern Victoria. Rowe (1972) describes one such profile examined at Big Hill (sample 233):

> "a thin layer of decomposing organic matter over a very dark brown or black organic loam 3 to 6" deep. The surface few inches has a strongly developed crumb structure changing to fine sub-angular block. Below the surface horizon, the influence of organic matter rapidly decreases, the texture becomes clayey, and colours become brown or yellowish brown. Structure deteriorates with increasing depth and porosity decrease. The soil is friable throughout. Weathering rock usually occurs at about 4 feet or deeper. However, numerous rock fragments may occur in the profile. Soil may extend along fissures into the underlying rock".

Shallow uniform soils are found on the spurs. Generally the horizons are brown to yellowish brown. Textures grade from clay loams in the Al horizon to coarse sand in the C horizon. There is decreasing pedality with increasing depth and stones and rocks are found throughout the profile. Spurs with southerly aspects tend to have soils which are moist and friable while those found on northerly aspects are dry and hard.

Soils in drainage lines tend to deep, black organic to sandy clay loams, although a profile studied on a perennial drainage line consisted of coarse sand (Laing 1981). They have decreasing pedality with increasing depth, an earthy fabric and a friable or loose consistency.

The similarity of the geological units, granitoids, in the experimental catchments has lead to the closeness of the soils developed with main differences being due to aspect and elevation.

A5 Climate

Snowfall, frost, interception of low cloud, fog and hail are other forms of precipitation occurring in the Victorian Alps.

In general, snow falls occur at elevations higher than 1000 m. The amount, distribution and duration of snow varies from year to year. Big Hill, within Springs Creek catchment, regularly receives snow cover for one to two months of the year (W. Smith, pers. comm.)

Rowe (1972) has cited frost as an important agent of erosion, particularly in alpine and sub-alpine areas. Firstly, bare soil becomes loose and friable as a result of frost action, and is therefore more susceptible to erosion by wind and water. Secondly, frost can prevent the establishment of herbaceous regeneration on bare soil at high elevations.

Frosts tend to be more severe and last longer with increasing elevation. However, sites in flat-bottomed, narrow valleys will be more frosty than those on the higher adjacent slopes (Rowe, 1978).

A6 Vegetation

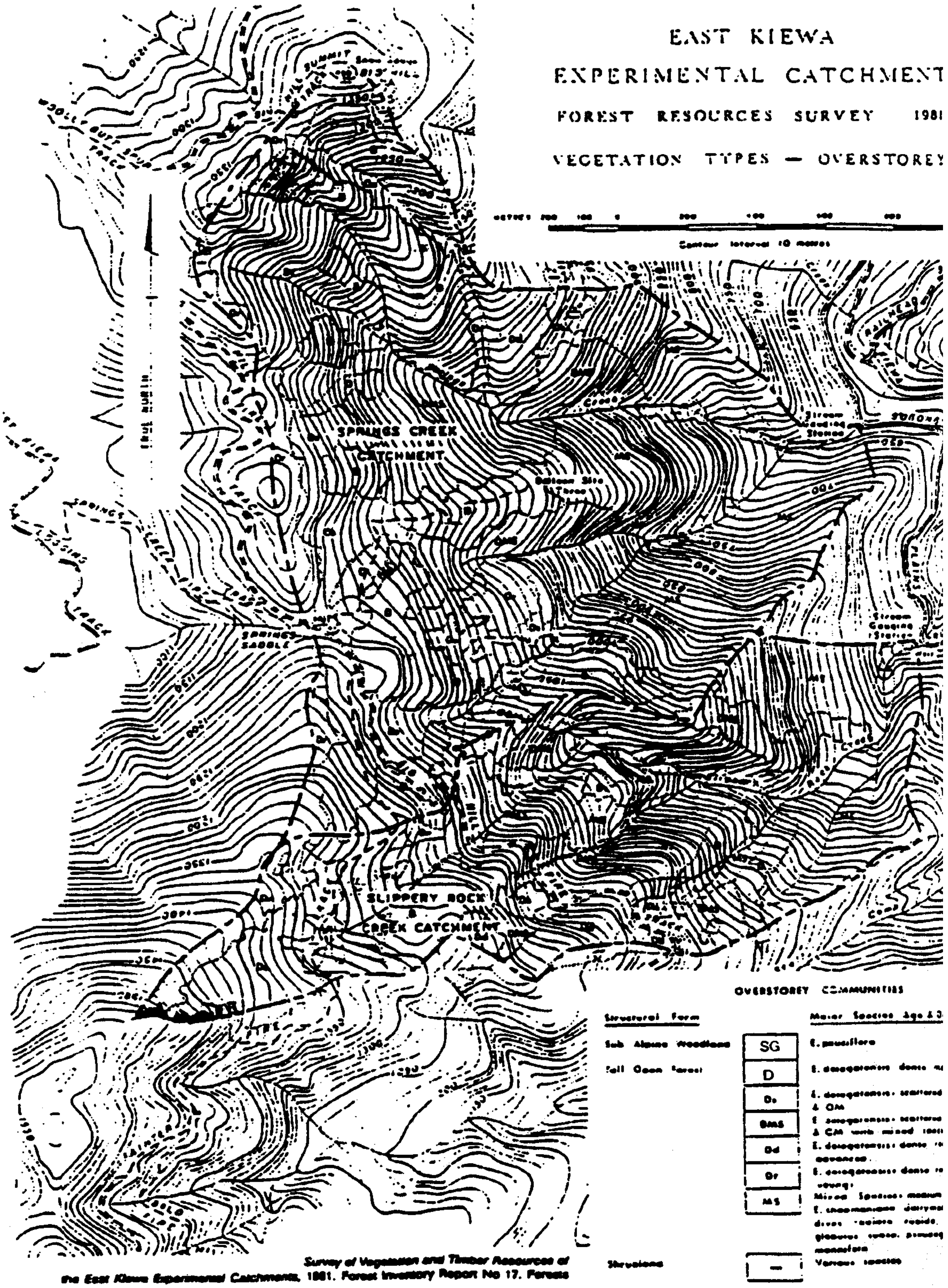
The vegetation of the experimental area has been described by Smith, Wehner and Black (1981). The catchments are predominantly covered by Open Forest III. At lower elevations (up to approximately 1100m) this consists of mixed eucalyptus Narrow-leafed peppermint (*Eucalyptus radiata*), Candlebark gum (*E. rubida*) and Broad-leafed peppermint (*E. dives*).

Above the mixed forest, Alpine Ash (*E. delegatensis* RT Baker) exists in almost pure strands, with some Mountain gum (*E. dalrympleana*) scattered amongst the Ash. Overstorey communities of the experimental area are depicted in Figure A2.

Most of the Alpine Ash is mature to overmature. The higher elevations show the effects of the wildfires of 1919 and 1939. Ash regrowth has extensive butt and bole damage. Severe dieback is apparent in overmature stands. White ants are also a problem in this area.

Ferns, shrubs and herbs provide a more or less continuous low understorey, particularly in the Alpine Ash zone. Riparian communities have a well developed tall understorey, often with a dense cover of tree ferns in the gullies flanked by a dense fern and low shrub stratum. Mountain Tea-Tree (*Leptospernum grandifolium*) is found at elevations above 1100m and is a species closely associated with hydrologically sensitive areas. (Clinnick, 1984)

Figure A2 Vegetation of the experimental catchments



Survey of Vegetation and Timber Resources of the East Kiewa Experimental Catchments, 1981. Forest Inventory Report No 17. Forests Commission, Victoria.

A7 Catchment Characteristics

A general map of the experimental catchment, the Al7 area and the Little Arthur Creek catchment is shown in Figure A4.

Catchment characteristics of the two experimental catchments, A17 and Little Arthur Creek, (Table Al) have been determined from contour maps of scale 1:25 000 or better. They highlight some differences which may affect transferring results from the experimental catchments to the other catchments in the Al7 area.

One of the more important characteristics is the aspect which is predominantly easterly in the experimental catchment. In Little Arthur Creek it is predominantly south and therefore wetter. The elevation at Little Arthur Creek and North and South Fainter Creek is also greater. Therefore these catchments are more likely to be subject to snowmelt and higher rainfall. The latter two are not as steep.

Bifurcation ratios (Table A2) can indicate a difference in either climate, rock type and/or stage of development of streams. If the ratio is similar for each order within a particular catchment it can be assumed the above factors are similar. A major difference between ratios can be seen at South Fainter Creek where the ratio is 63 for a stream order of 1 and 3 for a stream order of 2. This may be due to South Fainter Creek adjacent the Plains.

Figure A3 show the percentage of the catchment in a given height range.

The difference in shapes of the catchments is apparent. This may influence the shape and timing of hydrographs and may give individuality to the sediment transport mechanisms within each catchment.

Table A1 – Catchment characteristics of the A17 and Little Arthur Creek areas

Catchment	Area	Elevation (m)	Aspect/Slope		Stream
SPRINGS CREEK	244 ha	Max 1370 Min 620	Predominantly easterly slopes average at 50%	0.29	2.2 km
SLIPPERY ROCK CREEK	136 ha	Max 1520 Min 670	Predominantly easterly slopes average at 40%	0.26	2.7 km
LITTLE ARTHUR CREEK	195 ha *	Max 1360 Min 620	Predominantly westerly	0.21	3.0 km
BALD HILL CREEK		Max 1540 Min 715	Predominantly easterly	0.22	3.8 km
NORTH FAINTER CREEK	1304 ha	Max 1800 Min 850	Predominantly easterly	0.19	5.1 km
SOUTH FAINTER CREEK		Max 1800 Min 940	Predominantly easterly	0.22	4.0 km
GREENE CREEK	48 ha	Max 1600 Min 500		0.23	4.7 km
2nd ORDER CREEK	17 ha	Max 1180 Min 540		0.24	2.1 km

Area proposed for logging within this catchment

Table A2 – Bifurcation Ratios of the creeks in the A17 area

Springs Creek			Slipper Rock Creek			Bald Hill Creek		
Stream Order	Number of Segments	Bif. Ratio	Stream Order	Number of Segments	Bif. Ratio	Stream Order	Number of Segments	Bif. Ratio
1	11	3.6	1	7	3.6	1	19	4.8
2	3	3.0	2	2	2.0	2	4	2.0
3	1		3	1		3	2	2.0
							4	1

North Fainter Creek			South Fainter Creek			Little Arthur Creek		
Stream Order	Number of Segments	Bif. Ratio	Stream Order	Number of Segments	Bif. Ratio	Stream Order	Number of Segments	Bif. Ratio
1	20	3.3	1	19	6.3	1	11	5.5
2	6	3.0	2	3	3	2	2	2.0
3	2	2.0	3	1		3	1	2.0
4	1							

Greene Creek*			2nd Order Creek*		
Stream Order	Number of Segments	Bif. Ratio	Stream Order	Number of Segments	Bif. Ratio
1	234.6	1	4	4.0	
2	5	2.5	2	1	
3	2	2.0			
4	1				

* Contains part of Little Arthur Creek proposed logging area.

Figure A3 Catchment height by percentage area

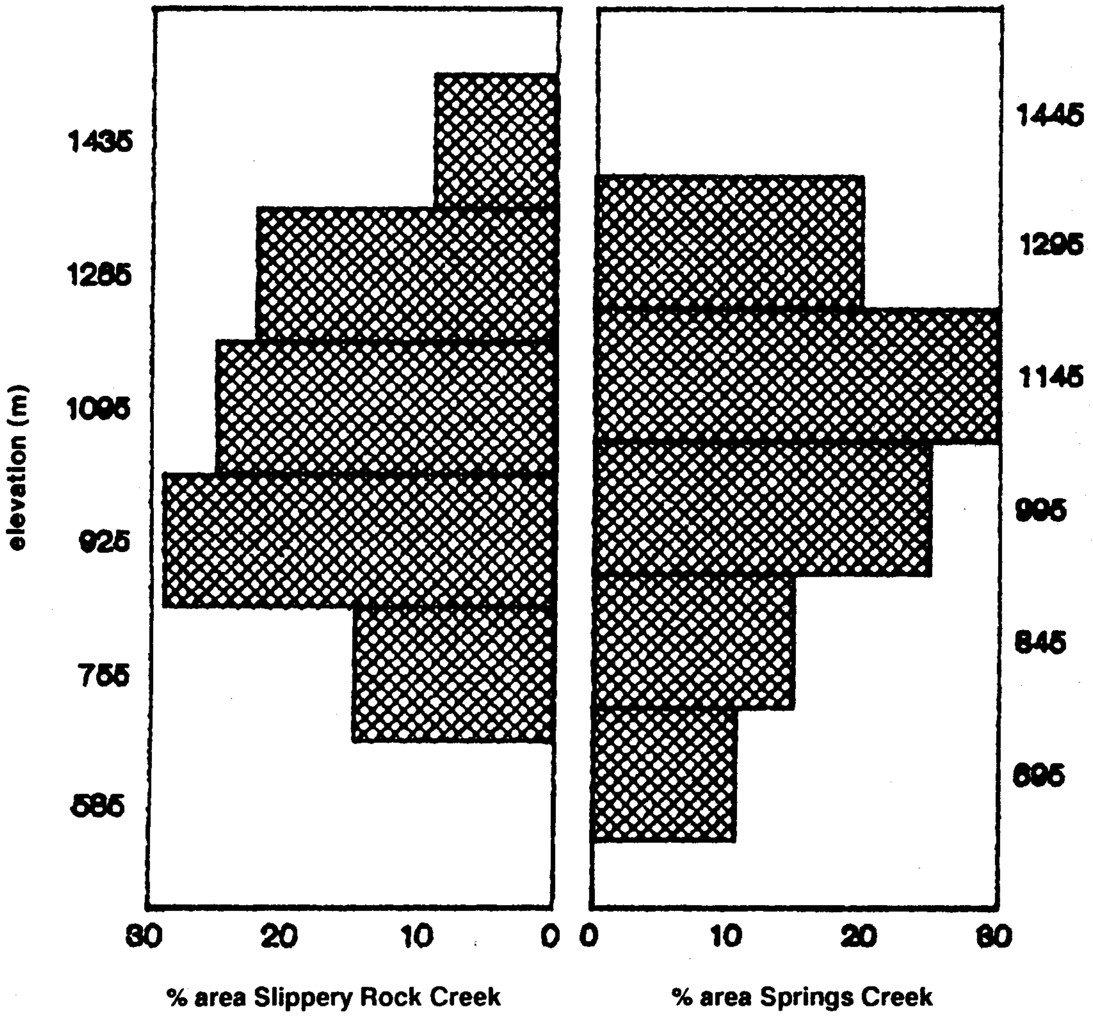
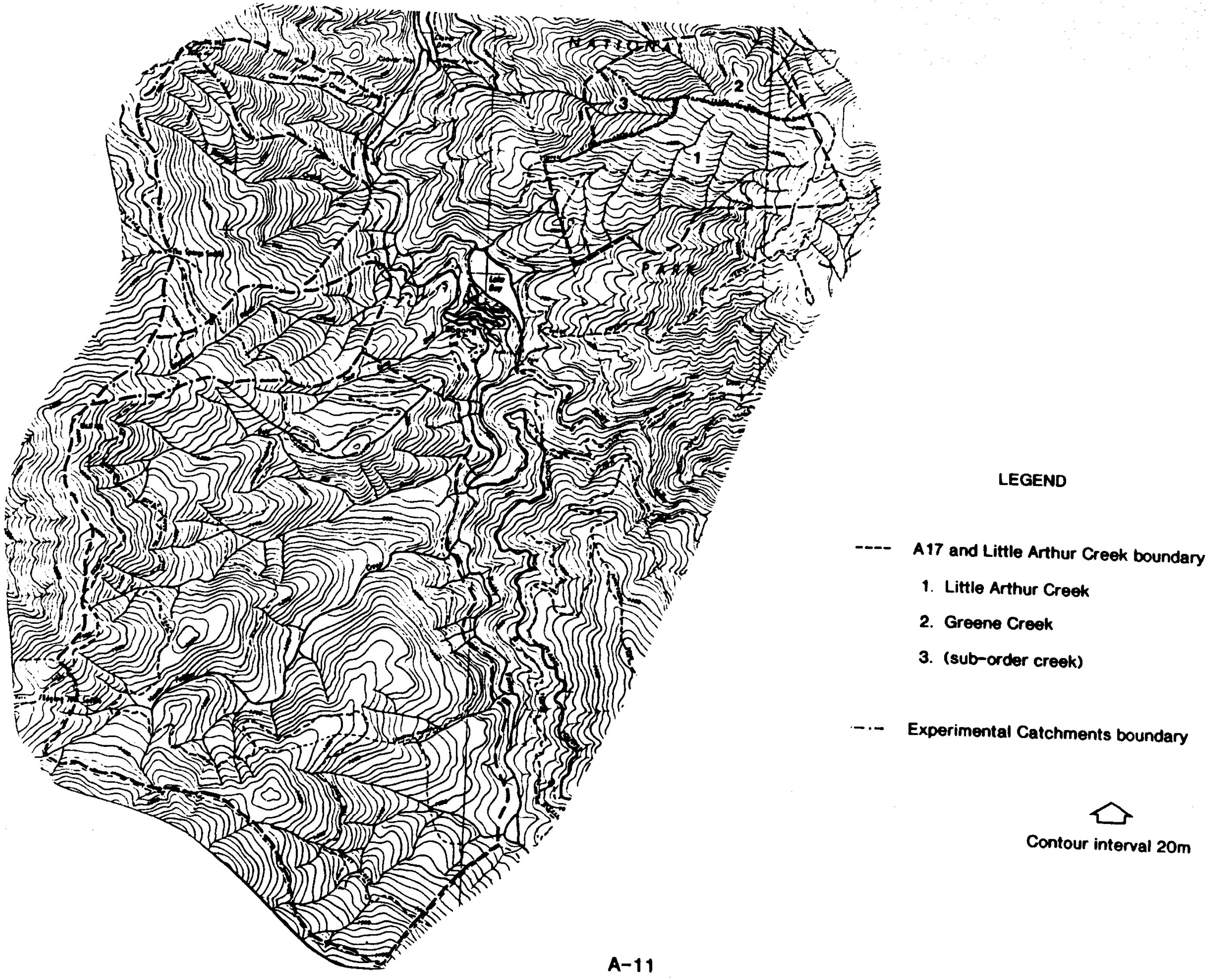


Figure A4 – A17 and Little Arthur Creek Catchments

Figure A4 A17 and Little Arthur Creek catchments



B INSTRUMENTATION

Details of the monitoring equipment are given in Table B1. Location of the gauges is shown in Figure C2.

The raingauge for Springs Creek catchment is located on the roof of the stream gauging station. The gauge for Slippery Rock Creek catchment is in a nearby clearing.

Details of weir plates have been given by Leitch (1982). Both water level recorders are driven by counterweights. Rainfall, water level and sample triggering are recorded on the same chart.

In each case, the inlet for the Manning sampler is located underneath a small waterfall in the stilling pond. Triggers were set to operate at 4-hour intervals in 1978. In March 1979, the interval was changed to 1-hour. Single samples are taken on days of low flow by manually triggering the sampler.

Table B1 - Details of Monitoring Equipment

Instrument	**Elevation (m)****	**Length of record**
Slippery Rock Creek Catchment		
Leopold & Steven (A71) water level recorder	660	23 May 1978 – 31 Dec 1987
Tipping bucket raingauge (0.2 mm bucket) (0.5 mm bucket in 1983 & 1984)	660	31 Aug 1978 – 31 Dec 1987
Manning automatic water sampler S4040	660	23 May 1978 – 31 Dec 1987
Springs Creek Catchment		
Leopold & Stevens (A71) water level recorder	620	10 May 1978 – 31 Dec 1987
Tipping bucket raingauge (0.2 mm bucket)	620	10 Jan 1979 – 31 Dec 1987
Manning automatic water sampler S4040	620	10 May 1978 – 31 Dec 1987
* Balloon Site No. 3 raingauge	960	1 May 1981 – 13 Apr 1987
* Balloon Site No. 3 snowgauge	960	25 Jun 1982 – 13 Apr 1987
* Big Hill snowgauge	1380	5 Apr 1979 – 13 Apr 1987
* Big Hill raingauge	1380	2 Jun 1982 – 13 Apr 1987

*readings taken at approximate monthly intervals
**information from contour map

C TREATMENT DIARY

A block diagram of the sequence of treatments in Springs Creek catchment is shown in Figure Cl.

Feb 1982: Treatment commenced with the construction of 53 km of advance roadings, using a D8 bulldozer.

11 Oct 1982: The following effects were noted at a joint inspection by FCV, SEC and SCA officers. "(i) Minimal erosion on track surfaces. Banks have been satisfactory. (ii) Some batters slumping (cut batters). (iii) Log crossings have coped with flows. No peak discharges experienced but crossings have contributed sediment to drainage lines."

Oct 1982 - Jan 1983: Harvesting using a D5 caterpillar bulldozer in Coupe 1. Two areas of 12 ha and 3 ha near the Southern edge of Springs Creek catchment were deadened (Figure C2). This yielded 2948 m^3 gross volume with 15% defect.

18 Jan 1983: Inspection by the West Kiewa Forest Committee. Noted in its Minutes about East Kiewa was "the drainage of roads and landings were discussed on site. Due to the very dry summer there is an abnormal amount of dry powdery potential mobile soil particularly on extraction roads."

18 & 19 Apr 1983: The area was subject to high intensity regeneration fires.

11 May 1983: The area was seeded with 1.4 kg raw seed/ha. Normal seed viability is approximately 100 000 to 125 000 viable seeds per hectare. Seed viability used for this coupe was 30 000 viable seeds per hectare.

21 May 1983: A seedling survey revealed that the area was stocked by 69% milacre plots with 12% of the area still containing receptive seed bed.

2 Jun 1983: Field Inspection. "Heavy storms had caused some soil movement along the lower logging road and in the lower coupe (3ha). One large rill has developed on the hill slope at the stream crossing below the lower logging coupe".

Oct 1983 - Jan 1984: The second coupe was harvested. Although 33.5 ha was logged only 6.5 ha of the coupe could be prepared for burning, due to the basal area of living stems after logging being in excess of 7 m^2/ha. The gross volume of timber produced was 2591 m^3 with 7% defect.

4 Mar 1984: Regeneration burn of 6.5 ha.

10 May 1984: The 6.5 ha was aerially seeded with 12 kg raw seed. Forty-one percent was stocked and 24% of the seedbed was still receptive at the time of the rust seedling survey of this coupe. An additional 4 kg of coated seed was hand sown to induce further regeneration on the receptive seedbed.

1984-1985: The remaining 27 ha of coupe 2 was relogged and cull felled in the 1984/85 harvesting season to reduce basal area and to allow regeneration burning. Again, difficulty was found in reducing the living basal area to less than 7 m^2/ha due to the large amount of culls. Extensive cullThe remaining 27 ha was relogged and cull felling was done by the Department of Conservation, Forests and Lands to enable coupe 2 to be prepared for burning. An additional 9.3 ha of coupe 2 was harvested (Figure C2). Coupe 2 had four stream crossings.

Dec 1984 - Feb 1985: The third coupe (15.9 ha) on the northern side of Springs Creek catchment was harvested. 6.3 ha was logged by contractors and a further 9.6 ha was logged by the Department of Conservation, Forests and Lands. This delayed regeneration burning.

28 Mar 1985: 33.9 ha of coupe 2 was burnt.

13 Apr 1985: Regeneration burning of coupe 2 took place. Three hectares of the coupe containing gully vegetation was poorly burnt due to high moisture content and fuel not having cured sufficiently.

For research purposes, it was hoped that a hot gully burn could take place as happens in an estimated 1:5 coupes at West Kiewa (C Leitch, pers comm). Vegetation in gullies trap sediment released from harvesting and prevent it from reaching the stream.

8 Jun 1985: Aerial seeding of coupe 2 with 44kg raw seed.

8 Jun 1985: Twelve hectares of coupe 3 were aerially seeded.

2 Oct 1985: Field Inspection. "(i) Although few of the logging roads and snig tracks were breached or barred at the closure of operations, there were only two situations where sediment was obviously delivered into a stream from tracks. (ii) Two sections of perennial stream totalling about 70 metres were exposed to hot slash burns. It was obvious that sediment movement into and from these areas was much higher than usual. The fire has destroyed obstructions which had previously stored sediment and had removed vegetation which had previously protected the stream banks."

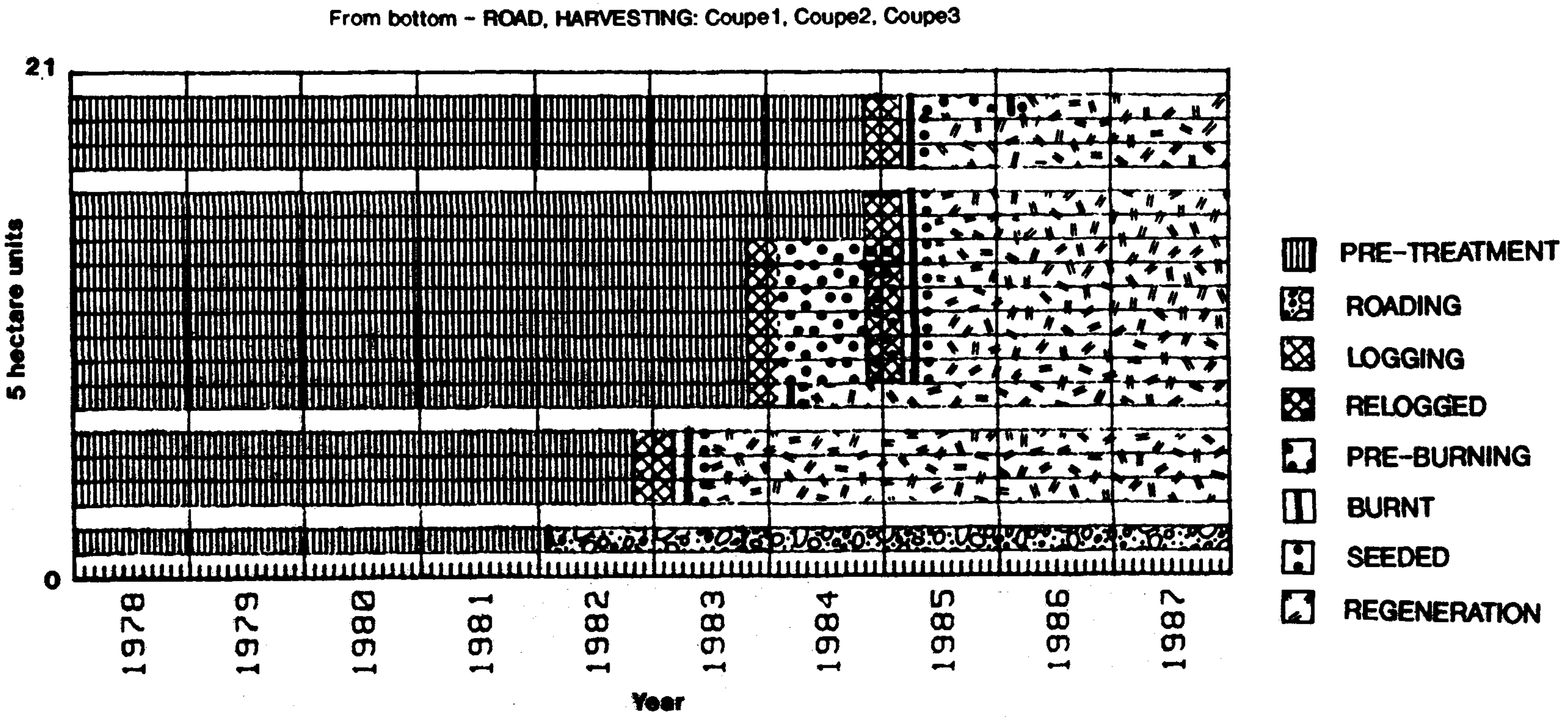
Feb 1986:	On the poorly burnt 3 ha remaining of coupe 3, a further regeneration burn was tried. Conditions for the burn were good with the exception of high fuel moisture content (> 10%). The burn was satisfactory in providing a good ash bed. The high moisture content prevented removal of the gully vegetation.
May 1986:	Hand seeding of 3ha area in coupe 3.

The steep slopes of the experimental catchments caused several problems. First, they prevented the operators from having control of where the trees fell. This resulted in some trees falling into streams and sliding. Culls near the lower fire control lines were actively felled into gullies and streams in the same way as log-bearing trees would have been because of the difficulty in re-establishing the control lines. Trees felled into the streams and gullies may have the effect of either dislodging sediment or providing a barrier against sediment removal. The second problem resulting from the steep slopes was that breaching and barring of logging roads and snig tracks was only carried out in a few places. It was reported that two places had significant but not substantial amounts of sediment eroding from the tracks and reaching the stream.

Another factor which could have an effect on sediment transport to the creek is that tree limbs were left where the tree fell.

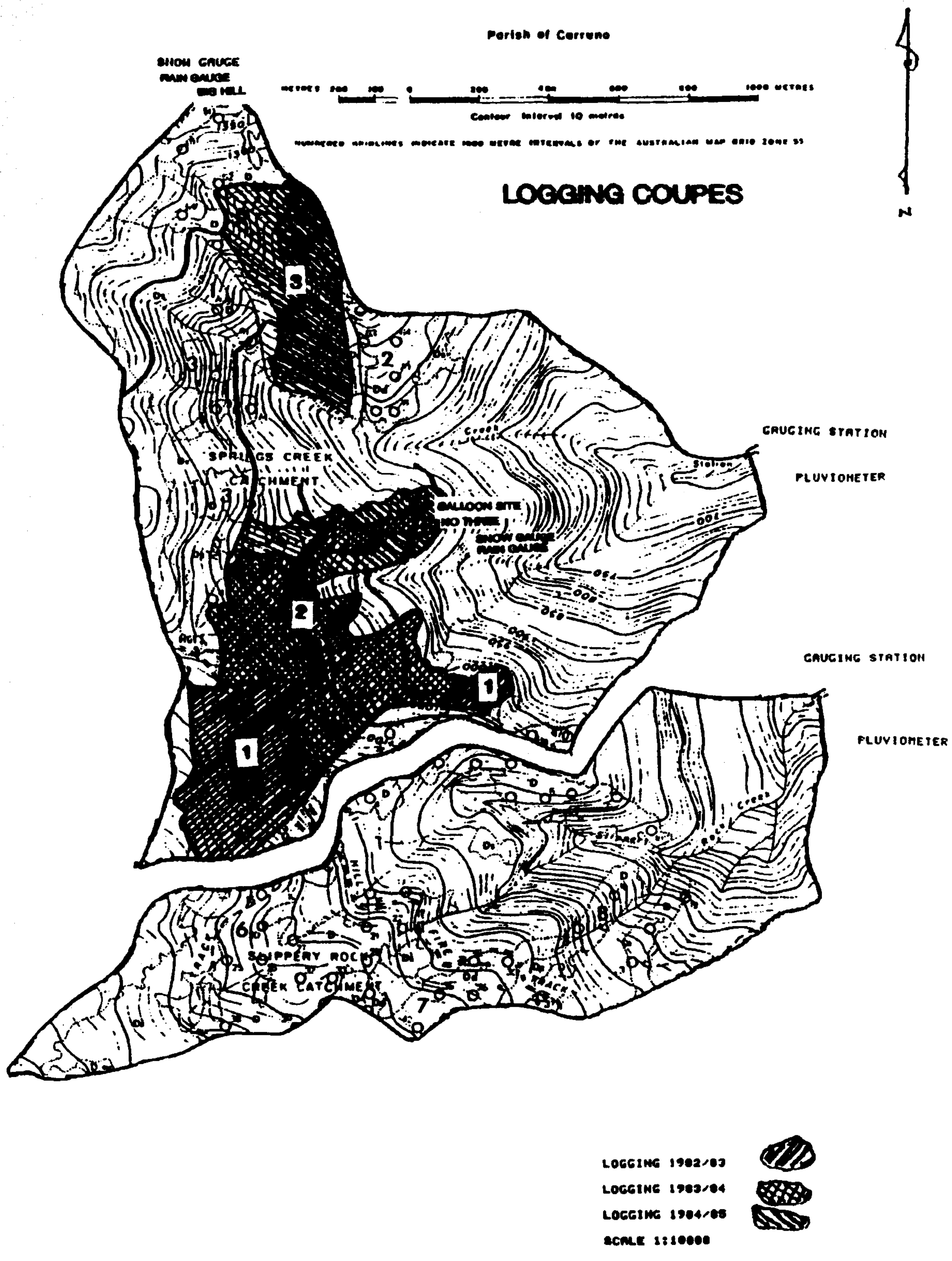
A total of 73.4 ha, (approximately 30%) of Springs Creek catchment was harvested. Harvested area is shown in Figure Cl.

Figure Cl Block diagram of the sequence of treatments carried out in Springs Creek catchment



From bottom - ROAD, HARVESTING: Coupe1, Coupe2, Coupe3

Figure C2 Area harvested in Springs Creek catchment and location of the gauges



D PROJECT TIMETABLE

November 1977	SEC, SCA and FCV officers selected areas for study.
Apr 1978	LCC proposed recommendations.
From May 1978	Rainfall, sediment and streamflow devices installed in experimental catchments. Calibration period commences.
Feb-Mar 1982	Treatment commenced with roading into Springs Creek Catchment.
Nov 1983	LCC final recommendations.
1985	Project transferred to LPD for analysis and reporting.
Feb 1986	Last regeneration burn.
31 Dec 1987	Measurements stopped.
Jan 1988	Equipment removed.

E DERIVATION OF REGRESSION EQUATIONS

Table El: LS Regression of mean daily event streamflow (log *l*/s)

Calibration Period May 1978 to May 1981
Dependent Variable = SCF
Independent Variable = SRF

Variable	n	Mean	Variance	Standard Deviation	Coefficient of Deviation
SRF	74	1.77	0.050	0.22	12.7
SCF	74	1.82	0.029	0.17	9.4

Correlation = 0.973
Selected degree of regression = 1
R^2 = 0.946
Standard error of the estimate = 0.04

Source	df	AOV		F-value
		Sum of squares	Mean square	
Total	73	2.14		
Regression	1	2.03	2.03	1269
X^1	1	2.03	2.03	1269
Residual	72	0.115	0.002	

	Coefficient	95% Confidence Interval	
		Lower limit	Upper limit
‘Constant’	0.5008	0.43	0.58
X^1	0.7430	0.70	0.78

Table E2: LS Regression of mean daily event sediment concentration (log mg/l)

Calibration Period May 1978 to May 1981
Dependent Variable = SCSC
Independent Variable = SRSC

Variable	n	Mean	Variance	Standard Deviation	Coefficient of Deviation
SRSC	47	1.62	0.11	0.33	20.6
SCSC	47	1.55	0.11	0.33	21.4

Correlation = 0.897
Selected degree of regression = 1
$R^2 = 0.805$
Standard error of the estimate = 0.148

Source	df	AOV Sum of squares	 Mean square	F-value
Total	46	5.06		
Regression	1	4.07	4.07	185
X^1	1	4.07	4.07	185
Residual	45	0.988	0.022	

Variable	Regression Coefficients		Standard error	
	Std. Format	E-format	Reg. Coeff.	T-value
'Constant'	0.106	0.106E+00	0.108	0.98
X^1	0.891	0.891E+00	0.065	13.62

	Coefficient	95% Confidence Interval	
		Lower limit	Upper limit
'Constant'	0.106	-0.11	0.32
X^1	0.891	0.76	1.02

F EVENT DATA

Table Fl: Explanation of column headings of event data

Code	Explanation	Units
Date	date recorded as day/month	-
SCSC	Springs Creek sediment concentration	mg/*l*
SRSC	Slippery Rock Creek sediment concentration	mg/*l*
SCF	Springs Creek flow	*l*/s
SRF	Slippery Rock Creek flow	*l*/s
SCF^	increase in Springs Creek flow	*l*/s
SRF^	increase in Slippery Rock Creek flow	*l*/s
SRRF	rainfall at Slippery Rock Creek	mm

Table F2: Event data: streamflow and sediment concentration

East Kiewa Event Data (>7 *l*/s Flow Increase) 1978

Date	SCSC	SRSC	SCF	SRF	SCF^	SRF^	SRRF
26/05	22.0	*	35.1	28.4	11.2	12.6	*
30/05	19.9	*	39.5	32.5	16.6	17.9	*
9/06	21.0	*	46.3	38.9	13.8	14.5	*
5/07	131.5	*	46.3	38.9	13.8	14.5	*
22/07	97.1	140.9	89.3	95.5	43.4	56.3	*
23/07	95.2	150.7	150.0	145.0	60.7	49.5	*
6/08	14.5	24.8	51.5	58.8	14.6	24.8	*
7/08	46.0	56.4	82.2	99.9	30.7	41.1	*
12/08	30.5	40.58	145.0	132.0	60.2	55.8	*
12/09	12.7	13.7	56.2	55.2	8.7	13.8	32.6
26/09	50.2	27.8	61.7	55.1	11.0	12.9	34.0
27/09	136.2	147.9	172.0	186.0	110.3	130.9	86.0
13/10	22.1	18.4	62.3	54.2	7.2	8.5	*
27/10	60.9	111.6	97.5	98.2	49.5	59.1	80.8
7/11	43.0	31.7	90.6	89.0	35.3	43.3	48.4
19/11	45.5	89.6	80.0	82.2	26.0	37.3	46.6
29/11	54.2	102.4	104.0	105.0	54.2	64.1	73.2

Missing Data = *

East Kiewa Event Data (>7 *l*/s Flow Increase) 1979

Date	SCSC	SRSC	SCF	SRF	SCF^	SRF^	SRRF
3/05	30.2	37.3	33.3	22.7	9.6	8.9	11.3
27/05	62.5	*	50.7	45.0	25.4	29.8	46.9
11/06	39.4	25.9	41.5	33.7	8.6	10.2	25.3
28/06	52.0	83.3	51.9	46.6	23.8	26.0	32.8
2/07	25.1	41.7	64.9	58.8	22.6	26.7	37.2
9/08	*	18.7	48.0	38.2	11.1	9.7	35.6
10/08	*	54.1	64.3	53.5	16.3	15.3	39.4
11/08	*	40.8	72.4	62.6	8.1	9.1	42.5
12/08	*	52.9	82.8	75.4	10.4	12.8	48.7
19/08	*	38.1	61.0	61.8	10.9	16.0	20.1
27/08	*	22.6	49.0	54.8	7.3	16.4	7.7
3/09	*	30.8	51.2	47.7	10.8	12.0	8.2
4/09	*	43.2	58.4	54.7	7.2	7.0	23.2
6/09	66.0	*	77.1	72.4	12.4	12.0	24.9
7/09	18.0	*	92.8	89.1	15.7	16.7	44.4
11/09	55.0	*	110.0	130.0	9.0	18.0	29.2
13/09	38.0	*	133.0	17.0	17.0	40.0	37.4
27/09	41.2	*	65.6	74.2	12.6	22.4	0.8
28/09	63.2	*	109.0	138.0	43.4	63.8	61.2
6/10	9.5	11.9	89.9	106.0	22.6	38.0	31.0
10/10	28.6	42.6	91.9	103.0	11.2	17.5	5.0
12/10	76.1	*	156.0	191.0	59.9	82.0	49.6
11/11	32.9	57.9	69.2	80.6	15.7	27.0	8.2

Missing data = *

East Kiewa Event Data (>7 *l*/s Flow Increase) 1980

Date	SCSC	SRSC	SCF	SRF	SCF^	SRF^	SRRF
8/03	115.9	102.2	49.6	35.4	28.4	21.7	71.2
23/04	64.0	115.0	45.1	39.7	25.5	27.4	66.8
11/05	70.0	73.5	60.0	46.6	37.7	32.5	52.2
20/05	32.0	45.7	43.6	30.0	21.7	16.4	41.6
31/05	14.4	17.3	36.9	28.2	8.8	7.8	10.5
27/06	80.4	119.2	42.7	36.2	21.6	23.7	58.0
29/06	27.5	24.5	78.5	57.0	17.6	15.0	56.0
4/07	22.1	21.4	66.8	51.3	12.9	14.1	22.0
18/07	7.0	17.2	53.3	43.2	10.5	9.7	16.8
27/07	35.9	56.9	42.5	38.4	8.6	13.7	30.0
28/07	321.6	202.3	17.0	175.0	127.5	136.6	88.0
7/08	16.3	25.1	77.4	65.0	23.3	22.8	50.0
20/08	*	35.4	57.3	51.7	10.3	14.7	23.6
21/08	50.8	*	297.0	259.0	11.0	16.0	38.0
27/08	23.2	15.2	226.0	195.0	24.0	23.0	30.0
23/09	21.5	*	123.0	114.0	12.0	13.0	31.2
27/09	14.4	*	134.0	112.0	16.0	12.6	34.0
3/10	43.0	29.8	152.0	148.0	41.0	50.5	44.0
10/11	31.2	28.5	101.0	84.5	28.4	27.4	34.0
20/11	28.8	25.3	81.7	67.8	18.3	16.9	23.0
12/12	134.0	65.7	135.0	113.0	85.1	77.0	101.0

Missing data = *

East Kiewa Event Data (>7 *l*/s Flow Increase) 1981

Date	**SCSC**	**SRSC**	**SCF**	**SRF**	**SCF^**	**SRF^**	**SRRF**
28/01	59.5	44.0	52.8	42.9	27.6	25.5	60.6
5/02	25.5	32.4	45.3	34.7	20.0	17.5	49.6
12/02	18.3	29.3	37.8	29.5	11.8	12.8	28.8
2/03	30.5	31.4	35.8	25.0	13.1	10.3	37.6
6/05	69.4	67.4	36.8	22.7	16.7	12.5	52.6
25/05	93.8	129.0	54.7	44.6	33.9	33.6	62.6
28/05	16.1	18.4	43.7	28.6	13.4	10.8	34.2
1/06	19.4	22.5	41.0	29.0	9.2	9.1	16.4
2/06	49.8	33.2	59.6	44.9	18.6	15.9	28.6
4/06	23.7	17.8	65.6	49.2	12.5	14.2	42.2
10/06	150.8	92.3	61.9	50.3	30.4	32.9	46.0
14/06	94.0	44.2	86.1	72.4	43.0	43.4	47.4
25/06	45.9	41.1	61.3	44.2	26.6	22.1	70.0
26/06	337.0	116.0	113.0	93.6	51.7	49.4	92.0
27/06	155.0	47.2	159.0	145.0	46.0	51.4	22.0
2/07	0.0	0.0	133.0	118.0	28.0	24.4	37.0
4/07	62.0	33.2	174.0	155.0	38.0	33.0	36.4
20/07	38.1	21.1	66.9	53.2	10.3	11.3	14.6
21/07	529.5	*	235.0	195.0	168.1	141.8	82.0
22/07	214.2	*	305.0	269.0	70.0	74.0	70.8
3/08	28.4	*	168.0	133.0	17.0	24.0	42.4
4/08	26.0	*	180.0	147.0	12.0	14.0	11.6
13/08	33.5	29.0	154.0	117.0	22.0	17.0	28.6
14/08	72.3	32.3	212.0	169.0	58.0	52.0	91.4
15/08	26.1	*	227.0	178.0	15.0	9.0	9.6
17/08	35.7	*	210.0	172.0	8.0	8.0	52.0
18/08	19.1	*	239.0	193.0	29.0	21.0	59.0
19/08	184.0	*	305.0	261.0	66.0	68.0	29.0
21/08	50.8	*	297.0	259.0	11.0	16.0	38.0
27/08	23.2	15.2	226.0	195.0	24.0	23.0	30.0
23/09	21.5	*	123.0	114.0	12.0	13.0	31.2
3/10	43.0	29.8	152.0	148.0	41.0	50.5	44.0
10/11	31.2	28.5	101.0	84.5	28.4	27.4	34.0
20/11	28.8	25.3	81.7	67.8	18.3	16.9	23.0
12/12	134.0	65.7	135.0	113.0	85.1	77.0	101.0

Missing data = *

East Kiewa Event Data (>7 *l*/s Flow Increase) 1982

Date	SCSC	SRSC	SCF	SRF	SCF^	SRF^	SRRF
25/01	271.6	87.4	100.0	75.4	63.7	53.5	127.2
8/03	65.8	28.6	40.5	26.1	12.5	9.9	44.4
23/03	33.4	41.3	43.8	28.5	16.3	14.0	35.4
21/05	25.0	55.8	43.6	30.7	12.7	13.7	22.4
28/05	50.9	38.8	52.4	33.9	24.1	19.6	58.0
31/05	31.7	24.2	53.1	37.1	11.0	12.6	31.0
17/09	96.7	80.8	46.9	37.8	20.5	23.1	48.0
29/09	32.8	18.3	38.3	23.9	11.3	7.9	21.4

Missing data = *

East Kiewa Event Data (>7 *l*/s Flow Increase) 1983

Date	SCSC	SRSC	SCF	SRF	SCF^	SRF^	SRRF
22/03	102.6	100.6	38.8	31.2	24.9	23.9	63.0
23/03	142.7	98.0	82.6	74.4	43.8	43.2	80.0
4/04	23.4	40.4	26.9	19.8	12.2	12.2	40.5
11/04	108.0	92.5	71.5	63.8	52.5	52.3	65.5
4/05	48.0	43.8	46.1	49.4	20.7	31.9	39.0
14/05	121.8	26.2	28.4	23.4	8.3	10.5	37.5
15/05	98.6	35.3	60.8	50.6	32.4	27.2	38.5
29/05	63.6	37.7	58.5	51.4	23.9	24.4	60.0
30/05	31.1	15.2	80.3	67.4	21.8	16.0	14.5
10/06	77.8	30.9	77.2	65.1	41.2	38.8	40.0
13/06	18.7	16.3	65.8	54.0	9.0	8.9	23.5
29/06	29.1	24.8	44.5	35.8	11.4	11.1	27.5
30/06	18.9	15.7	56.3	48.7	11.8	12.9	7.0
1/07	177.6	60.1	78.1	79.4	21.8	30.7	48.0
2/07	120.3	47.1	162.0	161.0	83.9	81.6	28.5
27/07	22.7	20.7	39.9	36.4	7.3	11.3	29.0
28/07	81.9	26.7	60.2	56.9	20.3	20.5	14.5
30/07	125.2	27.0	85.1	80.2	26.8	26.2	18.0
17/08	51.5	29.9	57.2	59.8	14.6	23.7	34.5
25/08	168.7	95.5	70.7	77.2	30.9	42.7	60.5
26/08	421.0	186.2	172.0	180.0	101.3	102.8	43.5
3/09	119.6	47.1	100.0	105.0	26.5	37.6	29.5
6/09	57.5	36.0	113.0	115.0	18.6	21.5	42.5
7/09	50.2	30.4	122.0	125.0	9.0	10.0	0.5
28/09	292.5	123.9	154.0	164.0	93.2	108.5	60.0
14/10	22.1	15.1	72.7	68.6	7.1	9.1	20.0
16/10	28.9	18.0	77.2	72.8	7.5	8.0	3.0
8/11	50.1	37.2	58.4	54.3	10.0	11.8	32.0
15/11	32.1	11.1	59.1	56.9	7.4	10.4	18.0
16/11	39.6	6.6	69.6	64.9	10.5	8.0	30.0
23/11	51.3	21.2	60.6	55.2	10.2	11.9	40.5
26/11	24.5	7.0	61.4	57.0	8.4	10.0	19.5
30/11	124.9	28.4	74.0	70.7	15.0	20.6	30.5

Missing data = *

East Kiewa Event Data (>7 *1*/s Flow Increase) 1984

Date	SCSC	SRSC	SCF	SRF	SCF^	SRF^	SRRF
16/01	459.9	91.2	61.8	55.9	21.0	24.6	29.5
26/01	70.2	18.7	56.9	43.9	16.5	13.3	40.0
21/02	63.2	28.2	39.3	30.9	8.3	10.2	21.0
25/03	22.2	45.8	38.2	28.2	11.3	12.3	32.5
21/04	20.0	15.3	39.6	26.1	11.1	8.2	13.0
1/06	60.4	32.1	37.7	26.3	12.2	10.8	23.5
16/07	160.3	43.9	38.8	30.6	12.3	15.5	28.5
9/08	183.7	42.2	50.4	45.1	19.9	23.5	63.5
10/08	68.7	27.2	78.7	69.2	28.3	24.1	26.0
18/08	154.4	42.9	90.8	76.0	39.8	37.1	50.0
19/08	117.2	27.8	103.0	87.0	12.2	11.0	26.5
20/08	946.3	247.6	128.0	124.0	25.0	37.0	57.5
21/08	771.3	113.3	168.0	165.0	40.0	41.0	32.5
25/08	45.8	35.4	126.0	125.0	8.0	10.0	23.5
27/08	418.3	69.6	177.0	177.0	49.0	50.0	26.5
11/09	33.7	33.2	84.8	95.8	19.8	39.5	34.0
17/09	100.2	14.1	74.0	69.7	9.8	16.5	26.5
21/09	31.7	33.2	86.1	86.1	11.4	19.8	28.0
3/10	508.7	171.1	125.0	151.0	60.2	95.3	85.0
4/10	172.8	45.2	145.0	167.0	20.0	16.0	7.0

Missing data = *

East Kiewa Event Data (>7 *l*/s Flow Increase) 1985

Date	SCSC	SRSC	SCF	SRF	SCF^	SRF^	SRRF
31/01	62.2	37.2	32.1	20.7	9.2	7.8	29.5
17/03	98.2	41.3	32.2	20.3	13.5	12.0	55.5
23/03	132.5	40.0	31.2	22.4	10.2	12.2	40.0
2/04	74.0	22.4	34.2	21.9	12.1	10.8	21.0
15/04	100.2	18.7	43.6	31.3	20.8	20.0	18.5
16/05	117.5	34.1	38.0	26.2	12.3	11.4	9.0
30/05	487.5	178.4	72.2	62.7	43.3	45.8	69.0
4/06	*	21.0	61.8	69.6	26.5	17.9	34.0
15/07	32.8	17.8	39.6	23.1	12.7	7.8	48.0
16/07	184.8	49.8	58.8	39.9	19.2	16.8	51.0
22/07	25.5	14.5	45.8	32.8	9.5	9.7	22.0
29/07	72.7	16.7	50.5	35.7	14.4	13.7	34.0
5/08	333.5	115.9	88.2	96.3	48.3	66.6	52.2
16/08	0.0	0.0	59.2	44.2	10.5	86.	29.5
17/08	100.0	25.3	75.8	56.4	16.6	12.0	0.0
22/08	738.4	182.2	104.0	116.0	52.1	79.3	66.0
23/08	729.8	232.7	170.0	184.0	66.0	68.0	60.5
26/08	249.7	96.5	157.0	172.0	31.0	41.0	25.0
11/10	58.6	26.8	49.8	36.7	11.4	12.8	26.8
17/10	60.1	27.0	50.0	37.3	9.9	11.3	21.4
10/12	16./	30.8	45.2	29.8	7.9	7.2	16.0

Missing data =- *

East Kiewa Event Data (>7 *l*/s Flow Increase) 1986

Date	SCSC	SRSC	SCF	SRF	SCF^	SRF^	SRRF
16/04	140.0	53.1	31.8	19.1	12.4	10.8	32.6
25/04	65.4	52.0	29.2	21.8	9.8	10.0	17.8
17/05	73.8	48.0	29.0	22.1	8.5	11.3	33.8
19/05	146.0	28.2	55.7	42.8	19.3	17.5	25.0
18/06	167.9	58.9	37.9	26.6	15.6	15.2	51.2
2/07	796.6	250.3	113.0	116.0	84.1	98.0	100.6
3/07	531.0	172.0	175.0	185.0	62.0	69.0	44.8
16/07	26.0	15.0	78.3	84.0	25.2	41.0	32.0
17/07	40.2	35.5	89.7	93.6	11.4	9.6	24.0
23/07	122.5	42.5	113.0	139.0	50.7	86.2	95.8
24/07	195.2	138.2	164.0	20.7	51.0	68.0	45.2
15/08	124.7	76.6	88.4	105.0	40.9	67.5	84.2
16/08	141.9	59.7	128.0	155.0	39.6	50.0	39.2
17/09	97.1	44.9	86.6	95.3	32.4	44.4	53.0
3/10	65.7	34.5	86.8	86.8	25.9	31.7	37.0
14/10	118.1	52.3	93.0	97.4	32.4	42.5	41.0
22/10	46.8	34.6	93.6	96.2	21.3	28.3	39.0
23/10	44.2	23.0	113.0	118.0	19.4	21.8	33.2
24/10	75.2	18.1	142.0	151.0	29.0	33.0	37.8
6/11	23.3	23.2	84.5	86.6	8.6	11.5	21.0
17/11	41.6	15.8	84.5	92.8	8.5	14.6	16.2
7/12	136.5	108.1	83.2	105.0	28.4	55.4	47.0
12/12	34.4	19.4	77.9	94.1	20.7	33.9	42.4
17/12	24.7	20.1	82.6	94.7	13.8	17.9	17.2

Missing data = *

East Kiewa Event Data (>7 *l*/s Flow Increase) 1987

Date	SCSC	SRSC	SCF	SRF	SCF^	SRF^	SRRF
3/01	23.5	19.7	61.6	61.4	10.8	14.7	28.6
20/02	159.2	96.0	56.7	51.4	23.6	28.6	54.0
28/02	27.6	29.3	51.7	46.7	19.0	23.5	42.8
7/04	54.8	38.9	54.4	45.2	24.9	26.4	32.0
28/04	94.1	34.9	47.3	37.4	19.2	20.9	45.0
3/05	142.4	50.3	54.3	52.2	8.1	24.4	2.4
13/05	88.3	23.7	38.6	27.2	8.1	8.3	36.8
26/05	200.1	70.6	52.4	41.0	18.1	17.7	43.0
19/06	81.9	27.6	41.9	32.0	9.5	11.0	28.2
20/06	271.6	89.2	96.9	104.4	55.0	72.4	61.2
22/06	158.9	45.5	115.3	131.9	21.0	35.1	49.0
15/07	76.0	54.2	63.1	59.6	15.9	24.3	33.8
31/07	0.0	0.0	65.6	59.5	7.4	9.3	31.0
24/08	54.0	36.1	80.7	87.2	24.0	36.6	34.0
1/12	86.6	79.6	59.0	50.5	20.3	25.4	53.4

Missing data = *

G STREAMFLOW DATA

Table G1 - Monthly Streamflow (*l*/s)

Date	**Springs Creek**	**Slippery Rock Creek**	**Date**	**Springs Creek**	**Slippery Rock Creek**
5/1978	*545.1	*163.0	3/1983	560.7	340.9
6/1978	*92.9	7.9.3	4/1983	685.8	436.7
7/1978	1547.5	1305.6	5/1983	1023.3	782.2
8/1978	2228.2	2096.9	6/1983	1276.0	981.2
9/1978	1933.7	1779.2	7/1983	1667.1	1471.3
10/1978	1867.1	1621.1	8/1983	1886.2	1723.1
11/1978	1852.0	1633.4	9/1983	2721.3	2614.3
12/1978	1662.2	1442.1	10/1983	2009.0	1800.2
1/1979	1146.2	856.6	11/1983	1679.7	1513.3
2/1979	787.5	535.7	12/1983	1544.0	1228.6
3/1979	779.2	504.8	1/1984	1236.6	9008.3
4/1979	801.1	494.9	2/1984	972.9	646.6
5/1979	784.5	506.3	3/1984	90.23	574.9
6/1979	872.4	619.9	4/1984	84.2	500.7
7/1979	1180.4	880.3	5/1984	802.8	492.5
8/1979	1463.3	1310.6	6/1984	795.5	482.0
9/1979	2378.7	2594.7	7/1984	962.4	629.1
10/1979	2633.9	2896.1	8/1984	2568.1	2321.5
11/1979	1636.7	1598.7	9/1984	2271.5	2072.5
12/1979	1225.4	1046.9	10/1984	2249.6	2115.3
1/1980	984.4	723.7	11/1984	1373.5	1104.4
2/1980	703.2	495.3	12/1984	1098.0	775.6
3/1980	710.8	447.2	1/1985	848.5	510.1
4/1980	635.9	422.2	2/1985	601.2	326.6
5/1980	810.4	549.0	3/1985	671.6	345.3
6/1980	856.2	567.7	4/1985	747.2	397.8
7/1980	1734.9	1396.4	5/1985	806.1	443.2
8/1980	1821.7	1501.8	6/1985	1137.0	723.4
9/1980	2161.8	1942.1	7/1985	1118.0	709.0
10/1980	1766.4	1431.3	8/1985	2484.0	2336.0
11/1980	1448.9	1152.4	9/1985	1614.0	1158.0
12/1980	1188.8	908.5	10/1985	1349.0	901.8
1/1981	942.4	682.4	11/1985	1134.0	714.6
2/1981	758.4	502.2	12/1985	1116.0	698.6
3/1981	743.9	450.0	1/1986	861.8	482.5
4/1981	634.2	355.1	2/1986	651.7	334.4
5/1981	786.0	450.2	3/1986	611.7	307.8
6/1981	1809.7	1378.8	4/1986	648.6	352.6
7/1981	4469.4	3685.6	5/1986	854.1	521.9
8/1981	6085.0	4951.0	6/1986	861.2	498.2
9/1981	3976.0	3387.4	7/1986	2883.0	2956.0
10/1981	3019.3	2533.0	8/1986	2342.0	2198.0
11/1981	2041.5	1592.8	9/1986	854.1	521.9
12/1981	1821.6	1275.9	10/1986	2595.0	2606.0
1/1982	1309.8	892.0	11/1986	2170.0	2178.0
2/1982	882.5	544.2	12/1986	1957.0	2044.0
3/1982	915.5	520.7	1/1987	1398.0	1237.0
4/1982	838.8	460.3	2/1987	964.4	617.8
5/1982	1010.1	577.3	3/1987	1046.0	672.5
6/1982	972.9	563.9	4/1987	964.4	617.8
7/1982	861.3	518.3	5/1987	1170.0	799.7
8/1982	929.7	593.7	6/1987	1625.0	1457.0
9/1982	892.3	550.9	7/1987	1625.0	1457.0
10/1982	779.0	421.6	8/1987	1828.0	1622.0
11/1982	576.0	304.5	9/1987	1615.0	1405.0
12/1982	504.3	241.5	10/1987	1559.0	1234.0
1/1983	334.4	147.5	12/1987	1176.0	831.1

* complete month

Table G2 - Baseflow Stormflow Separation

(linear ramp - slope 1.5 litres/second/day)

Calendar Year	Springs Creek			Slippery Rock Creek		
	Base	**Storm**	**Total**	**Base**	**Storm**	**Total**
1978*	381	66	446	537	126	680
1979	496	59	556	736	144	880
1980	465	60	525	633	100	733
1981	706	253	959	979	371	1349
1982	358	13	371	375	19	394
1983	470	91	561	667	176	842
1984	506	63	569	674	129	803
1985	431	52	483	485	104	589
1986	554	96	650	801	233	1034
1987	547	43	590	743	106	849
Median (mm) #	496	60	561	704	137	864
(%)	88	11	-	81	16	-

*incomplete year
1978 excluded

Table G3 - Baseflow recession gradients

	Slippery Rock Creek	**Springs Creek**	**Bogong Village Rainfall (mm)**
1978/79	0.96	0.79	1748.3
1979/80	0.95	0.70 Pre-	1626.7
1980/81	0.72	0.81 treatment	1848.3
1981/82	0.80	0.79	2240.5
1982/83	0.38*	0.57	1068.8
1983/84	0.98	0.67 Treatment	1967.1
1984/85	0.95	0.79	1467.7
1985/86	0.55*	0.52*	1487.9
1986/87	1.00*	0.67	2275.4

* outliers

Table G4 - Monthly rainfall Bogong Village (mm)

Date	Rainfall	Date	Rainfall	Date	Rainfall
5/1978	1133	8/1981	453.4	11/1984	33.4
6/1978	173.9	9/1981	111.4	12/1984	48.0
7/1978	282.7	10/1981	90.5	1/1985	45.8
8/1978	228.4	11/1981	132.5	2/1985	9.8
9/1978	234.3	12/1981	106.6	3/1985	123.9
10/1978	160.4	1/1982	120.1	4/1985	144.7
11/1978	252.8	2/1982	8.0	5/1985	152.7
12/1978	102.6	3/1982	105.6	6/1985	173.2
1/1979	33.6	4/1982	73.0	7/1985	181.8
2/1979	9.6	5/1982	169.2	8/1985	367.9
3/1979	40.7	6/1982	79.2	9/1985	28.3
4/1979	116.0	7/1982	695	10/1985	1513
5/1979	108.6	8/1982	613	11/1985	97.0
6/1979	158.0	9/1982	134.3	12/1985	139.4
7/1979	163.1	10/1982	51.1	1/1986	41.6
8/1979	257.6	11/1982	12.8	2/1986	32.4
9/1979	390.4	12/1982	54.7	3/1986	16.5
10/1979	203.8	1/1983	62.6	4/1986	105.8
11/1979	1123	2/1983	19.2	5/1986	165.4
12/1979	18.2	3/1983	179.0	6/1986	152.0
1/1980	46.5	4/1983	175.9	7/1986	543.8
2/1980	22.8	5/1983	247.0	8/1986	2403
3/1980	73.2	6/1983	191.5	9/1986	128.9
4/1980	72.2	7/1983	208.2	10/1986	324.1
5/1980	164.4	8/1983	213.5	11/1986	135.9
6/1980	190.0	9/1983	296.0	12/1986	218.0
7/1980	284.8	10/1983	108.7	1/1987	59.6
8/1980	201.6	11/1983	229.0	2/1987	90.8
9/1980	242.8	12/1983	68.0	3/1987	99.8
10/1980	215.8	1/1984	1773	4/1987	116.8
11/1980	93.5	2/1984	78.1	5/1987	172.6
12/1980	142.7	3/1984	79.2	6/1987	273.6
1/1981	132.5	4/1984	70.6	7/1987	226.8
2/1981	108.0	5/1984	563	8/1987	125.3
3/1981	62.0	6/1984	56.0	9/1987	98.2
4/1981	10.2	7/1984	156.0	10/1987	113.2
5/1981	167.8	8/1984	4793	11/1987	130.2
6/1981	406.5	9/1984	180.6	12/1987	79.6
7/1981	465.1	10/1984	133.9		

H SEDIMENT DATA

H1 Maximum sediment concentration

Table H1 - Maximum instantaneous sediment concentration

Date	Springs Creek	Slippery Rock Creek	Date	Springs Creek	Slippery Rock Creek
7/1978	300.3	4383	5/1983	268.3	174.0
8/1978	1013	71.7	6/1983	86.0	51.7
9/1978	322.0	224.7	7/1983	432.3	136.1
10/1978	160.0	317.7	8/1983	968.1	415.9
11/1978	125.8	718.5	9/1983	1078.9	470.4
12/1978	23.7	65.5	10/1983	1483	413
1/1979	18.9	303	11/1983	343.7	243.7
3/1979	128.9	73.8	12/1983	377.7	23.1
4/1979	75.2	157.9	1/1984	4887.7	628.0
5/1979	87.8	72.4	2/1984	900.0	142.8
6/1979	59.1	61.2	3/1984	59.2	405.7
7/1979	67.7	1423	4/1984	80.3	47.0
9/1979	161.2	676.7	6/1984	561.6	137.0
10/1979	82.0	184.9	8/1984	46973	1088.9
11/1979	80.0	135.6	9/1984	101.1	95.7
1/1980	10.8	31.1	10/1984	1932.2	764.5
3/1980	9032	427.6	1/1985	245.8	192.1
4/1980	394.8	561.5	3/1985	1034.6	382.1
5/1980	210.8	237.9	4/1985	720.0	68.5
6/1980	429.8	455.8	5/1985	2523.0	906.4
7/1980	1173.2	448.4	7/1985	1354.6	259.6
9/1980	146.0	222.9	8/1985	2111.9	755.7
10/1980	75.0	75.0	10/1985	283.7	169.1
11/1980	82.8	1182	11/1985	143.0	85.2
12/1980	382.1	183.6	12/1985	38.0	132.0
2/1981	863	143.6	1/1986	91.1	72.7
3/1981	155.8	642	4/1986	776.9	248.9
5/1981	4762	834.5	5/1986	352.2	389.0
6/1981	1987.0	619.2	6/1986	506.5	212.1
7/1981	331.5	131.6	7/1986	371.0	9093
8/1981	238.6	82.9	9/1986	240.3	136.7
10/1981	184.6	127.7	10/1986	352.1	190.5
11/1981	110.5	54.5	11/1986	86.5	66.7
12/1981	368.6	1453	12/1986	636.5	595.7
1/1982	2864.1	367.7	1/1987	135.2	71.0
3/1982	182.8	196.0	2/1987	915.1	563.0
4/1982	222.4	122.7	4/1987	2913	119.6
5/1982	803	143.1	6/1987	1308.0	219.0
7/1982	303	18.1	7/1987	559.7	254.2
8/1982	1032	45.4	8/1987	171.2	136.8
9/1982	7382	427.8	9/1987	69.0	67.9
12/1982	60.7	33.9	10/1987	937.2	2463
3/1983	525.1	327.0	11/1987	52.1	70.5
4/1983	633.7	602.6	12/1987	3952	744.2

H2 Transient sediment concentration

Table H2 - Transient sediment concentration (mg*l*/): Slippery Rock Creek

Date	Sediment Concentration	Date	Sediment Concentration
29/11/78	718.5	25/10/83	79.7
1/04/79	157.9	31/10/83	78.0
1/07/79	57.6	5/11/83	84.4
10/08/79	204.9	8/11/83	243.7
12/08/79	108.3	23/11/83	163.5
27/09/79	222.9	12/08/84	132.7
29/09/79	365.6	20/08/84	173.7
15/11/79	1163	20/08/84	780.9
8/03/80	99.6	21/08/84	712.6
8/11/80	118.2	22/08/84	162.0
7/01/81	73.2	23/08/84	457.5
6/05/81	133.2	27/08/84	183.6
9/05/81	2012	17/09/84	61.8
9/05/81	159.0	12/06/85	53.0
25/06/81	111.1	17/08/85	104.9
26/06/81	619.2	28/08/85	112.4
26/06/81	331.8	24/10/85	127.6
27/06/81	101.1	7/12/85	117.8
4/07/81	92.1	13/01/86	114.8
20/07/81	104.8	19/06/86	125.5
21/07/81	128.8	6/07/86	103.6
13/08/81	82.9	7/07/86	342.1
12/12/81	96.1	23/07/86	130.0
13/05/82	59.0	24/07/86	49523
28/05/82	102.7	24/07/86	1889.8
28/05/82	56.2	25/07/86	389.1
13/10/82	106.9	25/07/86	1881.5
7/11/82	60.4	15/08/86	132.4
8/12/82	1042	20/08/86	1473
1/01/83	321.4	3/09/86	211.1
4/05/83	133.5	17/09/86	136.7
26/08/83	3433	23/10/86	106.9
7/09/83	89.7	20/02/87	378.4

Table H3 – Transient sediment concentration (mg/*l*): Springs Creek

Date	Sediment Concentration	Date	Sediment Concentration
19/11/78	144.4	17/08/83	111.1
3/04/79	400.7	27/08/83	170.1
29/09/79	84.2	30/08/83	111.6
30/09/79	122.9	31/08/83	252.6
10/10/79	130.0	7/09/83	134.1
4/01/80	71.0	9/09/83	283.1
8/03/80	903.2	15/11/83	165.4
18/04/80	265.4	16/01/84	4887.7
4/07/80	114.3	21/02/84	900.0
28/07/80	1173.2	18/07/84	330.0
14/10/80	153.6	29/07/84	368.2
19/04/81	79.5	18/08/84	1481.8
10/06/81	1309.9	20/08/84	46973
21/06/81	79.5	26/08/84	216.7
25/06/81	108.4	26/08/84	793.3
26/06/81	1847.0	27/08/84	1843.6
26/06/81	1987.0	27/08/84	1736.5
26/06/81	1592.0	17/09/84	2158.2
27/06/81	1295.2	18/09/84	388.9
21/07/81	1353.1	21/09/84	158.1
21/07/81	2541.1	9/10/84	3202.0
24/07/81	1941.4	12/10/84	3130.0
25/07/81	196.5	31/01/85	165.1
27/07/81	1082	15/04/85	246.2
13/08/81	238.6	16/05/85	210.4
23/08/81	662.4	16/05/85	107.7
2/12/81	206.7	30/05/85	2523.0
6/12/81	713.5	16/07/85	1354.6
9/12/81	563.7	12/08/85	164.6
11/12/81	177.6	22/08/85	3055.0
13/01/82	115.8	23/08/85	2111.9
25/1/82	2864.1	26/08/85	897.6
6/02/82	129.7	28/08/85	415.1
12/08/82	2032	17/10/85	231.0
3/09/82	115.0	18/06/86	218.7
29/09/82	140.0	19/06/86	195.2
23/10/82	582	2/07/86	2347.6
1/01/83	2572.9	4/07/86	439.0
5/04/83	74.9	24/07/86	6343
16/05/83	135.2	26/07/86	2303
10/06/83	136.6	16/08/86	186.3
2/07/83	167.9	17/08/86	167.5
2/07/83	427.6	18/08/86	136.2
2/07/83	701.7	27/09/86	280.1
30/07/83	102.2	14/10/86	100.6
30/07/83	78.5	3/03/87	131.5

H3 Bedload

Bedload was measured at Slippery Rock Creek weir at the following times:

May 1981	after desilting
March 1982	before and after desilting
February 1983	weir not desilted
April 1984	after desilting

The aim was to measure the build-up of sediment in a given period of time, as. follows. After desilting the levels of sediment and bedrock were measured on a lm grid. A probe was lowered so that a flat plate sat on the silt, and the rod was then pushed through the silt to bedrock. The level of the probe was recorded. These measurements gave the control for measuring the amount of sediment in the weir approximately one year later. After this the weir was desilted and measured again.

The type of sediment within each grid was classified into Black Silt, Organic, Loose Silt, Sand, Gravel.

Table H4 - Sediment surveys

Sediment Survey 1981

	Sediment volume (cu.m)	dry mass per wet volume	Sediment mass (tonne)
Black Silt	10.4	0.35	3.7
Organic	17.3	0.18	3.1
Loose Silt	1.0	0.49	0.5
Sand	12.5	1.28	15.9
Gravel	2.4	1.36	3.3
Totals	43.7		26.6

Sediment Survey 1982

	Sediment volume (cu.m)	dry mass per wet volume	Sediment mass (tonne)
Black Silt} Organic}	5.9	0.35	2.1
Loose Silt	nil		
Sand	1.2	1.28	1.5
Gravel	nil		
Totals	7.1		3.6

J GLOSSARY OF TERMS

Exploratory data analysis

There is a strong emphasis in this report on exploratory data analysis (EDA). EDA encompasses graphical and tabular ways of examining and presenting data in forms which provide ready interpretation. Its most attractive features arc its non-parametric nature, and its resistance to outliers. EDA is based on the work of Tukey (1977).

Boxplot

One of the techniques used to summarise blocks of data is the boxplot. The middle half of the block is shown by the box. The box is 'notched' at the median. The confidence interval (approximately 95%) for the median is indicated by the taper on the box. Possible outliers are marked with ‘*’, and probable outliers by '0'. Examples of these plots are shown in the report (e.g. Figure 2.16 and 2.42).

Least Squares Regression

Ordinary linear regression is based on the assumptions: i) that the errors about the regression line have a Gaussian distribution with mean zero and constant variance, that observations and variables are independent.

This is the ‘least-squares’ (LS) method of regression, so named because the squares of deviations about the regression line are minimized. The LS method is not robust; it is very sensitive to isolated measurements which lie away from the regression line.

It is suspected that there may be outliers in the data sets being analysed. Therefore, it is important to have another method of analysis as a check on the LS regression. A resistant regression (as described below) is one such technique.

The independence of variables in a data set is often overlooked. As an example, consider a multiple regression relating sediment concentration to flow. If streamflow (x_1) is partitioned into baseflow (x_2) and stormflow (x_3), it is not valid to use x_2 and x_3 as independent variables because $x_2 + x_3 = x_1$. It is also not valid to use x_1 , x_2 , x_3 in the same equation for the same reason.

Resistant Analysis

Resistant analysis fits a straight line to a data set using a method which is insensitive to outliers. Details are given in Velleman & Hoaglin (1981). The data set is divided into three segments. The resistant line is determined which has equal median residuals in the upper and lower segments. This is done as an iterative procedure on a computer. All resistant analysis was done using the MINITAB software package.

Serial Correlation

One of the major assumptions of regression analysis is that the errors are independent. If it is not true, then the regression coefficients no longer have the minimum variance property, and the calculations of confidence intervals and t- and F- statistics may not be accurate.

Serial correlation in the error terms violates the second assumption of LS regression. Serial correlation occurs when each observation is dependent on the value of the previous observation. It is identified (i) by a trend in a plot of the regression residuals, (ii) values of the Durbin-Watson test statistic significantly different from 2.0.

A model which incorporates serial correlation in its structure is described in Appendix

Nonparametric test

The Mann-Whitney test assumes only that random and independent samples are taken from the populations under test, and that the distributions are similar. Details of how the test is calculated are given in Ryan *et al* (1985).

Results show the point estimate of the difference in the medians from the two samples and a 95% confidence interval for this difference. Obviously, if the confidence interval straddles zero then there is no significant difference in the medians.

The null hypothesis tested is that the medians of the two populations are equal. The alternative hypothesis is that the median of one population is shifted from the other. The level of significance of the test is given.

K MATHEMATICAL DERIVATIONS

K1 Linear regression with serial correlation in the error terms

This method estimates regression parameters, and has serial correlation structure in the error terms.

It assumes that the error terms follow a first order autogressive process. The regression model becomes

$$Yt = \beta_o + \beta_1 X_t + \varepsilon t \qquad \text{(K-1)}$$

$$\varepsilon_t = \rho\ \varepsilon t_{-1} + u_t \qquad \text{(K-2)}$$

where β_0, β_1 are constants
$| \rho | < 1$ indicates the amount of serial correlation
$u_t \sim N(0, \sigma^2)$ is random disturbance

Equation (K-1) has the form of a standard linear regression. Equation (K-2) describes the serial correlation in the error terms according to the above assumption.

Consider the transformation

$$Y'_t = Y_t - \rho\ Y_{t-1} \qquad \text{(K-3)}$$

Substituting equation (K-1) into this equation gives the following regression (after 3 lines of algebra).

$$Y'_t = \beta'_0 + \beta'_1 X'_t + U_t \qquad \text{(K-4)}$$

where $\beta'_0 = \dfrac{\beta_0}{1 - \rho}$ (K-5)

$$\beta'_1 = \beta_1 \qquad \text{(K-6)}$$

$$X'_t = X_t - \rho\ X_{t-1} \qquad \text{(K-7)}$$

Note that (i) the re-parameterised regression equation has independent error terms (ii) the intercept has changed according to equation (K-5) (iii) the slope of the regression line is unaltered.

In this application, p is estimated from the plot of e_t against e_{t-1}. (Value from the CORRELATION command in MINITAB). The regression model (equation (K-4)) is tested for serial correlation in the disturbances u_t using the Durbin-Watson test statistic. If the transformation has been valid, the Durban-Watson test statistic is not significant. A resistant line is fitted to the Y'_t - X'_t data as a check on the validity of the regression.

K2 Test for difference between two regressions coefficients

This test is described more fully in Davies and Goldsmith (1977).

Consider two regression lines with slopes b_1 and b_2, variance about the regression S_1^2 and S_2^2, and degrees of freedom Φ_1 and Φ_2.

Make an F-test for equality of variance about the regression. If they are not significantly different, then obtain the pooled variance about the regression.

$S^2 = (\Phi_1 S_1^2 + \Phi_2 S_2^2) / (\Phi_1 + \Phi_2)$

The variances of the estimates of the slopes are given by:-

$V(b_1) = S^2/\Sigma_1 (X - X)^2$

$V(b_2) = S^2/\boldsymbol{\Sigma}_2 (x - x)^2$

Consequently

$$V(b_1 - b_2) = S^2 \left(\frac{1}{\Sigma_1 (X - X)^2} + \frac{1}{\Sigma_2 (X - X)^2} \right)$$

Confidence limits for the difference can now be calculated using t with $(\Phi_1 + \Phi_2)$ degrees of freedom.

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