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SALINITY SAMPLING IN THE HELENA CATCHMENT, WESTERN AUSTRALIA

by
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SUMMARY

Stream sampling between 1974 and 1977 in the Helena Catchment, Western Australia, revealed a rapid decrease during summer in the number of flowing streams and an increase in the proportion of streams with higher total dissolved solids (TDS) content. In half of the 117 samples, base flow salinity exceeded 500 $mg.l^{-1}$ TDS.

Salt content of streams was strongly affected by land use on the upstream catchment. Land uses which were related to salinity increases include clearing for farming and pine plantations, and ringbarking. Data did not link logging activities with substantial salinity increase, and reasons for this are suggested.

Base flow salinity for ephemeral streams did not accurately predict groundwater salinity in adjacent aquifers and serious underestimates were recorded.

Since no part of the Catchment is safe from the threat of increased water salinity, clearing of the 4300 ha of uncleared private land within its boundaries could result in substantial increases in stream and reservoir salinity. Several courses of action which may help to prevent this are recommended.

N.B. Water salinity levels referred to in this paper as $mg \cdot l^{-1}$ refer to the total dissolved solids (TDS) unless otherwise specified.

INTRODUCTION

Mundaring Weir in the Helena Catchment (Fig. 1) was the second dam to be constructed for water supply in Western Australia.

Work began in 1889 and the wall, which was completed in 1902, was raised in 1951 and again in 1959. The Catchment covers an area of 1470 km^2. The reservoir's main tributaries are Rushy Creek, Helena River, Darkin River, Beraking Brook, Little Darkin River, Pickering Brook and Hay Creek, and when it is full it has a surface area of 7.61 km^2 and a capacity of 77 x 10^6 m^3 (Public Works Department (P.W.D), 1974).

Salinity has been a problem since the construction of the reservoir. After two years (1901 and 1902) with below-average stream flows, authorities expressed concern about the rate at which the reservoir would fill. In an effort to reduce evapotranspiration and thereby increase streamflow, an area of approximately 8000 ha (estimated from the area where regrowth is evident) near the reservoir was ringbarked in 1903. The project was successful, streamflow increasing to the point where some streams began to flow all year.

However, the turbidity and salinity of the water also increased; reports written in 1909 (P.W.D., 1963) refer to a 300% increase in the salinity of streams draining the ringbarked areas, and a maximum salinity of 1540 $mg \cdot l^{-1}$ of total dissolved solids (TDS) was recorded. On occasions, the salinity of the water in the reservoir reached 560 $mg \cdot l^{-1}$, a level

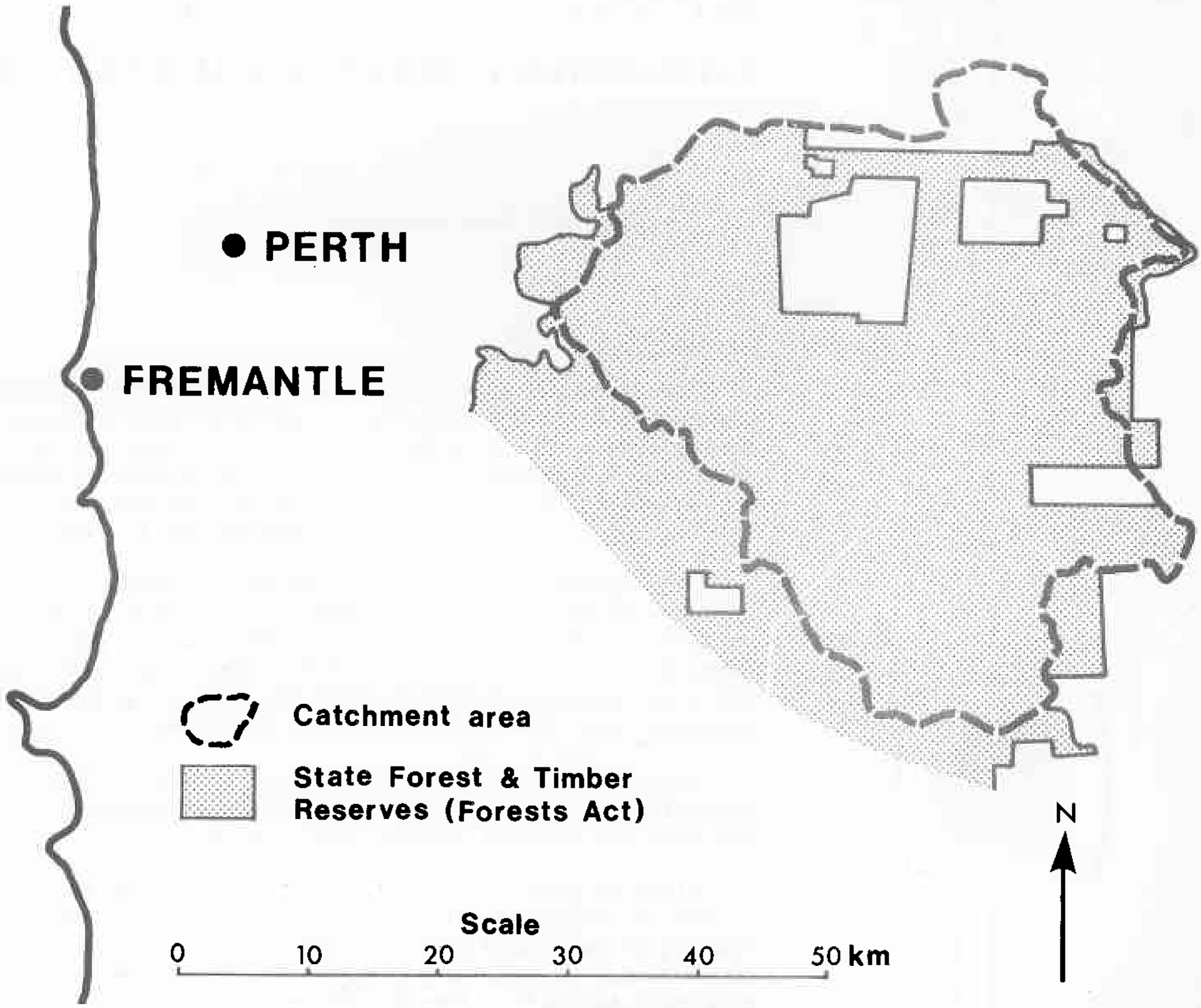

FIGURE 1: Location of Helena Catchment, showing State Forest and Timber Reserves

close to the limit tolerable for water supply (P.W.D., 1963). As the regrowth forest replaced the original stand, erosion and turbidity decreased and the quality of the water gradually improved. However, since the early 1960's the salinity of the reservoir water has again been increasing; during the period 1970-1975, TDS content of the reservoir has ranged between 220 and 590 $mg \cdot l^{-1}$ with a mean of approximately 400 $mg \cdot l^{-1}$.

The Catchment spans several rainfall zones, precipitation within its boundaries ranging from 600 to 1200 mm per annum. Saltfall, which occurs in the form either of dry dust or of salt dissolved in rain, varies with distance from the coast and is estimated to range between 95 $kg \cdot ha^{-1}$ chloride (NaCl) per annum (at Mundaring Weir) and 24 $kg \cdot ha^{-1}$ per annum (at the Catchment's eastern boundary) (Hingston, personal communication). This cyclic salt has accumulated in the soil profile as a result of evapotranspiration, and in some locations storage may exceed 8×10^5 $kg \cdot ha^{-1}$ (Batini et al., 1976).

Various factors thought to influence salt movement have been active within the Catchment area. They include the ringbarking mentioned above; the death of native plant species caused by dieback disease attributed to Phytophthora cinnamomi Rands (Batini, 1973); forestry operations such as logging, firewood removal for the Wundowie

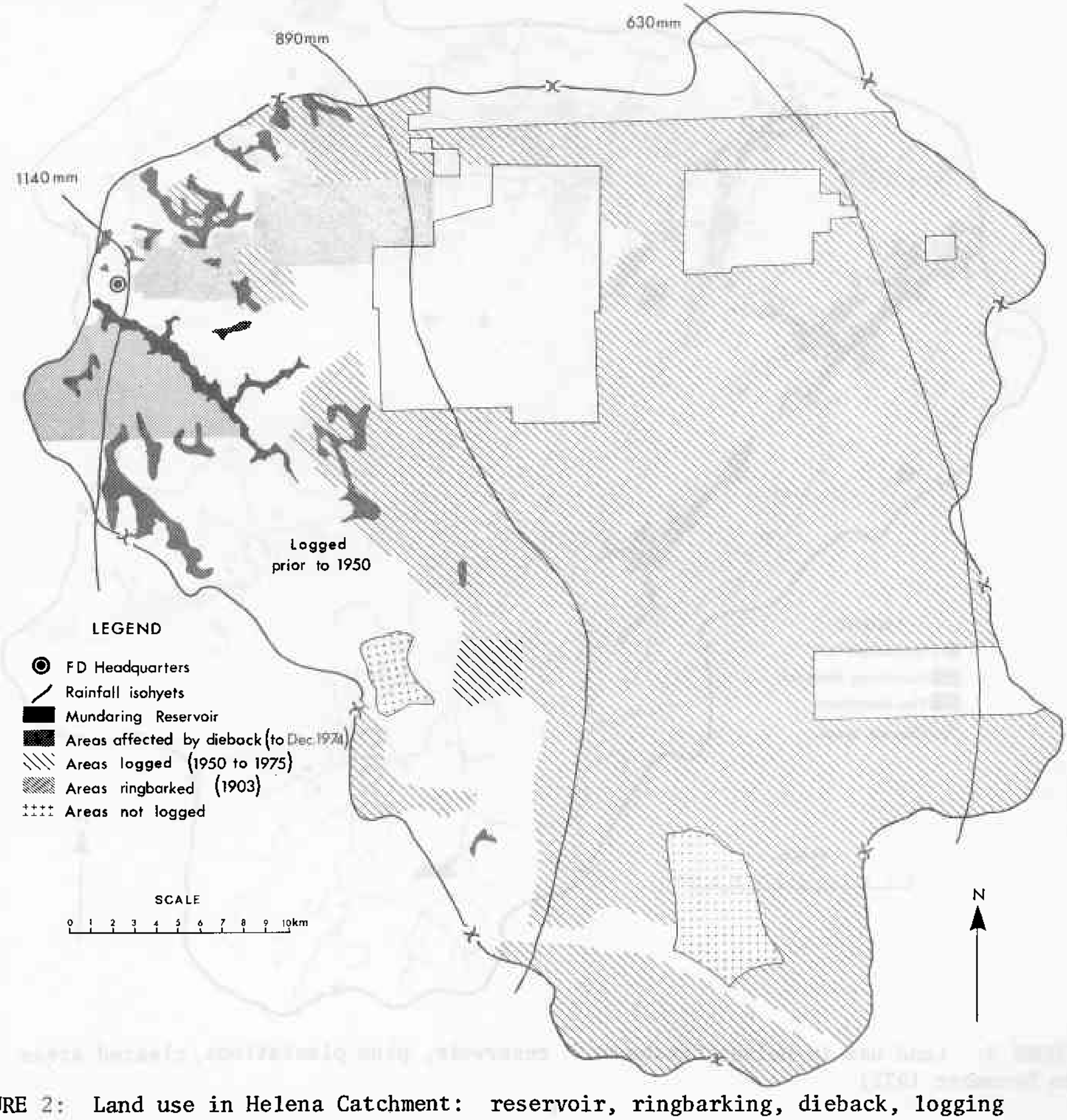

FIGURE 2: Land use in Helena Catchment: reservoir, ringbarking, dieback, logging

charcoal-iron plant, and the felling of wandoo (Eucalyptus wandoo) for industrial extracts; farming (5% of the total Catchment area is private property, approximately 43% of which has been cleared to serve mainly as grazing for sheep, cattle and horses, although some grain is also grown); and pine planting (Pinus radiata and to a lesser extent Pinus pinaster) on both repurchased farmland and areas cleared of native forest. Other areas have remained virtually untouched (Figs. 2 and 3).

Most of the land which is currently farmed was alienated before the problem of increasing water salinity was recognised. The P.W.D. has repurchased 12 000 ha of farmland within the Catchment area, mostly between 1956 and 1965, and affecting mainly farms which were largely uncleared. In some cases the cleared land has been replanted with pines, but in others no replanting has yet been carried out.

Because the Helena Catchment exhibits wide variation in rainfall, land usage, geomorphology and vegetation, it is a suitable area within which to study the relationship between these factors and stream salinity.

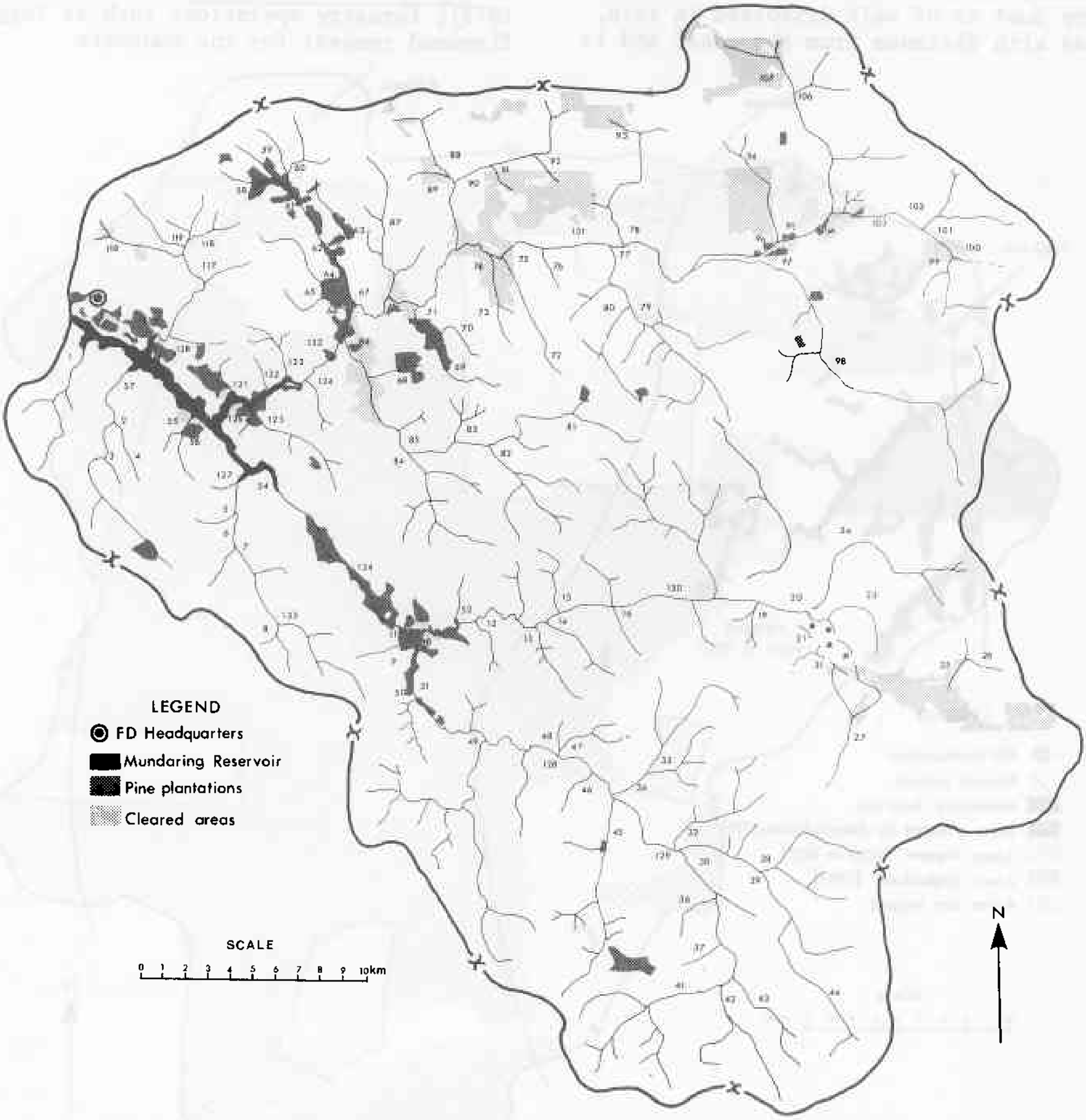

FIGURE 3: Land use in Helena Catchment: reservoir, pine plantations, cleared areas (to December 1972)

METHOD

Weekly stream sampling in the Helena Catchment (at 117 sites chosen to cover the range of conditions) began in late May 1974 and continued until all streams were dry (late January 1975). Weekly sampling was resumed at selected sites during the autumn of 1975 and continued until the summer of 1977.

At each sampling site a 200 ml sample of water was collected in a plastic sampling bottle which had been thoroughly rinsed. The electrical conductivity (EC) of each sample was measured using a Phillips Measuring Bridge and a flow-through conductivity cell (Hatch, 1976).

Base flow salinity was calculated as the mean salinity of the two samples collected immediately before streamflow ceased. Data for samples collected from a pool of non-flowing water were recorded individually, and for those pools which were obviously fed by seepage and whose water level remained nearly constant for several weeks, base flow salinity was estimated from these data.

Rainfall records were supplied by the Forests Department's Mundaring Weir headquarters located in the western section of the Catchment, and other pertinent data were obtained from records of the Forests Department and Public Works Department.

RESULTS

Rainfall

Rainfall during the winter of 1974 was considerably above average (Table 1); heavy rains in May and early June were followed by a dry period of approximately two weeks, an unusually wet July and August, and a second drier period before further heavy falls in October. The nature and periodicity of the rainfall resulted in large and sustained streamflows.

Stream salinity

The Western Australian Public Works Department classifies water into four broad salinity classes: fresh (<500 mg$\cdot$l^{-1}), marginal (501-1000 mg$\cdot$l^{-1}), brackish (1001-3000 mg$\cdot$l^{-1}) and saline (>3000 mg$\cdot$l^{-1}).

These classes have been used to classify the streams monitored during the sampling programme.

TABLE 1

Monthly rainfall (mm) at Forests Department Mundaring Weir headquarters

Month	1974	Average (1956 to 1973)
January	9.0	11.1
February	13.0	6.3
March	11.0	20.7
April	87.8	51.8
May	277.0	136.4
June	171.0	234.9
July	357.2	221.3
August	206.5	130.1
September	45.0	76.7
October	99.6	62.3
November	32.2	23.5
December	0	13.9
Total	1309.3	989.0

Time - The classification of streams (based on all samples collected) according to date of sampling and salinity class appears in Table 2, and Table 3 presents weekly salinity details recorded over the same time period for five representative streams.

Through spring and summer the percentage of flowing streams decreased rapidly and the proportion with higher TDS values increased. The slight reversals in these trends which were recorded on 9 October, 23 October and 20 November resulted from increased surface runoff caused by heavy falls of rain just before these sampling dates. In 50% of the streams, the estimated TDS values for base flow exceeded 500 mg$\cdot$l^{-1}, which is the potability standard currently set by the World Health Organisation as the highest salinity level desirable for domestic water supply.

Sampling sites are classified by P.W.D. salinity class in Figure 4 for flows on 30 October 1974 and in Figure 5 for base flows. Comparison of these two figures indicates the change in salinity in relation to time for a particular sampling site. The streams sampled show marked variability in TDS content; in some cases, adjacent sampling sites differed greatly whilst in others, considerable variation downstream was observed.

TABLE 2

Classification of streams by salinity class, base flow and date of sampling (percentage of total number of streams)

Salinity class	TDS ($mg \cdot l^{-1}$)	31.7.74	25.9.74	27.11.74	23.12.74	Base flow
Fresh	< 500	97	52	3	2	50
Marginal	501-1000	1	15	14	3	22
Brackish	1001-3000	2	9	10	4	18
Saline	> 3000	Nil	3	1	1	10
No flow	-	Nil	21	72	90	-

TABLE 3

TDS ($mg \cdot l^{-1}$) of five selected streams over 23 weeks (1974)

Date	Sampling site no.				
	81	57	120	132	75
17 July	72	246	265	261	888
31 July	50	151	193	252	319
8 Aug	50	N.A	169	236	N.A.
14 Aug	51	186	234	349	329
20 Aug	N.A.	N.A.	N.A.	N.A.	N.A.
28 Aug	72	268	344	515	N.A.
11 Sept	N.A.	329	504	831	1786
18 Sept	90	307	570	1222	N.A.
25 Sept	99	332	669	1076	3384
2 Oct	117	383	786	1330	3880
9 Oct	92	322	668	1226	3826
16 Oct	136	398	831	1625	4881
23 Oct	114	339	707	1527	4968
30 Oct	160	374	843	1573	5769
6 Nov	179	426	982	1762	6186
13 Nov		430	1228	2036	6670
20 Nov		464	1219	1950	6720
27 Nov		501	1440	2118	
4 Dec		571		2235	
11 Dec		651		2379	
17 Dec		685		2398	
23 Dec		716		2530	

N.A. = data not available

Land Use - Some of the pertinent land use changes and current land uses within the Catchment are shown in Figures 2 and 3 respectively. Data are summarised in Table 4, which classifies sampling sites by base flow salinity and by dominant land use on the upstream catchment.

Those areas which have been cleared for farming are consistently associated with brackish and saline base flows (sites 31, 74, 75, 78, 88, 89, 95, 101, 107 and 116). In a number of cases, whereas the base flow into the farm is fresh (25, 27, 72, 73, 94, 99 and 100), the base flow out is saline (31, 74, 75, 95) or brackish (101). There are some exceptions (91, 92 and 93) where saline base flows from farms were not recorded. At sites 91 and 92, the streams emerge from areas of deep sand and flow only during the heaviest falls of rain, drying up shortly after the rain ceases (influent). At site 93, the sample point was of necessity located just downstream from a farm dam, and samples were taken from the overflow; as streamflow approached base flow, the dam intercepted the flow of water so that sampling became impossible.

The planting of repurchased farmland with pines, which was carried out between 1962 and 1965, appears to have affected

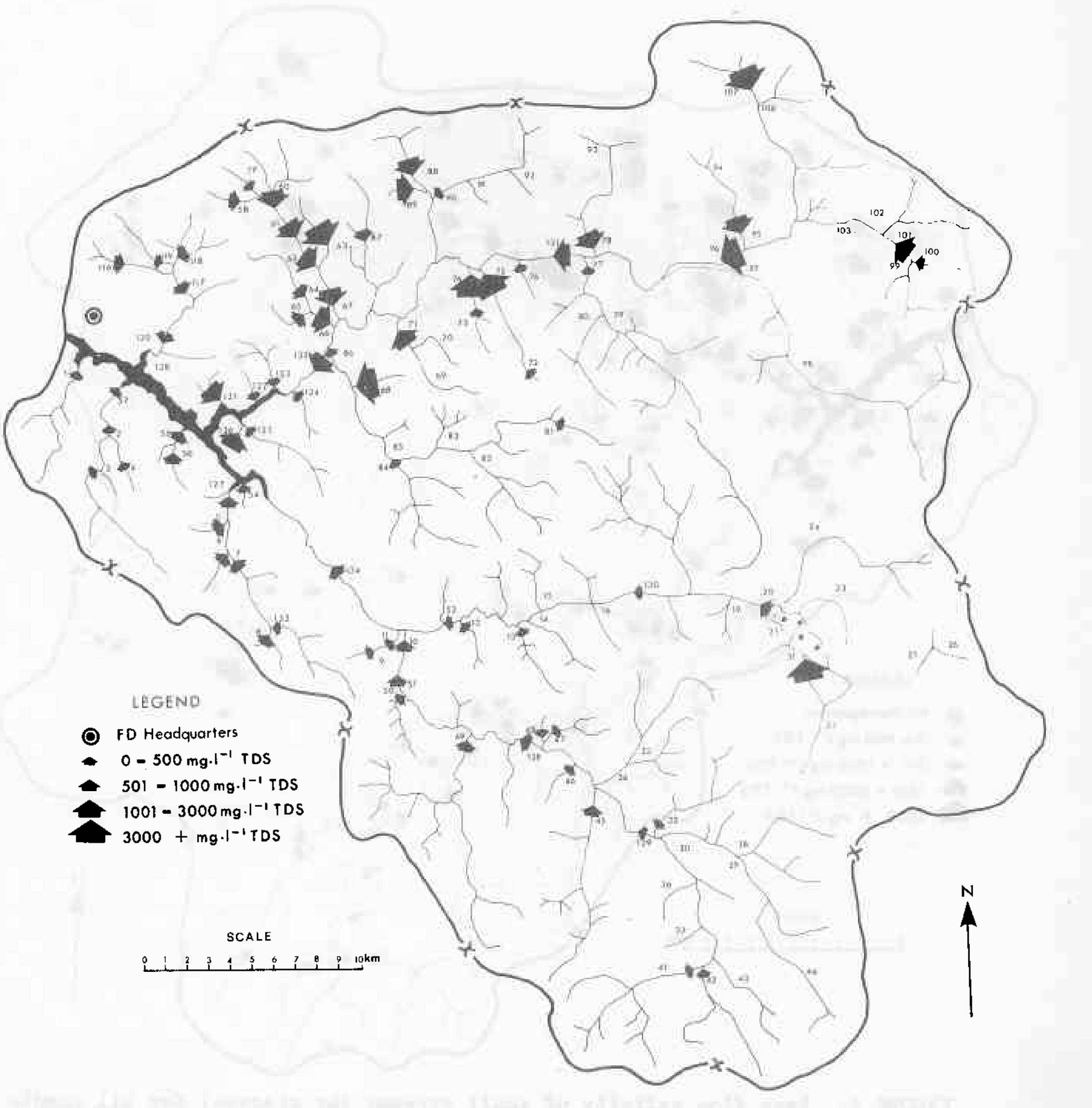

FIGURE 4: Salinity of small flowing streams (by classes) for samples taken on 30 October 1974. Arrows also indicate the direction of the flow

the total runoff considerably: a small farm dam (built on a spring between sites 69 and 71) which previously overflowed all year round now fills only partially during the winter months, and some areas which previously were waterlogged are now drier. Nevertheless, highly saline discharge into the streams is still occurring, and brackish and saline base flows are associated with these areas of replanted farm land (sites 68 and 71).

There is some evidence that streams which have pine plantations on part of their catchment have higher salt content of base flows (sites 55, 61, 62, 66, 121, 126 and 138). This indicates that further clearing of native forest for pine planting in the Helena Catchment should not proceed without a careful evaluation of possible changes in the hydrological and salt balances. No large extension to the existing area of pine is planned. Some samples were collected from a plantation established in an area which had previously been ringbarked and where salt discharge may not have been fully stabilised; in another case, the sample was obtained from an area which had been clearfelled before replanting. Root excavations suggest that pines do not have

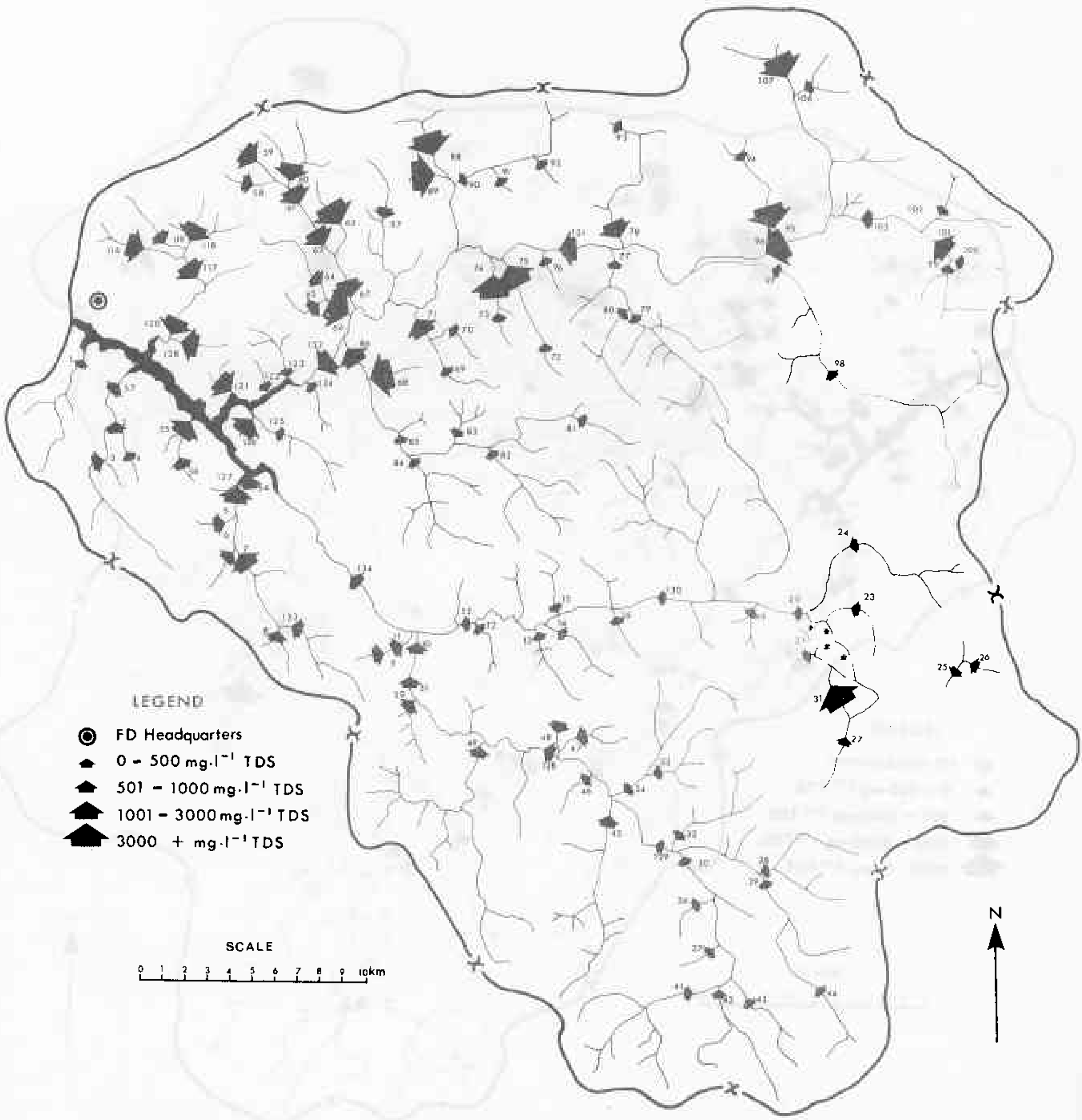

FIGURE 5: Base flow salinity of small streams (by classes) for all sample points. Arrows also indicate the direction of flow

TABLE 4

Sampling sites classified by their base flow salinity class and by the land use on the upstream catchment

Land use		TDS ($mg \cdot l^{-1}$) Fresh <500	Marginal 501-1000	Brackish 1001-3000	Saline >3000	Total
Farmland	Partly cleared	3	Nil	3	7	13
	Replanted	Nil	Nil	1	1	2
Pine plantations		Nil	1	6	1	8
Hardwood forest	Ringbarked	1	5	2	1	9
	Dieback affected	2	3	3	Nil	8
	Logged	53	12	2	Nil	67
Multiple land uses		Nil	5	4	1	10
Total		59	26	21	11	117

the same capacity as the original eucalypts to penetrate the clayey subsoils; consequently, they may be less effective in reducing salt water discharge. It is also possible that the pines have not had sufficient time to return the hydrological system to the pre-clearing condition.

Areas ringbarked in 1903 and areas affected by dieback disease (a more recent phenomenon) have base flow salinity values in the marginal and brackish ranges. The extremely high salinity recorded at site 63 was due to water contributed by a small tributary where exposure of the underlying pallid zone clays had caused a saline spring to develop.

Forest which has been logged usually has low base flow salinity. The sub-catchment of the Darkin River, which covers the southern half of the Helena Catchment, illustrates this tendency; within this area, the only saline base flow (site 31) is associated with a farm clearing. Most of the base flow salinities recorded in forested catchments were in the fresh (<500 $mg \cdot l^{-1}$) class. Logging activity within these catchments had ranged from light selection treatment to virtual clearfelling for sawlogs and firewood in some areas (including the catchments of sites 13, 14, 23, 32, 36, 37, 81, 82, 84, 94 and 98). It is important to note the term clearfelling in this context does not mean clearing the site of all trees. Only the saleable trees greater than 50 cm in diameter are logged; the remainder, comprising about 50% of the original canopy, are not affected. In the Little Darkin sub-catchment, some sections of which were logged before 1920 and others between 1930 and 1940, brackish base flow salinity was recorded at two sites (7 and 127), but this may be attributable to the area's geomorphology rather than to land use.

Geomorphology - The landforms within the Helena Catchment have been mapped by the CSIRO (Mulcahy et al., 1972). As with rainfall, the influence of land use is so strong that it tends to mask the effects of geomorphology on base flow salinity.

However, the Darkin River sub-catchment, which is forested except for one small pine plantation and one farm (Fig. 3), is an area where the effects of geomorphology on base flow salinity can be examined. As Figure 5 indicates, most of the observed base flows in the upper reaches were fresh, with the exception of the farm sample (31) and the pine plantation (45), and ranged from 80 to 150 $mg \cdot l^{-1}$. As the streams approached the

"Darkin surface" (Mulcahy et al., 1972), cutting more deeply into the soil profile, base flow salinities rose to 350-400 $mg \cdot l^{-1}$ (Darkin River, 52) and 750-800 $mg \cdot l^{-1}$ (Beraking Brook, 51). This trend is not unexpected, since many of the small streams in the upper sub-catchment areas flow only after sustained rainfall (influent), and consequently have low base flow salinities. With increasing dissection of the landscape by the stream bed, the groundwater is more likely to contribute to the base flow TDS content (effluent), so that base flow salinity rises.

Above-average salinity levels were recorded in two sub-catchments of the Little Darkin. The valley of this stream is steeply incised in comparison with the valleys of the other streams, dropping 270 m in elevation in 21 km as against 90 m in 48 km for Darkin River, 120 m in 40 km for Beraking Brook and 120 m in 18 km for Pickering Brook. The resultant exposure of the underlying weathered clays and the greater likelihood of intersecting the groundwater table may account for these above-average values.

Rainfall - Shea et al. (1975) observed that base flow salinities in hardwood forest catchments increased as the rainfall decreased, and that the high salinity values were related to subdued topography and sluggish stream flow. However, no such trends emerge from the present study, many of the low base flow salinities being recorded at sample sites located in the low rainfall zone (630-890 mm per annum). This disparity is due partly to the unsuitability of the technique for measuring the base flow salinity of influent streams, partly to the dominance with which land use influences salinity, generally masking the effects of rainfall, and partly to the contrast in rainfall between the two study areas, Shea's data deriving from zones of higher rainfall (900-1250 mm).

It is certain, however, that the streams within the lower rainfall zones of the Helena Catchment are prone to salinity increases after land has been cleared for agricultural purposes. Furthermore, it appears that no part of the Catchment can be considered free from a potential salt problem.

Base flow salinity

The observed base flow salinities have also been examined with reference to:
(1) their variation from year to year,
(2) their relationship with the average and weighted average salinities, and
(3) their relationship with the salinity of the groundwater table.

Variation from year to year - Sampling was continued for ten selected streams. Salinity data for 1974, 1975 and 1976 are shown in Table 5. Comparison with P.W.D. data for the years 1968-1974 shows that although base flow salinities vary from year to year, the differences are not great; general salinity trends are evident, and this suggests that reasonable inferences may be drawn from a single year's data.

As is indicated in Figure 6, which compares TDS content of three of the selected streams over a two-year period, high salinity values may be recorded at the beginning of winter. These high-volume brackish and saline flows are attributed to the flushing out of the accumulated salt from salt pans, pools, seeps and springs by the early winter rains, and represent a considerably greater threat to dam salinity than do the low-volume saline base flows.

Average and weighted average salinities - Whereas the calculated base flow salinity value reflects the highest salinity levels of a stream, the average salinity and the weighted average salinity (weighted for flow rates) are considerably lower and may therefore provide a more satisfactory indication of the stream's salinity.

P.W.D. data gathered over six years (1968-1974) from eight gauged streams within the Helena Catchment suggest that average and weighted average salinities are approximately 60% and 30% respectively of the base flow salinity. In 1974 (Fig. 7), a year of above-average rainfall and flows, average salinities were approximately half the calculated base flow salinities (range 43% to 62%) and weighted average salinities were approximately one fifth of the calculated base flow salinities (range 15% to 30%).

Groundwater table salinity - Base flow salinity has been used to estimate the salinity of the groundwater table in the area drained by a particular stream (La Sala, 1967; Shea et al., 1975). If it provides an accurate indication of groundwater salinity, then it may be used to forecast the effects of changes in land use on stream salinity. A model which predicts the size and direction of likely changes has been developed by Peck (1975).

TABLE 5

Comparison of base flow TDS level estimates (mg·l^{-1}) for different sampling sites and years

Sampling site No.	Name	1968-1974 P.W.D. data*	1974	1975	1976
134	Darkin River	950	890	856	904
120	Rushy Creek	1671	1600	1597	1681
1	Hay Creek	456	350	N.A.	N.A.
57	Pickering Brook	739	700	676	547
127	Little Darkin River	1182	1170	1088	1268
61	Helena Brook	1914	2150	2193	1906
131	Helena River	1756	1800	N.A.	N.A.
72	Wellbucket Road	N.A.	220	89	64
81	Yarra Road	N.A.	170	220	71
132	Helena River	2718	2465	2665	3032

* P.W.D. 90th percentile sodium chloride values (mg·l^{-1}) converted to TDS (mg·l^{-1})

N.A. = data not available

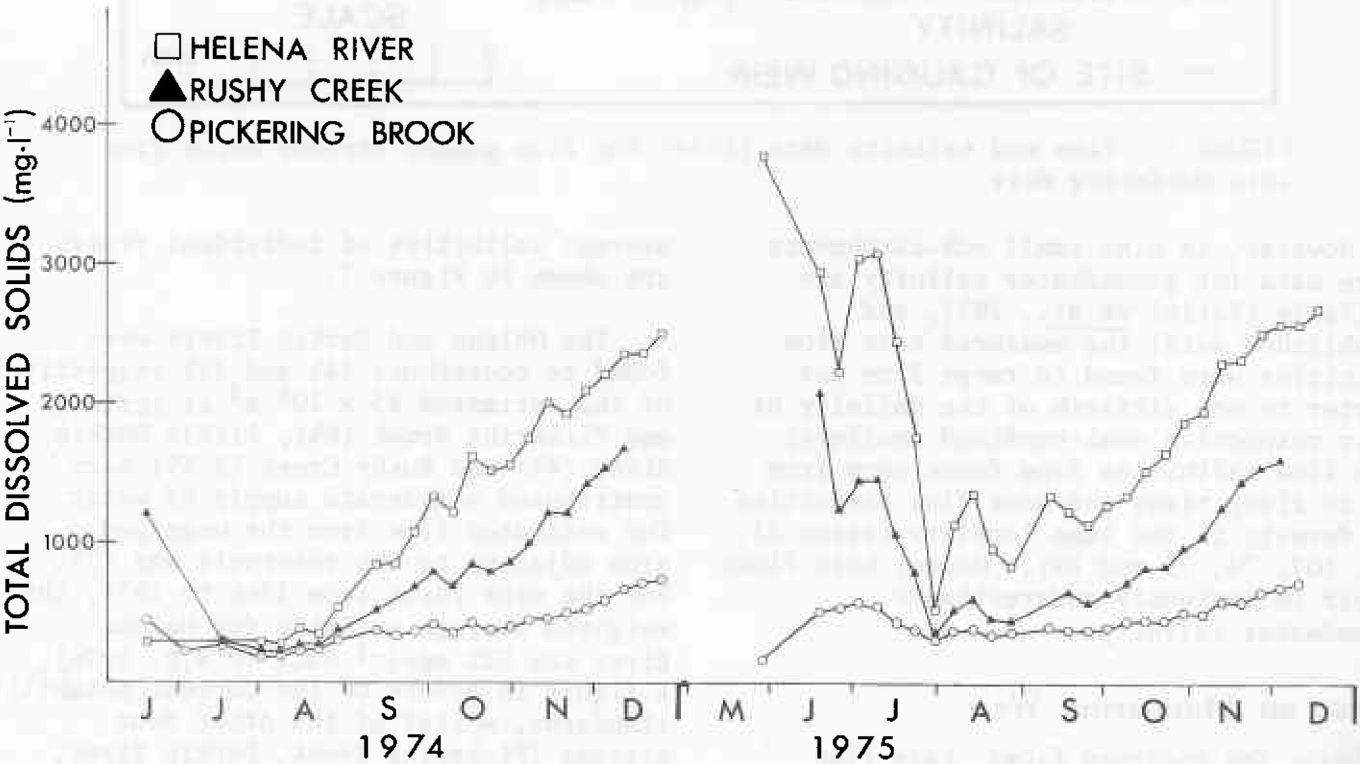

FIGURE 6: Electrical conductivity of three gauged streams from June 1974 to December 1975

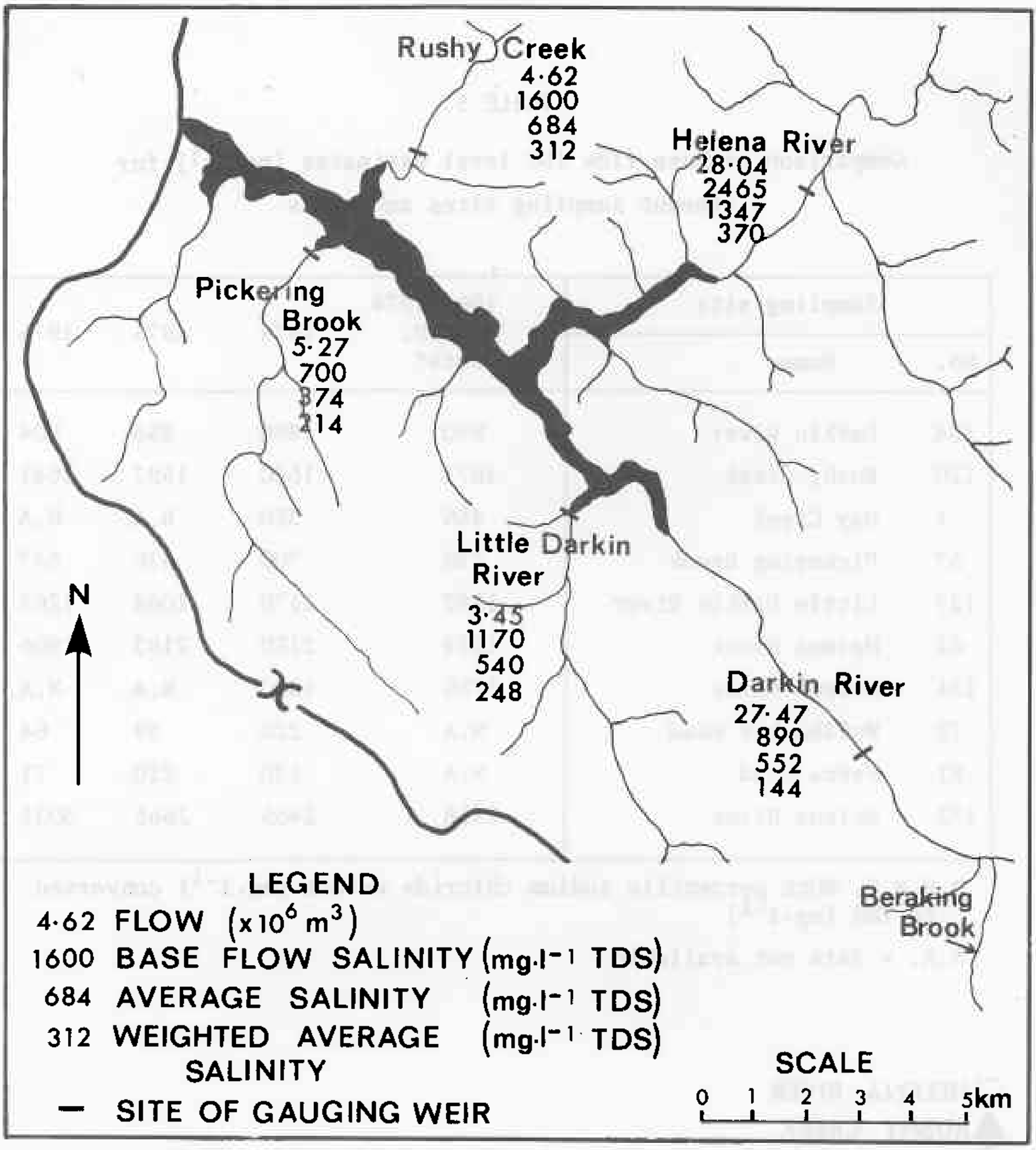

FIGURE 7: Flow and salinity data (1974) for five gauged streams which flow into Mundaring Weir

However, in nine small sub-catchments where data for groundwater salinity are available (Batini et al., 1977, and unpublished data) the measured base flow salinities were found to range from one quarter to one sixtieth of the salinity of their respective semi-confined aquifers; base flow salinities from farms were from ten to fifty times the base flow salinities for forests in the same locality (sites 31, 101, 107, 74, 75 and 89). Hence, base flows appear to seriously underestimate groundwater salinity.

Effect on Mundaring Weir

Inflow - The recorded flows, base flow salinities, and average and weighted average salinities of individual rivers are shown in Figure 7.

The Helena and Darkin Rivers were found to contribute 34% and 33% respectively of the estimated 83 x 10^6 m^3 of inflow, and Pickering Brook (6%), Little Darkin River (4%) and Rushy Creek (5.5%) each contributed a moderate supply of water. The estimated flow from the ungauged area adjacent to the reservoir was 17%. For the nine years from 1966 to 1974, the weighted average salinity for Helena River was 522 mg·l^{-1} NaCl (P.W.D., 1976), a figure in excess of the current potability standards, whilst of the other four streams (Pickering Brook, Darkin River, Rushy Creek, Little Darkin River) only

Rushy Creek, with a weighted average salinity of 395 $mg \cdot l^{-1}$ NaCl, has approached the current standards.

The average annual inflow over the past 70 years has been calculated at 53×10^6 m^3. Streamflow data for five of the major tributaries for the years 1969 to 1974 indicate an average annual inflow of 32.5×10^6 m^3, of which 7×10^6 m^3 represents the estimated flow from the ungauged 112 km^2 of Catchment area adjacent to the reservoir (Loh, personal communication). Between 1969 and 1974 the average contribution of the Helena and Darkin Rivers, the sub-catchments of which represent approximately 85% of the total Catchment area, was about 50% of the inflow. In 1974 they contributed 67% of the 83×10^6 m^3 total inflow, but in contrast, the total inflow for 1969, a year of serious drought, was only 5.9×10^6 m^3, about 40% of this being contributed by the two rivers. Consequently, in a critical drought year, approximately 15% of the Catchment area contributes 60% of the inflow to the dam.

Overflow - The maximum storage capacity of Mundaring Weir is 77×10^6 m^3 (P.W.D., 1974), and the estimated inflow for 1974 of 85×10^6 m^3 resulted in a considerable flow over the crest and spillway. The overflow, which commenced on 25 July 1974, continued for 70 days until 3 October; water again overflowed for 11 days from 7 October 1974 and for a further 5 days from 23 October 1974. At its peak, the water level in the reservoir was 0.38 m above the maximum crest height (with gates in position). Such sustained overflows have been rare since the gates were fitted in 1959.

Salinity of water in the reservoir - Data for 1974 (P.W.D., 1976) show that whilst the TDS values of surface and depth samples were markedly different during periods of inflow, differences during the rest of the year were slight. During the summer and autumn of 1974, values for both surface and depth samples were between 420 and 460 $mg \cdot l^{-1}$. At the end of 1974, the average salinity of water in the reservoir was between 260 and 280 $mg \cdot l^{-1}$.

Further clearing on private property

Land-clearing activity is associated with high salinity levels in streams, and for this reason it must be of great concern to catchment managers. As a considerable amount of privately owned land within the Helena Catchment remains uncleared, it is important to consider the possible effects on water salinity should these areas be cleared.

The likely increase in salinity has been estimated from Peck's (1975) model. The inputs to the model are estimates of the salinity of the groundwater table, the area to be cleared (expressed as a fraction of the total Catchment area), and the increase in recharge due to clearing. The figure for groundwater salinity, 5000 $mg \cdot l^{-1}$, was obtained by taking the average of the base flow salinities from a number of cleared areas. The area of private property subject to clearing, calculated from aerial photographs of the Catchment taken in 1972, is approximately 4300 ha (2.9%). The increase in recharge has been estimated as 60 mm per annum as follows. Uncleared catchments in locations similar to the uncleared private property yield about 20 mm per annum (approximately 2 to 2.5% of the rainfall) as streamflow; removal of the existing vegetation in favour of short-lived, shallow-rooted annuals is likely to influence the groundwater recharge considerably, and an increase of at least threefold seems reasonable.

Applying these figures to Peck's model, the estimated mean increase in river salinity if all the privately held land is cleared is 370 $mg \cdot l^{-1}$. If the salinity of the groundwater table is estimated as 3000 $mg \cdot l^{-1}$ and the recharge as 40 mm per annum, the mean increase in salinity becomes 140 $mg \cdot l^{-1}$, and if values of 7000 $mg \cdot l^{-1}$ and 80 mm per annum are used, the estimated increase becomes 690 $mg \cdot l^{-1}$.

To test the model's reliability in providing estimates of increases in stream salinity, it was applied to data collected in the sub-catchments of the Helena and Darkin Rivers. Approximately 950 ha (1.45%) of the Darkin's sub-catchment have been cleared, and the weighted average salinity of the streamflow is 210 $mg \cdot l^{-1}$ NaCl. Within the Helena's sub-catchment, where 2200 ha (3.8%) have been cleared, the salinity is considerably higher at 550 $mg \cdot l^{-1}$ NaCl. Assuming a base flow salinity of 5000 $mg \cdot l^{-1}$ NaCl, a recharge of 60 mm per annum and an additional clearing of 2.35% within the sub-catchment of the Darkin River, the estimated increase in stream salinity is 316 $mg \cdot l^{-1}$ NaCl. The calculated stream salinity of the Darkin River would therefore be 526 $mg \cdot l^{-1}$ NaCl, a value very close to that recorded for the Helena River (550 $mg \cdot l^{-1}$ NaCl). Similarly, the apparent rise in the salinity of the reservoir since 1960 (about 220 $mg \cdot l^{-1}$) can be accounted for by the farm clearing (3500 ha) carried out since then.

The present salinity of the water in the reservoir is close to the maximum set by the World Health Organisation, and any further increase would be undesirable. An increase of 140 $mg \cdot l^{-1}$ in the salinity of the Helena and Darkin Rivers could increase the salinity of the reservoir water by 80 $mg \cdot l^{-1}$; increases of 350 to 400 $mg \cdot l^{-1}$ would raise salinity by 220 to 240 $mg \cdot l^{-1}$; an increase of 700 $mg \cdot l^{-1}$ in the salinity of these rivers would nearly double the current salinity level in the reservoir, and as a result of this its water might have to be mixed with that from other reservoirs before distribution.

These predictions are based on average salinity increases after clearing. Whilst the rate of the increases depends on the patterns of clearing and rainfall, evidence suggests that a total increase in reservoir salinity of 220 to 240 $mg \cdot l^{-1}$ is likely if all private property is cleared.

However, the model has not yet been tested, and although field investigations have begun, data may not be available for some years; these predictions must therefore be regarded with caution.

DISCUSSION

Data gathered during this investigation show that land use exerts considerable influence on the base flow salinity of small streams in the Helena Catchment. The greatest salinity changes are associated with clearing for farming, and other changes in land use which affect salinity are, in order of decreasing significance: clearing followed by pine planting; ringbarking; jarrah dieback disease; forest logging.

The sampling technique used did not link cutting with serious increases in stream salinity, although other land uses had measurable effects. In areas cut over since 1950, the prescription has varied from light selection to heavier felling, but even in those areas which have been heavily logged, no substantial increases in base flow salinity were observed. There are a number of possible reasons for this.

Firstly, the sampling technique itself may not be suitable for detecting slight changes in salinity since the seasonal variations are quite considerable (Table 3).

Secondly, although cutting took place from 2 to 15 years before sampling, it is possible that salt mobilised by this activity had not yet reached the sampling points. However, because farm clearings, pine plantations and dieback areas are often adjacent to streams, their effects on stream salinity are likely to appear sooner.

Thirdly, large amounts of salt are stored in the profile of wandoo (*Eucalyptus wandoo* Blakely) flats and ridges (Batini *et al.*, 1976), and the groundwater table in valleys in these areas is often saline. Whereas both jarrah (*Eucalyptus marginata* Sm.) and wandoo have been felled for sawmilling, culling for green firewood has concentrated on jarrah, largely ignoring wandoo, powderbark wandoo (*Eucalyptus accedens* W.V. Fitzg.) and marri (*Eucalyptus calophylla* R.Br.). A change in the silvicultural system and a heavy cut of wandoo for firewood could result in increased reservoir salinity; however, a more selective operation may not be economically attractive.

Fourthly, logging may have affected groundwater table salinity, but few samples of groundwater were taken during this investigation. Detailed studies of the effects of heavy logging operations on salt flow in small sub-catchments (150 to 500 ha) are now in progress.

The effects of ringbarking on salinity are considerable, and have persisted for a number of years. Ringbarking differs from logging in that its purpose is to kill most of the trees; regeneration occurs as a result of seed shed or lignotuberous advance growth. Logging is a more selective operation, removing fewer trees and leaving some species (such as marri) undisturbed; regeneration occurs from seed, by advance growth and by suckers from the cut stump, and is usually rapid.

Although the stream sampling technique is useful for comparing the effects of different land uses, its value as an indicator of the groundwater salinity, and therefore as a predictive tool, is questionable. Many of the streams sampled do not appear to be fed by the groundwater table (effluent), but flow only during periods of high rainfall (influent), so that their base flow salinity may not be an accurate indication of the salinity of the adjacent aquifers. Underestimates by a factor as great as 60 have been observed.

The most accurate method of predicting salinity increases in a particular area involves recording salinity changes in adjacent and similar areas. Although the base flow salinity of many streams in the eastern section of the Helena Catchment is less than 500 $mg \cdot l^{-1}$, this area cannot necessarily be considered salt-free, for adjacent catchments which are partially cleared for farming have saline base flows. Evidence indicates that most of the Helena Catchment is susceptible to an increase in salt flow resulting from inappropriate land use.

The flushing effect observed in the reservoir in years of above-average rainfall is short-lived, and has occurred much less frequently since the gates were fitted in 1959. Reservoir salinity in December 1976 was 380 $mg \cdot l^{-1}$, having increased by 160 $mg \cdot l^{-1}$ in the 18 months following the overflow which occurred during the winter of 1974, and as the salinity of the water is already high by present water supply standards, all land use activity in the Catchment area must be examined critically.

Of the 4700 ha which have been cleared (estimated by aerial photography in December 1972), 68% is privately owned and farmed. The other 32% is under governmental control. Of this, approximately 590 ha are State Forest, and various types of revegetation are occurring. An area cleared for pine planting (between sites 85 and 86) is regenerating to native forest; this regeneration is adequate and no further action is considered necessary. Other areas have been replanted with pines or with eucalypts.

The remaining 930 ha are part of several farms repurchased by the P.W.D. and are controlled by that organisation. Even though previous work with pines suggests that control of salt flow may not be achieved for some time after replanting, serious consideration should be given to artificially revegetating the cleared sections of these farms with a deep-rooted perennial crop. Experimental reforestation with eucalypts and pines is being carried out in some areas.

Alternatives regarding the cleared privately owned land are: repurchase by the Crown; encouraging the practice of agricultural techniques which use more water; or taking no action at all. However, the 4300 ha (57%) of privately owned land which are not yet fully cleared are of greater importance than the cleared areas. The effects on stream and reservoir salinity, were these areas to be fully cleared, are likely to be considerable. Preventive measures, which would affect only a few farm owners, include repurchasing all the uncleared privately held land or banning further clearing.

Alternative management strategies for controlling reservoir salinity are also available. These include diluting marginal waters with purer supplies; removing the gates to increase flushing; changing the current salinity standards; investigating the possibilities of reservoir mixing and drawing water from the least saline strata; scouring the higher density, saline flows; studying the effects of the recently completed pumpback scheme from the lower Helena pipehead dam; and increasing surface flow of fresh water from the critical areas close to the reservoir.

CONCLUSIONS

In view of the trends in salinity levels and the importance of the reservoir, it is concluded that:
(1) all cleared areas under Crown control (930 ha) be revegetated with a deep-rooted perennial crop as soon as possible;
(2) any further clearing of privately owned land be temporarily prohibited;
(3) any proposed new forestry practice be thoroughly investigated before it is implemented on an operational scale;
(4) further data be collected for the accurate appraisal of alternative reservoir management strategies.

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