Water Authority
of Western Australia

WATER RESOURCES DIRECTORATE

The Effect Of Non-Valley Reforestation On Water Quality And Quantity In The Padbury Reservoir Catchment And Its Regional Implications

Report No. WS 5

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ABSTRACT

Salinities in excess of 1000 mg/L TSS developed in the Padbury Reservoir in the mid 1970's as a result of extensive clearing of its catchment (900 mm mean annual rainfall) over the previous forty years. Between 1977 and 1983 high density non-valley tree planting of 70% of the catchment was implemented to establish a commercial plantation and provide an expected salinity relief. The majority of the side slopes were planted to *Pinus radiata* which accounted for about 80% of the reforestation.

In the first 9 years following the initial reforestation:

(i) Annual streamflow volumes decreased by 50 to 100 mm;

(ii) Flow - weighted mean annual salinity reduced for a given streamflow volume;

(iii) However, since streamflows also substantially reduced, there was no improvement on average in stream salinity with below average rainfall years showing an increase and wetter years a decrease.

This response demonstrates that non-valley reforestation alone is not a suitable strategy for water quality rehabilitation of a small water resource catchment. For large (regional) catchments (greater than 1000 km^2) this strategy can be beneficial because side slope tree planting also substantially decreases stream salt load. The cleared land located in below 900 mm rainfall areas of regional catchments generally contribute a large proportion of catchment salt load with a much smaller proportion of streamflow. Non-valley reforestation in this region would result in an overall improvement in catchment salinity. Tree planting in higher rainfall regions would have the opposite effect.

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CHAPTER 1 : INTRODUCTION

In 1976 water quality problems developed in the water supply of Balingup, a town situated in the south-west of Western Australia. The water supplied from the nearby Padbury Reservoir had salinities in excess of 1000 mg/L Total Soluble Salts (TSS) resulting in numerous consumer complaints. The cause of this high salinity was attributed to the large proportion of clearing in the reservoir's catchment over the previous forty years.

Short term solutions such as reservoir scour and diversion of saline streamflows were instigated in 1976 and 1977, respectively. These policies were initially successful. However, in subsequent years below average rainfalls and associated low inflows restricted the ability to scour and divert saline streamflows. In the summer of 1982/83 the Padbury Reservoir was supplemented from a neighbouring town's (Greenbushes) fresh water supply (hereafter referred to as augmentation). This has alleviated most of the salinity problems and provided more reliability in Balingup's supply.

In addition to the short-term solutions, a longer term catchment management policy was initiated in 1976 to rehabilitate the catchment so that it would yield good quality water in the following decades water. The then Forests Department, now part of the Department of Conservation and Land Management (CALM), proposed to purchase land in the region for its softwood planting programme. With support from the Water Authority, CALM convinced the government to purchase the privately owned land on the Padbury Reservoir catchment primarily to establish a commercial pine plantation. Providing an expected salinity relief to the Padbury Reservoir was seen as a secondary benefit. Between 1977 and 1983, CALM planted pines on the majority of the lower and upper slopes of the catchment. Eucalypts were also established during this period in some of the areas that were unsuitable for pine growth.

The initial plantings in 1977 were largely on the eastern tributary subcatchment and thus provided an opportunity to evaluate the effectiveness of the trees in controlling stream salinity. A gauging station was established on the eastern tributary in the following year to record streamflow and electrical conductivity of the water (a measure of water salinity). The aim of this report is to evaluate the effect of pine plantations on water quality and yield. This was achieved by analysing the first nine years of record from the gauging station between 1978 and 1986 inclusive. For this reason, this study concentrates on the subcatchment defined by the gauging station.

This report describes the land use history of the catchment and provides analysis and discussion on the effect of the plantings on streamflow yield and salinity. Conclusions are then drawn about the suitability of non-valley tree plantations for reducing stream salinity and the implications for further management strategies of the catchment are considered. The value of high density commercial plantations as part of a large water resource catchment management strategy is also discussed.

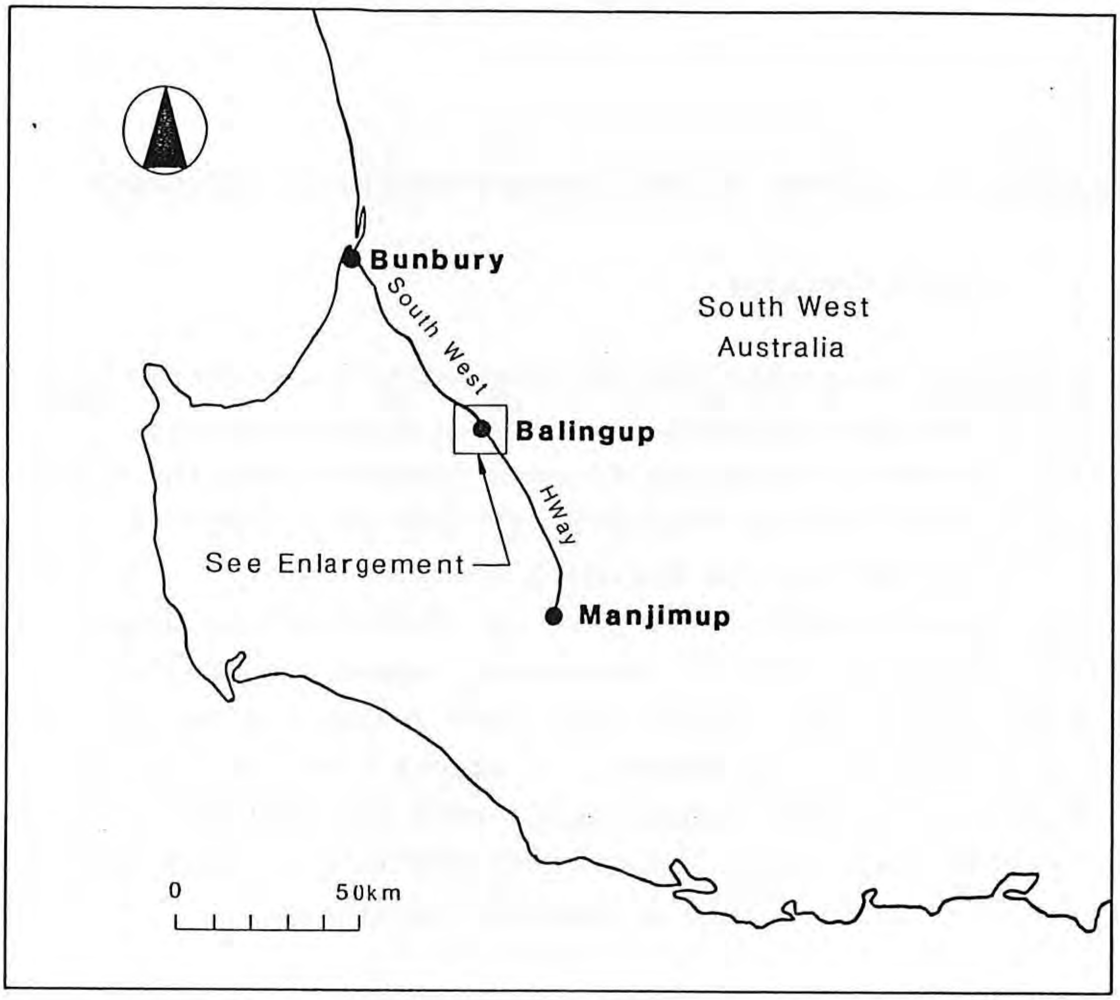
CHAPTER 2 : HISTORY OF THE PADBURY RESERVOIR CATCHMENT

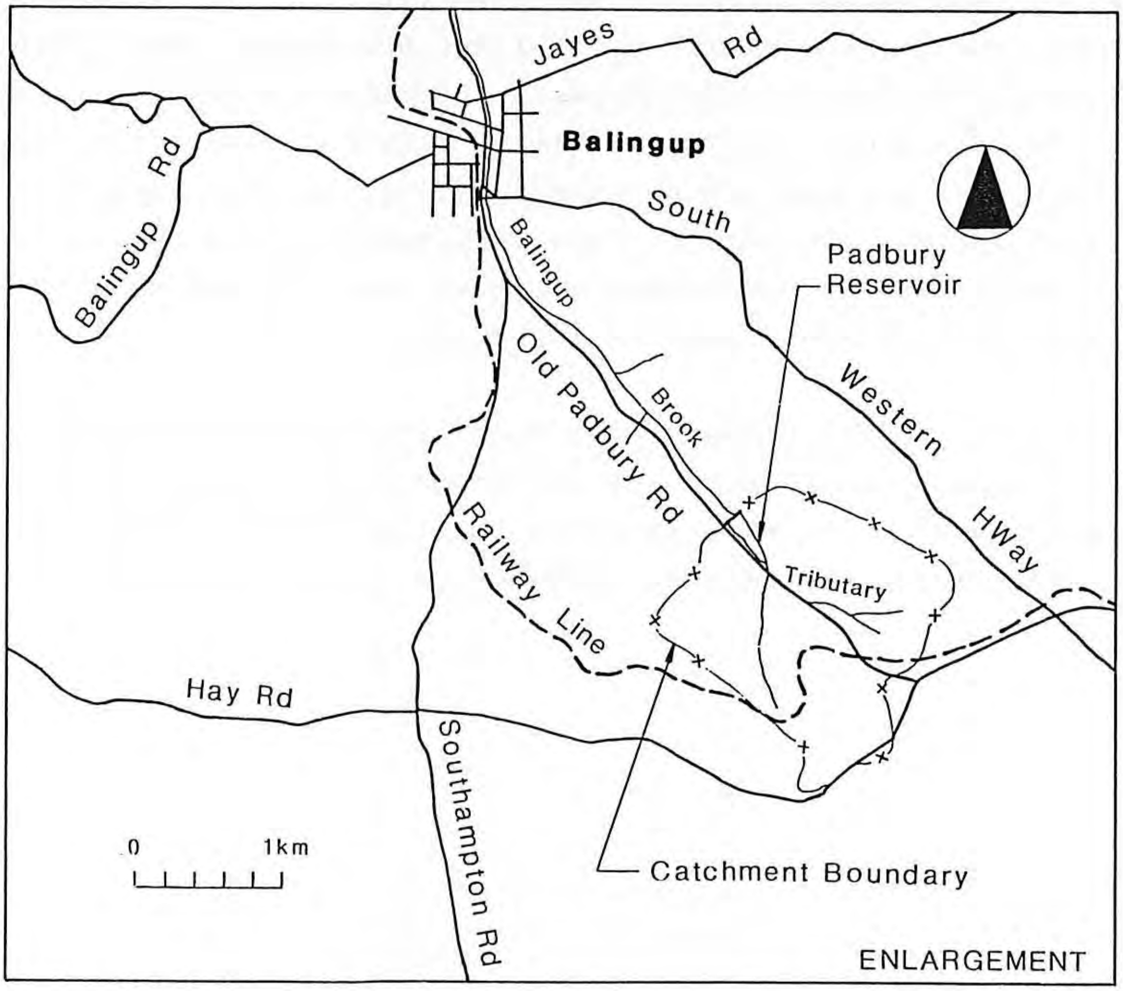
2.1 The Study Area

The Padbury Reservoir and its catchment are situated near the town of Balingup (Figure 1). Figure 2 presents the (sub)catchment boundaries for the reservoir and the Padbury Road Gauging Station (Station No.: 609 011), the latter being located on the eastern Balingup Brook Tributary. An eastern subcatchment reaching out past the South Western Highway is also shown in Figure 2. This area, named the 'Culvert Subcatchment', has in the past been assumed to be part of the Padbury Reservoir Catchment. A recent field inspection indicated that this subcatchment does not contribute to the streamflow into Padbury Reservoir due to a railway line culvert diverting the flow into a separate catchment.

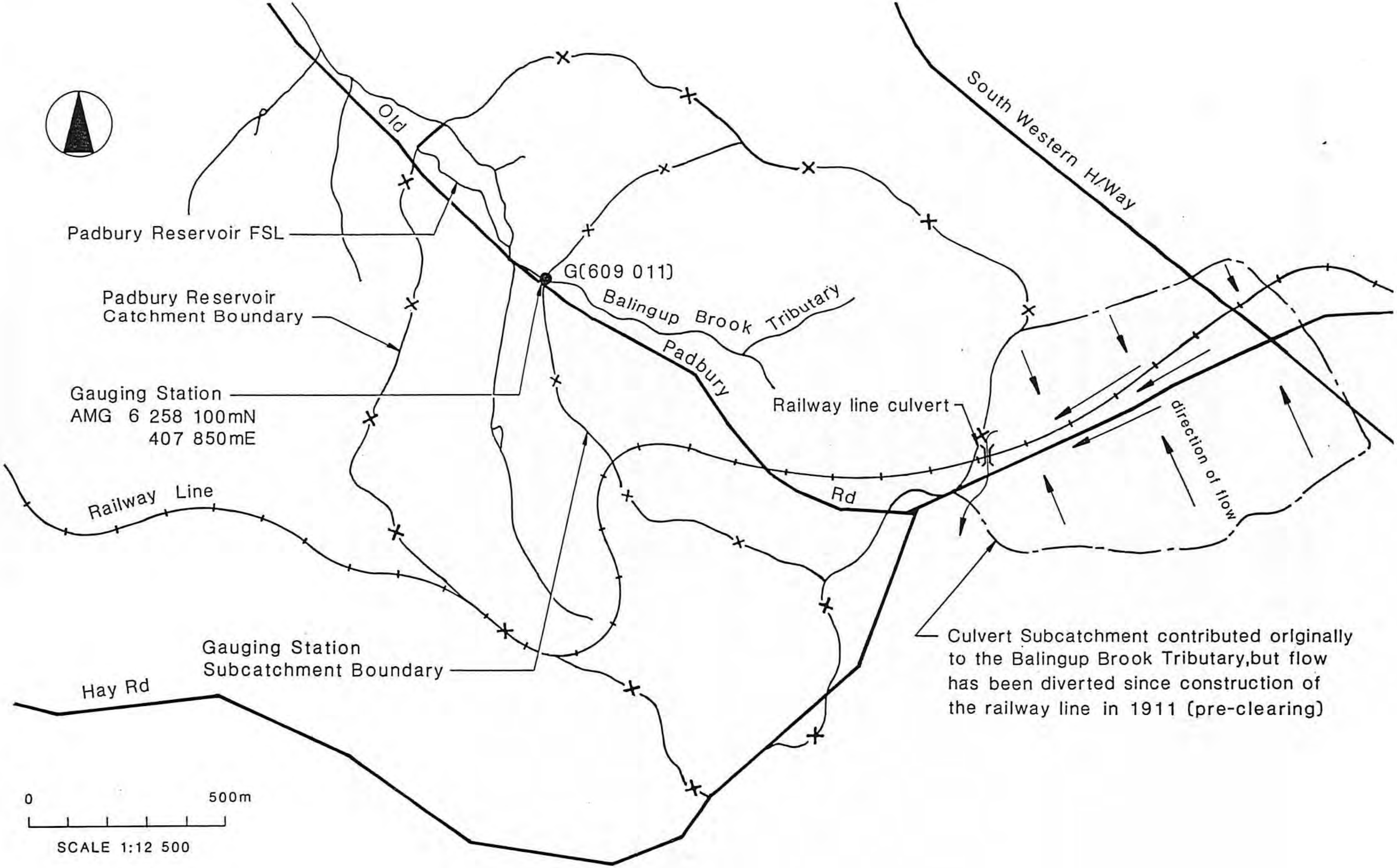
The physical characteristics of the Balingup area is best summarised by its rainfall and geomorphology. Balingup has a long term average annual rainfall of 900 mm and thus falls directly on the division between intermediate and low rainfall zones of the Darling Range. These regions respectively define where marginal and severe stream salinities will result from agricultural development. The landscape of this region is characterised by undulating plateaus with incised valleys and soils ranging from loams to laterites.

The areas of the Padbury Reservoir and Padbury Road Gauging Station (sub)catchments are 1.964 and 0.933 square kilometres respectively. It must be noted that the Padbury Reservoir catchment is considered a small water supply catchment.





Locality Plan of Padbury Reservoir **Fig. 1**



Padbury Reservoir and Balingup Brook Tributary (Sub)catchments **Fig.2**

2.2 The Land Use History of the Padbury Road Gauging Station (609 011) Subcatchment

Table 2.1 lists the history of land use changes in the Padbury Road Gauging Station Subcatchment. The areas of planting or clearing and its percentage of the subcatchment are listed together with the proportion of the subcatchment under forest at a given time. Forested in this context is defined as either uncleared native forest or the plantations established by CALM.

Land use changes in the gauged subcatchment have occurred in two distinct periods, namely from 1911 to 1976 and 1977 to 1983 when clearing and reforestation respectively dominated the changes in land use. The discussion on land use history in the following two sub-sections will concentrate on these periods. A brief history of the Padbury Reservoir and the Balingup Town Water Scheme is included.

2.2.1 The Clearing Years - Pre 1976

Prior to the construction of the railway line in 1911, the catchment was covered entirely by jarrah forest which in south-western Australia is characteristic for areas with 900 mm annual rainfall. Agricultural development commenced in the 1930's in the valley areas around the current reservoir site and the eastern tributary of the Balingup Brook (Figure 3). As a result of this clearing only 47% of the gauged subcatchment was left under native forest.

In the early 1950's further significant clearing took place in the northern segment of the western Balingup Brook Tributary.

<u>Table 2.1</u> : Land Use Changes in the Padbury Road Gauging Station (609 011) Subcatchment

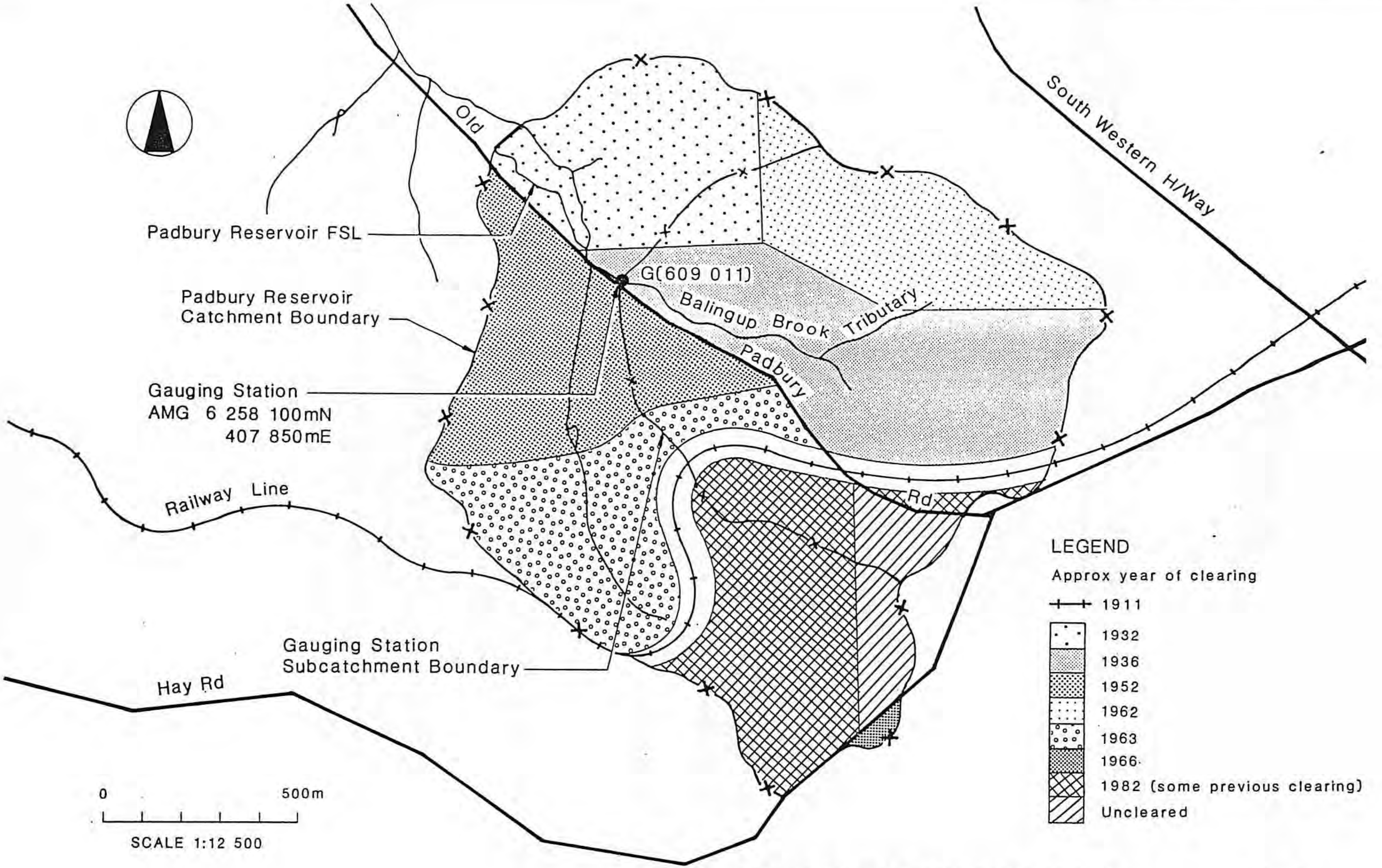
YEAR	SPECIES	CLEARED Area ha (% of Subcatch)	PLANTED Area ha (% of Subcatch.)	FORESTED (2) % of Subcatch.
1911(3)	-	6.9 (7.4)	-	92.6
1932	-	3.6 (3.9)	-	88.7
1936	-	38.8 (41.6)	-	47.1
1952	-	6.1 (6.5)	-	40.6
1962	-	22.7 (24.3)	-	16.3
1963	-	3.7 (4.0)	-	12.3
1977	P. radiata	-	43.0 (46.1)	58.4
1977	E. globulus	-	11.1 (11.9)	70.3
1978	E. globulus	-	2.8 (3.0)	73.3
1978	E. resinifera	-	0.1 (0.1)	73.4
1980	P. radiata	-	7.2 (7.7)	81.1
1982	-	6.1 (6.5)	-	74.6
1983	P. radiata	-	2.3 (2.5)	77.1

notes : (1) Area of Gauging Station (609 011) Subcatchment = 93.3 ha (= 0.933 km^2)

(2) Either native forest or recent plantations

(3) Railway line was constructed

(4) The stem density history of the above plantings is presented in table A.1 in Appendix A.



Approximate Clearing History Fig.3

This increased the portion of cleared land in the gauged subcatchment to 60% with the upper slopes under forest and the lower slopes and valleys under pasture.

As the town of Balingup grew in the 1950's it was recognised that a Town Water Supply would have to be developed. In January 1957, as part of the investigation for the town water supply, a gauging station was built on the Balingup Creek (Station No.: 609 057) at a point just upstream of the present reservoir. Data were recorded until December 1962 when the station was closed due to the construction of the reservoir. The mean annual runoff over this period was approximately 100 mm and the average flow-weighted mean annual stream salinity was 500 mg/L TSS. The lowest flow year was in 1959 with an annual runoff of approximately 25 mm and average flow-weighted salinity of 765 mg/L TSS. For the period of record the water quality was described as marginal, but acceptable. A decision to proceed with the project was made in 1962 and the Padbury Reservoir, with a full supply of 61.33 x $10^3 m^3$, was completed in 1963.

Around the time of the dam construction further clearing took place. This accounted for approximately 28% of the subcatchment and mostly encompassed the north eastern upper slopes. The land use then remained unchanged until 1977 with only 12% of the subcatchment under native forest.

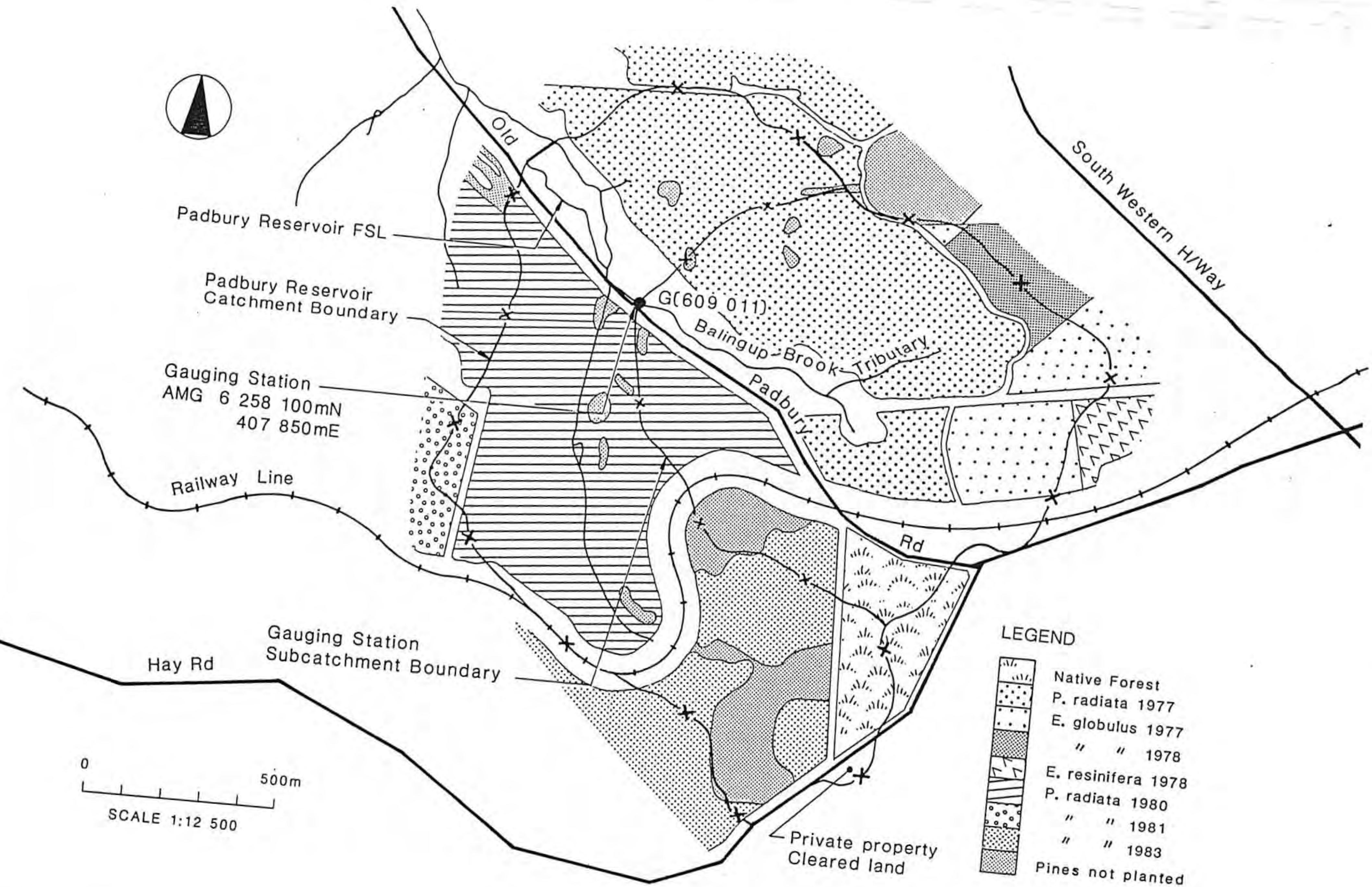
The quality of water supplied to the town of Balingup deteriorated in the 1970's to the point where in 1976 there was a large number of consumer complaints. The two phases of clearing in the mid 1930's and the early 1960's were the cause for the high salinities experienced in the town water supply. As previously discussed, the first phase involved predominantly valley and lower side slope clearing to about 50% of the subcatchment. When gauging for the proposed Padbury Reservoir commenced 25 years later, the effects of this initial clearing were already evident with average flow-weighted mean annual stream salinities of 500 mg/L TSS observed. At this time, the salinities within the subsequently gauged subcatchment may well have been higher than 500 mg/L TSS since it had a larger proportion of land cleared in the 1930's (compare Table 2.1 and Table 2.2). Typical stream salinities in an uncleared catchment of similar rainfall are 200 to 300 mg/L TSS (Borg et al, 1987).

The second phase of clearing in the 1950's and 1960's encompassed a further 30% of the gauged subcatchment in the upper slope areas. Over the period from 1978 to 1982, the average flow-weighted mean annual salinities had risen to 1370 mg/L. Although the generally below average rainfall between 1978 and 1982 would have contributed to the high salinities, it is apparent that the large salinity increase between 1960 and 1980 (approximately 870 mg/L TSS) is much greater than would have occurred if salinity had increased linearly with area cleared.

This non-linear response to valley and upslope clearing of a catchment in a 750 mm annual rainfall area was examined by Hookey (1987) using a two-dimensional ground water model. It was concluded that, following valley clearing, there can be a delay of over 30 years in saline ground water discharge to streamflow. However, if in the decades following valley development there is substantial side slope clearing, the time delay for groundwaters contributing to streamflow is greatly reduced. Furthermore, the subsequent rate of discharge of the saline groundwaters is much more rapid than would be estimated if a linear increase in discharge with area cleared was assumed.

2.2.2 The Planting Years - Post 1976

In 1976 CALM purchased the farm that covered most of the Padbury Reservoir Catchment with the intention of planting all suitable soils to pine. Figure 4 and Table 2.1 presents the



Planting History Fig 4

planting history for the Padbury Road Gauging Station Subcatchment since 1977.

Before planting began in 1977, only 12% of the subcatchment was under forest. In that year 46% and 12% respectively of the subcatchment were planted with Pinus radiata in the suitable soils of the eastern side slopes and Eucalyptus globulus on the rocky ridges above this. A further 11% of the subcatchment was planted with pines and eucalypts between 1978 and 1980. In 1982 CALM cleared the high ground south of the railway line and in the following year replanted those areas with suitable soils to pines.

The stem density history of the pine and eucalypt plantations is detailed in Table A.1 in Appendix A. In summary, the eucalypts were planted at a density of 625 stems per hectare (stems/ha) and have not been thinned. The pines were planted at a higher density of 1100-1330 stems/ha and were culled (non-commercial thinning) to 500-750 stems/ha after 6 years. These densities and timing of culling are typical for commercial pine plantations.

The land use has not changed since 1983. At present 77% of the subcatchment is forested with 56% under pines, 15% under globulus and 6% under native forest. The majority of the reforestation (82%) took place in 1977. Of the remaining 23% of land that is classified as not forested, 10-15% is in the valley of the eastern Balingup Brook Tributary. This has a vegetation cover of mostly pasture with some shrubs and river gums (Eucalyptus rudis). Hence, the Padbury Road Gauging Station subcatchment can presently be described as having a land use of side slope pine plantations and a cleared valley.

The western tributary of the Padbury Reservoir Catchment was not planted with pines until 1980 due to opposition from local residents objecting to large scale pine plantations near the town. Because the eastern Balingup Brook Tributary was substantially planted in 1977, it was decided in 1978 to study the effects of the treatment on the eastern tributary rather than the whole catchment. The gauging station was installed and began operation in February 1978.

As a result of the consumer complaints about the high salinity of the water in 1976, a reservoir management policy of scouring the deeper saline water from the reservoir base after the early winter rainfalls was introduced. Due to the short time periods over which mixing occurred in the dam, this approach was integrated with a more effective diversion policy in 1977. This proved successful in 1977 and 1978, but insufficient inflow occurred in 1979 to allow saline diversion operations to be carried out. Consequently, during the 1979/80 summer the salinities increased once again beyond acceptable levels. Loh (1982) concluded that adequate quantities of good quality water were not likely to occur except in years of above average streamflow. Additionally, good quality water only flowed for a very short period of time (1 to 3% of the time) making the saline diversion policy extremely difficult to operate. It was thus concluded that an alternative supply of good quality water would have to be found.

Out of all the proposals suggested, the augmentation of the Padbury Reservoir from the Dumpling Gully Dam at Greenbushes was chosen. This scheme involved the construction of a pipeline between the two locations and was implemented in the summer of 1982/83 at an approximate cost of $250,000. Augmentation has since proven successful with water of acceptable salinities being supplied to the town of Balingup when pumping of water from Greenbushes has taken place.

2.3 Comparison of the Padbury Reservoir Catchment with its Gauged Subcatchment

As for the gauging station subcatchment (Table 2.1), the land use history of the Padbury Reservoir Catchment is given in Table 2.2. Figures 3 and 4 show the location and distribution of clearing and reforestation.

Table 2.2 : Land Use changes in the Padbury Reservoir Catchment

YEAR	SPECIES	CLEARED	PLANTED	FORESTED (2)
		Area ha (% of Catch)	Area ha (% of Catch.)	% of Catch.
1911(3)	-	11.5 (5.9)	-	94.1
1932	-	26.4 (13.4)	-	80.7
1936	-	39.7 (20.2)	-	60.5
1952	-	29.3 (14.9)	-	45.6
1962	-	24.5 (12.5)	-	33.1
1963	-	25.5 (13.0)	-	20.1
1966	-	0.7 (0.4)	-	19.7
1977	P. radiata	-	60.1 (30.6)	50.3
1977	E. globulus	-	11.1 (5.7)	56.0
1978	E. globulus	-	2.8 (1.4)	57.4
1978	E. resinifera	-	0.1 (0.1)	57.5
1980	P. radiata	-	44.5 (22.6)	80.1
1981	P. radiata	-	1.6 (0.8)	80.9
1982	-	28.8 (14.7)	-	66.2
1983	P. radiata	-	14.8 (7.5)	73.7

notes : (1) Area of Padbury Reservoir Catchment
= 196.4 ha (= 1.964 km^2)

(2) Either native forest or recent plantations

(3) Railway line was constructed

To access the effects of pine plantations on water quality and quantity in the Padbury Reservoir Catchment from the data for the Padbury Road Gauging Station Subcatchment, it is necessary to examine their land use histories. Comparing Tables 2.1 and 2.2 shows that even though differences in timing exist, the total levels of clearing and reforestation are very similar between the total catchment and the gauged subcatchment. Therefore, in the long term, the response of the (sub)catchments to reforestation will be similar so that observations from the gauging station can be applied to the reservoir.

The only possible deviation in response may occur during the 1980's. This would be a result of the period between 1977 and 1980 when the gauged subcatchment had 24% more land replanted (17% more forested land) than the reservoir catchment. The consequence of this would be that about a 3 year time lag would exist in the response of the total catchment relative to the subcatchment. This would continue until a time when the water use of the younger pines in the western tributary is of the same magnitude as those in the eastern tributary, estimated to be at the beginning of the 1990's. It must be noted that the magnitude of this time lag is unknown and it is thus possible that its effect is insignificant.

CHAPTER 3 : THE EFFECT ON WATER QUALITY AND QUANTITY

3.1 General

All annual hydrological data presented in this report is listed in Table A.2 of Appendix A. Note that the average annual rainfall for the Balingup town (CBM 009 505) was 770 mm during this study (1978-86), this being well below the long term average of 900 mm.

A description of the computing involved in manipulating and analysing the raw data is given in Appendix B. The only comment to be made here is that for the last 7 years of record (1980-86), the flow-weighted mean annual stream salinity (S) was calculated by dividing the streams annual salt load (L), determined from continuous conductivity recording, by its annual streamflow volume (Q), as given in equation (3.1).

$$S = \frac{L}{Q} \qquad \text{-- (3.1)}$$

In the two initial years of record, 1978 and 1979, the quality of the continuous conductivity trace was insufficient to accurately calculate salt loads. The weekly sampling that was in operation at this time was used to calculate the annual flow-weighted mean salinity, S, as follows

$$S = \frac{\Sigma\, S_i\, Q_i}{\Sigma\, Q_i} \qquad \text{-- (3.2)}$$

where Q_i is the flow rate of the stream at the time when the sample with the TSS concentration S_i was collected. This method of calculating stream salinity for greater than 50 samples per annum is estimated to be very comparable ($\pm$ 5%) with the more accurate technique of calculating the total salt load (Barrett and Loh, 1982).

For conciseness of wording, the following shall apply in the ensuing chapters:

(i) The Padbury Road Gauging Station (609 011) subcatchment is referred to as the treated Balingup catchment.

(ii) All quantities discussed are annual values.

(iii) The streamflow data is given in terms of streamflow volume per unit catchment area and is expressed in units of millimetres.

(iv) The flow-weighted mean annual stream salinity has units of milligrams Total Soluble Salts per litre of water (mg/L TSS) and is referred to as stream salinity.

3.2 Streamflow Yield

To detect if there has been any change in streamflow due to reforestation, a comparison was made between the water yields of the treated Balingup catchment and a control catchment, Thomson Brook (Gauging Station No. 611 111). This is presented in Figure 5 for the nine years of record from 1978 to 1986.

The Thomson Brook catchment is located approximately 20 kilometres north of the Padbury Reservoir Catchment in the Darling Range. It was chosen as a control for this study because it has the same lateritic soils and a similar average annual rainfall (950 mm per annum) as the Balingup Area. There has been no significant changes in land use in this catchment since the 1960's and it is presently 55% forested. The largest limitation of using this control catchment is that it has a drainage area of 102 square kilometres, 100 times larger than the Balingup catchment. Since only annual streamflow values are examined in this study, the areas of the catchments is of secondary importance to the rainfall and landform characteristics which are similar for the two sites.

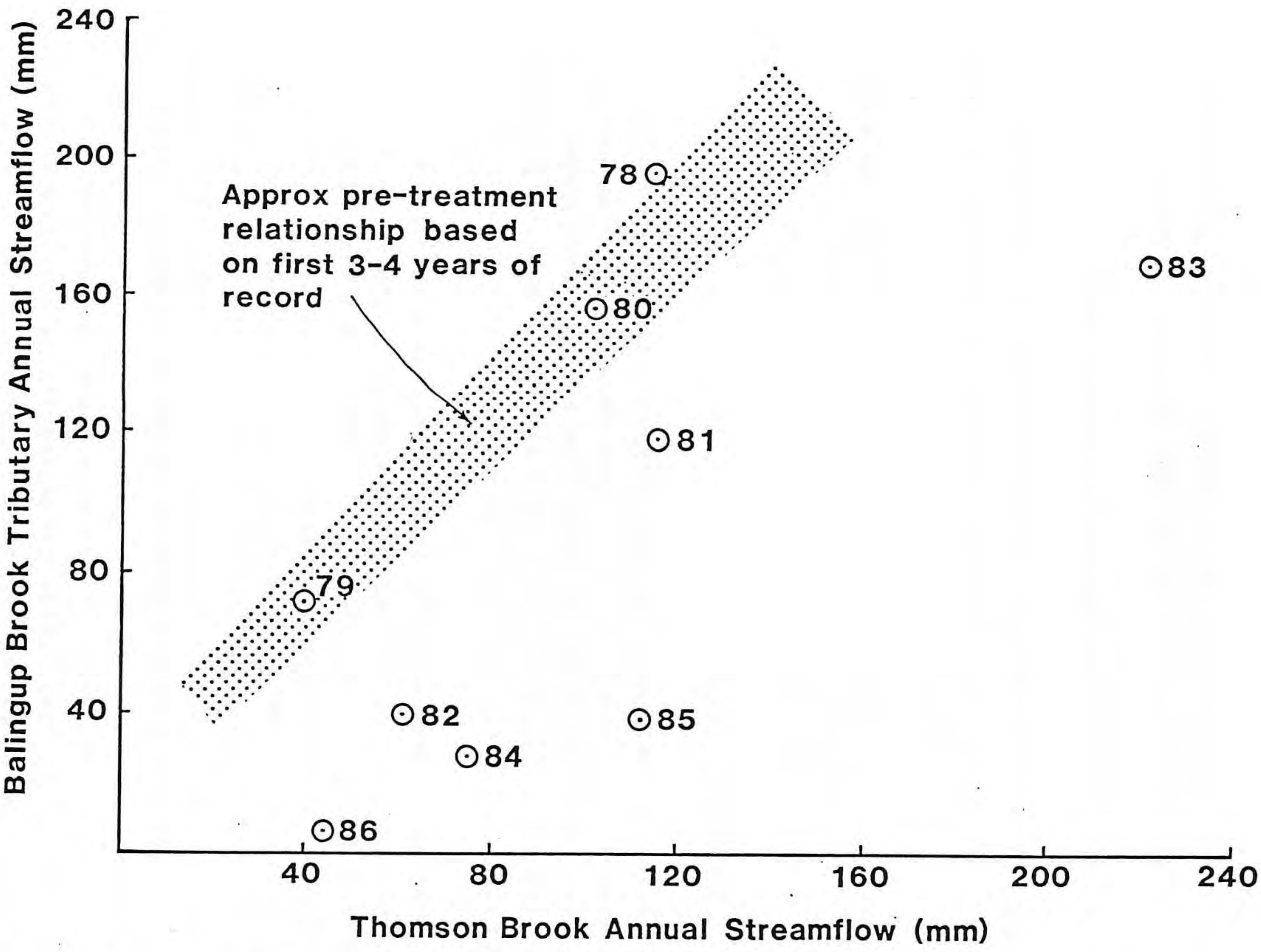


Fig.5 BALINGUP BROOK TRIBUTARY VERSUS THOMSON BROOK ANNUAL STREAMFLOWS

Figure 5 illustrates that the streamflow yield of the catchment has decreased as a result of reforestation. An approximate pretreatment relationship between the two catchments is shown in stipple. It was derived by considering linear regressions of the data for the first 3 and 4 years (1978-80 and 1978-81). This demonstrates that in the later years, 1982 to 1986, there was a reduction in streamflow for the Balingup catchment. Since no pre-reforestation flow volume relationship is defined for the two streams, it is not possible to accurately quantify these reductions. As a rough estimate it would seem in the later low rainfall years of this study, the streamflow yields have decreased somewhere in the range of 50 to 100 mm. This reduction in streamflow can be largely attributed to the water use of the side slope pine plantations which in 1986 covered 56% of the treated catchment (79% of the reforested area) with an average stand age of 8.3 years and average stem density of 570 stems/ha.

The same conclusions can be drawn by examining Appendix C where the streamflow volume of the Balingup Brook Tributary is plotted against respectively the streamflow yield of the Ludlow River and the annual rainfall at Balingup. The Ludlow River (Claymore) (GS No. 610 007) is another suitable control catchment situated 20 kilometres west of Balingup. It has a mean annual rainfall of 950 mm, lateritic soils, a catchment area of 10.1 square kilometres and has not had any significant clearing within the catchment. A linear regression of the first 3 years of record (1978 to 1980) is presented on the streamflow plots for these two controls and as for Thomson Brook indicate a similar reduction in streamflow for the Balingup Brook Tributary in the later years of the study.

3.3 Stream Salinity Flow Relationship

To evaluate the effect of reforestation on stream salinity, the Balingup Brook Tributary stream salinity was plotted against its streamflow volume (Figure 6). If one compares the salinity flow relationship based on the best fit of an equation of the form (Loh and Stokes, 1981):

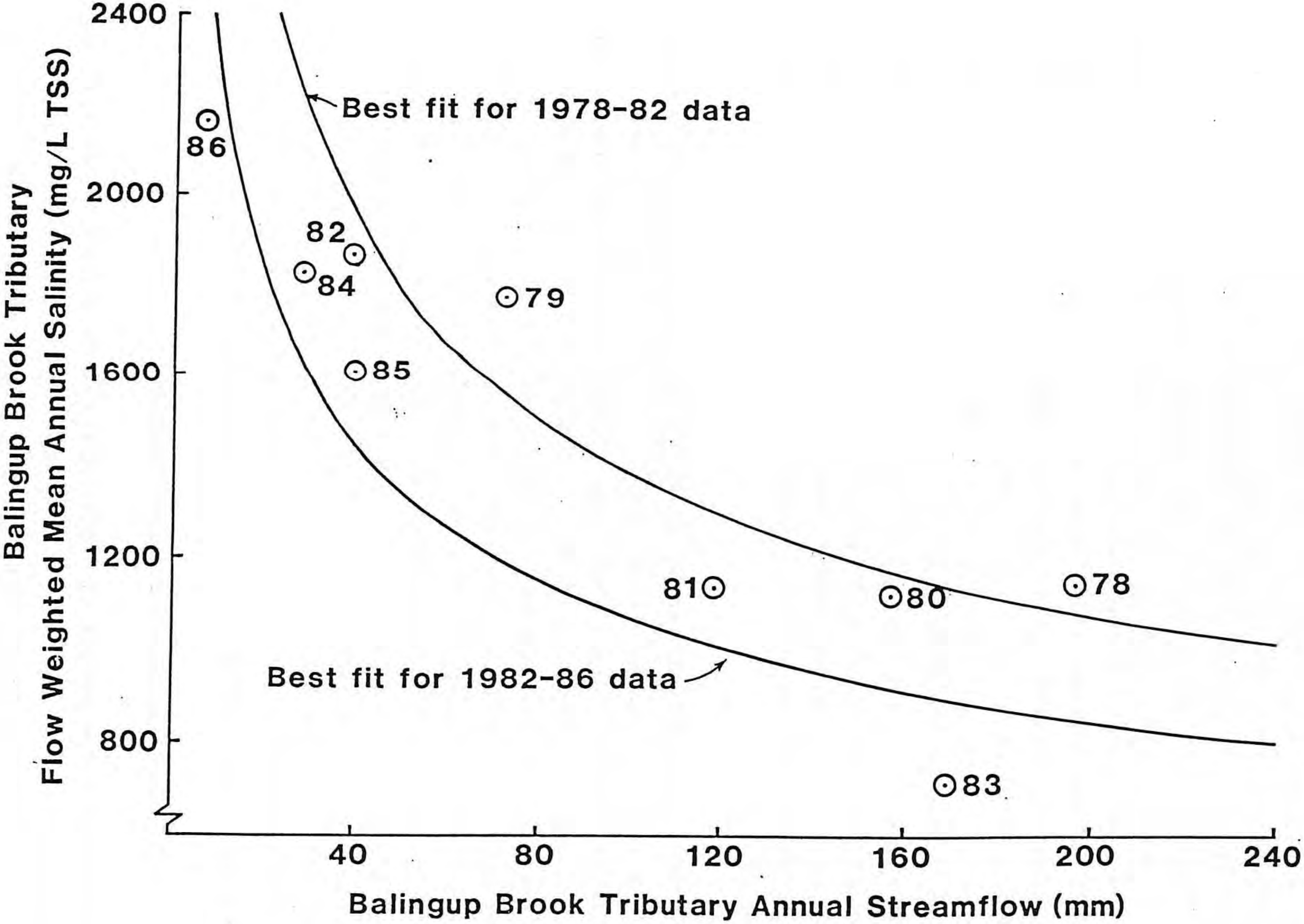


Fig.6 BALINGUP BROOK TRIBUTARY SALINITY FLOW RELATIONSHIPS

$$S = a\ Q^{-b} \qquad \text{-- (3.3)}$$

where S = stream salinity (mg/L)
Q = streamflow volume (mm), and
a,b = coefficients dependent on the characteristics of the catchment.

for the first 5 years (1978-82) and last 5 years (1982-86) of data, it appears that the Balingup salinity flow relationship has changed such that there has been a reduction in salinity for a given flow volume. Note that the curves are affected by the fact that four of the last five years had low streamflow yields compared to the earlier years of the study. Hence, the relationship for the 1978-82 data is strongly influenced by data points in the higher flow range and the 1982-86, except for 1983, by data in the lower flow range. This is a result of the lower rainfall in recent years and the reduction in streamflow as a consequence of reforestation.

As an alternative and more conclusive approach to curve fitting, examining the relative positions of the data points in Figure 6 for given years clearly demonstrates that stream salinity has decreased for a given annual streamflow volume. The positioning of the 1983 data point relative to 1978 and 1980 and the 1985 coordinate relative to 1979 and 1982 are examples which reflect this trend.

3.4 Stream Salinity

Figure 6 showed that the stream salinity streamflow relationship has changed due to reforestation. Compared to the first few years after planting, stream salinity at a given flow volume would now be lower. However, recall from Figure 5 that tree planting also reduced streamflow. Thus, to determine if reforestation of the side slopes has decreased the salinity in the stream to below what it would have been had no land use change taken place, a process set out schematically in Figure 7 was used. This approach requires data prior to reforestation for the streamflow of the treated catchment and a suitable control catchment so that adequate prediction of the pre-reforestation flow volumes and salinities can be made. Figure 7 illustrates these pretreatment relationships together with, for the purpose of illustration, two years of hypothetical data following reforestation. The procedure to follow is demonstrated where the subscripts O and E represent respectively the observed values as a consequence of reforestation and the best estimates that these values would have been had no land use change occurred. In the example, year 1 indicates an effective increase in salinity while year 2 indicates an effective decrease in salinity relative to what would have occurred had there been no reforestation.

As discussed in chapter 2, the Padbury Road gauging station was established on the Balingup Brook Tributary in 1978 after 58% of the treated catchment had been planted to pines and eucalypts in the previous year. Hence, no pre-reforestation data is available. For the purpose of this analysis the first 3 years of record (1978 to 1980) were used to represent the pre-reforestation conditions and was thus used to define the pretreatment relationships discussed in Figure 7. This is acceptable since the water use of the plantings in the earlier years of this study would have been small. It is fortunate that these 3 years encompassed low and high rainfall years and therefore produce relationships valid over a range of streamflows.

The greatest limitation of the analysis was the adequacy of the control for predicting untreated streamflow volumes at Balingup. The three controls considered : Thomson Brook (GS No : 611 111), Ludlow River (Claymore) (GS No : 610 007) and Balingup Town Rainfall (CBM 009 505) produced a wide range of flows and salinity changes. As a consequence of this scatter, the results for all three controls have been included in this

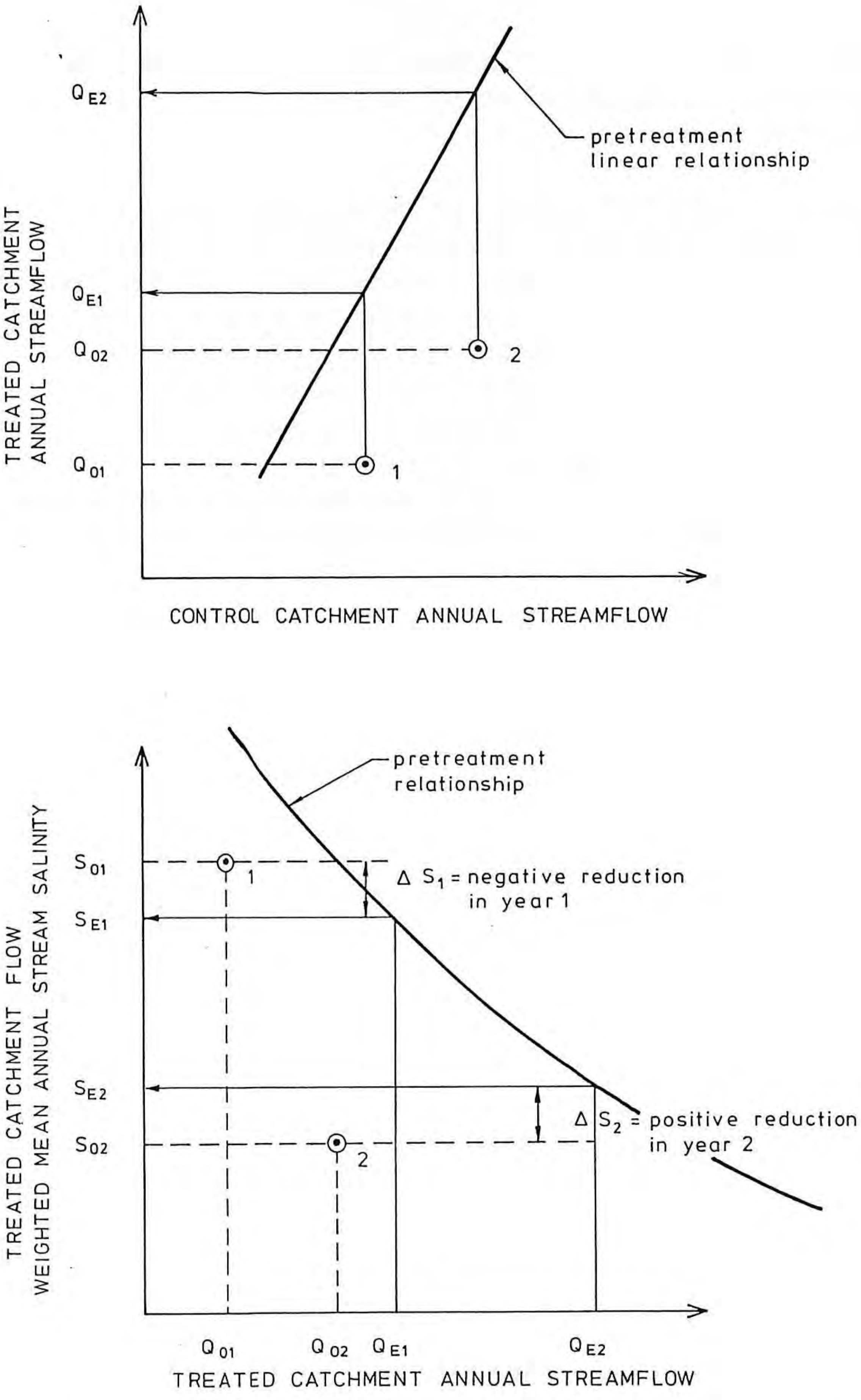


FIG. 7 PROCESS TO DETERMINE IF REFORESTATION HAS REDUCED STREAM SALINITY

report. The data and pretreatment relationships used in predicting the changes in stream salinity (Table 3.1) are presented in Appendix C.

Table 3.1 demonstrates that for the six years from 1981 to 1986, there has been an average increase in stream salinity in the range of 140 to 300 mg/L. The wettest two years, 1981 and 1983, show the only reductions in stream salinity. The other four years had well below average annual rainfalls and gave increases in stream salinity. This trend for salinities to reduce in wet years and increase in dry years allows an argument to be made that if the average rainfall at Balingup during the period of this study had been its long term average, no substantial change in stream salinity would have been observed.

Table 3.1 : Predicted Changes in Stream Salinity as a Result of Reforestation at Balingup

Year	Observed Stream Salinity (mg/L TSS)	Change in Stream Salinity (mg/L TSS) Based on the Following Controls (1)		
		Thomson Brook	Ludlow River	Balingup Rainfall
1981	1140	40	-145	- 99
1982	1867	411	133	414
1983	710	-104	- 65	-361
1984	1826	490	637	428
1985	1601	486	186	78
1986	2159	486	390	373
AVERAGE		301	189	139

Notes :

(1) The difference between the observed stream salinity at Balingup following reforestation and the best estimate of what this value would have been had no land use change occurred.

(2) Due to no pre-reforestation data being available for Balingup, the first three years of record (1978-80) were used to define the appropriate pretreatment relationships.

(3) Refer to Appendix C for the pretreatment relationships and a graphical presentation of the data used in the analysis.

CHAPTER 4 : INTERPRETATION OF RESULTS

4.1 Introduction

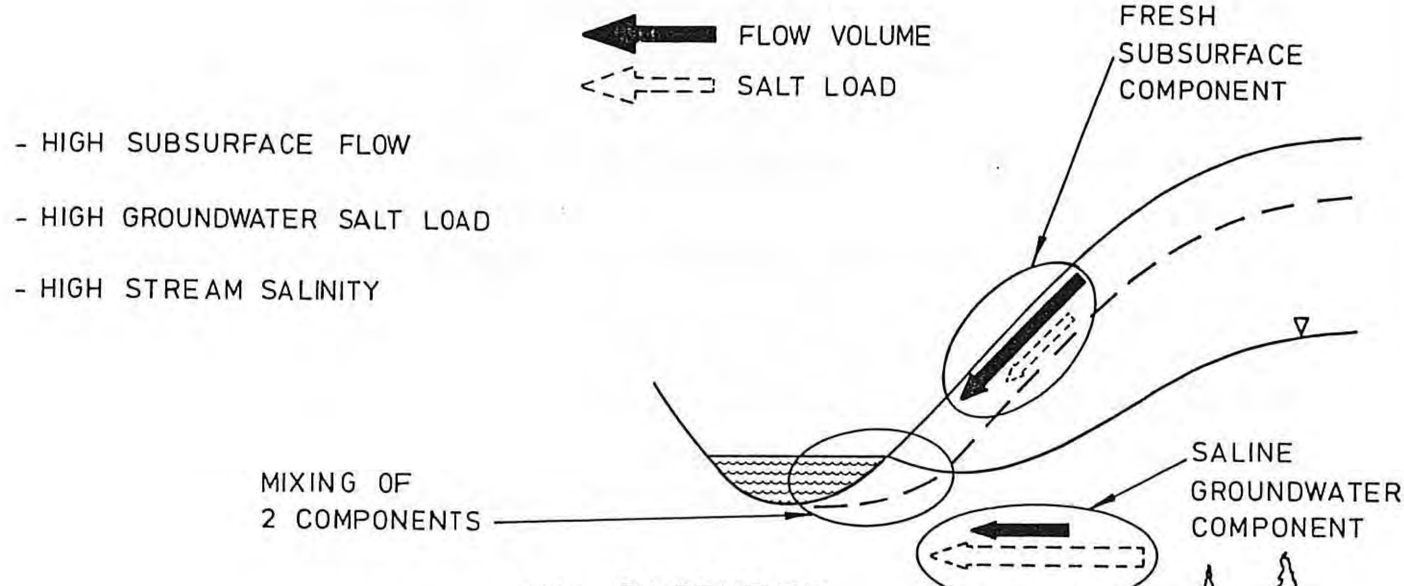
The previous chapter has shown that complete non-valley reforestation substantially reduces water yield from a catchment without any improvement in water quality. This indicates that tree planting of this nature is not a suitable management strategy for a small water resource catchment like Balingup. Prior to reforestation of the Balingup catchment it was believed that side slope reforestation would reduce recharge to the deep saline groundwaters resulting in less salt discharging into the valley areas. As a consequence, a reduction in stream salinity was assumed to follow. For the first 10 years at Balingup this has not been the case. This chapter will examine why stream salinity has not decreased and if there is any chance for improvement in the future. The different components of water and salt contributing to streamflow will be the centre of discussion. Implications for future management of the Padbury Reservoir catchment follow from this.

4.2 Water and Salt Fluxes Contributing to Streamflow

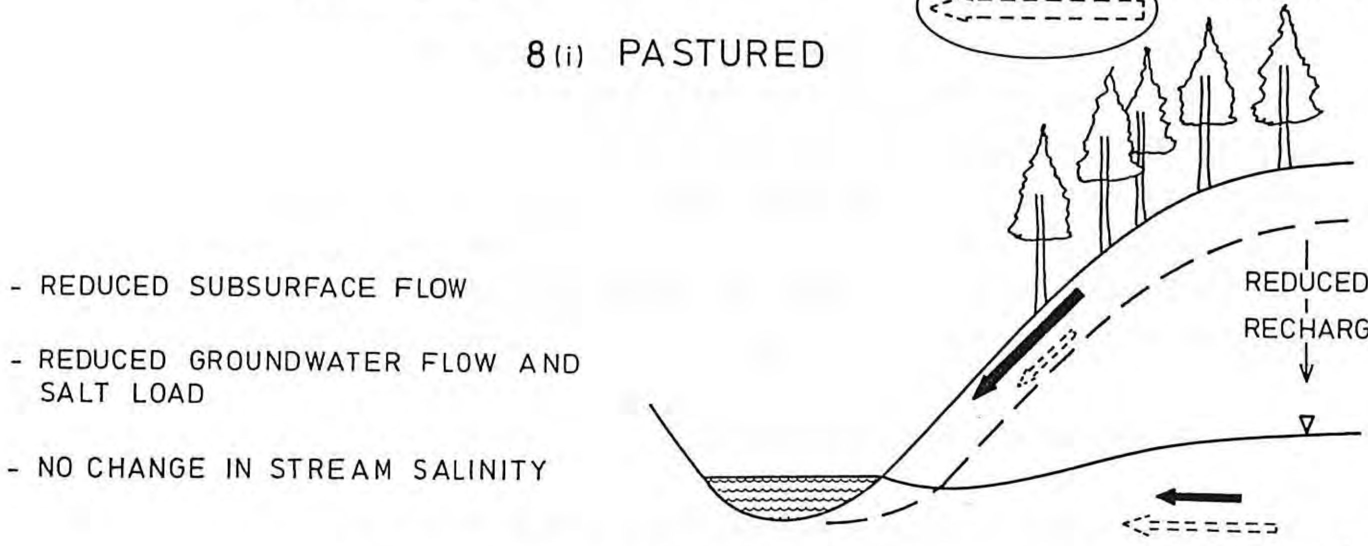
4.2.1 Pasture

Figure 8(i) demonstrates the mechanisms involved in streamflow generation of a catchment that has been cleared and pastured for many years. It illustrates that for lateritic soils there is conceptually two components that generate streamflow, a shallow subsurface component (which for simplicity includes surface runoff) and a groundwater component (Schofield, 1987). These mix and contribute to streamflow along and adjacent to the stream.

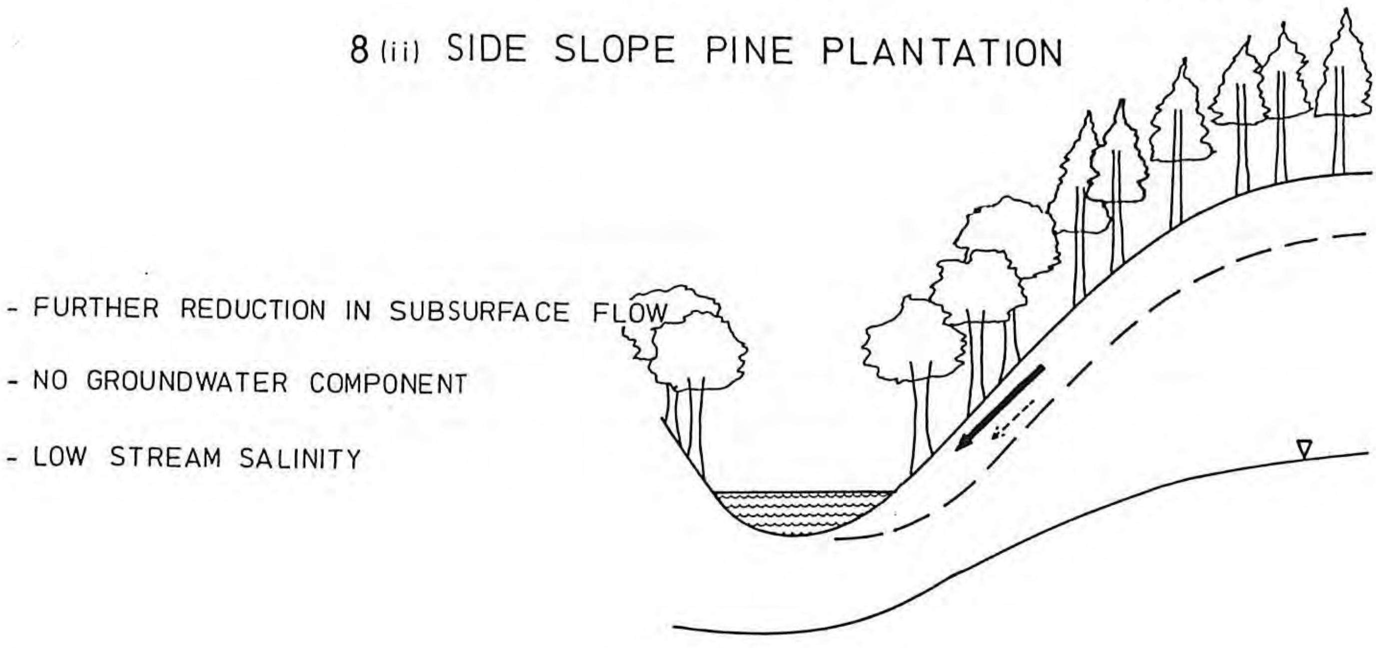
FIG. 8 LONG TERM EFFECTS OF THREE DIFFERENT LAND USES



8 (i) PASTURED



8 (ii) SIDE SLOPE PINE PLANTATION



8 (iii) SIDE SLOPE PINE PLANTATION WITH SALT TOLERANT EUCALYPTS IN VALLEY

Stokes and Loh (1982) investigated the relative proportions of these components for a cleared catchment, Wights, located in a 1150 mm rainfall zone in the Wellington catchment. It was found that for the 1980/81 water year, the flow volumes for the shallow subsurface and groundwater were respectively 76% and 24% of the streamflow. The salt load of the shallow subsurface and groundwater components showed the opposite characteristic with proportions of 16% and 84% respectively. A similar result was observed at Batalling Creek (PWD 1981) located in a lower 650 mm rainfall zone. In 1978 the percentages of the subsurface and groundwater components of streamflow volume and salt load were 86% and 14%, and 7% and 93% respectively.

From these studies it can be concluded that for a catchment that has been pastured for a long time, the shallow subsurface component represents a large proportion of streamflow (approx. 80%) and is fresh (< 500 mg/L TSS), while the groundwater contributes 90% of the stream salt load and is very saline (> 3000 mg/L TSS). It must be noted that these proportions vary with average annual rainfall and for wet and dry years.

4.2.2 Side Slope Reforestation

From this understanding of the mechanisms involved in streamflow generation of the Balingup catchment prior to reforestation, it can be concluded that the large reductions observed in streamflow yield following tree planing are attributable to similar reductions in the shallow subsurface flow volume since the latter contributes to most of the former. This is illustrated in figure 8(ii) together with the added effect of reducing the quantity of side slope recharge to the deep groundwaters. With time this lowers the level (gradient) of the groundwaters and hence decreases the groundwater component contributing to streamflow.

A reduction in recharge and a lowering of groundwaters can be concluded since reductions of 2.0 to 3.0 metres have been observed by Anson et al. (1987) for reforested areas with similar stand ages and replanting percentages as that of the pines and eucalypts at Balingup. This can be further substantiated by considering a plot of annual salt load versus annual streamflow for the nine years of record at Balingup. The salt load (L) of the Balingup Brook Tributary is calculated by multiplying stream salinity (S) by streamflow volume (Q)

$$L = S \cdot Q \qquad \text{-- (4.1)}$$

Substituting the general salinity flow relationship (equation (3.3)) into this gives:

$$L = a\, Q^{-b+1} \qquad \text{-- (4.2)}$$

Equation (4.2) describes a relationship between salt load and streamflow volume based on the coefficients a and b. These were estimated in section 3.3 for the salinity flow relationships of the first five and last five years of data (1978-82 and 1982-1986 respectively) as displayed in Figure 6. Figure 9 presents the equivalent salt load flow relationships which indicate that salt load (L) has substantially reduced for a given flow volume (Q) in the later years of this study. A change in the relationship of this nature can only occur if there has been a reduction in the saline groundwater component (reduction in side slope recharge). This intricacy of the salt load flow relationship can be understood by noting that the groundwater is a large salt, small flow component. If the groundwater component halved, there will be a substantial reduction in stream salt load with a corresponding much smaller decrease in streamflow yield. This response will shift the data point away from the salt load flow relationship such that for a given streamflow volume there will be a significant decrease in stream salt load.

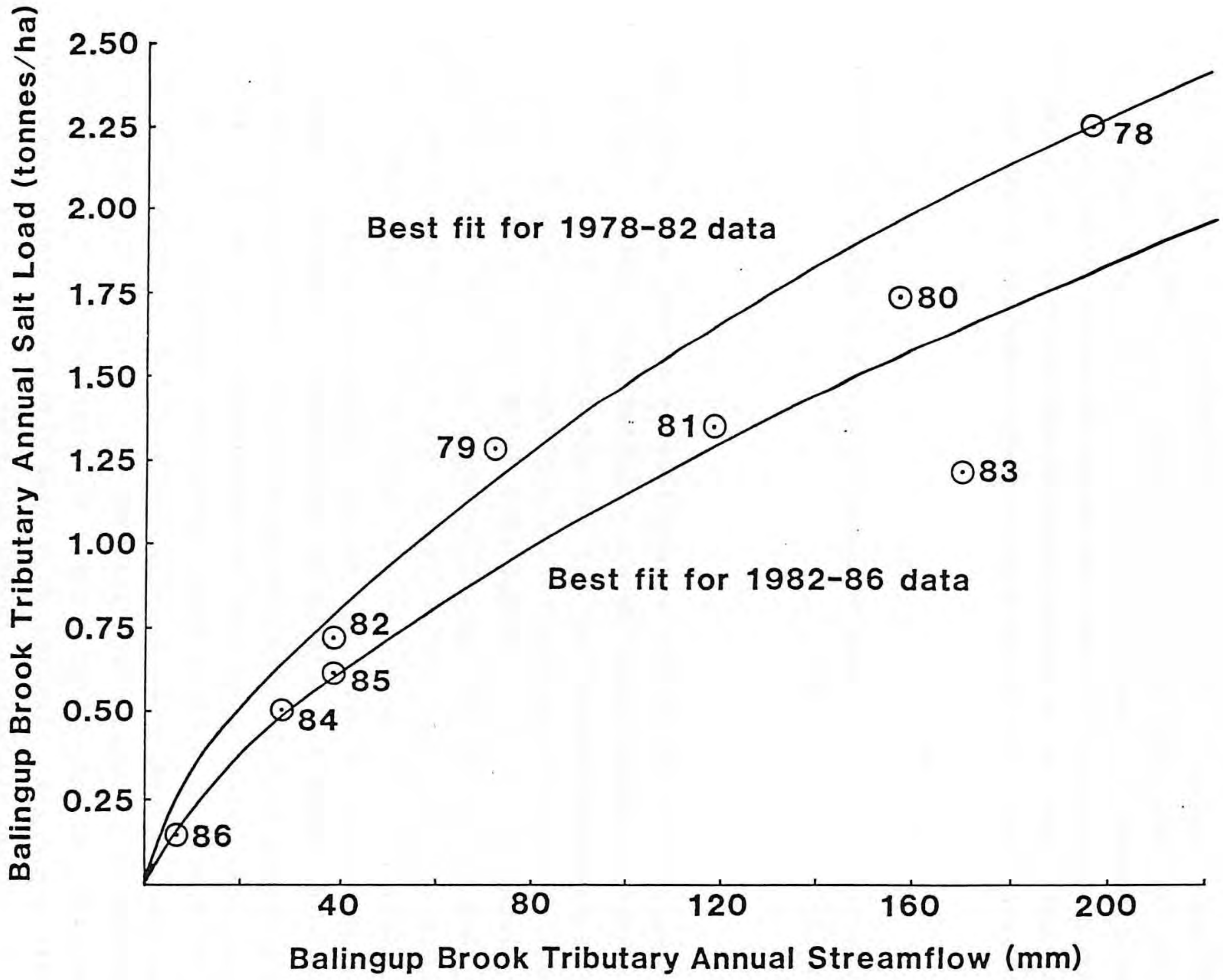


Fig.9 BALINGUP BROOK TRIBUTARY SALT LOAD FLOW RELATIONSHIPS

The first 10 years following non-valley reforestation has shown that stream salinities have not improved. This is largely a product of the trees having a bigger water use impact on the shallow subsurface waters than that of the deeper groundwaters. In a longer time frame, it can be argued that salinity may improve due to a further lowering of the saline groundwaters while the shallow subsurface system remained unchanged. This would be a consequence of the slower response of the deep groundwaters relative to the shallow subsurface system and the greater ability of more mature trees to extract deeper waters.

4.3 Implications for the Padbury Reservoir Catchment

The present land use of the Padbury Reservoir catchment has substantially reduced streamflow without any improvement in stream salinity. This is exemplified by only one of the nine years in this study having an annual flow-weighted mean stream salinity of less than 1000 mg/L TSS. This response indicates that future management of this water resource will have to be of a different nature.

Following the discussion on the water and salt fluxes contributing to streamflow in section 4.2, it can now be confidently argued that to optimally reduce stream salinity it is necessary to completely stop saline groundwaters from contributing to streamflow. Figure 8(ii) demonstrates this cannot be achieved by the present land use since side slope pines have no influence on the groundwater table near the stream. To reduce groundwater levels locally around the stream, vegetation with large water use is required in the valley as illustrated in Figure 8(iii). Salt tolerance is required for survival in the highly saline valley environment and thus eucalypts in general are far more suitable than pines.

A report by Hookey et al (1987) examined the water use of eucalypts above saline groundwater. It was concluded that to achieve groundwater reductions it is important that the species maintains a high rate of transpiration in later summer and autumn. The reasoning behind this is that some eucalypts only freely transpire in winter and spring when moisture is abundantly available in the shallow soil profile. Most eucalypts substantially lower their transpiration rates in late summer-autumn when the soil profile becomes dry. However, some species such as E. microcarpa, E. woollsiana, E. sideroxylon and E. botryoides have been found to maintain a high transpiration rate during this period. This can only occur if water is being tapped from the deeper saline groundwater system and thus these eucalypts are more likely to have a significant effect on lowering the groundwater table.

The implications for the Padbury Reservoir catchment is that all valley areas should be planted to appropriate eucalypts. The time frame in which substantial improvement in stream salinity will occur is uncertain. Anson et al. (1987) observed reductions in groundwater of greater than 2.0 metres within 8 years of reforestation. Noting that there will be an additional period of time, to leach the salts that has accumulated in the valley, before stream salinity will significantly decrease, a time frame of 10 years does not seem unreasonable.

An unavoidable further reduction in streamflow yield would result from this additional tree planting. Thinning of the side slope pines and eucalypts in the future would possibly offset this.

CHAPTER 5 : REGIONAL IMPLICATIONS

5.1 Introduction

Reforestation in the small water resource catchment at Balingup did not significantly decrease stream salinity. Flow volumes and salt loads, however, have decreased substantially. The latter can be concluded since annual salt load has decreased for a given annual streamflow (Figure 9 in sub-section 4.2.2) and streamflow yields have reduced (Figure 6 in section 3.2).

Large water resource catchments (greater than 1000 km^2) generally encompass a wide range of rainfalls, landforms and land uses. In general, the areas with >900 mm average annual rainfall generate most of the catchment streamflow, while the areas with <900 mm average annual rainfall produce most of the catchment salt load.

Using the Balingup results, this chapter evaluates the effect of tree planting on a regional scale on the salt and water balance of a large catchment. Tree planting in different rainfall zones of large catchments is examined.

From the above, it can be inferred that reforestation in the low rainfall areas would substantially reduce the total salt load in the catchment, while there would be little impact on the total streamflow. This would lower the salinity of the water yielded by the catchment. Conversely, if planting took place in the higher rainfall areas of a regional catchment, there would be little change in the catchments total salt load, but a substantial reduction in its total streamflow.

To assess the effect of non-valley reforestation in more detail, long term average salinities of the Wellington Reservoir and Warren River catchments under four regional land uses were examined. Figure 10 gives the locations of these catchments. The annual rainfall ranges from 600 to 1200 and 600 to 1400 mm for the Wellington and Warren catchments, respectively. A lateritic landscape is characterisitc of the two localities.

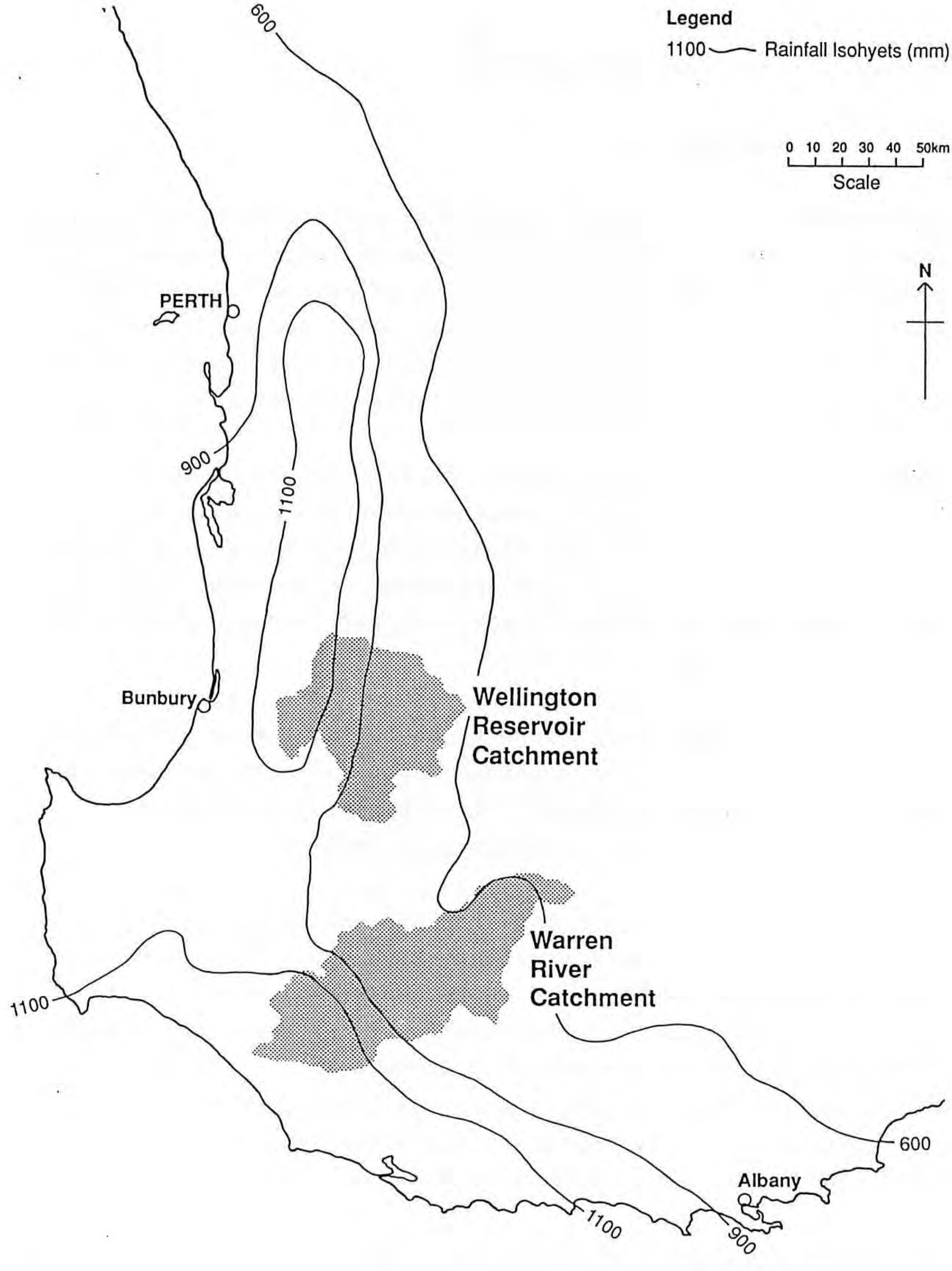


Figure 10
Location of the Wellington Reservoir and Warren River Catchments

5.2 Regional Experiments

5.2.1 Unchanged Land Use

The first regional land use considered is that which existed in 1980 after clearing controls were placed on the two catchments in the late 1970's. The results for this land use serve as a bench mark for comparison with the other regional reforestation scenarios examined.

5.2.2 50% Non-valley Reforestation of Areas With <900 mm Annual Rainfall

At present, the cleared land with less than 900 mm average annual rainfall in the Wellington and Warren catchments produce 80% of the catchments' salt load (refer to Tables E.1 and F.1 in Appendices E and F). As reasoned in the introduction of this chapter (section 5.1), reforestation in this region should yield an improvement in catchment salinity.

A 50% reforestaton of the cleared land is considered the most appropriate case to examine due to the unsuitability of the soils and the lower economic return of wood crops in this low rainfall region.

5.2.3 90% Non-valley Reforestation of Areas With >900 mm Annual Rainfall

The cleared land in the higher rainfall regions of the Wellington and Warren Catchments yield relatively fresh streamflow. A reduction of this diluting component would be expected to worsen catchment salinity.

The favourable soil types and high rainfall of this region makes commercial tree planting more desirable than in lower rainfall areas. Therefore, 90% reforestation was analysed.

5.2.4 Total Reforestation of Areas With >900 mm Annual Rainfall

The previous discussion has proposed that non-valley reforestation in high rainfall regions will have the opposite effect to replanting trees in lower rainfall areas, that is, an increase in salinity will result. Section 4.3 suggested that valley planting will substantially reduce stream salt load and hence stream salinity. Hence, it can be argued that the increase in catchment salinity resulting from non-valley commercial tree planting can be offset by additional uneconomic valley reforestation. Therefore, the effect of total reforestation of all cleared land with an average annual rainfall of greater than 900 mm was investigated.

5.3 Analysis Approach

This section provides a brief discussion of the analysis approach used in examining the average long-term catchment salinities for the four regional experiments previously mentioned. A more detailed discussion of the analysis is given in Appendix D. The results in tabular format, are presented in Appendix E (Tables E.1 to E.4) and Appendix F (Tables F.1 to F.4) for the Wellington Reservoir and Warren River catchments respectively.

The analysis performed is structured on a model developed by Loh and Stokes (1981) for predicting for an average year the long term salinity of the Wellington catchment. This approach divides a catchment into different zones based on long term average annual rainfalls and soil types. The varying contributions of salt and streamflow for forested and cleared land in these zones are taken into account.

Unchanged Land Use

For this land use, the water and salt yields (and hence salinity) for the different zones of the Wellington and Warren catchments were adopted from unpublished figures (1982) calculated using the model developed by Loh and Stokes (1981).

Partial Non-Valley Reforestation

The model developed to simulate non-valley reforestation is based on the results gained from the Balingup study. All cleared land that is reforested is assumed to have a constant reduction in streamflow of 100 mm or 75%, whichever is the smaller. The corresponding reduction in salt load cannot be accurately quantified due to the scatter of the data at Balingup. However, limits dependent on the reduction in streamflow can be set.

The upper salt load bound is computed by estimating the reduction in salt load, corresponding to the reduction in streamflow, from the 'pretreatment' stream salt load flow relationship (equation (4.2)). This represents the situation where tree planting has only reduced the shallow subsurface waters contributing to streamflow. The saline groundwater levels, and hence the salt load flow relationship, remain unaffected.

Section 3.4 demonstrated an increase in stream salinity for the below average rainfall years of this study. It was suggested that if average annual rainfalls had taken place, no change in stream salinity on average would have occurred. This condition was thus chosen as a suitable lower bound. Therefore, the proportionate reduction in salt load is equal to that for streamflow volume, that is, the salinity remains constant.

As a result of calculating upper and lower limits on catchment salt load, the catchment salinities are similarly bounded.

Total Reforestation

Total reforestation of cleared land is assumed in the long term to restore the hydrology to that of a native forest. Therefore, calculations similar to that performed for an unchanged land use were repeated (Loh and Stokes, 1981).

5.4 Results and Discussion

The predicted Wellington Reservoir and Warren River average long term catchment salinities resulting from four regional land uses are listed in Table 5.1. Some limitations exist in the analysis performed (as discussed in section D.3 of Appendix D) and the estimated catchment salinities therefore only serve as an indicative tool of the implications of regional reforestation.

Table 5.1 demonstrates that the Wellington and Warren catchments show a similar response for each of the three regional reforestations schemes. A change in the catchments' salinities ranging from a decrease of over 20% to an increase of 5% are predicted for the below 900 mm rainfall reforestation scenario. As previously discussed, the upper limit (increase of 5%) represents the situation where the reforestation has no effect on the groundwaters. This occurence is most unlikely. Greater emphasis should be placed on the lower catchment salinity limit which assumes stream salinity is unchanged following tree planting.

Extensive non-valley reforestation in the greater than 900 mm average annual rainfall areas of the Wellington and Warren catchments is estimated to give approximate increases in salinity of 25 mg/L TSS (2%) and 90 mg/L TSS (8%) respectively. The greater increase in salinity associated with the Warren is because it had a much larger proportion of cleared land in this region. Furthermore, it is important to note that total reforestation of the cleared land in these higher rainfall areas is predicted to give similar increases in catchment salinity to that of the non-valley tree planting.

In summary, there is only likely to be a salinity benefit to a large water resource catchment when the cleared land in the less than 900 mm annual rainfall areas is reforested. Conversely, tree planting in higher rainfall regions would most likely produce a rise in catchment salinity.

Table 5.1 : The Predicted Wellington Reservoir and Warren River Catchment Salinities Resulting from Four Regional Land Uses

	PREDICTED AVERAGE CATCHMENT SALINITY (mg/L TSS)			
		<900 mm(1)	>900 mm(1)	
CATCHMENT	Unchanged Land Use	50% Reforest.(2)	90% Reforest.(2)	Total Reforest
Wellington Reservoir	1096	859-1147(3)	1115-1126(3)	1114
Warren River	1266	962-1309(3)	1341-1363(3)	1378

notes : (1) Long term average annual rainfall

(2) Non-valley reforestation of cleared land.

(3) Corresonds to lower and upper bound respectively.

CHAPTER 6 : CONCLUSIONS

6.1 Padbury Reservoir Catchment

(i) Annual streamflow yields have reduced by 50 to 100 mm in the later low rainfall years of this study. This reduction is largely a result of the water use of the established plantations.

(ii) The salinity flow relationship has changed such that there has been a reduction in annual flow-weighted mean salinity for a given streamflow volume.

(iii) It can be interpreted from (i) and (ii) that non-valley reforestation reduces both the fresh shallow sub-surface and saline groundwater components contributing to streamflow (as defined in section 4.2).

(iv) There has been on average an increase in stream salinity (140 to 300 mg/L TSS) as a result of non-valley reforestation with 8 of the 9 years of this study having flow-weighted mean annual stream salinities in excess of 1000 mg/L TSS. It is likely that stream salinities will improve in the future if the side slope trees can further lower the groundwater table.

(v) The response observed to date demonstrates that there is no water quality and quantity benefit for a small water resource catchment in the first 10 years following non-valley reforestation. Planting the cleared valley areas in the Padbury Reservoir Catchment to suitable eucalypts will further reduce streamflows and should subsequently show substantial improvement in water quality.

6.2 Regional Implications

High density commercial (non-valley) reforestation, because it can substantially reduce stream salt load, has value as part of a large water resource catchment management policy. This is because significant reductions in salt load from subcatchments which yield large quantities of salt will result in an improvement in overall catchment salinity.

Chapter 5 investigated the effect of non-valley reforestation on the Wellington Reservoir and Warren River catchments' salinities. First order computations indicated that there will only be a salinity benefit when the cleared land in the less than 900 mm annual rainfall areas is reforested. Tree planting in higher rainfall regions will result in large reductions in catchment water yield with smaller proportionate decreases in salt load producing an overall rise in catchment salinity.

CHAPTER 7 : REFERENCES

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APPENDIX A

STEM DENSITY INFORMATION AND ANNUAL HYDROLOGIC DATA USED IN THIS STUDY

Table A.1 : The Stem Density History of the Replantings on the Padbury Road Gauging Station (609 011) Subcatchment.

SPECIES	INITIAL PLANNING		CULLING (2)	
	Year	Stem Density (stems/ha)	Year	Stem Density (stems/ha)
P. radiata	1977	1100	1983	500
E. globulus	1977	625	-	-
E. globulus	1978	625	-	-
E. resinfera	1978	625	-	-
P. radiata	1980	1330	1986	750
P. radiata	1983	1330	-	-

Notes : (1) This table is correct up to 1986.
(2) Corresponds to non-commercial thinning

Table A.2 The Annual Hydrologic Data Analysed in this Study

YEAR	BALINGUP BROOK TRIB. (GS NO. 609 011) Streamflow Volume (mm)	Salt Load (tonnes /ha)	Flow-weighted Mean Salinity (mg/L TSS)	BALINGUP TOWN RAINFALL (mm)	THOMSON BROOK (611 111) Streamflow Volume (mm)	LUDLOW RIVER (CLAYMORE) (610 007) Streamflow Volume (mm)
78	195.8	2.24	1144	844	113.5	30.6
79	71.8(2)	1.27	1772	650	39.2(2)	6.3
80	156.5(2)	1.74	1120	926	101.1	30.9(2)
81	118.3	1.35	1140	822	114.7	21.4
82	38.9	0.73	1867	708	61.3	6.4
83	169.5	1.20	710	966	220.9	82.1
84	28.2	0.51	1826	732	74.5	27.1
85	38.7	0.62	1601	681	111.8	15.5
86	6.3	0.14	2159	607	44.4	5.7

Notes: (1) Area of Balingup Brook Tributary Catchment (Padbury Road Gauging Station) = 0.933 km^2
Area of Thomson Brook Catchment = 102 km^2
Area of Ludlow River (Claymore) Catchment = 10.1 km^2

(2) Streamflow volumes derived from incomplete record.

APPENDIX B

COMPUTATION OF ANNUAL SALT LOAD

Computation of Annual Salt Load

The annual flow-weighted mean stream salinities (S) for the last 7 years of record (1980-86) were calculated using equation (3.1). This requires the annual salt loads (L) and streamflow volumes (Q) which were calculated by manipulating and analysing continuous conductivity (compensated to $25^{o}C$) and streamflow stage records.

Traditionally, the stage record (used to determine streamflows via a rating curve) has been of good quality due to Hydrographers' conscientious efforts. The conductivity trace has not received such detailed attention. This is reflected by every year of conductivity record in this study, except 1986, having missing or poor quality traces for periods of greater than a month. The filling in of missing record and correction of poor quality traces was achieved by a combination of the direct comparison with non-continuous grab sample conductivities and the application of the Hall Model (Loh et al 1984).

Salt loads were evaluated using both stage and conductivity traces as follows:

(1) The stage (m) values are transformed into flow rates ($m^3 s^{-1}$) by a rating curve. This step is performed automatically when retrieving flow data.

(2) Conductivity Cd (mS/m) is transformed into salinity T.S.S. (mg/L TSS) using the following equation:

$$\text{T.S.S.} = 5.2\ Cd + 40.0 \qquad Cd < 353\ \text{mS/m}$$
$$\text{T.S.S.} = 5.882\ Cd - 203.0 \qquad 353 < Cd < 1707\ \text{mS/m}$$
and
$$\text{T.S.S.} = 7.82\ Cd - 3500.0 \qquad Cd > 1707\ \text{mS/m} \qquad \text{--(B.1)}$$

Note that equation (B.1) is only valid for the Padbury Road gauging station (609 011).

(3) The flow and T.S.S. traces are then multiplied together and divided by 1000 to produce a new record of salt flow in units of kg/sec.

(4) The salt flow trace is then integrated with time to give salt load for the period required (daily, monthly, annual).

All computing was performed on the FACOM computer using the State Water Resources Information System. The continuous and non-continuous data was retrieved in a working file format from the CONREC and WAND data bases respectively. All manipulation of the data was performed using the suite of programs available in the Working File System, WRWFILES. This system is user interactive and can save to a file a log of the users input. This is known as HLL (Higher Level Language) and can be used to rerun the job. Listing B.1 is the HLL used in this study (located in WRHTEST.HYDRES.CNTL(RWBSALT) on the FACOM). As input, it requires yearly 1 hour working files of conductivity (PADCON82) and flow rate (PADFLW82). The HLL calculates and creates daily (PADDAY82), monthly (PADMON82) and annual (no file) working files that contain salt loads, flow volumes and flow-weighted salinities. These files together with their statistics are then dumped to an output file.

Listing B.1

```
WH205    DATE 87.9.16  TIME 16:27:35  WRHTEST.HYDRES.CNTL(RWBSALT)

PROGRAM WFFUNC
INFILE  1 WRHTEST.WFILE.PADCON82
OUTFILE  2 VOLREF=WRIPROD.REF99
CARDS
*FUNC     WFPLIN
*OUTVAR   Q324101
*OUTCOL   2
*INCOL    Q141111
*X-INPUT
          NRANGE= 4
          DELIM=1.0
          DELIM=353.0
          DELIM=1707.0
          A=0.0         ,B=0.0
          A=5.2         ,B=40.0
          A=5.882       ,B=-203.0
          A=7.82        ,B=-3500.0
*END
;
PROGRAM WFLINT
INFILE  3 WRHTEST.WFILE.PADFLW82
INFILE  2
OUTFILE  4 VOLREF=WRIPROD.REF99
CARDS
*END
;
PROGRAM WFFUNC
INFILE  4
OUTFILE  5 VOLREF=WRIPROD.REF99
CARDS
*FUNC     WFMULT
*OUTVAR   GM/SEC
*OUTCOL   4
*INCOL    2
+I        3
*FUNC     WFSCAL
*OUTVAR   Q343001
*OUTCOL   4
*INCOL    4
*X-INPUT
          SCALE=0.001
*END
;
PROGRAM WFTRAN
INFILE  5
OUTFILE  6 VOLREF=WRIPROD.REF99
CARDS
*TIMELIM,24000001011982,24000031121982
*PERIOD  DAILY
*TRANSP Q343001 Q341005 IT=1 OT=5 RC=    SF=1.0
*END
;
PROGRAM WFTRAN
INFILE  5
OUTFILE  7 VOLREF=WRIPROD.REF99
CARDS
*TIMELIM,24000001011982,24000031121982
*PERIOD  DAILY
*TRANSP S200001 S210005 IT=1 OT=5 RC=    SF=1.0
*END
;
PROGRAM WFMRGE
```

```
INFILE  6
INFILE  7
OUTFILE  8 VOLREF=WRIPROD.REF99
CARDS
*MERGE  WQTIME  WQTIME  A
*END
;
PROGRAM WFFUNC
INFILE  8
OUTFILE  9 WRHTEST.WFILE.PADDAY82 OLD
CARDS
*FUNC     WFQUCH
*OUTVAR   Q341005
*OUTCOL   2
*INCOL    2
*X-INPUT
          OLDQL=05 ,NEWQL=04
*FUNC     WFQUCH
*OUTVAR   S210005
*OUTCOL   3
*INCOL    3
*X-INPUT
          OLDQL=05 ,NEWQL=04
*FUNC     WFDIV
*OUTVAR   GM/L
*OUTCOL   4
*INCOL    2
+I        3
*FUNC     WFSCAL
*OUTVAR   Q324101
*OUTCOL   4
*INCOL    4
*X-INPUT
          SCALE=1000.0
*END
;
PROGRAM WFTRAN
INFILE  9
OUTFILE 10 VOLREF=WRIPROD.REF99
CARDS
*TIMELIM,24000031011982,24000031121982
*PERIOD  MONTHLY
*TRANSP Q341005 Q341005 IT=5 OT=5 RC=   SF=1.0
*END
;
PROGRAM WFTRAN
INFILE  9
OUTFILE 11 VOLREF=WRIPROD.REF99
CARDS
*TIMELIM,24000031011982,24000031121982
*PERIOD  MONTHLY
*TRANSP S210005 S210005 IT=5 OT=5 RC=   SF=1.0
*END
;
PROGRAM WFMRGE
INFILE 10
INFILE 11
OUTFILE 12 VOLREF=WRIPROD.REF99
CARDS
*MERGE  WQTIME  WQTIME  A
*END
;
```

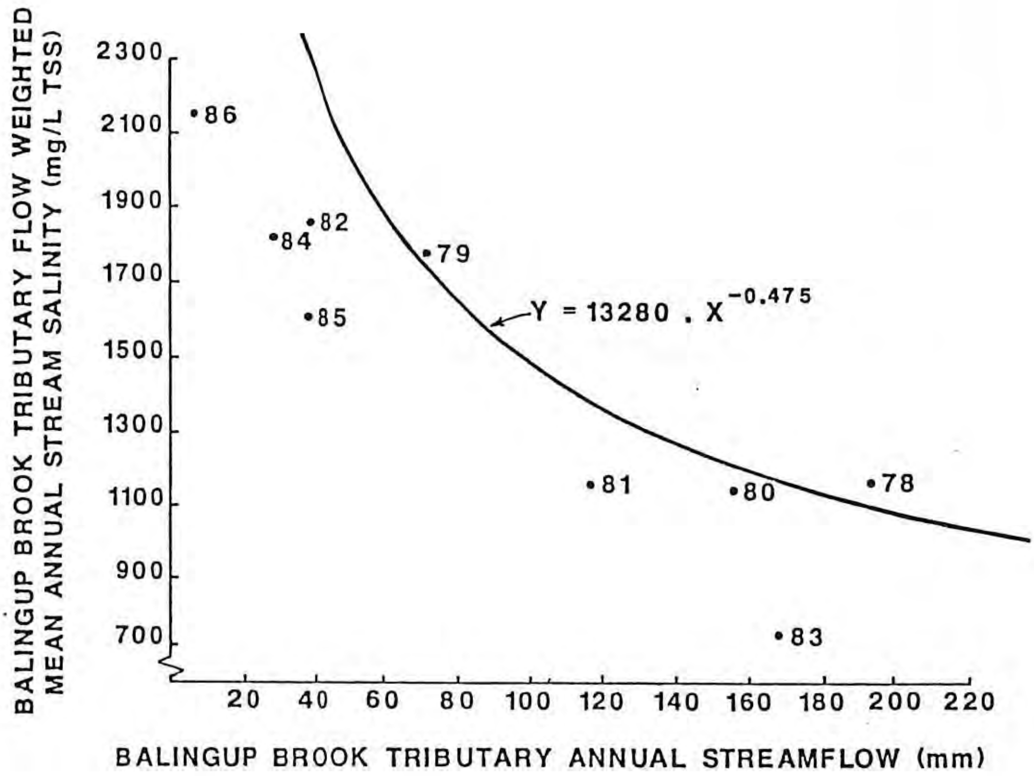
```
PROGRAM WFFUNC
INFILE 12
OUTFILE 13 WRHTEST.WFILE.PADMON82 OLD
CARDS
*FUNC    WFQUCH
*OUTVAR  Q341005
*OUTCOL  2
*INCOL   2
*X-INPUT
         OLDQL=05 ,NEWQL=04
*FUNC    WFQUCH
*OUTVAR  S210005
*OUTCOL  3
*INCOL   3
*X-INPUT
         OLDQL=05 ,NEWQL=04
*FUNC    WFDIV
*OUTVAR  GM/L
*OUTCOL  4
*INCOL   2
+I       3
*FUNC    WFSCAL
*OUTVAR  Q324101
*OUTCOL  4
*INCOL   4
*X-INPUT
         SCALE=1000.0
*END
;
PROGRAM WFTRAN
INFILE 13
OUTFILE 14 VOLREF=WRIPROD.REF99
CARDS
*TIMELIM,24000031121982,24000031121983
*PERIOD  YEARLY
*TRANSP Q341005 Q341005 IT=5 OT=5 RC=   SF=1.0
*END
;
PROGRAM WFTRAN
INFILE 13
OUTFILE 15 VOLREF=WRIPROD.REF99
CARDS
*TIMELIM,24000031121982,24000031121983
*PERIOD  YEARLY
*TRANSP S210005 S210005 IT=5 OT=5 RC=   SF=1.0
*END
;
PROGRAM WFMRGE
INFILE 14
INFILE 15
OUTFILE 16 VOLREF=WRIPROD.REF99
CARDS
*MERGE  WQTIME  WQTIME  A
*END
;
PROGRAM WFFUNC
INFILE 16
OUTFILE 17 VOLREF=WRIPROD.REF99
CARDS
*FUNC    WFQUCH
*OUTVAR  Q341005
*OUTCOL  2
```

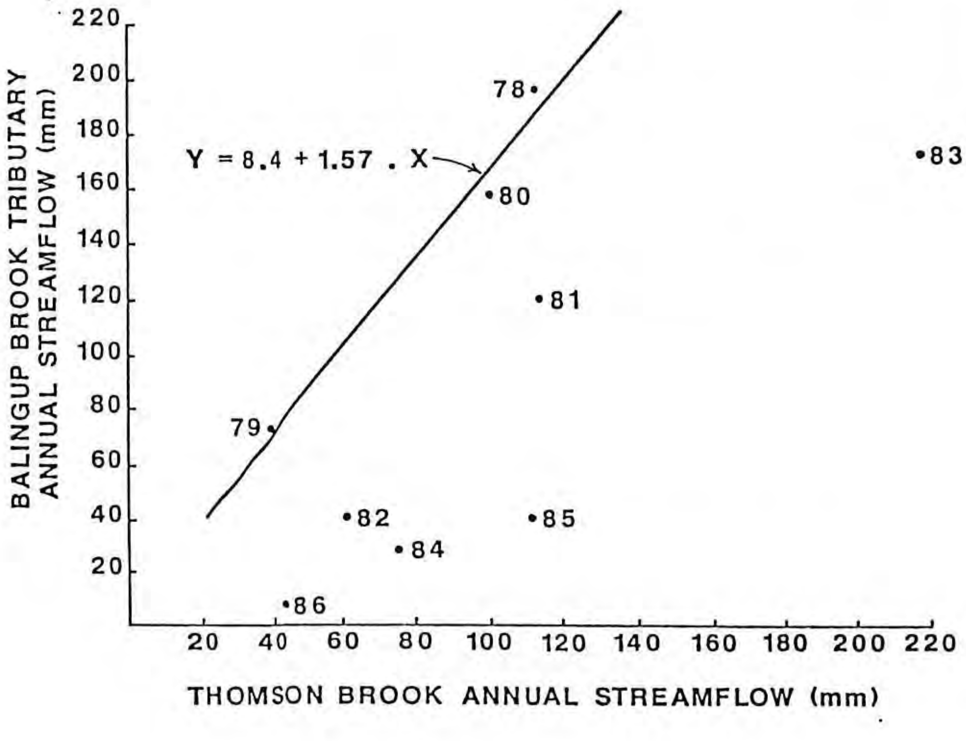
```
*INCOL    2
*X-INPUT
          OLDQL=05 ,NEWQL=04
*FUNC     WFQUCH
*OUTVAR   S210005
*OUTCOL   3
*INCOL    3
*X-INPUT
          OLDQL=05 ,NEWQL=04
*FUNC     WFDIV
*OUTVAR   GM/L
*OUTCOL   4
*INCOL    2
+I        3
*FUNC     WFSCAL
*OUTVAR   Q324101
*OUTCOL   4
*INCOL    4
*X-INPUT
          SCALE=1000.0
*END
;
PROGRAM WFDUMP
INFILE  9
CARDS
*COLUMNS 1
+C        2        ND=4 ,
+C        3        ND=4 ,
+C        4
*END
;
PROGRAM WFSTAT
INFILE  9
CARDS
;
PROGRAM WFDUMP
INFILE 13
CARDS
*COLUMNS 1
+C        2        ND=3 ,
+C        3        ND=3 ,
+C        4
*END
;
PROGRAM WFSTAT
INFILE 13
CARDS
;
PROGRAM WFDUMP
INFILE 17
CARDS
*COLUMNS 1
+C        2        ND=2 ,
+C        3        ND=2 ,
+C        4
*END
;
PROGRAM WFSTAT
INFILE 17
CARDS
;
END
```

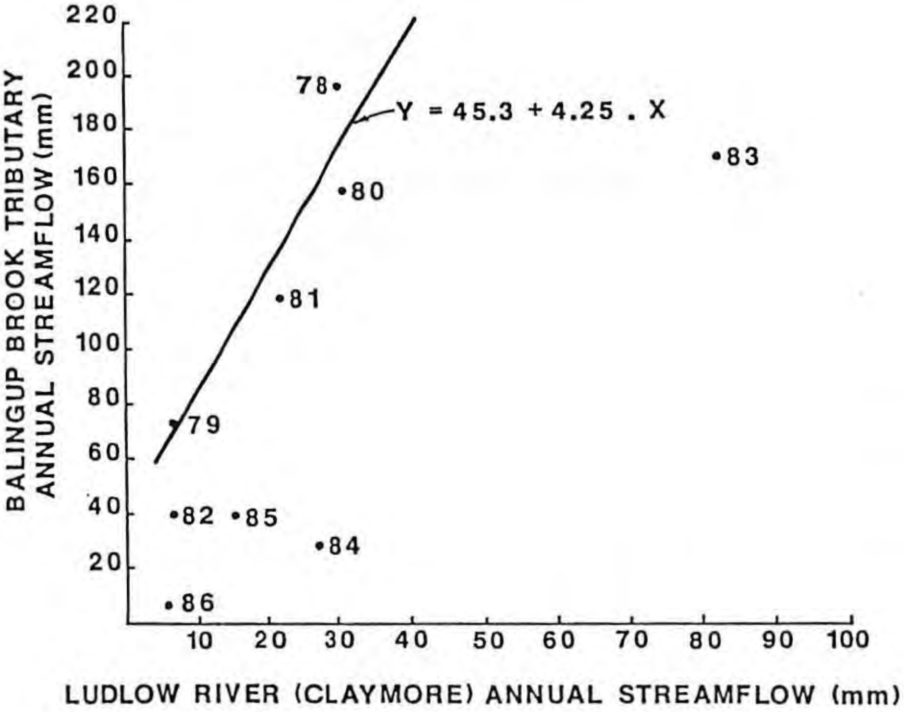
APPENDIX C

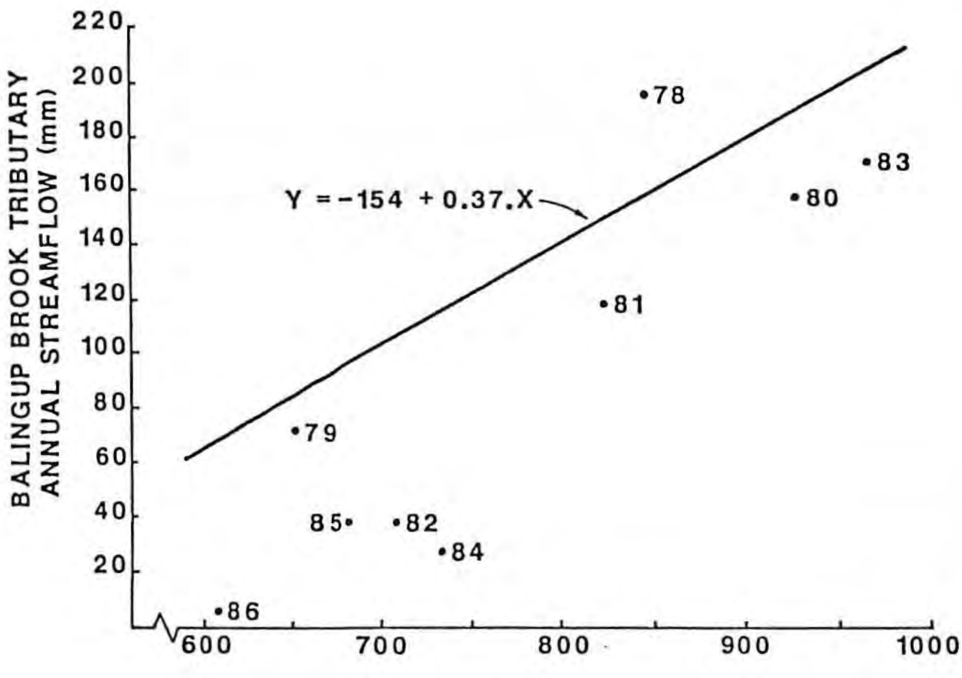
PRETREATMENT RELATIONSHIPS USED IN DETERMINING IF REFORESTATION HAS REDUCED STREAM SALINITY

Pretreatment Relationships Used in Determining if Reforestation has Reduced Stream Salinity.









Notes: (1) All curves presented are pretreatment relationships based on the first 3 years of record (1978-80)

(2) The results of the analysis (as described in Figure 7) are given in Table 3.1

APPENDIX D

MODELLING THE EFFECT OF REGIONAL REFORESTATION ON CATCHMENT SALINITY

D.1 General

The method of analysis presented in this appendix is structured on a model developed by Loh and Stokes (1981) for predicting the salinity of the Wellington Reservoir catchment following clearing. Extension of the model to simulate partial and total reforestation in the Wellington catchment was performed in this study. The application of this model to the Warren River catchment was considered acceptable since both catchments have similar landforms and rainfall zones and the results of the analyses only serve to be indicative, not predictive.

The method of analysis divides a catchment into 10 zones of differing average annual rainfall for a lateritic soil and one which represents sandy soils for any rainfall (Table D.1). The varying contributions of salt and streamflow for the forested and cleared land in these zones are taken into account in the calculation of the long-term catchment salinity. Note that the transients and time frame between tree planting and a new salinity equilibrium being reached are not considered in this model.

All computations are performed using a tabular approach presented in Appendices E and F for the Wellington and Warren catchments respectively. The format and use of these tables is described in the following section. Note that different probabilities of exceedance, apart from the mean as analysed in this study, can be examined using this technique.

The following summary of the notation used in the equations in this appendix will aid in conciseness of wording:

Q - flow volume ($10^6 m^3$)

q - flow volume per unit area (mm)

L - salt load (10^6 kg TSS)

ℓ - salt load per unit area (kg TSS/m^2)

S - salinity (mg/L TSS)

A - area (km^2)

T - total catchment

F - forested land

C - cleared land

P - partial reforestation

i - represents a zone defined by its rainfall and/or landform

x - the fraction of cleared land within a zone that is reforested

D.2 Modelling

D.2.1 Unchanged Land Use

The (total) catchment salt loads and flow volumes for the unchanged land use is presented in Tables E.1 and F.1. These reflect the ultimate salt loads and flows likely to develop as a result of clearing carried out prior to the introduction of catchment clearing controls in the late 1970's. They do not include any of the effects of partial reforestation that have taken place since the controls were imposed. The values adopted here were calculated in 1982 (unpublished) and are based on the simple regional model outlined by Loh and Stokes (1981). This analysis considered in its estimate of salinity for each zone, the different components of shallow subsurface and groundwater contributing to streamflow for the cleared areas (as defined in section 4.2).

The contributions of streamflow and salt for the natural forested land is given by:

$$QF_i = AF_i \cdot qF_i \qquad - (D.1)$$

$$LF_i = AF_i \cdot \ell F_i \qquad - (D.2)$$

where i represents a given zone and qF_i and ℓF_i are listed in Table D.1. The cleared land component is then simply the difference between the total and forested components.

Table D.1: The Rainfall Zones Together with their Coefficients Used in Regional Reforestation Analysis.

Zone	ANNUAL Rainfall(2) (mm)	FOREST Streamflow qF (mm)	Salt load ℓF (kg/m^2)	EXPONENT in eqn. (D.6) C
0	1300+	210	0.027	0.65
1	1250	180	0.027	0.60
2	1150	140	0.025	0.60
3	1050	112	0.022	0.50
4	950	76	0.027	0.50
5	(3)	59	0.012	-
6	850	42	0.011	0.20
7	750	10	0.001	0.15
8	675	5	0.0005	0.10
9	625	5	0.0005	0.10
10	600-	3	0.0003	0.10

Notes: (1) All values correspond to averages.

(2) As of 1980

(3) Corresponds to sandy soils (i.e., Collie Coal Basin). All other zones have lateritic soils.

$$QC_i = QT_i - QF_i \qquad - (D.3)$$

$$LC_i = LT_i - LF_i \qquad - (D.4)$$

This separation of the total catchment streamflows and salt loads into its forested and cleared components, as performed in Tables E.1 and F.1, is the basis of the regional reforestation analysis to be discussed.

D.2.2 Partial Non-Valley Reforestation

The tabular approach used in modelling non-valley reforestation is presented in Tables E.2, F.2, E.3 and F.3. This analysis begins by assuming that the streamflow generated from the reforested cleared land reduces in magnitude by the smaller of 100 mm or 75%. A ratio of the reforested land streamflows after and before tree planting (RQC) is computed. The flow volume of all previously cleared land that has been partially reforested (QCP) is then:

$$QCP_i = (1 - x + x.\ RQC_i).\ QC_i \qquad -- (D.5)$$

where QC corresponds to the cleared land flow volume prior to reforestation (Tables E.1 and F.1).

As discussed in section 5.3, the salt load of the cleared land following partial reforestation can only be estimated by a lower bound, upper bound approach.

Upper Salt Load Bound

The upper bound is computed using the pretreatment salt load flow relationship equation (4.2). This equation can be rewritten in terms of a coefficient c such that

$$L = a\ Q^{c}; \qquad c = - b + 1 \qquad - (D.6)$$

The coefficient b, and hence c, was estimated for the cleared land in each rainfall zone by Loh and Stokes (1981). More conservative values of c (Table D.1) were considered appropriate and thus examined. Equation (D.6) can be restructured to give the ratio of the salt load following reforestation to that before (RLC) as a result of a similar reduction in streamflow (RQC).

$$RLC_i = RQC_i^{\ c} \qquad \text{-- (D.7)}$$

The upper bound (UB) salt load of the partially reforested cleared land (LCP) is therefore;

$$LCP_{i\ UB} = (1-x + x.(RQC_i^{\ c})).LC_i \qquad \text{-- (D.8)}$$

where LC is the salt load of the cleared land before trees were planted.

Lower Salt Load Bound

The lower limit of salt load, as also discussed in section 5.3, is estimated to be the situation where the proportionate reductions in salt load (RLC) and streamflow (RQC) are the same (salinity remains constant).

$$RLC_i = RQC_i \qquad \text{- (D.9)}$$

Hence, the lower bound (LB) salt load of the partially reforested cleared land is

$$LCP_{i\ LB} = (1 - x + x\ .\ RQC_i).\ LC_i \qquad \text{- (D.10)}$$

The addition of the streamflow (equation (D.5)) and upper and lower bound salt loads (equations (D.8) and (D.10)) of the partially reforested cleared land to that of the respective forested components (equations (D.1) and (D.2)) gives the total catchment streamflow and salt loads. As a result of this upper bound, lower bound approach for estimating salt loads, the catchment salinities are similarly bounded as given by equations (D.11) and (D.12).

Upper Bound $$STP_{i\ UB} = \frac{LTP_{i\ UB}}{QCP_i} = \frac{LCP_{i\ UB} + LF_i}{QCP_i + QF_i} \qquad \text{-- (D.11)}$$

Lower Bound $$STP_{i\ LB} = \frac{LTP_{i\ LB}}{QTP_i} = \frac{LCP_{i\ LB} + LF_i}{QCP_i + QF_i} \qquad \text{-- (D.12)}$$

D.2.3 Total Reforestation

The long-term average streamflow and salt loads generated from a totally reforested land is assumed in this analysis to be equal to that of a native forest. Thus, the same tabular format as used for an unchanged land use (Tables E.1 and F.1) was applied to this scenario of reforestation. As presented in Tables E.4 and F.4, the only difference in analysis is that the catchment response for the totally reforested zones is determined by considering all land within that zone to be covered by native forest.

D.3 Limitations of Analysis

Many limitations exist in the analysis discussed in this appendix. The most significant of these occur in the model developed by Loh and Stokes (1981) applied to the unchanged land use case. This assumes that the response of streamflow and stream salt load is linear with area cleared, independent of the location of the clearing within each sub-catchment. In the case of the reforestation modelling this simplification was similarly assumed. Present research indicates that in general a non-linear relationship exists (Hookey, 1987).

The prediction of long-term salinity following partial non-valley reforestation is based solely on the results of the Balingup study situated in a 900 mm rainfall area. Extrapolation of the observed response to other rainfall areas, as assumed in this analysis, is recognised as a simplistic approach, justified here only to provide a first order approximation of the regional implications. An example of this approximation is that reforestation was assumed to reduce streamflow by 100 mm for all rainfall zones. Loh and Stokes (1981) demonstrated that the additional streamflow generated following catchment clearing varies with average annual rainfall. This characteristic would be expected to also apply to reforestation.

A further limitation of using the Balingup results in developing a long-term reforestation salinity model is that all trends established only correspond to the first 9 years of record. It is possible that the treated catchment's long-term response will vary greatly with that of the first 10 years.

APPENDIX E

WELLINGTON RESERVOIR CATCHMENT

- REGIONAL REFORESTATION

ANALYSIS TABLES

ZONE		TOTAL CATCHMENT					NATURAL FOREST						CLEARED LAND			
		AREA km²	SALT 10^6 kg	FLOW $10^6 m^3$	SALIN. mg/L		AREA Km²	SALT kg/m²	SALT 10^6 kg	FLOW mm	FLOW $10^6 m^3$		AREA Km²	SALT 10^6 kg	FLOW $10^6 m^3$	FLOW mm
		AT	LT	QT	ST		AF	eF	LF	qF	QF		AC	LC	QC	
0		—	—	—	—		—	·027	—	210	—		—	—	—	—
1		74	2·4	14·4	167		68·4	·027	1·85	180	12·3		5·6	0·6	2·1	380
2		141	5·3	23·1	229		121	·025	3·03	140	16·9		20·2	2·3	6·2	307
3		235	7·3	29·0	252		217	·022	4·77	112	24·3		17·6	2·5	4·6	262
4		324	15·4	30·6	503		279	·027	7·53	76	21·2		45·0	7·8	9·4	210
5		277	5·8	23·5	247		220	·012	2·64	59	13·0		57·0	3·2	10·5	180
6		447	28·8	32·7	881		329	·011	3·62	42	13·8		118	25·2	18·8	160
7		754	52·7	24·9	2116		582	·001	0·58	10	5·8		172	52·2	19·1	111
8		389	47·8	11·6	4121		280	·0005	0·14	5	1·40		109	47·7	10·2	93
9		189	53·4	10·0	5340		75	·0005	0·04	5	0·04		114	53·4	9·7	85
10		—	—	—	—		—	·0003	—	3	—		—	—	—	—
TOTAL		2830	218·9	199·8	1096		2171		24·2		108·7		658	195	90·6	

COMMENTS: ① Corresponds to an average year.

Table E.1 : Wellington Reservoir Catchment
- Unchanged Land Use

Table E.2 : Wellington Reservoir Catchment

- 50% Non-valley Reforestation of Zones with

< 900 mm Annual Rainfall

ZONE	CLEARED LAND REFORESTED (x = 50%)		UPPER BOUND			L.B.	TOTAL CATCHMENT	UPPER B.		LOWER B.	
		FLOW $10^6 m^3$	C		SALT 10^6 kg	SALT 10^6 kg	FLOW $10^6 m^3$	SALT 10^6 kg	SALIN. mg/L	SALT 10^6 kg	SALIN. mg/L
	RQC	QCP	C	RLC = RQC^c	LCP_{UB}	LCP_{LB}	QTP	LTP_{UB}	STP_{UB}	LTP_{LB}	STP_{LB}
0	—	—	—	—	—	—	—	—	—	—	—
1	1·0	2·1	—	—	—	—	14·4	2·4	167	2·4	167
2	1·0	6·2	—	—	—	—	23·1	5·3	229	5·3	229
3	1·0	4·6	—	—	—	—	29·0	7·3	252	7·3	252
4	1·0	9·4	—	—	—	—	30·6	15·4	503	15·4	503
5	1·0	10·5	—	—	—	—	23·5	5·8	247	5·8	247
6	0·375	12·9	0·20	0·82	23·0	17·3	26·7	26·6	996	20·9	783
7	0·25	11·9	0·15	0·81	47·3	32·6	17·7	47·9	2706	33·2	1876
8	0·25	6·4	0·10	0·87	44·6	29·8	7·8	44·7	5731	29·9	3833
9	0·25	6·1	0·10	0·87	49·9	33·4	6·2	50·0	8065	33·5	5403
10	—	—	—	—	—	—	—	—	—	—	—
TOTAL		70·1					179·0	205·4	1147	153·7	859

COMMENTS : ① 50% non-valley reforestation in zones 6 to 9.
② Corresponds to an average year

Table E.3 : Wellington Reservoir Catchment
- 90% Non-valley Reforestation of Zones with
> 900 mm Annual Rainfall

ZONE		CLEARED LAND REFORESTED (x=90%)							TOTAL CATCHMENT				
			FLOW $10^6 m^3$	UPPER BOUND			L.B.		FLOW $10^6 m^3$	UPPER B.		LOWER B.	
				C		SALT 10^6 kg	SALT 10^6 kg			SALT 10^6 Kg	SALIN. mg/L	SALT 10^6 Kg	SALIN. mg/L
		RQC	QCP	C	RLC = RQC^C	LCP_{UB}	LCP_{LB}		QTP	LTP_{UB}	STP_{UB}	LTP_{LB}	STP_{LB}
0		—	—	—	—	—	—		—	—	—	—	—
1		0·74	1·6	0·60	0·83	0·5	0·5		13·9	2·3	165	2·3	165
2		0·67	4·4	0·60	0·79	1·9	1·6		21·3	4·9	230	4·6	216
3		0·62	3·0	0·50	0·79	2·0	1·6		27·3	6·8	249	6·4	234
4		0·52	5·4	0·50	0·72	5·9	4·5		26·6	13·4	504	12·0	451
5		1·0	10·5	—	—	—	—		23·5	5·8	247	5·8	247
6		1·0	18·8	—	—	—	—		32·7	28·8	881	28·8	881
7		1·0	19·1	—	—	—	—		24·9	52·7	2116	52·7	2116
8		1·0	10·2	—	—	—	—		11·6	47·8	4121	47·8	4121
9		1·0	9·7	—	—	—	—		10·0	53·4	5340	53·4	5340
10		—	—	—	—	—	—		—	—	—	—	—
TOTAL			82·7						191·8	215·9	1126	213·8	1115

COMMENTS: ① 90 % non-valley reforestation in zones 1 to 4.
② Corresponds to an average year.

Table E.4 : Wellington Resevoir Catchment

- Total Reforestation of Zones with

> 900 mm Annual Rainfall

ZONE	TOTAL CATCHMENT				NATURAL FOREST					CLEARED LAND			
	AREA	SALT	FLOW	SALIN.	AREA	SALT		FLOW		AREA	SALT	FLOW	
	km²	10^6 Kg	$10^6 m^3$	mg/L	Km²	kg/m²	10^6 Kg	mm	$10^6 m^3$	Km²	10^6 Kg	$10^6 m^3$	mm
	AT	LT	QT	ST	AF	ℓF	LF	qF	QF	AC	LC	QC	
0	—	—	—	—	—	·027	—	210	—	—	—	—	—
1	74	2·0	13·3	150	74	·027	2·0	180	13·3	—	—	—	—
2	141	3·5	19·7	178	141	·025	3·5	140	19·7	—	—	—	—
3	235	5·2	26·3	198	235	·022	5·2	112	26·3	—	—	—	—
4	324	8·7	24·6	354	324	·027	8·7	76	24·6	—	—	—	—
5	277	5·8	23·5	247	220	·012	2·6	59	13·0	57·0	3·2	10·5	180
6	447	28·8	32·7	881	329	·011	3·6	42	13·8	118	25·2	18·8	160
7	754	52·7	24·9	2116	582	·001	0·6	10	5·8	172	52·2	19·1	111
8	389	47·8	11·6	4121	280	·0005	0·1	5	1·4	109	47·7	10·2	93
9	189	53·4	10·0	5340	75	·0005	0·04	5	0·04	114	53·4	9·7	85
10	—	—	—	—	—	·0003	—	3	—	—	—	—	—
TOTAL	2830	207·9	186·6	(1114)	2260		25·8		117·9	570	181·7	68·3	

COMMENTS: ① Total Reforestation of all cleared land (valley and slopes) of zones 1 to 4. ② Corresponds to an average year.

APPENDIX F

WARREN RIVER CATCHMENT

- REGIONAL REFORESTATION

ANALYSIS TABLES

Table F.1 : Warren River Catchment

- Unchanged Land Use

ZONE	TOTAL CATCHMENT AREA km^2	SALT $10^6 kg$	FLOW $10^6 m^3$	SALIN. mg/L	NATURAL FOREST AREA km^2	SALT kg/m^2	SALT $10^6 kg$	FLOW mm	FLOW $10^6 m^3$	CLEARED LAND AREA km^2	SALT $10^6 kg$	FLOW $10^6 m^3$	FLOW mm
	AT	LT	QT	ST	AF	ℓF	LF	qF	QF	AC	LC	QC	
0	296	11·7	76·3	153	229	·027	6·2	210	48·1	67	5·5	28·2	420
1	199	7·8	38·2	204	186	·027	5·0	180	33·5	13	2·8	4·7	360
2	285	13·5	51·7	261	215	·025	5·4	140	30·1	70	8·1	21·6	310
3	290	19·8	50·5	392	170	·022	3·7	112	19·0	120	16·1	31·5	260
4	365	26·2	42·4	618	255	·027	6·9	76	19·4	110	19·3	23·0	210
5	—	—	—	—	—	·012	—	59	—	—	—	—	—
6	475	16·4	26·4	621	420	·011	4·6	42	17·6	55	11·8	8·3	160
7	745	38·2	20·0	1910	620	·001	0·6	10	6·2	125	37·6	13·8	110
8	665	104	24·0	4333	430	·0005	0·2	5	2·2	235	103·8	21·8	90
9	450	141	26·2	5382	150	·0005	0·1	5	0·8	300	140·9	25·4	85
10	265	94·6	18·0	5256	35	·0003	0·01	3	0·1	230	94·6	17·9	78
TOTAL	4035	473·2	373·7	1266 ①	2710		32·7		177	1325	440·5	196·7	

COMMENTS : ① Corresponds to an average year.

Table F.2 : Warren River Catchment
- 50% Non-valley Reforestation of Zones with
< 900 mm Annual Rainfall

ZONE	CLEARED LAND REFORESTED (x=50%)						TOTAL CATCHMENT				
		FLOW $10^6 m^3$	UPPER BOUND			L.B.	FLOW $10^6 m^3$	UPPER B.		LOWER B.	
			C		SALT 10^6 kg	SALT 10^6 kg		SALT 10^6 kg	SALIN. mg/L	SALT 10^6 kg	SALIN. mg/L
	RQC	QCP	C	RLC = RQC^C	LCP_{UB}	LCP_{LB}	QTP	LTP_{UB}	STP_{UB}	LTP_{UB}	STP_{LB}
0	1·0	28·2	—	—	—	—	76·3	11·7	153	11·7	153
1	1·0	4·7	—	—	—	—	38·2	7·8	204	7·8	204
2	1·0	21·6	—	—	—	—	51·7	13·5	261	13·5	261
3	1·0	31·5	—	—	—	—	50·5	19·8	392	19·8	392
4	1·0	23·0	—	—	—	—	42·4	26·2	618	26·2	618
5	—	—	—	—	—	—	—	—	—	—	—
6	0·375	6·0	0·20	0·82	10·7	8·1	23·6	15·3	648	12·7	538
7	0·25	8·6	0·15	0·81	34·1	23·5	14·8	34·7	2345	24·1	1628
8	0·25	13·6	0·10	0·87	97·1	64·9	15·8	97·3	6158	65·1	4120
9	0·25	15·9	0·10	0·87	131·8	88·1	16·7	131·9	7898	88·2	5281
10	0·25	11·2	0·10	0·87	88·5	59·1	11·3	88·5	7832	59·1	5230
TOTAL		164·3					341·3	446·7	1309	328·2	962

COMMENTS: ① 50 % non-valley reforestation in zones 6 to 10.
② Corresponds to an average year.

Table F.3 : Warren River Catchment

- 90% Non-valley Reforestation of Zones with > 900 mm Annual Rainfall

ZONE	CLEARED LAND REFORESTED (x=90%)						TOTAL CATCHMENT				
		FLOW $10^6 m^3$	UPPER BOUND			L.B.	FLOW $10^6 m^3$	UPPER B.		LOWER B.	
			C		SALT 10^6 Kg	SALT 10^6 Kg		SALT 10^6 Kg	SALIN. mg/L	SALT 10^6 Kg	SALIN. mg/L
	RQC	QCP	C	RLC = RQC^c	LCP_{UB}	LCP_{LB}	QTP	LTP_{UB}	STP_{UB}	LTP_{LB}	STP_{LB}
0	0·76	22·1	0·65	0·84	4·7	4·3	70·2	10·9	155	10·5	150
1	0·72	3·5	0·60	0·82	2·3	2·1	37·0	7·3	197	7·1	192
2	0·68	15·3	0·60	0·79	6·6	5·7	45·4	12·0	264	11·1	244
3	0·62	20·6	0·50	0·79	13·0	10·5	39·6	16·7	422	14·2	359
4	0·52	13·1	0·50	0·72	14·5	11·0	32·5	21·4	658	17·9	551
5	—	—	—	—	—	—	—	—	—	—	—
6	1·0	8·8	—	—	—	—	26·4	16·4	621	16·4	621
7	1·0	13·8	—	—	—	—	20·0	38·2	1910	38·2	1910
8	1·0	21·8	—	—	—	—	24·0	104	4333	104	4333
9	1·0	25·4	—	—	—	—	26·2	141	5382	141	5382
10	1·0	17·9	—	—	—	—	18·0	94·6	5256	94·6	5256
TOTAL		162·3					339·3	462·5	1363	455	1341

COMMENTS: ① 90 % non-valley reforestation in zones 0 to 4
② Corresponds to an average year.

Table F.4 : Warren River Catchment

- Total Reforestation of Zones with

> 900 mm Annual Rainfall

ZONE	TOTAL CATCHMENT				NATURAL FOREST					CLEARED LAND			
	AREA km^2	SALT $10^6 Kg$	FLOW $10^6 m^3$	SALIN. mg/L	AREA km^2	SALT kg/m^2	SALT $10^6 Kg$	FLOW mm	FLOW $10^6 m^3$	AREA Km^2	SALT $10^6 Kg$	FLOW $10^6 m^3$	FLOW mm
	AT	LT	QT	ST	AF	ℓF	LF	rF	QF	AC	LC	QC	
0	296	8.0	62.2	130	296	·027	8.0	210	62.2	—	—	—	—
1	199	5.4	35.8	150	199	·027	5.4	30	35.8	—	—	—	—
2	285	7.1	39.9	178	285	·025	7.1	40	39.9	—	—	—	—
3	290	6.4	32.5	200	290	·022	6.4	12	32.5	—	—	—	—
4	365	9.9	27.7	357	365	·027	9.9	76	27.7	—	—	—	—
5	—	—	—	—	—	·012	—	59	—	—	—	—	—
6	475	16.4	26.4	621	420	·011	4.6	42	17.6	55	11.8	8.8	160
7	745	38.2	20.0	1910	620	·001	0.6	0	6.2	125	37.6	13.8	110
8	665	104	24.0	4333	430	·0005	0.2	5	2.2	235	103.8	21.8	90
9	450	141	26.2	5382	150	·0005	0.1	5	0.8	300	140.9	25.4	85
10	265	94.6	18.0	5256	35	·0003	0.01	3	0.1	230	94.6	17.9	78
TOTAL	4035	431.0	312.7	1378	3090		42.3		225	945	388.7	87.7	

COMMENTS: ① Total Reforestation of all cleared land (valley and slopes) of zones 0 to 4. ② Corresponds to an average year.