The Effect of Logging Stream Buffers on Stream Sediment Concentration and Turbidity.

Results from the Southern Forest of Western Australia.

by H. Borg, I. C. Loh and R. W. Bell

Report No. WS 23

July 1988

Water Authority
of Western Australia

The Effect of Logging Stream Buffers on Sediment Concentration and Turbidity.

Results from the Southern Forest of Western Australia.

by

H. Borg,

I. C. Loh

and

R. W. Bell

Report No. WS 23

July 1988

Water Authority
of Western Australia

CONTENTS

SUMMARY

In 1983 the Western Australian Government decided to manage the Shannon Basin in the southern forest of Western Australia as if it were a National Park. This made a large volume of timber unavailable for cutting. The Western Australian Government subsequently directed the Forest Department of Western Australia to assess the feasibility of changing the size and distribution of road, river and stream buffers to make up for at least part of the timber resources no longer available from the Shannon Basin.

In the summer of 1984/85 stream buffers were logged at two locations in the southern forest of Western Australia to evaluate the effect on suspended sediment concentration and turbidity in the streams. All cut-over areas were regenerated to forest soon after logging. At one location the width of a stream buffer was reduced from the usual 100 m to 50 m. At the other location stream buffers and part of an adjacent hillslope were clear-felled. There was no detectable effect on suspended sediment concentration and turbidity in either trial.

The rainfall during the study period was below average and no high intensity rainfall event occurred. This probably did not affect the results from the trial where a stream buffer was reduced to 50 m in width since data in the literature indicate that a 30 m wide buffer is generally sufficient to protect water quality in areas of flat to moderate slopes as in these trials. The effect on the results from the trial where stream buffers and part of an adjacent hillslope were clear-felled is not clear. Although some measures were taken in this trial to minimise the risk of soil erosion and an ensuing increase in suspended sediment concentration and turbidity in the streams, it is uncertain whether they would have been sufficient to prevent it had the rainfall been higher, or had a high intensity rainfall event occurred. Due to the potential risk of a deterioration in water quality, the clear-felling of buffers along watercourses should therefore not be made a general practice. A reduction of buffer width along watercourses on the other hand seems possible without any negative effect on water quality.

1. INTRODUCTION

The southern forest of Western Australia is defined as the forested land in the State which drains into the Southern Ocean. The research discussed in this report was conducted in a part of the southern forest which is known as the Woodchip Licence Area since the opening of a woodchip mill in Manjimup in 1975 (Fig. 1). In 1983 the Western Australian Government decided to manage the Shannon Basin, which is within this area, as if it were a National Park. This made some 1.3 million m^3 of sawlog quality karri and some 400 000 m^3 of sawlog quality jarrah unavailable for cutting.

The Western Australian Government subsequently directed the then Forests Department of Western Australia, which in 1985 became part of the Department of Conservation and Land Management W.A., to assess the feasibility of changing the size and distribution of road, river and stream buffers to make up for at least part of the timber resources no longer available from the Shannon Basin. A buffer is defined here as a strip of undisturbed forest comprised of overstorey and understorey vegetation which is left along a watercourse to protect water quality, or along a road for aesthetic reasons. Buffers also serve as habitats and movement corridors for wildlife. In the southern forest of Western Australia they are usually kept along both sides of most major and some minor roads, and along both sides of most rivers and some streams. Buffers are typically 400, 200 and 100 m wide on each side of roads, rivers and streams, respectively (Forests Department of Western Australia 1973).

Reducing the width of road, river and stream buffers was one of the options considered to make more timber available. In 1984 several trials were initiated to evaluate the feasibility and consequences of reducing the width of buffers. A total of 12 locations were selected for these trials. At one location the existing buffers on both sides of a stream were clear-felled. At the other 11 locations the width of the buffer left after logging on one side of a road or watercourse was reduced to 200 m or less along roads (6 locations), to 100 m along rivers (3 locations), and to 50 m along streams (2 locations). All cut-over areas were regenerated to forest soon

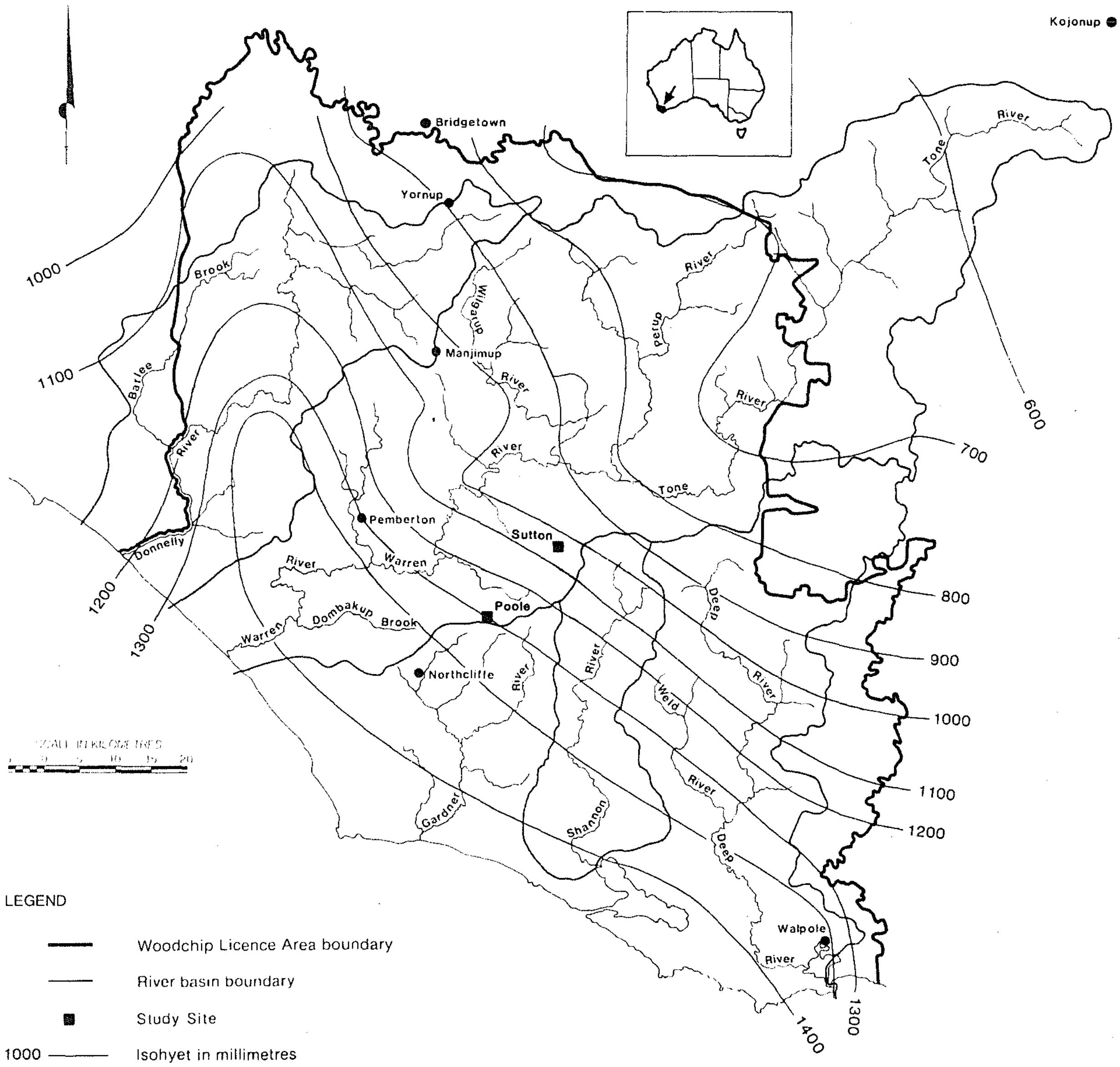


Figure 1

Map of the study area. (Isohyets from Loh and King 1978.)

after the completion of logging. Following approval by the (Western Australian) Environmental Protection Authority, logging for these trials commenced in late 1984.

To date the road buffer trials have not been reported on. The Water Authority of Western Australia collected stream sediment and turbidity data for two of the three stream buffer trials during 1985 and 1986. These are the data presented here. Additional data for these two trials as well as data for the other stream buffer trial and the three river buffer trials are given by Hordacre and Batini (1987). All data from the three stream and the three river buffer trials are summarised by Borg et al. (1988). For a complete discussion of the effects of logging of stream and river buffers on the watercourses and water quality the reader is therefore referred to the paper by Borg et al. (1988).

2. METHODS AND INSTRUMENTATION

2.1 Logging and regeneration

Figure 1 gives the location of the two trials discussed here. The trials were named after the forest blocks they were in. As typical for the region, the streams in the trial areas usually only flow from May through December. The soil in the trial areas is also typical for the region, consisting of 30 to 100 cm of loam on top of 5 to 20 m of clay (McArthur and Clifton 1975). The loam has a high infiltration capacity so that surface runoff usually only occurs when enough water is perched on top of the clay, which has a low infiltration capacity, to completely saturate the overlying loam. A mixture of karri (*Eucalyptus diversicolor*), jarrah (*Eucalyptus marginata*) and marri (*Eucalyptus calophylla*) occupied the Poole trial area. The Sutton trial area was dominated by karri interspersed with some marri. Slopes were generally less than 5°, except in a small section in the Sutton trial where slopes of up to 20° occurred.

Just prior to logging all areas to be cut were delineated with unsurfaced, ungraded tracks by clearing the scrub with a bulldozer. No drains were constructed and no form grading was carried out on these tracks. Throughout the study period the existing logging roads servicing the trial areas were maintained in a well graded and well drained condition.

For soil erosion and an associated increase in sediment concentration and turbidity in a stream to take place, soil particles must first be dislodged from soil aggregates and then transported to a stream. During logging dislodging is achieved by the impact of falling trees and, more importantly, by their subsequent removal and the concurrent movement of machinery. Soil aggregates are most susceptible to break-up when they are wet. More than 80% of the annual rainfall in south-west Western Australia occurs from May through October. Hence, to limit the break-up of soil aggregates, logging for the trials was carried out in the comparatively dry period between November and May. To further reduce the impact of logging on water quality, scrub rolling prior to logging was kept to a minimum, snig tracks were kept at acute angles with the watercourses where possible, no logs were snigged or machinery driven across the watercourses, and, except in a few accidental cases, no trees were felled across watercourses. Also, in both trials small earth banks were pushed across snig tracks and other potential flow channels at 30 to 50 m intervals shortly after the completion of logging to divert any runoff into piles of debris or patches of vegetation. This is a standard practice in the region.

Much of the Sutton area had been clear-felled and regenerated between 1978 and 1981 (Fig. 2). For the trial a section of the buffers retained along both sides of the stream after these operations and a portion of an adjacent hillslope not previously logged were clear-felled between January and May 1985. In the Poole trial the 100 m wide buffer retained along the watercourses after clear-felling the area between the eastern and western fork of Big Hill Brook in the previous 12 months was reduced to 50 m in width between December 1984 and March 1985 (Fig. 2).

In the Poole trial all cut-over areas were burnt to dispose of the debris from logging in April 1985, shortly after the completion of logging, and then left to regenerate from natural seedfall. The remaining stream buffer on the western side of the coupe was burnt prior to burning of the cut-over areas. This was necessary since without recently burnt forest downwind of the regeneration burn there would have been a considerable risk of the fire escaping due to the prevailing easterly winds in the region at this time of the year.

Dislodged particles are transported to a stream by surface runoff. The larger the runoff volume, the more material can be moved. Fast flowing water can also dislodge soil particles and on long or steep slopes surface runoff may reach sufficient velocities to do so. Debris and understorey vegetation left after logging help to prevent high runoff velocities, often slow down runoff sufficiently to cause sediments to settle, and also filter out some sediment. However, to ensure good regeneration the debris and understorey vegetation must

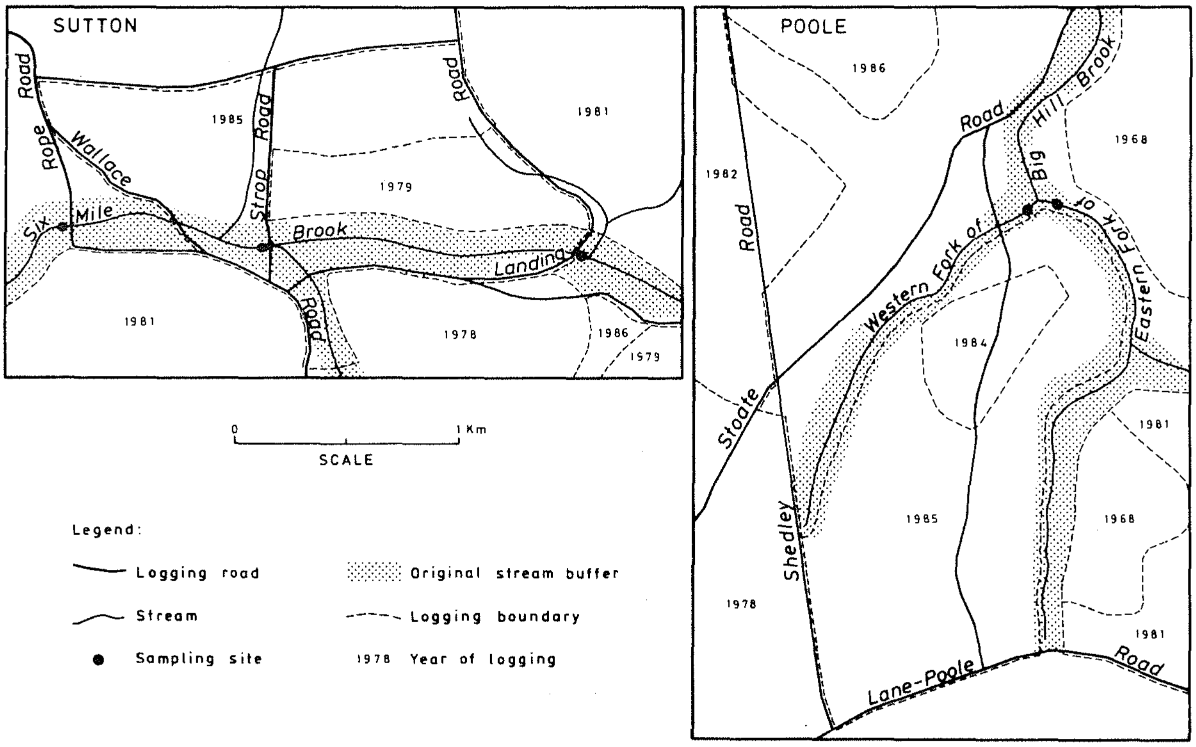


Figure 2

Sketch of the Sutton and Poole trial areas. (Year of logging is the year when logging was completed.)

eventually be removed. This is accomplished most efficiently by burning the cut-over areas. In south-west Western Australia virtually all the surface runoff in a given year occurs from June through October. Because the entire stream buffer was removed, burning in the Sutton trial was delayed until November so that the logging debris and the remaining vegetation would minimise the risk of erosion by runoff and the amount of sediment reaching the stream. Burning at this date also left the most time for regrowth of vegetation before the onset of the next runoff period. After burning, the cut-over areas were hand-planted in a 2 by 4 m spacing with nursery-raised karri seedlings.

2.2 Water quality sampling

Three sampling sites were established in the Sutton trial along Six Mile Brook, one at Landing Road, one at Strop Road 1500 m downstream of the Landing Road site, and one at Rope Road a further 1000 m downstream (Fig. 2). Between the Landing Road and the Strop Road site only the existing stream buffers were clear-felled. Between the Strop Road and the Rope Road site part of the existing stream buffers and a portion of an adjacent hillslope were clear-felled. Two sites were monitored in the Poole trial, one on the eastern fork (buffer not burnt) and one on the western fork (buffer burnt) of Big Hill Brook (Fig. 2).

In late 1984 a staff gauge and a stage height sampler were placed in the stream channel at each of the five sampling sites. Monitoring began in January 1985 and was terminated at the end of December 1986. During this period each site was visited at least once a fortnight, but typically more frequently. At each visit the stream water level was determined using the staff gauge, and a 500 mL water sample was taken manually from the stream. In the Sutton trial water level readings and water samples were also collected throughout a few individual rainfall events. The time of sampling was recorded for all data obtained during a visit. Between visits water samples were collected by the stage height samplers when the stream water level rose beyond a selected height. The collection times for these samples are unknown. The stage height sampler and the procedure for collecting water samples during site visits are described in detail by Bowyer (1973).

All measured stream water levels were converted to streamflow rates using a relationship between these two parameters derived from concurrent water level and flow measurements at each site. All water samples were analysed in the laboratory for the concentration of suspended sediments less than .063 mm in diameter, hereafter simply referred to as sediment concentration, and turbidity as described by Bowyer (1973). Flow-weighted mean values of sediment concentration and turbidity, X, were computed as

$$X = \Sigma q_i x_i / \Sigma q_i$$

where q_i is the streamflow rate at the time when the water sample with sediment concentration or turbidity x_i was collected.

Sediment concentrations below 5 mg/L cannot be measured accurately. A concentration of 5 mg/L can be visualised as two pulverized sandgrains mixed with 1 litre of water. Most water samples which contained less than 5 mg/L of sediments were registered as <5 mg/L on the data base, although in some cases the actual measured value was registered. For consistency all these values were set equal to 3 mg/L in the data analysis.

3. RESULTS

3.1 Sutton trial

Flow-weighted mean values and frequency distributions for the sediment concentrations and turbidities observed at Landing Road, Strop Road and Rope Road during the study are given in Table 1. All samples obtained during site visits and all those obtained from stage height samplers are included in this table. In most samples the sediment concentration was below 5 mg/L, and in only few samples did it exceed 20 mg/L. Flow-weighted mean annual sediment concentrations ranged from 5 to 11 mg/L and did not vary consistently between sites or years. Most samples had a turbidity below 5 NTU (Nephelometric Turbidity Units), and only some had a turbidity above 20 NTU. Flow-weighted mean annual turbidities ranged from 4 to 8 NTU. They did not vary consistently between the Strop Road and Rope Road site, but were lowest at Landing Road in both years.

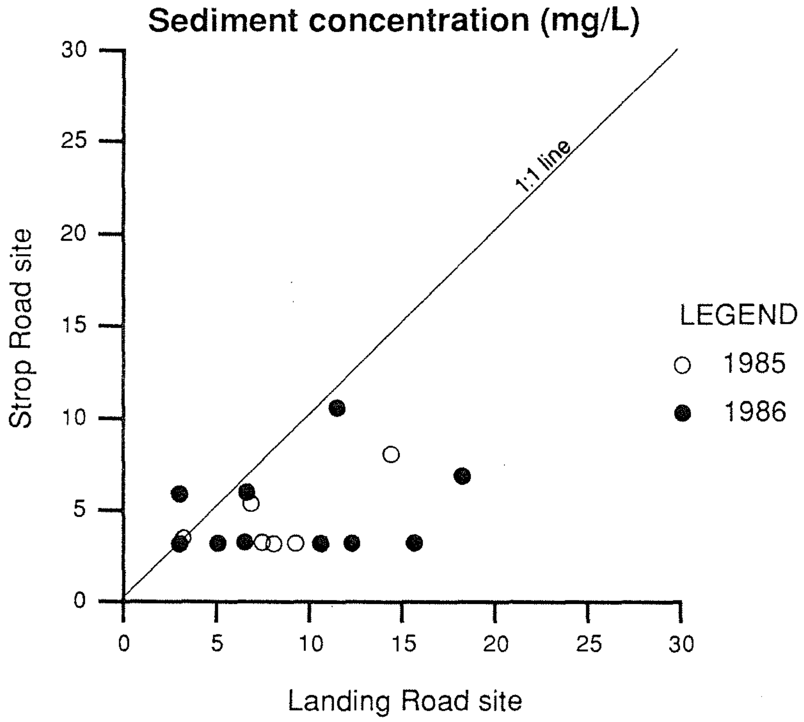
For a more accurate assessment of the effect of clear-felling the stream buffers between Landing Road and Strop Road, the water samples collected from both sites during visits and within two hours of each other, hereafter referred to as paired samples, were compared. The sediment concentrations were generally lower at the Strop Road site than at the Landing Road site (Fig. 3). In both years the flow-weighted mean sediment concentration computed from the paired samples was therefore also lower at Rope Road (Table 2). The observed turbidities were roughly equal at both sites for values below 5 NTU, but tended to be lower at Strop Road for values above 5 NTU (Fig. 3). The flow-weighted mean values were similar at both sites (Table 2).

Since the Landing Road site is upstream and the Strop Road site downstream of the clear-felled stream buffers, the lower sediment concentrations and turbidities should have occurred at Landing Road rather than Strop Road. Dilution by the addition of water to the stream between the two sites may have been the reason for this reversal, but it could also have arisen from a reduction in the flow

Table 1 : Frequency distribution of the suspended sediment concentrations and turbidities for all samples collected at the three sampling sites in the Sutton trial. (The numbers in brackets are the flow-weighted means for the samples).

year	concentration [mg/L]	Landing Road number of samples		Strop Road number of samples		Rope Road number of samples	
1985	<5	54		127		14	
	5-10	13		16		7	
	10-20	5		5		5	
	20-50	3		1		4	
		75	(11)	149	(5)	30	(11)
1986	<5	100		22		12	
	5-10	34		28		7	
	10-20	26		15		5	
	20-50	4*		3		0	
		164	(6)	68	(10)	24	(7)
both years	<5	154		149		26	
	5-10	47		44		14	
	10-20	31		20		10	
	20-50	7		4		4	
		239	(9)	217	(5)	54	(10)
	turbidity [NTU]						
1985	<5	66		136		19	
	5-10	10		14		8	
	10-20	0		0		2	
	20-50	0		0		2	
		76	(4)	150	(4)	31	(8)
1986	<5	115		15		9	
	5-10	39		29		11	
	10-20	8		21		2	
	20-50	2		3		0	
		164	(4)	68	(8)	22	(7)
both years	<5	181		151		28	
	5-10	49		43		19	
	10-20	8		21		4	
	20-50	2		3		2	
		240	(4)	218	(4)	53	(7)

* includes one sample of 54 mg/L



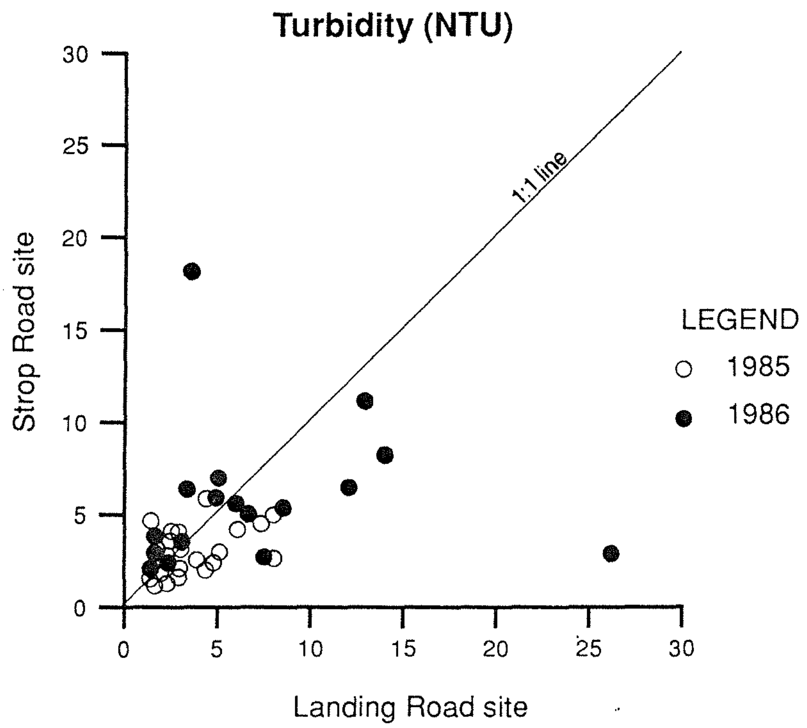


Figure 3

Comparison of paired sediment samples, and paired turbidity samples from the Landing Road site and the Strop Road site.

Table 2 : Frequency distribution of the suspended sediment concentrations and turbidities for the paired samples collected at the Landing Road and Strop Road site. (The numbers in brackets are the flow-weighted means for the samples).

		Landing Road		Strop Road	
year	concentration [mg/L]	number of samples		number of samples	
1985	<5	42		47	
	5-10	6		2	
	10-20	1		0	
	20-50	0		0	
		49	(6)	49	(4)
1986	<5	9		14	
	5-10	3		3	
	10-20	6		1	
	20-50	0		0	
		18	(5)	18	(3)
both years	<5	51		61	
	5-10	9		5	
	10-20	7		1	
	20-50	0		0	
		67	(6)	67	(4)
	turbidity [NTU]				
1985	<5	47		51	
	5-10	5		1	
	10-20	0		0	
	20-50	0		0	
		52	(3)	52	(3)
1986	<5	9		8	
	5-10	5		8	
	10-20	3		2	
	20-50	1		0	
		18	(4)	18	(5)
both years	<5	56		59	
	5-10	10		9	
	10-20	3		2	
	20-50	1		0	
		70	(3)	70	(3)

velocity between the two sites which would have caused some of the sediments to settle.

The effect of the concurrent clear-felling of part of the stream buffers and part of an adjacent hillslope between Strop Road (upstream) and Rope Road (downstream) was also evaluated in more detail using paired samples. The observed sediment concentrations were similar at both sites, except for one relatively high value at Rope Road (Fig. 4). Due to this sample the flow-weighted mean annual sediment concentration computed from the paired samples in 1985 was higher at Rope Road than at Strop Road. In 1986 it was the same at both sites (Table 3). In 1985 turbidities were generally higher at Rope Road, but in 1986 they were generally higher at Strop Road (Fig. 4), which is reflected in the flow-weighted means (Table 3).

The one relatively high sediment concentration and the two relatively high turbidities recorded at Rope Road in 1985 may have been due to the logging (Fig. 4). However, they may have been due to inaccuracies in the collection of water samples for the analysis of stream sediment concentration and turbidity and the analysis itself. Such inaccuracies are common, especially in the range of values encountered in this study. This becomes the more likely explanation if one considers that only one sample had a relatively high sediment concentration, but two had a relatively high turbidity. Since sediment concentration and turbidity are related (Abawi and Stokes 1982) there should have been two samples with a relatively high sediment concentration. The same can be argued for the relatively high turbidity recorded at Strop Road in 1986 since no corresponding high sediment concentrations was noted (Fig. 3).

The data collected in this trial throughout individual rainfall events were not analysed separately because the observed sediment concentrations and turbidities did not vary during the events and were virtually all below 5 mg/L and 5 NTU, respectively. There was no distinct relationship between streamflow rate and sediment concentration or streamflow rate and turbidity at either of the three sites (Appendix A).

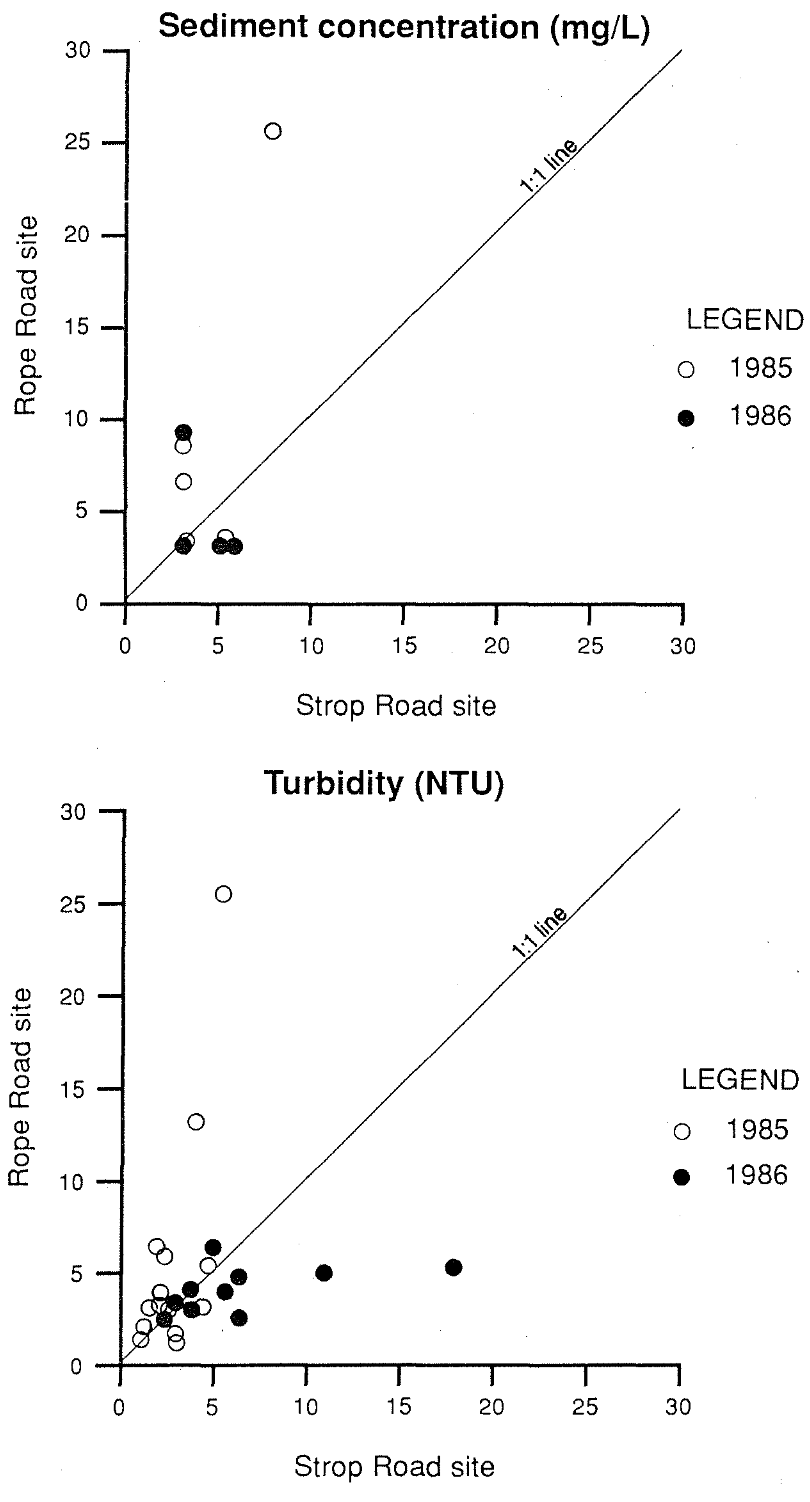


Figure 4

Comparison of paired sediment samples, and paired turbidity samples from the Strop Road site and the Rope Road site.

Table 3 : Frequency distribution of the suspended sediment concentrations and turbidities for the paired samples collected at the Strop Road and Rope Road site. (The numbers in brackets are the flow-weighted means for the samples).

year	concentration [mg/L]	Strop Road number of samples		Rope Road number of samples	
1985	<5	13		12	
	5-10	2		2	
	10-20	0		0	
	20-50	0		1	
		15	(5)	15	(11)
1986	<5	9		11	
	5-10	4		2	
	10-20	0		0	
	20-50	0		0	
		13	(3)	13	(3)
both years	<5	22		23	
	5-10	6		4	
	10-20	0		0	
	20-50	0		1	
		28	(4)	28	(8)
	turbidity [NTU]				
1985	<5	15		11	
	5-10	1		3	
	10-20	0		1	
	20-50	0		1	
		16	(3)	16	(10)
1986	<5	6		9	
	5-10	4		3	
	10-20	2		0	
	20-50	0		0	
		12	(5)	12	(4)
both years	<5	21		20	
	5-10	5		6	
	10-20	2		1	
	20-50	0		1	
		28	(4)	28	(8)

3.2 Poole trial

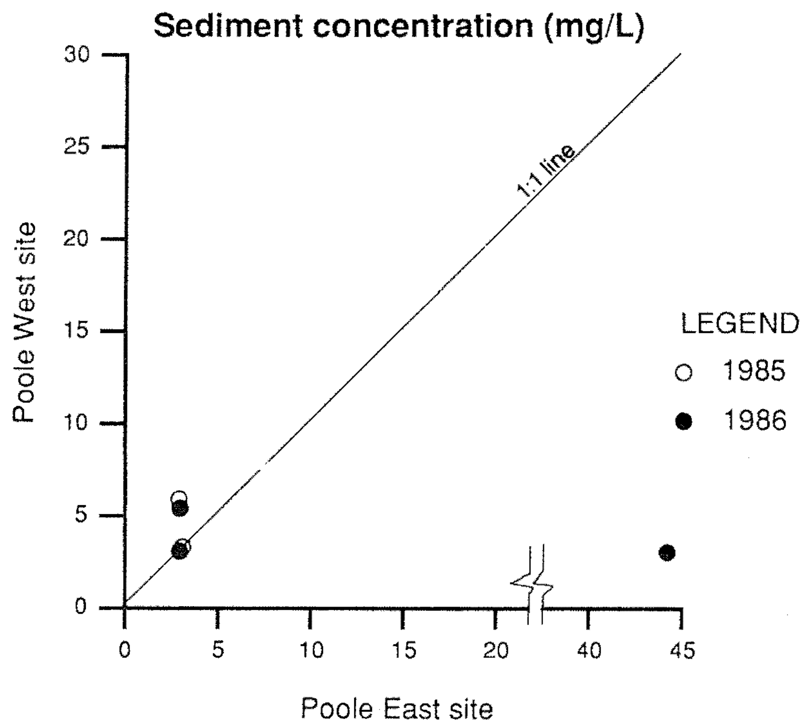
Table 4 gives the frequency distribution and flow-weighted mean values for all sediment concentrations and turbidities observed at the Poole East and West site, respectively. As for the Sutton sites most sediment concentrations were below 5 mg/L and only a few were above 20 mg/L. The flow-weighted means ranged from 4 to 8 mg/L and were not consistently different between years or sites. Again as in the Sutton trial, most turbidities were below 5 NTU and only a few were above 20 NTU. In 1985 the flow-weighted mean was higher at Poole West due to two samples of high turbidity, but in 1986 it was the same at both sites.

Figure 5 compares the paired sediment samples for the two Poole sites. Except for one high value at Poole East in 1986 similar sediment concentrations were observed at both sites. Due to this high value the flow-weighted mean sediment concentration computed from the paired samples was higher at Poole East in 1986, while in 1985 it was similar at both sites (Table 5). The paired turbidities were generally well matched between the two sites apart from one high value at Poole West in 1985, and one high value at Poole East in 1986 (Fig. 5). The flow-weighted mean was therefore higher at Poole West in 1985, and higher at Poole East in 1986 (Table 5).

As for the Sutton sites, there was no distinct relationship between streamflow rate and sediment concentration or streamflow rate and turbidity at either of the two Poole sites (Appendix B).

Table 4 : Frequency distribution of the suspended sediment concentrations and turbidities for all samples collected at the two sampling sites in the Poole trial. (The numbers in brackets are the flow-weighted means for the samples).

		Poole East		Poole West	
year	concentration [mg/L]	number of samples		number of samples	
1985	<5	21		25	
	5-10	2		5	
	10-20	2		5	
	20-50	1		0	
		26	(4)	35	(6)
1986	<5	13		13	
	5-10	4		5	
	10-20	4		3	
	20-50	1		3	
		22	(8)	24	(7)
both years	<5	34		38	
	5-10	6		10	
	10-20	6		8	
	20-50	2		3	
		48	(5)	59	(6)
	turbidity [NTU]				
1985	<5	26		30	
	5-10	1		4	
	10-20	0		0	
	20-50	0		2	
		27	(2)	36	(8)
1986	<5	16		19	
	5-10	5		5	
	10-20	1		0	
	20-50	0		0	
		22	(4)	24	(4)
both years	<5	42		49	
	5-10	6		9	
	10-20	1		0	
	20-50	0		2	
		49	(3)	60	(7)



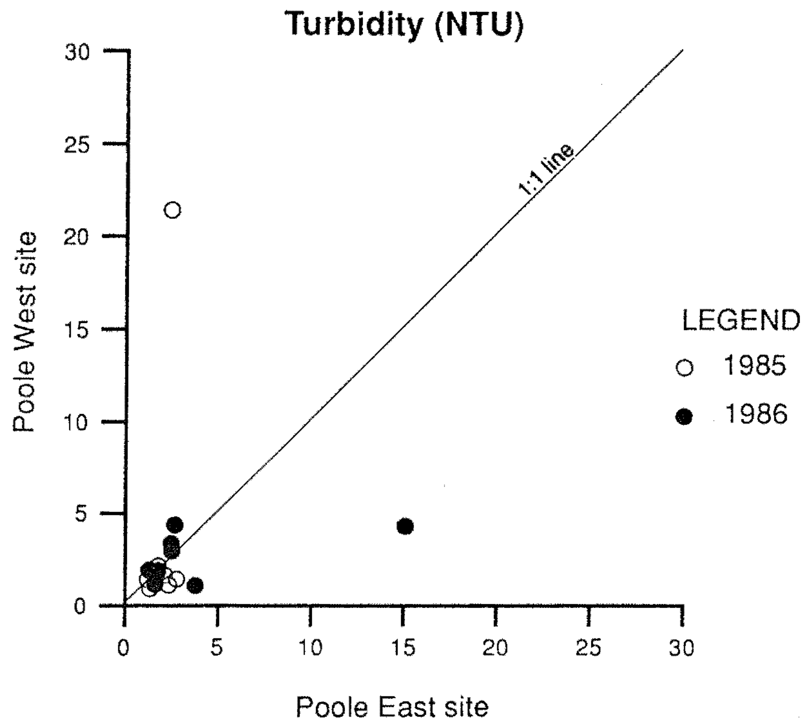


Figure 5

Comparison of paired sediment samples, and paired turbidity samples from the Poole East site and the Poole West site.

Table 5 : Frequency distribution of the suspended sediment concentrations and turbidities for the paired samples collected at the Poole East and Poole West site. (The numbers in brackets are the flow-weighted means for the samples).

		Poole East		Poole West	
year	concentration [mg/L]	number of samples		number of samples	
1985	<5	11		10	
	5-10	0		1	
	10-20	0		0	
	20-50	0		0	
		11	(3)	11	(4)
1986	<5	10		9	
	5-10	0		2	
	10-20	0		0	
	20-50	1		0	
		11	(9)	11	(4)
both years	<5	21		19	
	5-10	0		3	
	10-20	0		0	
	20-50	1		0	
		22	(5)	22	(4)
	turbidity [NTU]				
1985	<5	12		11	
	5-10	0		0	
	10-20	0		0	
	20-50	0		1	
		12	(2)	12	(11)
1986	<5	10		11	
	5-10	0		0	
	10-20	1		0	
	20-50	0		0	
		11	(4)	11	(3)
both years	<5	22		22	
	5-10	0		0	
	10-20	1		0	
	20-50	0		1	
		23	(2)	23	(9)

4. DISCUSSION

In the southern forest of Western Australia flow-weighted mean annual sediment concentrations in unlogged and completely forested catchments are generally below 10 mg/L and often below 5 mg/L (Steering Committee 1980; Borg et al. 1987). Most of the samples have concentrations below 5 mg/L and only a few have concentrations above 20 mg/L (Borg et al. 1987). Turbidity data for such catchments are not available. However, using a correlation between sediment concentration and turbidity presented by Abawi and Stokes (1982) 5 mg/L is about equal to 7 NTU, 10 mg/L is equivalent to 11 NTU, and 20 mg/L corresponds to 18 NTU. The sediment concentrations and turbidities observed in the Sutton and Poole trial were therefore within the range of the values for unlogged and completely forested catchments in the region. Furthermore, they did not vary consistently or significantly between the sampling sites. This means that logging of the stream buffers in the two trials had no detectable effect on stream sediment concentration and turbidity.

The width required for a buffer to effectively protect a watercourse increases with the slope of the adjacent area. The slopes in the Poole trial area were generally below 5^{o}. According to an equation published by Trimble and Sartz (1957), which relates slope to required buffer width, buffers only 15 m wide on each side of the watercourses would have been adequate in the Poole trial area. Buffers that size have been found to be effective and a width of 30 m appears to be generally sufficient for slopes up to about 15^{o} and sometimes even for much steeper slopes (Clinnick 1985). Hence, the 50 m wide buffer left in the Poole trial was larger than necessary so that it is not surprising that reducing the buffer width from 100 to 50 m did not affect sediment concentration and turbidity in the streams. It is not clear why burning of the buffer on the western fork of Bill Hill Brook had no noticable effect on these two parameters either. It is possible that runoff entering the buffer infiltrated into the soil before it reached the stream.

In the Sutton trial existing stream buffers were clear-felled without leading to an increase in stream sediment concentration and turbidity. It seems that the remaining understorey vegetation, the debris from logging and the earth banks pushed across potential runoff channels prevented any increase in 1985. The waste disposal burn later removed most of the debris and the remaining understorey vegetation. However, the timing of the burn just after the end of the 1985 runoff season apparently allowed for sufficient regrowth before the start of the 1986 runoff season, particularly of shrubs and grasses, to prevent a detrimental effect on stream water quality in 1986.

The risk of soil erosion and an ensuing increase in stream sediment concentration and turbidity increases with the length and steepness of the exposed slope. Between Landing Road and Strop Road, where only the existing stream buffers were clear-felled, a slope just 100 m long with less than 5^{o} grade was exposed on either side of the stream and therefore presented only a relatively small erosion risk. However, between Strop Road and Rope Road part of the existing buffers and part of a hillslope north of the stream were clear-felled. Logging the hillslope and the buffers concurrently exposed a slope over 200 m long with grades up to 20^{o}. This presented a much greater erosion risk and runoff with high sediment concentrations and turbidities was observed and photographed on this slope (Water Authority of Western Australia, unpublished records), but dissipated before it reached the stream. It is uncertain if the blocking of potential runoff channels and the timing of the burn would have been sufficient to contain a high volume of turbid runoff generated by a high intensity rainfall event, especially on the hillslope. No such event occurred during the study.

In 1985 and 1986 the annual rainfall in the southern forest of Western Australia was 13 and 21%, respectively below the long-term mean (Borg et al. 1987). Streamflow rates in these years were also below average. This probably did not affect the results from the Poole trial since the review by Clinnick (1985) indicates that the 50m wide buffer retained in this trail is larger than required to protect the watercourses, but it may have affected the results from the Sutton trial. Higher rainfall generally generates more runoff, which carries the potential for more erosion and hence higher stream sediment concentrations and turbidities. However, erosion is affected more by short-term rainfall intensities which lead to high runoff rates than by the total annual rainfall. Wetter years therefore do not necessarily lead to higher stream sediment concentrations and turbidities.

5. CONCLUSIONS

Reducing the stream buffer in the Poole trial to half the usual width did not affect sediment concentrations and turbidities in the watercourses. In light of this result and the review by Clinnick (1985) the 200 m and 100 m wide buffers generally prescribed for rivers and streams in the southern forest of Western Australia, respectively, appear unnecessarily large, at least on flat to moderate slopes. It therefore seems possible to reduce the width of river and stream buffers to 100 m and 50 m, respectively, without a detrimental effect on water quality, to increase the volume of timber available for logging in the region.

Due to the preventive measures taken, clear-felling of stream buffers did not result in obvious changes in stream water quality. However, more serious effects might have been observed had there been a high intensity rainfall event. Due to the potential risk of erosion and deterioration in water quality, the complete removal of buffers along watercourses should not be made a general practice.

Flora, fauna and other forest values were not considered here, but should be assessed before stream and river buffers are logged on an operational scale. Other ways to obtain additional timber should be reviewed as well. If, in the end, logging of stream and river buffers is carried out, it should be restricted to the dry season and logging prescriptions similar to the ones used in the trials discussed here should be applied to minimise the risk for erosion and an increase in sediment concentrations and turbidities. Also, since roads and tracks are often a major source of sediments (Brown 1985), they should be well constructed, well drained and located away from the watercourses.

6. ACKNOWLEDGEMENTS

We wish to thank Don Barrett, Peter Helsby, Peter Clews, Mark Williams, Piers Goodman and John Manera from the Manjimup office of the Water Authority of Western Australia for collecting and analysing the water quality samples, and Karen Lemnell and Peter Van De Wyngaard for their help in preparing the manuscript.

7. REFERENCES

Abawi, G.Y. and Stokes, R.A. (1982) - Wights catchment sediment study 1977-81. Public Works Department of Western Australia, Water Resources Technical Report No. 100.

Borg, H., Hordacre, A. and Batini, F. (1988) - Effects of logging in stream and river buffers on watercourses and water quality in the southern forest of Western Australia. Australian Forestry (in press).

Borg, H., King, P.D. and Loh, I.C. (1987) - Stream and ground water response to logging and subsequent regeneration in the southern forest of Western Autralia. Interim results from paired catchment studies. Water Authority of Western Australia, Water Resources Directorate, Hydrology Branch Report No. WH 34.

Bowyer, R.O. (1973) - Methods of measurement and analysis of sediment loads in streams. Public Works Department of Western Australia, Water Resources Section, Planning, Design and Investigation Branch Bulletin No. 6, Part A.

Brown, G.W. (1985) - Forestry and water quality. Oregon State University Book Stores, Corvallis.

Clinnick, P.F. (1985) - Buffer strip management in forest operations: a review. Australian Forestry 48:34-45.

Forests Department of Western Australia (1973) - Environmental impact statement on the woodchipping industry agreement proposals for Western Australia.

Hordacre, A. and Batini, F. (1987) - Logging in river and stream reserves. Department of Conservation and Land Management W.A., internal report.

Loh, I.C. and King, B. (1978) - Annual rainfall characteristics of the Warren, Shannon and Donnelly river basins. Public Works Department of Western Australia, Water Resources Technical Report No. 78.

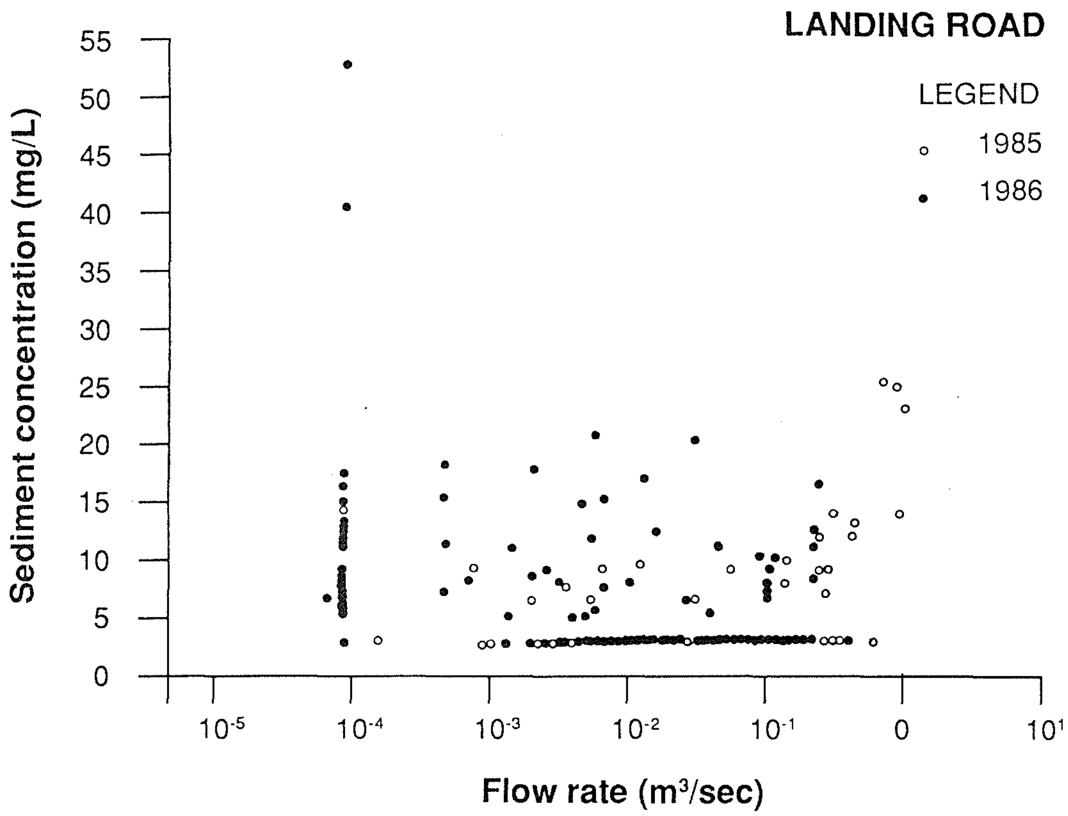
McArthur, W.M. and Clifton, A.J. (1975) - Forestry and agriculture in relation to soils in the Pemberton area of Western Australia. CSIRO, Division of Soils, Soils and Land Use Series No. 54.

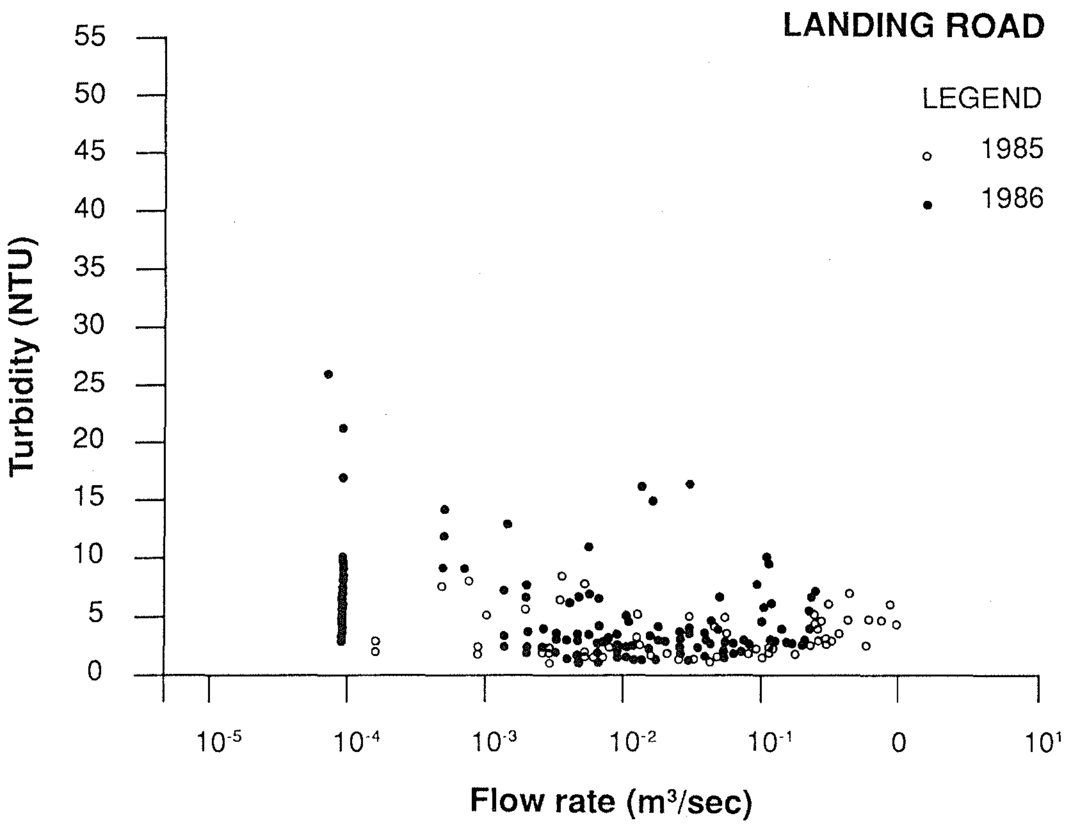
Steering Committee (1980) - Research into the effects of the woodchip industry on water resources in south Western Australia. (Western Australian) Department of Conservation and Environment, Bulletin No. 81.

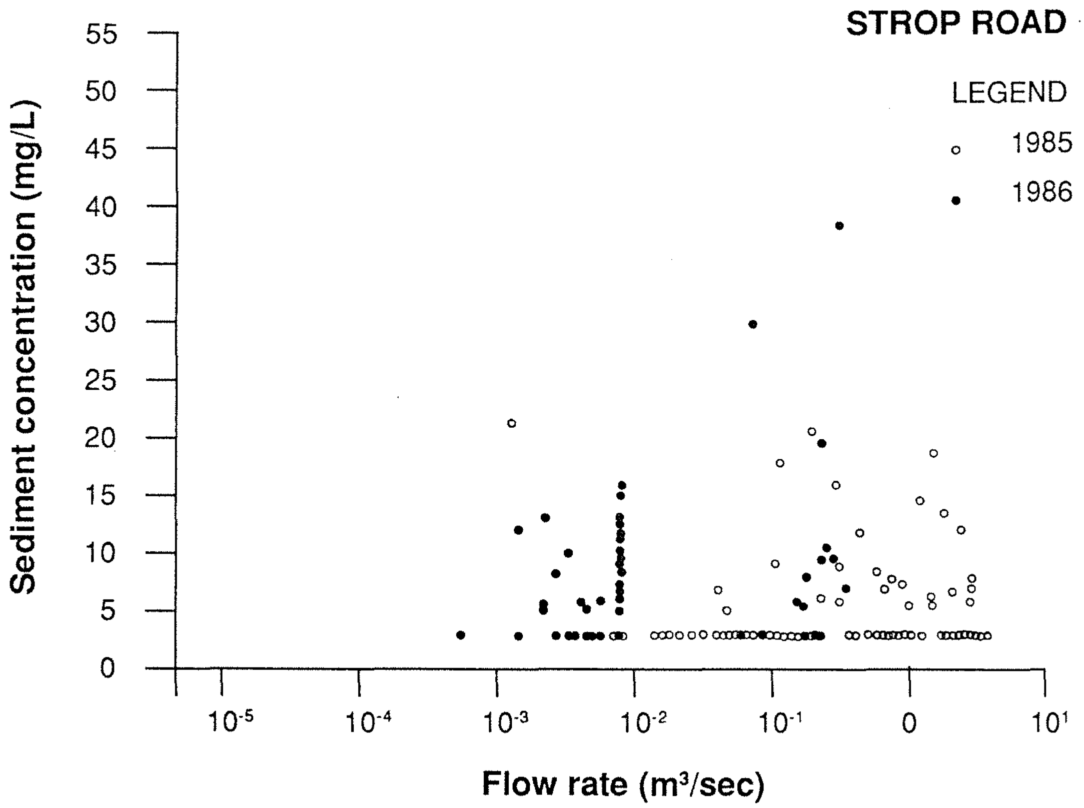
Trimble, G.R. and Sartz, R.S. (1957) - How far from a stream should a logging road be located ? Journal of Forestry 55:339-341.

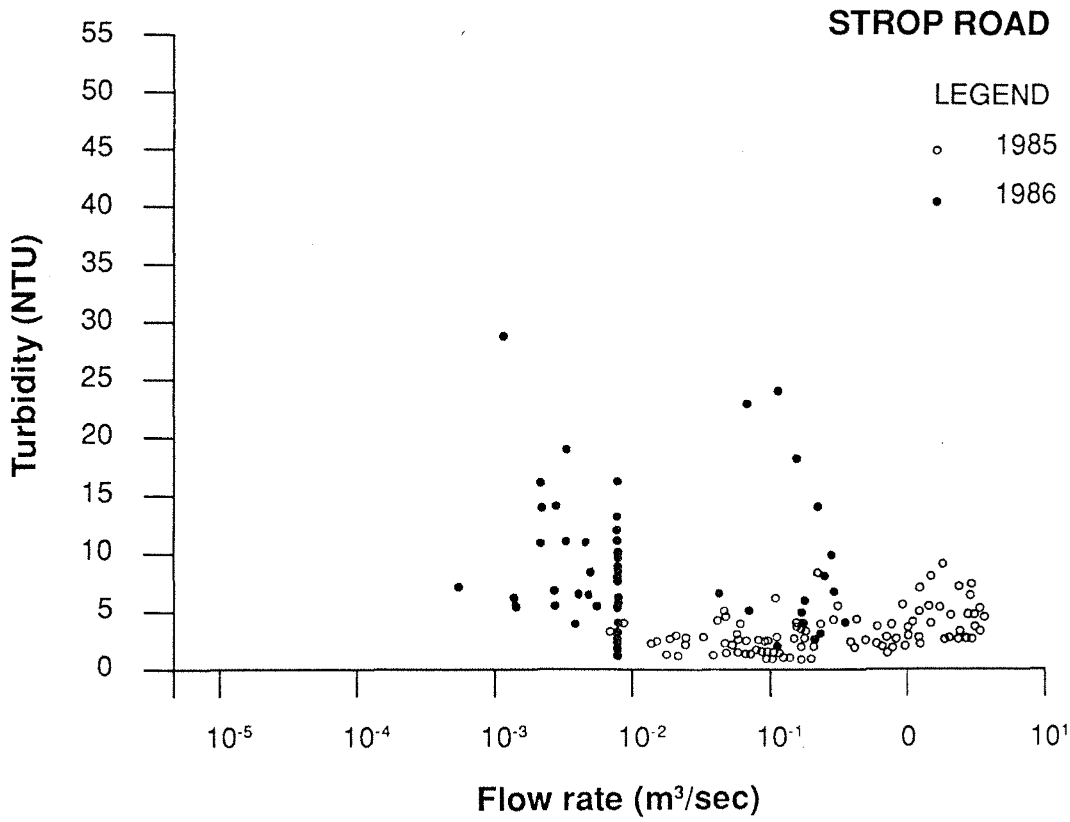
Appendix A

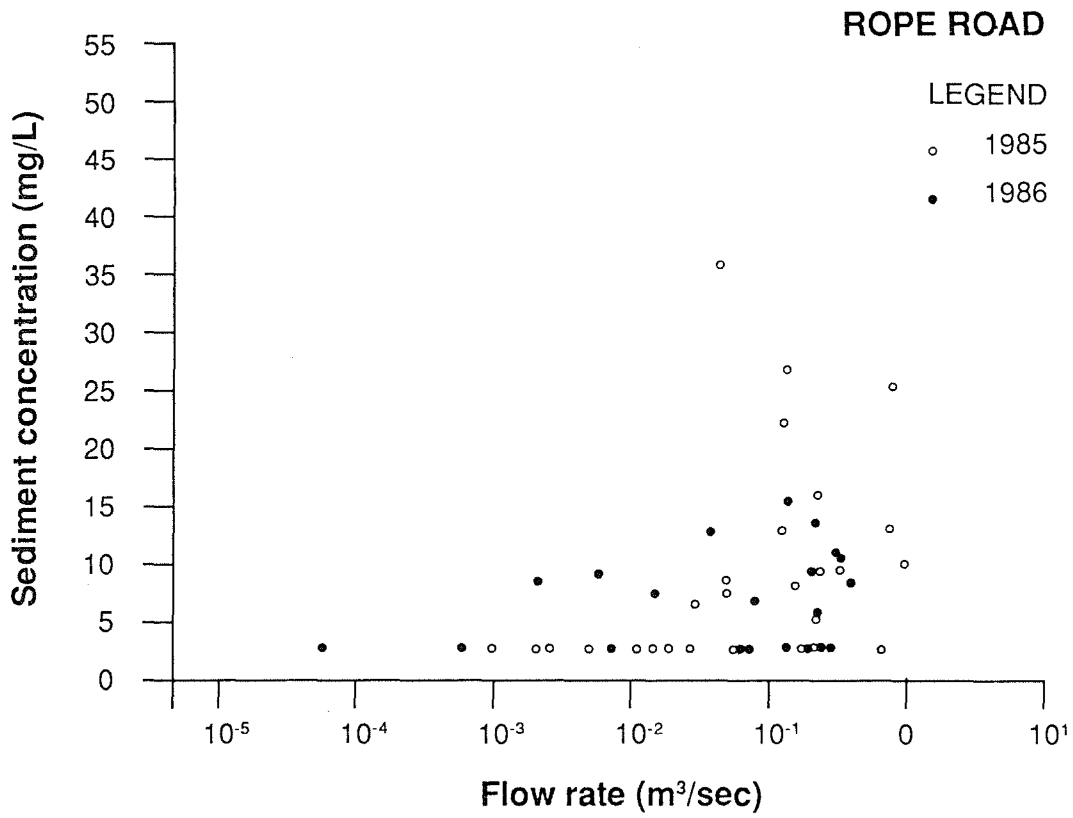
Relationship between streamflow and sediment concentration, and streamflow and turbidity at the three sampling sites in the Sutton trial.

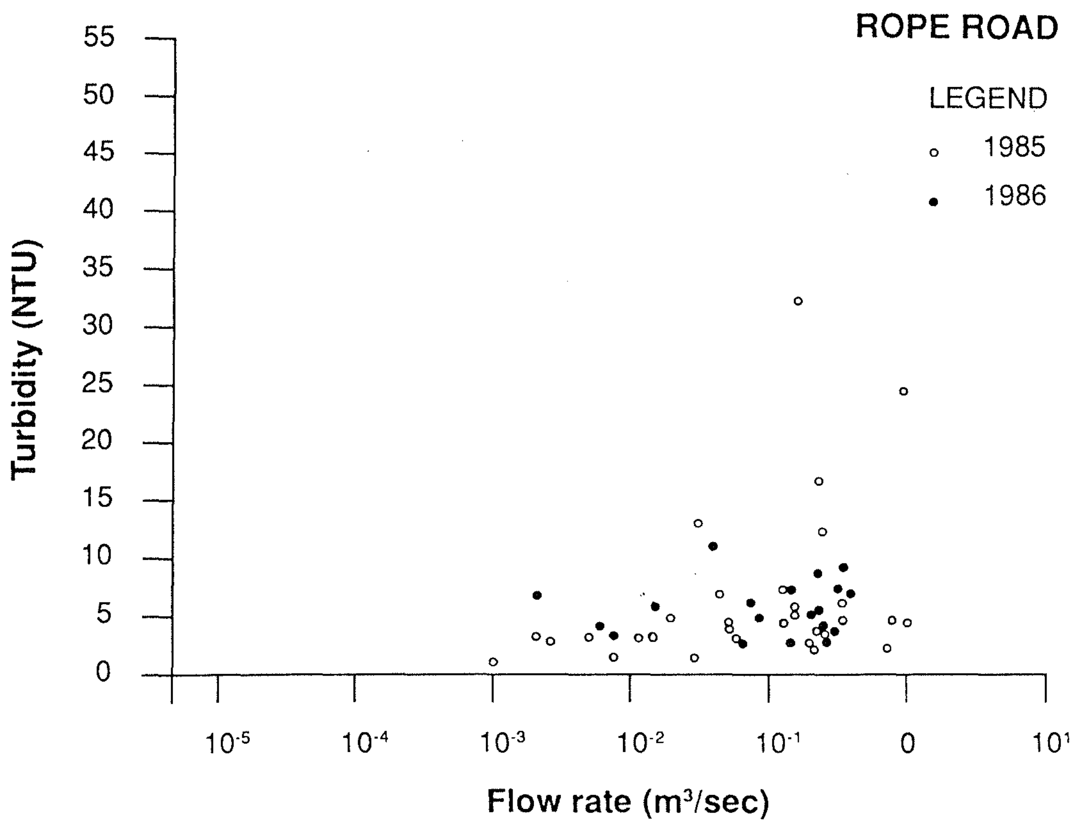

LANDING ROAD
LEGEND
1985
1986
Sediment concentration (mg/L)
55
50
45
40
35
30
25
20
15
10
5
0
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
0
10^{1}
Flow rate (m^3/sec)


LANDING ROAD
LEGEND
1985
1986
Turbidity (NTU)
55
50
45
40
35
30
25
20
15
10
5
0
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
0
10^{1}
Flow rate (m^3/sec)


STROP ROAD
LEGEND
1985
1986
Sediment concentration (mg/L)
55
50
45
40
35
30
25
20
15
10
5
0
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
0
10^{1}
Flow rate (m³/sec)

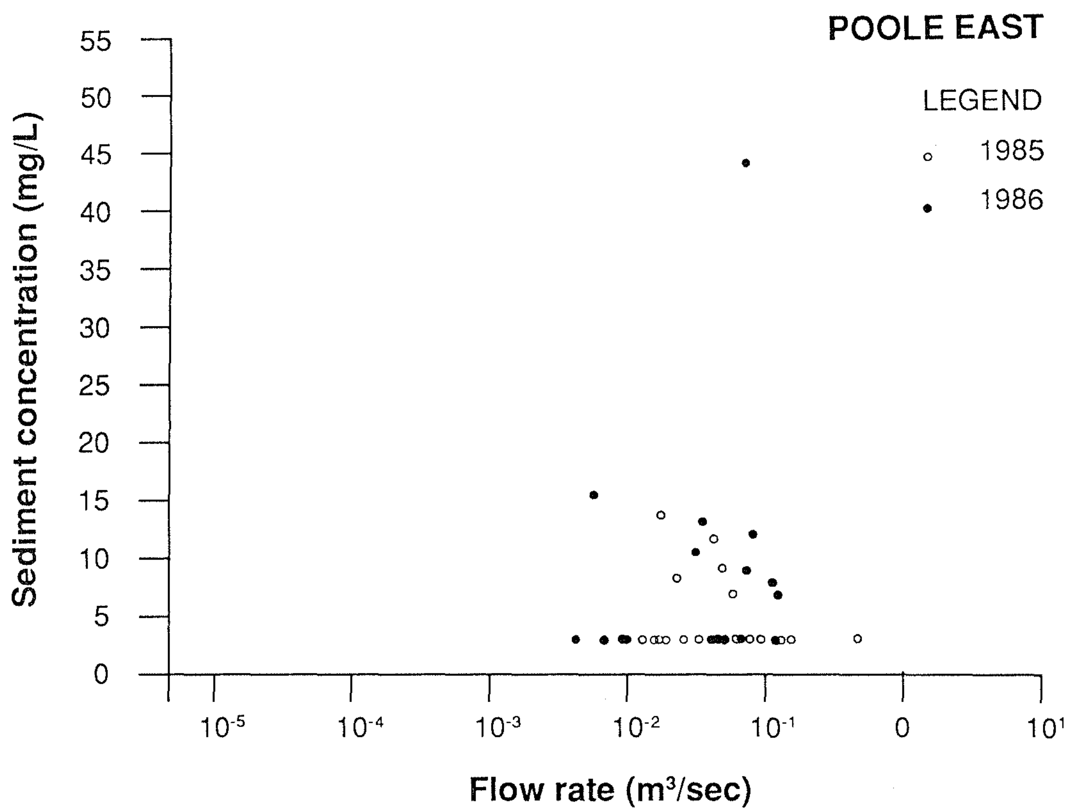

STROP ROAD
LEGEND
1985
1986
Turbidity (NTU)
55
50
45
40
35
30
25
20
15
10
5
0
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
0
10^{1}
Flow rate (m³/sec)

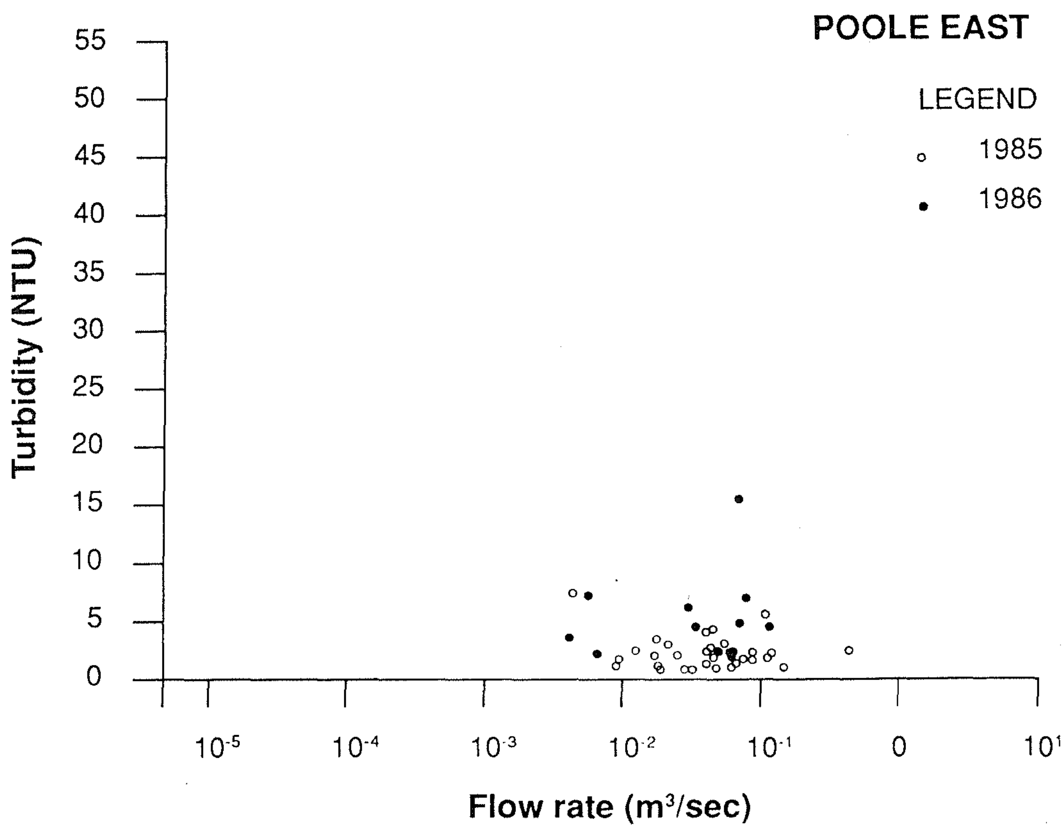

ROPE ROAD
LEGEND
1985
1986
Sediment concentration (mg/L)
55
50
45
40
35
30
25
20
15
10
5
0
10-5
10-4
10-3
10-2
10-1
0
101
Flow rate (m3/sec)

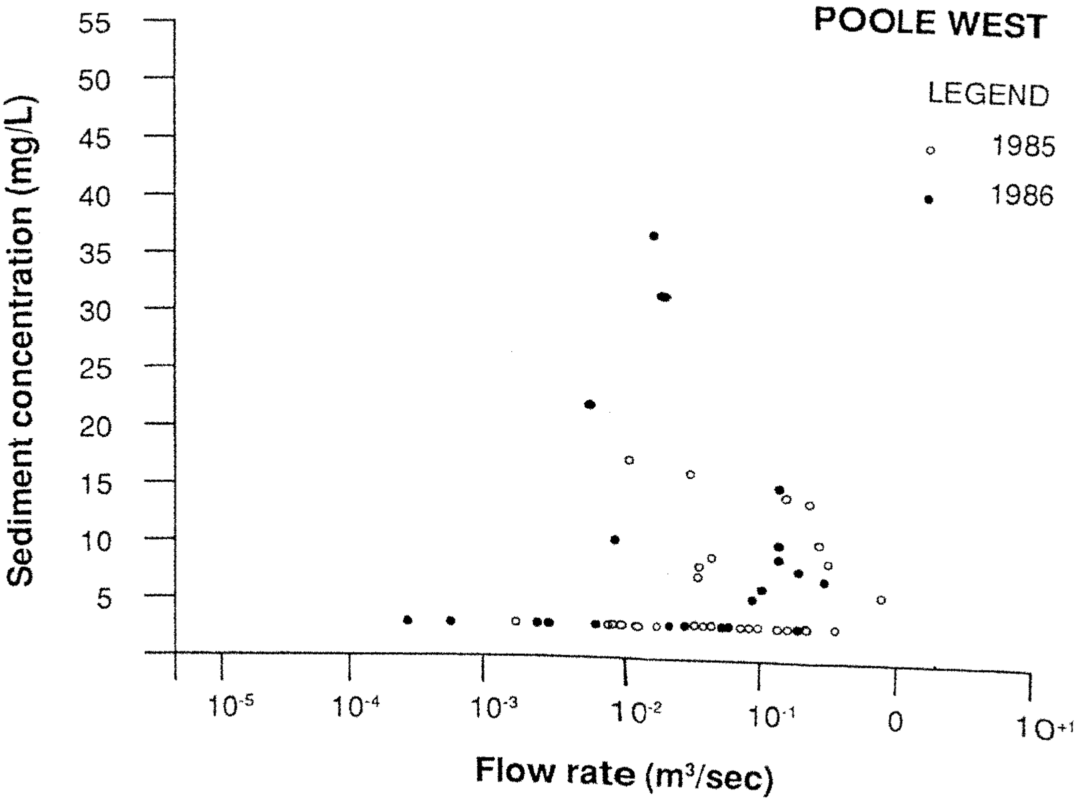

ROPE ROAD
LEGEND
1985
1986
Turbidity (NTU)
55
50
45
40
35
30
25
20
15
10
5
0
10-5
10-4
10-3
10-2
10-1
0
101
Flow rate (m3/sec)

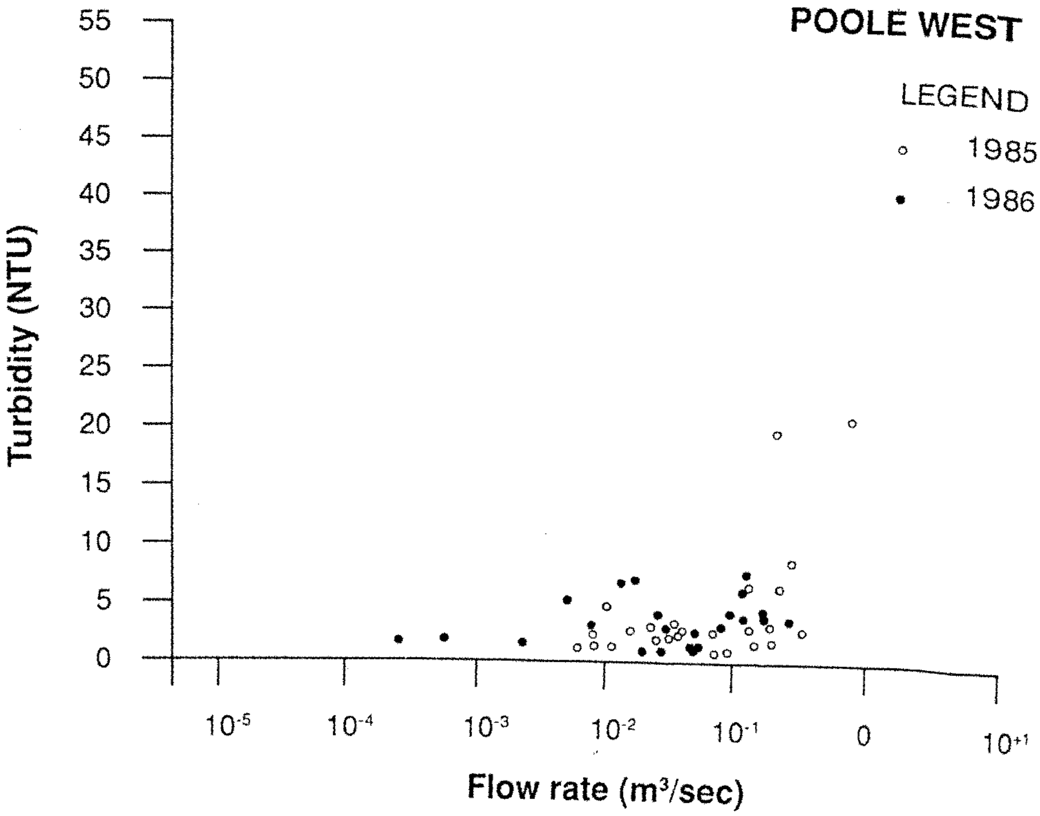
Appendix B

Relationship between streamflow and sediment concentration, and streamflow and turbidity at the two sampling sites in the Poole trial.


POOLE EAST
LEGEND
1985
1986
Sediment concentration (mg/L)
55
50
45
40
35
30
25
20
15
10
5
0
10-5
10-4
10-3
10-2
10-1
0
101
Flow rate (m3/sec)


POOLE EAST
LEGEND
1985
1986
Turbidity (NTU)
55
50
45
40
35
30
25
20
15
10
5
0
10-5
10-4
10-3
10-2
10-1
0
101
Flow rate (m3/sec)


POOLE WEST
LEGEND
1985
1986
Sediment concentration (mg/L)
55
50
45
40
35
30
25
20
15
10
5
10-5
10-4
10-3
10-2
10-1
0
10+1
Flow rate (m3/sec)


POOLE WEST
LEGEND
1985
1986
Turbidity (NTU)
55
50
45
40
35
30
25
20
15
10
5
0
10-5
10-4
10-3
10-2
10-1
0
10+1
Flow rate (m3/sec)