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WORKSHOP ON LAND USE

AND STREAM SALINITY

WORKSHOP ON LAND USE AND STREAM SALINITY

to be held at the CSIRO Seminar Room,
Floreat Park, Tuesday 8 June, 1976.

The workshop is jointly sponsored by:

The Department of Conservation and Environment

The Commonwealth Scientific and Industrial Research Organisation

The Public Works Department

NOTE: Matters expressed within these papers are not to be quoted without prior reference to the particular author.

PROGRAMME

Chairman - M.J. Mulcahy

8.30 - 8.40	Introduction (D.B. Collett)
8.40 - 9.15	Groundwater Studies (B3, B4, W4, C)
9.15 - 9.50	Discussion
9.50 - 10.10	Morning Tea
10.10 - 10.50	Stream Sampling (B7, W1, W3, F)
10.50 - 11.30	Discussion
11.30 - 11.45	Rehabilitation (B5)
11.45 - 12.00	Discussion
12.00 - 1.20	Lunch
1.20 - 1.45	Paired Catchments (B6, W2, C)
1.45 - 2.10	Discussion
2.10 - 2.40	Modelling (B1, B2, P)
2.40 - 3.10	Discussion
3.10 - 3.30	Afternoon Tea
3.30 - 3.50	Summary (J.W. Holmes)
3.50 - 4.55	General Discussion
4.55 - 5.00	Conclusion

B - Bauxite mining projects

W - Woodchip projects

C - CSIRO projects

P - PWD projects

F - Forests Department projects

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RESEARCH INTO THE EFFECTS OF BAUXITE MINING IN THE DARLING RANGE

PROJECT 3: GROUNDWATER STUDIES IN REHABILITATED MINED AREAS

by A.S. Harley, Geological Survey of W.A.

ABSTRACT

Grids of bores were drilled over three mined areas to study the groundwater response to mining and rehabilitation. Preliminary data show that a groundwater mound will build up rapidly below and down-slope of the pit after clearing and mining, due to both absence of transpiration and increased infiltration. As the regeneration becomes established so the mound will decrease, and may become a trough within several years. The groundwater discharge below the mine pit can initially be up to several times that of the original discharge and will be fresher in quality. The highest salt storage values are generally in the top ten metres of the soil profile and are independent of the position of the water table. The salt in storage is predominantly sodium chloride.

INTRODUCTION

An inter-departmental panel examined the Alcoa mining areas at Jarrahdale and Del Park and selected three sites for intensive grid drilling and groundwater monitoring (Project 4, Fig.1). The sites lie on the sides of youthful valleys in the high rainfall jarrah/marri forest, which is severely affected by dieback. They are dissimilar with respect to the pit size, type of reafforestation, and amount of rainfall. Drilling was completed at the Del Park site in autumn, 1974, but the other two sites were not finished until spring, 1975.

BORE COMPLETION

The bores have been cased with 32 mm, 38 mm, or 40 mm P.V.C. Those at Del Park have been slotted below 2 m b.n.s., Location 5 and bores R1 to R8 at Location 6 are slotted over the basal 6 m, and the remainder at Location 6 have been slotted below 3 m b.n.s.

SALT STORAGE

All cores have been analysed for salinity, density, moisture content, and pH. Table 1 shows the average total soluble salt content in the unsaturated, water table fluctuation, and saturated zones. The range is from 0.001% to 0.022% T.S.S. Sodium chloride makes up the bulk of the salt content.

GROUNDWATER MONITORING

Water levels and salinities, and downhole salinities, have been monitored on a monthly basis since April, 1974, at Del Park, June, 1975, at Location 5, and October, 1975, at Location 6.

(i) DEL PARK MINE SITE, AREA 9

20 bores were drilled by April, 1974, on a south-facing slope. 2 lines of 5 bores were drilled across the pit and into the partially-cleared forest below, and two control lines were drilled in the forest to the west (Fig.1). Four bores were cored and a further two partially cored.

Geology

The bores were designed to penetrate through the overburden to the fresh bedrock. However only 3 went into fresh bedrock, but a further 6 went into recognisable weathered bedrock. The general profile is of laterite passing into a mottled clay and terminating in granite, granite-gneiss, or dolerite.

Hydrology

Mining was completed in December, 1972, and the area reafforested with Eucalyptus resinifera and saligna by June, 1973. Unfortunately the pre-mining groundwater configuration is not known, however, as the original topographic contours lay on an approximately east-west line with the gradient to the south, it is assumed that the water table was a subdued reflection of the topography.

Contouring of the bore water levels shows that a groundwater mound has built up following clearing and mining (Fig.1). However a complete assessment is complicated by the presence of an inferred north-trending dolerite dyke just to the west of the bores, the forest area south of the pit has been partially cut, and the area to the east of the pit has been cleared.

Figure 2 is a composite of the results from 15 of the bores, the remaining 5 having given only intermittent results due to their drying up in summer or, in the case of bore 3416, vegetable oil has affected the water level probe. The conclusion is that the water table salinity and level is dependent on the amount of rainfall. The delay between the minimum salinity and maximum water level is more apparent than real when the results are broken down further. The fall in the December, 1974, water level may be a sampling error, or could be an event which has not been recognised, such as unusually high temperatures.

The data was further examined on separating the bores into three areas. These are the forest area to the west, the pit area, and the area to the south of the pit which has been partially felled. The water level composites show similar trends but the range in the downslope of the pit bores is different in that in 1974 it shows the minimum fluctuation of the three areas, but the maximum in 1975. This could be because the groundwater recharge has a significant influence on the water level, hence the rise is less affected by the direct recharge from rainfall. The salinity composite of the downslope of the pit bores shows the widest range and this could be due to the relatively shallow depth of the water table below ground level (Table 2), hence rainfall recharge in winter picks up less pellicular salt through the unsaturated zone, and in summer evaporation and possibly transpiration from the vegetation has a greater effect, coupled with increased groundwater salinity as the bores are further down the flow lines.

Bestow (in press) has studied the first year's results and the following are some of his conclusions:-

1. The net recharge to the water table below the mine pit has been estimated by salt balance to average 34% higher than below the forest area. However owing to the basis of the estimate this figure may be up to 13% lower if leaching of salt from the unsaturated zone was still occurring in the forest.

2. Groundwater discharge from below the mine pit is two to three times that of the groundwater discharge from below the forest. This is due to a lack of transpirative loss once water has reached the water table.

3. The development of a large groundwater mound is mainly due to the absence of transpirative loss from the water table and only in minor degree is it due to a greater infiltration.

4. The groundwater mound represents an increase in the groundwater storage and is presently in balance. It may be expected to recede when transpirative use both reduces the accession of water to the water table and increases withdrawal of water from it.

5. The average specific yield is approximately .039 and the hydraulic conductivity is .035 $m^3/day/m^2$.

6. The release of salt from the unsaturated zone in the mine pit is very small, but leaching is taking place in the zone of water table fluctuation. The same may be occurring below the forest.

7. The present salt imbalance is such that 1.22 times as much salt is being discharged downwards of the pit as is received in rainfall.

8. Although there is salt leaching taking place below the mine pit, the lack of transpirative loss from the water table means that the additional salt is discharged in a larger quantity of water, and hence is diluted to a salinity that is now lower than that of the main body of groundwater.

(ii) JARRAHDALE MINE SITE, LOCATION 5 (ALCOA CRAIGS RIDGE 6 AND 7)

30 auger holes and 4 cored holes were drilled by June, 1975, in six lines down a southwesterly slope in an old mining area northwest of the Jarrahdale mine office. The remaining 4 cores holes were drilled in September, 1975. Figure 3 shows the layout of the cored and augered holes in the two pits and in the control forest area.

Geology

Only the cores have been geologically logged and these show that the laterite is up to 5 m thick, passing down into mottled sandy clays, and terminating in a weathered bedrock of granite, gneiss, or dolerite.

Hydrology

Mining in the western pit (C.R. 6) was finished in July, 1971, and replanted with E. microcorys by July, 1972. Mining in the eastern pit (C.R. 7) was finished by June, 1970, and replanted with E. globulus by July, 1972.

Unfortunately there is no record of the original groundwater configuration before or immediately after mining, but it is assumed that the pre-mining water table was a subdued reflection of the topography.

Figure 3 shows the potentiometric contours for September, 1975, the first time that it was possible to monitor all the bores. The potentiometric surface is more complex than that at Del Park, and in addition a number of the higher bores are dry or have a damp bottom due to either pellicular or capillary water. A low groundwater mound appears to have built up downslope of the pit in C.R. 7. However in the eastern portion of the C.R. 6 pit there is the suggestion of a trough forming. The difference in the groundwater configuration in the two pits is probably because the E. microcorys is far more advanced in growth than E. globulus, hence the transpiration is much higher. The density of the tree planting in C.R. 6 might also be slightly greater. Because the C.R. 6 pit is so much greater in area than that of C.R. 7 one could expect changes to the groundwater table to be more extreme. This may be shown by continued monitoring.

The reduced water table levels and salinities were plotted as a composite of all the results, and then the bores were divided into three groups, according to whether they were in the pits or the forest, and the monitoring results plotted as group composites. Some of the bores has to be ignored because they were dry or dry for part of the period.

Between September, 1975, and January, 1976, the C.R. 6 pit bores had the greatest fall in water level and the C.R. 7 pit bores had the lowest fall, which suggests that the evapotranspiration is highest in the C.R. 6 pit. Another feature is that the salinity has not risen very much in response to summer conditions. This was also seen in the results from two of the areas in the Del Park study. However some of the water levels are within the unslotted section of casing and may not be reflecting true water table salinities.

(iii) LANGFORD PARK, LOCATION 6 (ALCOA RIFLE RANGE A EAST)

6 auger holes (R1 to R6) and two core holes (R7 and R8) were drilled in September, 1975, around and in the mining pit. As the bore layout gave insufficient coverage a further 12 auger bores were put down in November, 1975 (Fig.4).

Geology

Only the 2 cored holes have been geologically logged. In R7 the laterite is about 6 m thick, passing into a predominantly brown clay, whereas the profile in R8 is mainly a mottled sandy clay, suggestive of a more acid rock type, i.e., a weathered granite or gneiss. Neither bore struck bedrock although some parts of the basal core in R8 gave the impression of being very weathered granite.

Hydrology

Mining was completed by May, 1968, and the pit and most of the cleared area around it was replanted with Pinus pinaster by July, 1969.

There are no pre-mining groundwater records, so it is assumed that the water table was a subdued reflection of the topography. Figure 4 shows the potentiometric contours for early December, 1975, the first time it was possible to monitor all the bores. If the assumption that the pre-mining potentiometric contours paralleled those of the topography is correct, then a groundwater trough has formed below and downslope of the pit. This is attributed to both transpiration and interception from the dense pine plantation in and around the pit. It is not certain why a mound has apparently developed between bores R12 and R18, but this could be due to additional recharge from off the haul road which has not been planted, and the lack of transpiration from the area around R12 which was cleared but not replanted.

From October, 1975, the water levels have fallen consistently and the salinities have generally risen.

CONCLUSIONS

1. After clearing and mining a groundwater mound will rapidly build up below and downslope of the pit due to both the absence of transpiration and to a lesser extent greater infiltration.

2. Groundwater discharge from below the mine pit will initially be up to several times that of the original discharge due to the lack of transpiration loss.

3. In the high rainfall areas the groundwater discharge from below the pit is fresher than before mining, due to the increase in volume of water.

4. Present studies at Del Park indicate that about 20% more salt is discharged in the groundwater downslope of the pit than is being received in rainfall. However as the volume of water has increased the concentration of salt will be less than that under pre-mining conditions.

5. As the regeneration becomes established so the groundwater mound will decrease and can become a trough. This is due to transpiration reducing the accession of recharge to the water table and increasing withdrawal from it, and to a lesser extent interception.

6. The drawdown of the groundwater mound will depend on the density and type of vegetation planted.

7. The increase in water usage by the regrowth will decrease the groundwater discharge and increase the salinity.

8. A significant trough has developed at Langford Park within 6½ years of planting Pinus pinaster. There also appears to be a trough forming under the C.R. 6 pit at Jarrahdale after 3 years of planting E. microcorys.

9. Modelling of the Del Park results indicates that leaching of salt is taking place in the zone of water table fluctuation. However, other results suggest that all the salt in storage is not necessarily mobilized.

10. Results from Del Park indicate that the average specific yield is 0.039, and the hydraulic conductivity is 0.035 $m^3/day/m^2$.

11. Studies indicate that the water table reaches its maximum height in early spring and falls to its minimum in late autumn. However, the timing is very dependent on the rainfall pattern.

12. Water table salinities are less predictable than the water levels, but they generally have an inverse relationship to the water levels.

13. The greatest salt storage values are generally in the top ten metres of the soil profile, and are independent of the position of the water table.

14. Sodium chloride generally accounts for the bulk of the salts stored in the soil profile.

15. At the present time the mined areas appear to cause little concern with regard to groundwater salinity problems.

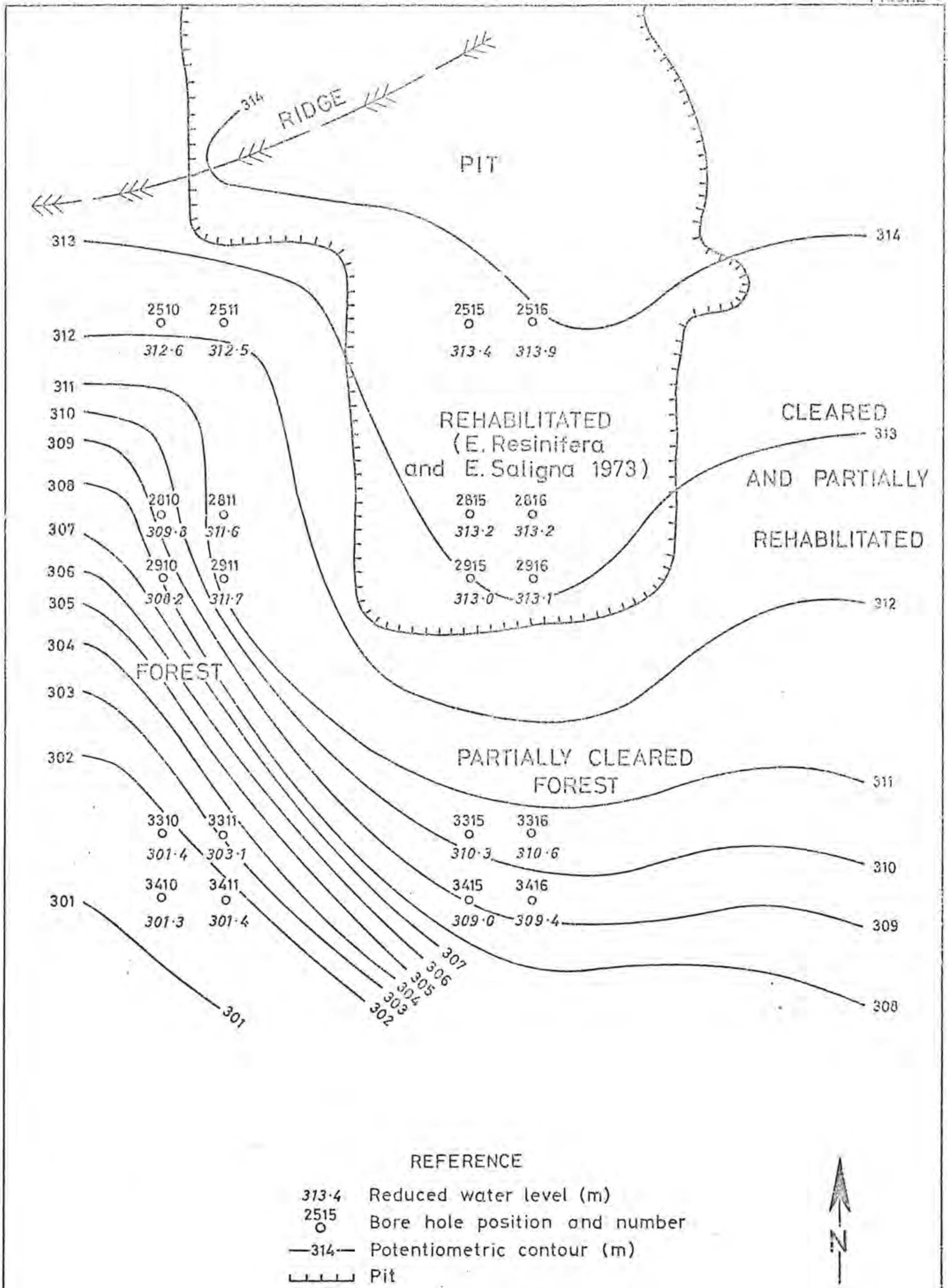
TABLE 1. BAUXITE MINING: PROJECT 3. ARITHMETIC MEANS OF THE TOTAL SOLUBLE SALTS (%) AND pH.

(*Less than 50% of section sampled)

	DEL PARK (AREA 9)							LOCATION 5, JARRAHDALE							LOCATION 6, LANGFORD PARK	
BORE (P = PIT BORE)	2810	2816P	3310	3311	3315	3415	J.1P	J.5P	J.10P	J.18	J.23	J.25	J.31P	J.35P	R.7	R.8P
Unsaturated zone (1) T.S.S.%	0.005	0.003	0.004	–	0.011	–	–	0.004	0.002	0.003	0.003*	0.003	0.003	0.003	0.002	0.006
pH	5.4	5.0	5.2	–	5.8	–	–	5.9	5.4	5.0	5.4*	5.0	5.0	5.4	5.2	4.9
Zone of water table fluctuation (2) T.S.S.%	0.005	0.004*	0.011	–	0.007	0.006*	0.005*	–	0.003	0.004*	0.004	0.004	–	0.005	–	–
pH	5.1	5.2*	4.7	–	4.6	4.7*	4.9*	–	5.4	5.85*	5.4	5.0	–	5.1	–	–
Saturated zone (3) T.S.S.%	–	–	0.011*	0.010*	0.015*	0.009*	0.009	–	0.008	–	0.007	0.003	–	0.007	–	–
pH	–	–	4.9*	4.9*	4.75*	5.1*	4.9	–	4.8	–	5.5	5.1	–	5.5	–	–
Maximum T.S.S.% value	0.011	0.004	0.020	0.014	(0.022) 0.015	0.011	0.011	0.005	0.013	0.006	0.009	0.005	0.007	0.012	0.004	0.016
Depth(m)	7.29 8.14	3.72 4.26 4.95	22.55	15.98	(Surface) 7.80	10.61	7.18	4.34	8.20	10.22 10.69	11.09 11.19	7.58	9.86	11.74	Surface	8.63
Zone	(1)	(1&2)	(3)	(3)	(1) (3)	(3)	(3)	(1)	(3)	(1)	(3)	(1)	(1)	(3)	(1)	(1)

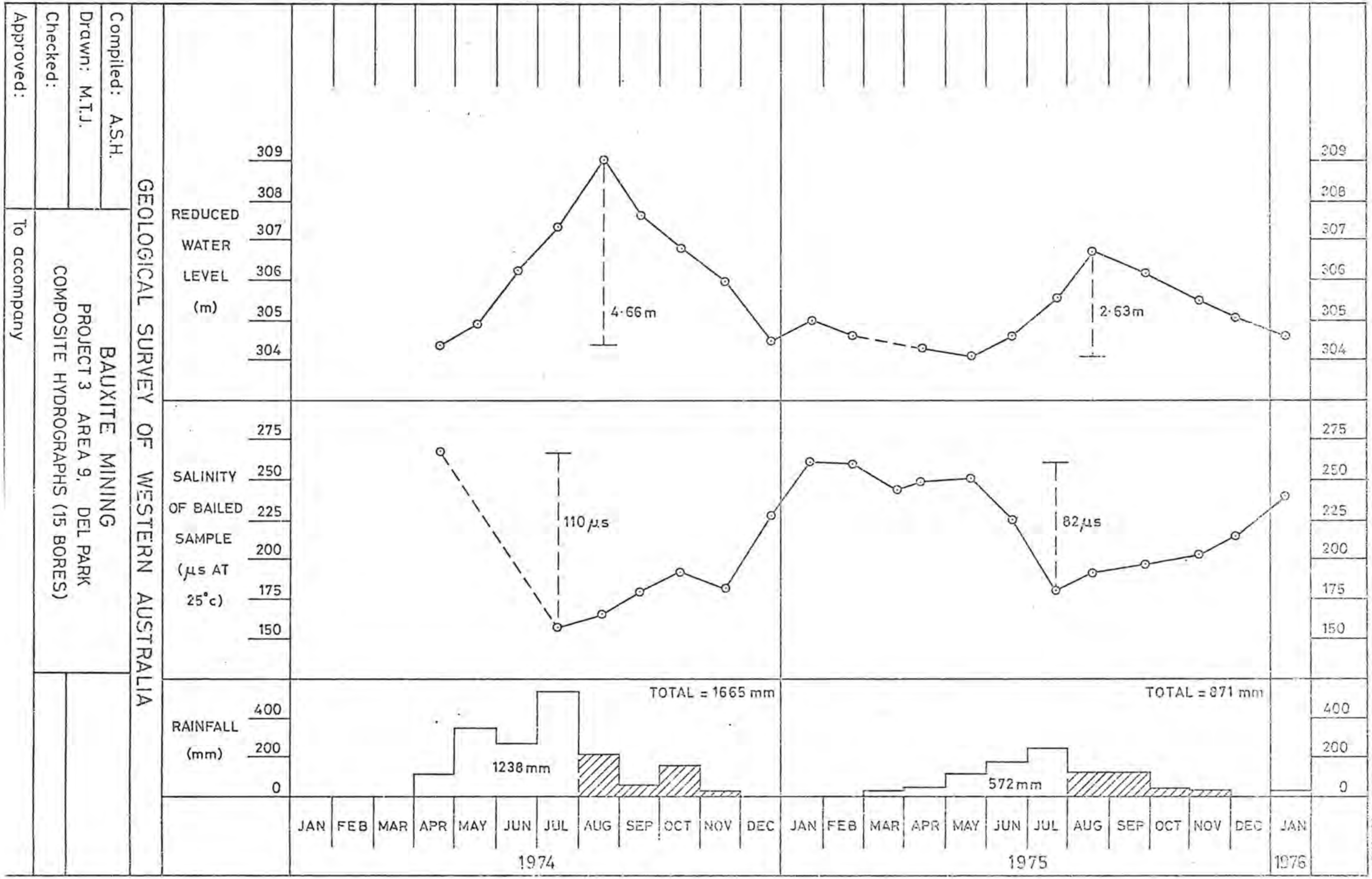
TABLE 2. MAXIMUM AND MINIMUM COMPOSITE WATER LEVELS (b.n.s.)

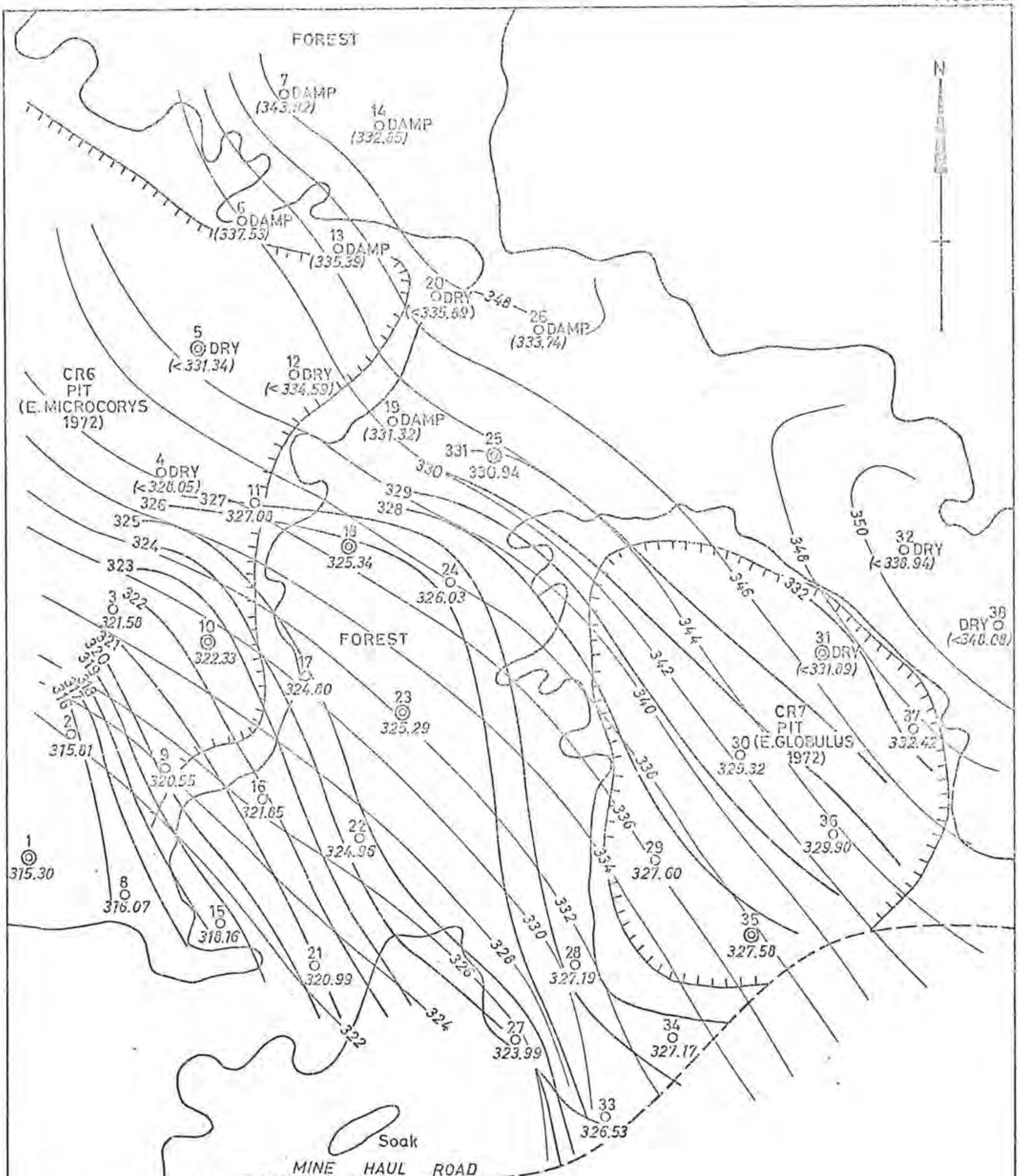
	FOREST BORES	PIT BORES	BORES DOWNSLOPE OF PIT
April, 1974	15.88 m	9.59 m	6.37 m
August, 1974	11.24 m	4.52 m	2.00 m
May, 1975	16.05 m	9.98 m	6.52 m
August, 1975	14.08 m	6.91 m	2.91 m



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

Compiled. A.S.H.	BAUXITE MINING	SCALE 0 20 40 metres
Drawn. D.B.C.	PROJECT 3 AREA 9 – DEL PARK	
Checked.	POTENTIOMETRIC CONTOURS AUGUST, 1974	
Approved.	To accompany	


Compiled: A.S.H.
Drawn: M.T.J.
Checked:
Approved:
To accompany
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
BAUXITE MINING
PROJECT 3 AREA 9. DEL PARK
COMPOSITE HYDROGRAPHS (15 BORES)
REDUCED WATER LEVEL (m)
309
308
307
306
305
304
4·66 m
2·63 m
SALINITY OF BAILED SAMPLE (µs AT 25°c)
275
250
225
200
175
150
110 µs
82 µs
RAINFALL (mm)
400
200
0
TOTAL = 1665 mm
1238 mm
TOTAL = 871 mm
572 mm
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN
1974
1975
1976
FIGURE 2

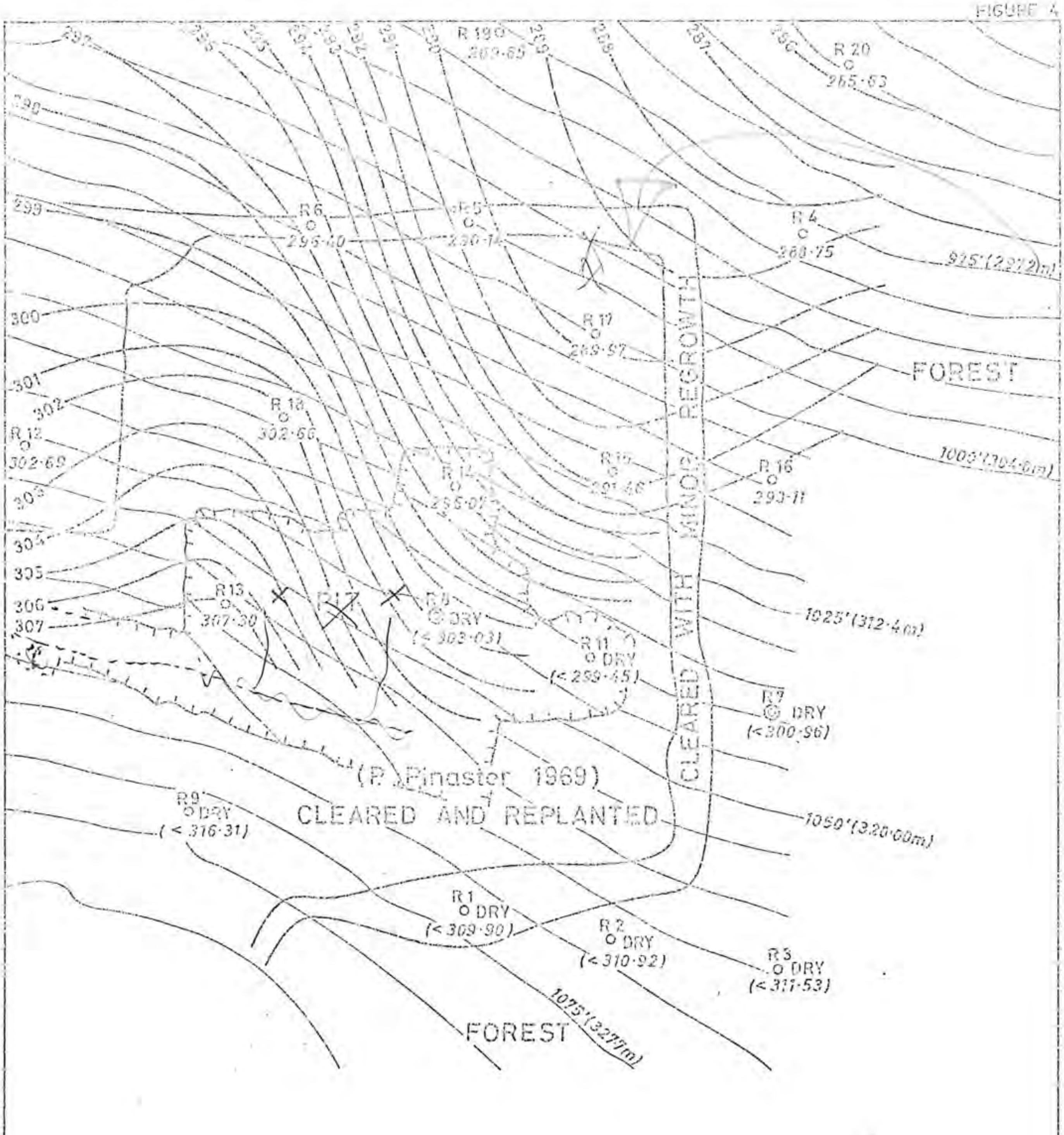


REFERENCE

325.29	Reduced water level (m)	———	Edge of forest clearing
◎ 5	Core drill hole position and number	⊥⊥⊥⊥⊥	Pit
○ 2	Auger drill hole position and number	—327—	Potentiometric contour (m)
—326—	Pre-mining topographic contour (m)		

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

Compiled: A.S.H.	BAUXITE MINING	SCALE 0 50 metres
Drawn: M.T.J.	PROJECT 3 LOCATION 5 JARRAHDALE	
Checked:	POTENTIOMETRIC CONTOURS SEPTEMBER, 1975	
Approved:	To accompany	



REFERENCE

- 302·66 — Reduced water level (m)
- ◎ R8 — Cored bore position and number
- ○ R18 — Auger bore position and number
- —292— Potentiometric contour (m)
- —975'— Topographic contours in 5 feet intervals
- ⊔⊔⊔ Pit boundary

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

Compiled: A.S.H.	BAUXITE MINING	SCALE 0 20 40 60 metres
Drawn: D.B.C.	PROJECT 3 LOCATION 6 – LANGFORD PARK	
Checked:	POTENTIOMETRIC CONTOURS DECEMBER, 1975	
Approved:	To accompany	

RESEARCH INTO THE EFFECTS OF BAUXITE MINING IN THE DARLING RANGE

PROJECT 4 : GROUNDWATER STUDIES IN FUTURE MINING AREAS.

by A.S. Harley, Geological Survey of W.A.

ABSTRACT

Eight sites north and east of Dwellingup,and a site east of Kirup, have been drilled as part of a medium to long term project in future bauxite mining areas. Preliminary salt storage analyses show that the high rainfall areas will probably not be a future groundwater salinity problem, whereas the medium rainfall areas will be more prone to at least temporary increases in groundwater salinity in the small sub-catchments studied. Some results indicate that not all the salt in storage is necessarily mobilised. The salt in storage is predominantly sodium chloride, and the highest values are often in the top ten metres of the soil profile.

INTRODUCTION

This is a medium to long term project designed both to study the effects of mining and rehabilitation on a known groundwater situation, and to define areas where mining might have a deleterious effect on the groundwater due to mobilisation of salt in storage.

The main areas of studies are at the Huntly minesite in the high rainfall, jarrah/marri forest, in a similar situation to the Project 3 minesites, and along a transect east of Dwellingup on the sides of mature valleys in the high to medium rainfall, die-back-free jarrah forest (Fig.1). A smaller study is being carried out at a site east of Kirup in the medium rainfall, jarrah/marri forest.

An inter-departmental panel examined the Dwellingup area and chose the locations. The two sites at Huntley were drilled in autumn, 1975. Six sites on the Dwellingup transect were exploratorially drilled in autumn, 1976, and two of these sites have been more intensively drilled. A further site will be grid drilled next spring in the Project 6 catchment pair yet to be chosen in the medium rainfall area.

(i) HUNTLY MINESITE

Two areas are under investigation at the minesite, the northern one is on the western side of a shallow dissected tributary of the Little Dandalup Creek, and the other is on the northern side of a more deeply dissected tributary of the South Dandalup River (Fig. 2).

Two lines of bores were drilled at each site, with one bore on each line a cored hole, the remainder solid auger holes. On each site one of the lines was designed to act as a control. Drilling was completed by May, 1975.

However, the study has been considerably complicated. Both the northern area and part of the southern area were partially cleared for logs in May, 1975. The southern area is now not to be mined, apart from bore H9. In the northern area everything was cleared up to within 15 m of bores H1A to H4 in February, 1976, and this is soon to be extended up to the track, although mining will not begin until spring. The control line from H6 to H8 will then be cleared and mined a year later.

GEOLOGY

The cores show that the laterite is up to 9 m thick on the upper slopes but thins considerably to the valley floors. Mottled clay and sandy clay underlie the laterite, and the bedrock appears to be generally a micaceous granite. A weathered dolerite was intersected in one of the bores.

COMPLETION

The bores have been completed with 32 mm P.V.C. casing with only the basal 6 m slotted, except for bore H1 which was slotted over 12 m.

SALT STORAGE

The cores have been analysed for salinity, density, moisture content, and pH. Table 1 shows the average total soluble salt content over 5 m intervals to bedrock. The range is from 0.001% to 0.092% T.S.S. The cores from the southern area are slightly more saline than those from the northern area, and in all the cores, except those from H9 and in the salt bulge in H16, the total soluble salt is nearly completely sodium chloride.

Of particular interest is the fact that the highest soil salinities occur in the zone of water table fluctuation in bore H16, which lies near the bottom of the slope in undisturbed forest, presumably under stable hydraulic conditions. The average pellicular moisture salinity over this zone is 6 300 µs, yet the highest water table salinity recorded is 890 µs, which suggests that the salts in these salt bulges are not necessarily mobilised by the groundwater.

GROUNDWATER MONITORING

Water levels and salinities, and downhole salinities, have been monitored on a monthly basis since May, 1975.

HYDROLOGY

Unfortunately the groundwater table will be affected by the partial felling, so the 'undisturbed' pre-mining groundwater configuration is not known. However, Figure 2 shows the potentiometric contours for June, 1975, the first full set of results after drilling and only about a month after the partial felling.

In the northern area the potentiometric contours swing across the topographic contours due to the influence of the creek. However in the southern area the potentiometric contours show that the water table is a subdued reflection of the groundslope, and hence it appears that the postulated form of the pre-mining potentiometric surface at Del Park, Jarrahdale, and Langford Park is essentially correct. Subsequent monthly potentiometric contours in both areas are similar in form to those shown in Figure 2.

Reduced water level and salinity composite curves for the bores from each of the two areas have been drawn. These show that water levels reached a maximum in September/October and then have fallen fairly consistently. It is interesting that although the groundwater gradient is steeper in the southern area there is less vertical movement during the year, possibly because of the lower elevation. H9 has been excluded because the water table has steadily risen since clearing in October. H8 is odd in that it has risen since October, which might be in response to the general partial clearing in the area.

The salinity graphs are more complex. They appear to show a more rapid response to rainfall, but it is not known why the composite salinities suddenly increased in August, fell again, and have shown little variation since. One problem is that in most cases the water table is above the slotted section.

(ii) KIRUP

Three bores were drilled in the Mullalyup Brook valley about 9 km east of Kirup as part of an investigation of a heavy mineral and kaolinite claim. However, there are no immediate plans to mine the area for bauxite. K1 is near the divide, K2 is midslope, and K3 is on the valley floor.

GEOLOGY

Only K2 intersected any laterite, although laterite does occur around K1 and the top 2½ m of core were not recovered. K3 passed through about 1½ m of alluvial sand. In bores K1 and K2 over 20 m of mottled micaceous sandy clay were drilled and they bottomed in mica-schist, whereas K3 went through a thinner section of greeny-grey clay and bottomed in a weathered gneiss.

COMPLETION

All bores were cased with 32 mm P.V.C. and the basal 6 m was slotted.

SALT STORAGE

The cores have been analysed for salinity, density, moisture content, and pH. Table 1 shows the average total soluble salt content over 5 m intervals to bedrock. The range is from 0.001% to 0.158% T.S.S. Generally the T.S.S. % is made up of only sodium chloride.

All three bores had a significant salt bulge but at different levels in relationship to the water table. There appears to be an overall increase in soil salinity downslope.

GROUNDWATER MONITORING

Water levels and salinities have been monitored on a monthly, or more frequent, basis since June, 1975, and the creek just below K3 has also been concurrently sampled.

HYDROLOGY

No potentiometric contours can reasonably be drawn as the bores are over 1 000 m apart on very different levels. However, the individual bore reduced water levels and salinities have been analysed. These show that although K1 and K3 are the furthest apart both in distance and elevation their hydrographs are more similar than that of K2, this similarity between K1 and K3 could be due to their proximity to the creek. K2 shows the greatest range of water-level (3.4 m) and appears to respond fastest to recharge.

The groundwater salinities are relatively dissimilar. Over the period June, 1975, to January, 1976, salinities in K1 fluctuated between 986 μs and 1 086 μs, K2 between 275 μs and 361 μs, and K3 1 987 μs and 2 617 μs. The creek ranges between 512μ s and 3 128 μs. However, the fact that the casing is only slotted over the basal 6 m could make the readings slightly spurious. Although K1 is nearer the divide it has a higher average soil salinity in the saturated zone which may account for the water salinity being higher than that in K2.

Salt storage analysis from the K3 cores show that the average pellicular moisture salinity in the zone of water table fluctuation is 10 670 μs compared to 1 480 μs over the basal 6 m slotted section. The monitored groundwater salinity is much lower than the former but higher than the latter. It will be interesting to see what the base flow salinity of the creek will be.

In conclusion there is a fair range of groundwater salinity and some of the salt storage values are significant.

(iii) DWELLINGUP TRANSECT SITES 1 TO 6

As part of the long term programme 6 sites are being investigated on a transect approximately east of Dwellingup in the medium rainfall jarrah/marri forest. (Fig.1). Alcoa's present plans are to mine Site I in 1982, and then move progressively eastwards. One problem has been that as the area is a relatively long term mining proposition from Alcoa's point of view, and in the quarantine area, the ore bodies have not yet been fully defined, and so placing the sites has been difficult.

Initially the plan was to drill 4 cored holes at each site covering the top-slope, mid-slope, and bottom-slope topographic situations, analyse the results, and then on 3 sites drill a further 5 cored holes and 20 solid auger holes in a grid pattern transecting an ore body. Drilling began in December, 1975, but, because of the need to finish as many sites as possible before winter quarantine restrictions two sites had to be picked for the grid drilling before the initial programme was completed.

Site 1 (Fig.3) was selected for further drilling because the two top-slope bores had relatively high soil salinities. In order to determine the position of the grid a series of vacuum bores were drilled, and the area to the south was eliminated because of the resulting low soil salinities. For correlation purposes several vacuum holes were drilled around two cored holes and the vacuum sample soil salinities compared well with the core analyses.

Site 4 was selected for various reasons, and was in fact moved further northwest down the valley from its original position to cover a possible ore body, due to the availability of an Alcoa plan showing the approximate ore body position.

At the present time the initial coring programme and the grid drilling on sites 1 and 4 have been finished. Grid drilling near or at site 6 has been delayed until next spring.

The only results to hand are the soil analyses for which the average T.S.S. % has been calculated for each 5 m interval (Table 1). Based on these figures the following conclusions can be made.

(i) There is a general easterly trend of increasing salt in storage. However, site 1 is higher than either sites 2 or 3, which have very similar values.

(ii) The highest values and the highest 5 m interval average in each bore are generally in the top 10 m.

(iii) There is no consistency in the topographic position of the most saline bore on each site. However, on site 4 the most saline bore on the two cored lines is in approximately the same topographic position (mid-slope).

(iv) Sodium chloride generally accounts for the bulk of the T.S.S. % figure.

CONCLUSIONS

1. At the present time Huntly does not appears to involve a future groundwater salinity problem.
2. Kirup could be more of a problem because of the wide range of water salinities found between the three bores and the creek.
3. There appears to be a general easterly trend of increasing salt in storage from Huntly to site 6.
4. The greatest salt storage values and the highest five-metre interval averages are often in the top ten metres of the soil profile.
5. Evidence from Huntly and Kirup suggests that not all the salt in storage is necessarily mobilised, and this would imply that the groundwater is flowing along preferred paths both in the horizontal and vertical directions.
6. Sodium chloride generally accounts for the bulk of the salts stored in the soil profile.
7. Vacuum drilling appears to be a reliable cheap method of investigating soil salinities above the water table.

ACKNOWLEDGEMENTS

Alcoa's cooperation with the drilling, and Forests Research for analysis of the soil salinities.

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PROJECT 4 - AVERAGE T.S.S. % PER 5 METRE INTERVAL

TABLE 1

Bore	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	Maxi-mum Value	Depth (m)
HUNTLY MINESITE											
H.1	0.002	0.008	0.009	0.007	0.007	0.007*				0.011	(6.51 (11.07 (11.83 (17.15
H.8	0.007*	0.002	0.005	0.005	0.008*					0.012	21.64
H.9	0.005	0.003	0.004	0.006	0.014	0.011	0.014*			0.021	30.66
H.16	0.023*	0.037	0.008	0.005	0.005	0.004*				0.092	5.73
DWELLINGUP TRANSECT											
1/1 (East)	0.080	0.121	0.040	0.020	0.034	0.025	0.014			0.177	4.92
1/1	0.023	0.057	0.039	0.033						0.091	8.75
1/2	0.002	0.003	0.003	0.004	0.004	0.006	0.010	0.008		0.012	(30.84 (32.36
1/3	0.005	0.010	0.019	0.008	0.007	0.006	0.005	0.005	0.004*	0.028	13.37
1/4	0.028	0.009	0.009	0.009	0.007	0.006	0.004*			0.079	4.19
2/1	0.006*	0.001	0.001	0.004	0.004					0.011	Topsoil
2/2	0.004*	0.005	0.007	0.010	0.008	0.019*				0.019	25.04
2/3	0.011	0.034	0.008	0.005	0.004	0.003	0.003			0.053	5.69
2/4	0.011	0.010	0.007	0.004						0.013	3.48
3/1	0.008*	0.002	0.002	0.003	0.005	0.005	0.009*			0.013	Topsoil
3/2	0.013*	0.004	0.003	0.002	0.003					0.013	Topsoil
3/3	0.005	0.002	0.006	0.012						0.014	(15.74 (16.50
3/4	0.025	0.011	0.007	0.007	0.007	0.007*				0.049	4.09
4/6	0.003*	0.003	0.009	0.013	0.016	0.017	0.013	0.010*		0.023	26.97
4/7	0.004*	0.008								0.013	Topsoil
4/8	0.015	0.042	0.012	0.012	0.011	0.009	0.006*			0.120	6.65
4/9	0.014*	0.014	0.010	0.011	0.010	0.009	0.011*			0.030	7.23
4/10	0.023	0.030	0.016							0.068	4.98
4/21	0.004*	0.003	0.010	0.026	0.061	0.026	0.010	0.011	0.015*	0.071	24.67
4/22	0.005*	0.002	0.006	0.007	0.011	0.012	0.013	0.012		0.014	23.34
4/23	0.174*	0.204	0.026	0.013	0.013	0.012	0.008			0.357	5.71
4/24	0.003*	0.028	0.011	0.010	0.011	0.006	0.007*			0.054	5.83
4/25	0.053	0.014	0.009	0.009	0.007	0.007				0.124	3.38
5/1	0.003	0.013	0.077	0.062						0.088	14.02
5/2	0.003	0.003	0.025	0.051	0.043	0.037*				0.075	17.23
5/3	0.004	0.047	0.068	0.045	0.049					0.118	9.66
5/4											
6/1	0.003	0.006	0.047	0.042	0.017	0.012	0.013	0.016	0.013*	0.076	14.83
6/2	0.008	0.016	0.119	0.114	0.061	0.025	0.020			0.155	12.45
6/3	0.056	0.217	0.040	0.034	0.036	0.037	0.036			0.407	6.52
6/4	0.051	0.012								0.125	1.81
KIRUP											
K.1	0.008*	0.006	0.006	0.028	0.006	0.004*				0.039	17.12
K.2	0.002	0.041	0.055	0.018	0.011	0.007	0.003			0.125	9.23
K.3	0.036	0.097	0.024	0.014						0.158	(5.26 (5.80

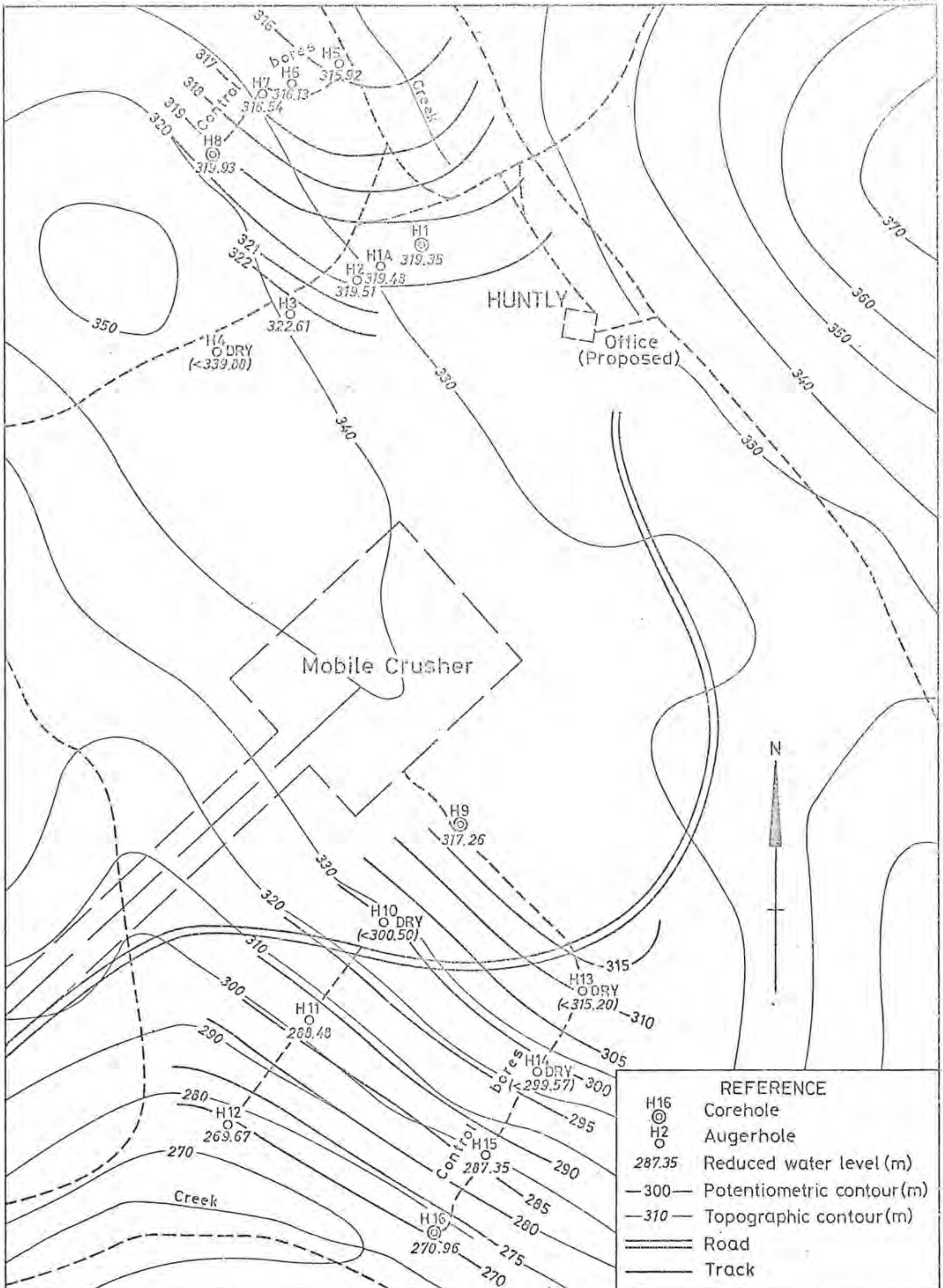
*Less than 50% of interval sampled.

FIGURE

BAUXITE MINING PROJECTS 3 AND 4 LOCATION PLAN

PINJARRA 1:250,000 TOPO. MAP (SI 50-2)

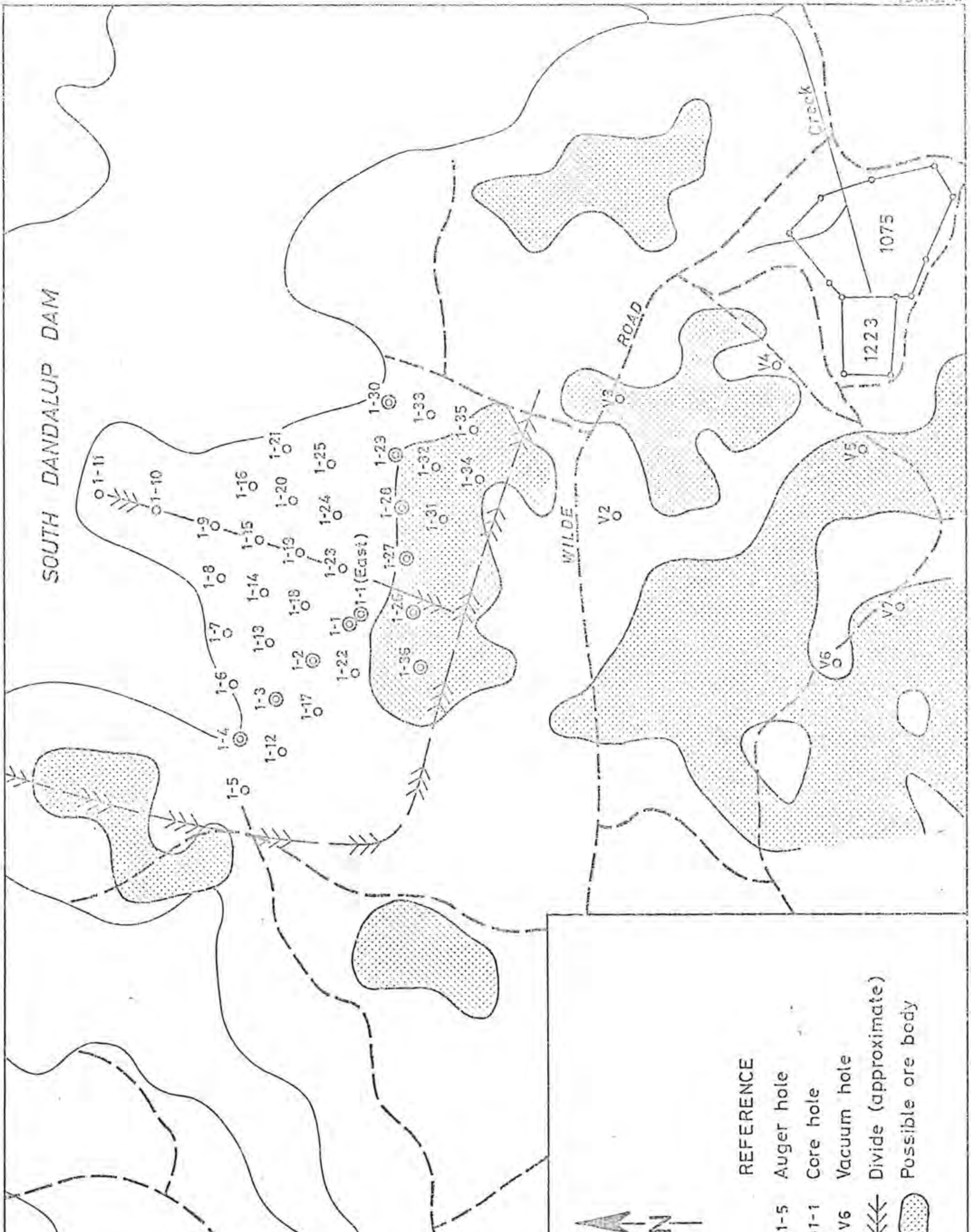
☐ PROJECT 3 ○ PROJECT 4



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

Compiled: A.S.H.	BAUXITE MINING	SCALE 0 100 metres
Drawn: M.T.J.	PROJECT 4	
Checked:	HUNTLY MINESITE POTENTIOMETRIC CONTOURS, JUNE 1975	
Approved:	To accompany	

FIGURE 3



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

Compiled: A.S.H.	BAUXITE MINING	SCALE 0 200 400 metres
Drawn: D.B.C.	PROJECT 4 SITE 1	
Checked:	DWELLINGUP TRANSECT	
Approved:	To accompany	

GROUNDWATER STUDIES IN THE MANJIMUP WOODCHIP LICENSE AREA

P.C. Kimber and D. Whiteley (1)

ABSTRACT

The first year's work in establishing hydrological studies in five cutting coupes is described. The coupes cover the range of rainfall/forest combinations found in the area. Summarised data of the first year's monitoring is presented. They are considered inadequate to characterise the different coupes until a further year's data have been accumulated.

Core analysis from groundwater bores demonstrated that salt loads in the soil profile varied greatly within a coupe. The salinity risk should be judged from the mean salt load of all the bores within a coupe.

1. INTRODUCTION

The objectives of the study are to determine the effects of heavy cutting in dry sclerophyll (jarrah dominated) forest and clear cutting in wet sclerophyll (karri dominated) forest on the following hydrological factors.

a) Salt content and fluctuations in level of the ground water table.

b) Yield, salinity and sediment load changes in streamflow.

Monitoring to determine pre-cutting hydrological characteristics is planned to cover two years. Cutting will take place in summer 1976-77 and post cutting measurements will continue for at least two years.

2. ESTABLISHMENT

2.1 Selection of study areas.

Sub catchments, which also constituted entire felling coupes, were selected throughout the broad range of combinations of forest type and rainfall represented in the woodchip license area.

An apparently comparable area was selected adjacent to each coupe to remain as an uncut control.

(1) Forests Department, Manjimup.

TABLE 1 Coupe characteristics

Name	Estimated Rainfall mm/an	Soils	Forest types
Crowea	1400	Mainly red earths. Yellow podsols on upper slopes to west and south	Karri, grading to marri/ jarrah mixture on podsols.
Poole	1200	Mainly red earths. Yellow podsols on upper slopes to N and W.	Karri, grading to marri/ jarrah mixture on podsols.
Iffley	1250	Mainly gravelly podsolics and lateritic gravels. Strong laterite influence.	Jarrah/marri mixture.
Leeuwin	1150	Not surveyed.	Jarrah/marri mixture. Karri on depositional soils of valley.
Mooralup	860	Yellow and red podsols. Slight lateritic influence at head of catchment.	Jarrah/marri mixture.

Low rainfall jarrah forest was excluded from the study as results from Project 2 (paired catchment) studies in the zone would be available early enough for practical application.

The characteristics of the coupes are listed in Table 1.

2.2 Groundwater bores

Ten bores were drilled in each coupe on a grid pattern (see Legend to Table 4). An additional 2 bores were drilled in each control area. Bores were sunk at least 3 metres into the ground water table, or to bedrock where no water table existed.

All bores were cored at approximate one metre intervals. Cores were analysed for bulk density, moisture content, pH, total soluble salts, and sodium chloride. Soil cores were described by Geological Survey Branch, Department of Mines.

2.3 Soil moisture bores

Neutron probe access bores were established at the rate of six per coupe and two in each control area. They were sited in pairs a few metres apart on upper slope, middle slope, and valley floor situations. The control pair was sited on one of these situations.

2.4 Stream gauging weirs

Concrete stream gauging weirs with a metal vee notch were established on the streams draining Crowea, Iffley and Leeuwin coupes in March 1975. Construction of weirs in Poole and Mooralup is nearing completion. Assessment of water level was made by direct reading from a staff gauge. Continuous water level recorders are to be installed.

The stilling pond associated with each weir (except Crowea) has been lined with concrete to act as a sediment trap.

2.5 Rainfall

Six five-inch rain gauges were located across the centre of each coupe beneath the tree canopy.

2.6 Survey

The following surveys are planned or have been completed.

Soils - recently completed
Vegetation - initial survey of dominant species completed. Further detailed surveys are planned to determine total species representation and cover.
Levelling boreheads - in progress
Aerial photography - a) in colour to aid in estimating vegetation cover and type; is in progress.
b) for contouring the coupes; is planned to take place after cutting.

3. MEASUREMENTS

3.1 Field

A summary of measurement techniques and intervals follows.

Item	Method (and accuracy)	Frequency
Ground water bores		
1) Salinity	Bailed sample	Monthly
2) Water table depth	'Plopper' (PWD design) (.01 metre)	Monthly
Soil moisture	Neutron probe	Monthly
Streamflow	Staff-gauge (.005 metre)	3x a week
Stream salinity	Bailed sample	Monthly
Stream-suspended sediment	Bailed sample	3x a week
Rain fall	Standard gauge (.01mm)	3x a week

3.2 Laboratory

Total dissolved solids are calculated from bailed water samples with a Philips PW9504 conductivity meter.

Suspended sediment loads are measured by extraction with a micropore filter and weighing.

3.3 Data handling

All data are recorded on computer work sheets.

Data relating to the flow, salinity and suspended sediment of streams are maintained with a view to relating the various levels of these parameters to cumulative rainfall and to storm rainfall.

4. RESULTS

Monitoring of bore, stream, and soil moisture characteristics has been in progress for less than a year, hence only broad trends may be apparent at this stage.

Leeuwin coupe was withdrawn from the study in December 1975 but some data collected from this coupe are included in the results.

4.1 Ground water bores

The analysis of salt content of the cores from groundwater bores was used to estimate total salt loads in the soil profile. Table 2 lists these estimates.

The coupes can be divided into two groups based on mean salt loads in the soil profile. Crowea, Poole and Leeuwin exhibit relatively light loads of around 100 t/ha or less. Iffley and Mooralup both exceed 300 t/ha.

Within a coupe the salt load varied considerably from bore to bore and only one coupe, Crowea, exhibited uniformly low salt values.

4.1.2 Ground water salinities

Thorough analysis of the data has not been considered worthwhile at this stage. Means and ranges of the levels of total dissolved solids for each coupe are shown in Table 3.

TABLE 3

Salt content of ground water table May 1975 - April 1976

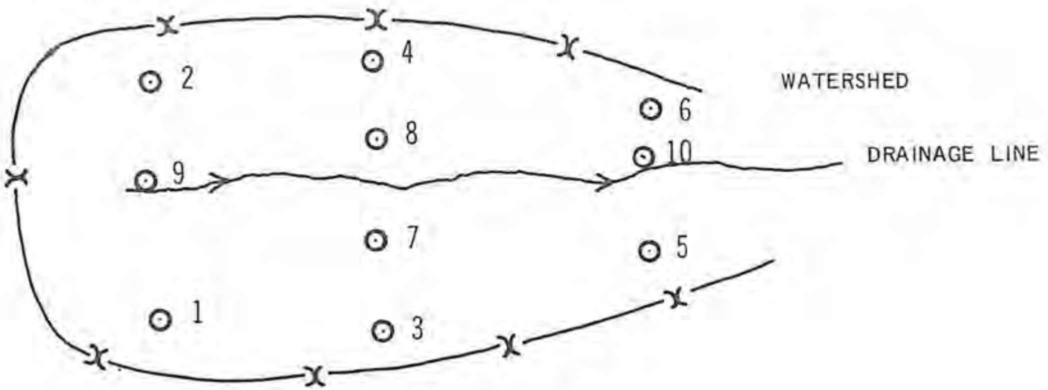
Coupe	No. of bores contributing (1)	Total dissolved solids mg/l	
		Mean	Range
Crowea	9	339	127 - 760
Poole	10	712	296 - 2332
Iffley	11	762	285 - 1583
Leeuwin	11	509	148 - 1280
Mooralup	1	9237	-

Note (1) - The two control bores are included.

TABLE 2 SALT LOADS IN THE SOIL PROFILE

Coupe	Salt load - tonnes/ha (Bore number)										
	1	2	3	4	5	6	7	8	9	10	Mean
Crowea	53.8	34.9	13.4	78.0	40.5	86.1	81.5	20.5	27.9	113.4	55.0 ± 10.48
Poole	N.A.	23.3	23.7	171.8	39.1	161.9	69.7	27.8	33.7	64.6	68.4 ± 19.44
Iffley	542.3	531.2	353.2	180.4	383.7	556.7	29.1	99.6	267.7	146.2	309.0 ± 61.44
Leeuwin	17.3	106.8	112.9	14.6	21.8	210.4	66.5	200.4	72.6	300.4	112.4 ± 30.41
Mooralup	422.9	167.7	426.2	629.0	346.5	404.4	546.5	177.1	73.2	126.0	331.9 ± 59.38

LOCATION OF BORE NUMBERS



The very wide ranges of values recorded in Table 3 parallel the variation of salt loads in the soil profile shown in Table 2.

4.1.3 Fluctuations in the ground water table level

The results of measuring the depth of the groundwater tables are shown in Table 4.

TABLE 4

Fluctuations in ground water tables
May 1975 to May 1976

Coupe	Fluctuation of water level (metres) Mean	Range	No. of bores with no water	No. of flowing bores
Crowea	2.17	0.10 - 5.50	2	1
Poole	3.42	1.00 - 4.50	2	0
Iffley	1.58(1)	1.00 -11.60	1	2
Leeuwin	1.37	0.45 - 4.50	0	2
Mooralup	0.59	0.45 - 0.73	10	0

Notes (1) Mean excluding one aberrant reading of 11.60 metres.
(2) The two control bores are included.

Variation between bores within a coupe was large. Little can be deduced from the between coupe means at this stage. Trends may become clearer after a further year's measurement.

4.2 Soil moisture

A relative estimate of soil moisture was made by comparing the count in the shield of the neutron probe with that at the measurement point in the access tube. Measurements were taken at 40 cm intervals to a depth of 6 metres. This technique has been adequate to demonstrate wetting and drying cycles, but the 6 metre depth of access tube is inadequate to sample zones which fail to receive moisture in the lowest rainfall coupe, Mooralup.

Data collected to date have shown the wetting of the soil profile is fairly uniform to 6 metres depth in all coupes. This contrasts with work done in sand at Gnangara where a wetting front has been found to occur which proceeds down the soil profile with increasing water input.

4.3 Streamflow characteristics

The data pertaining to precipitation and streamflow for the three coupes where gauging weirs were operative are shown in Table 5. All three coupes are in the higher rainfall zone.

TABLE 5 SURFACE WATER CHARACTERISTICS
JUNE - DECEMBER 1975

Measurement	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
CROWEA							
Rainfall mm	129	91	47	39	27	17	3
Streamflow m^3/ha (1)	187	990	603	259	176	73	18
Stream salinity TDS mg/l		114	102	149	167	230	
Suspended sediment mg/l			73.6	68.9	67.5	52.8	
IFFLEY							
Rainfall mm	120	75	35	37	17	38	7
Streamflow m^3/ha	378	721	403	248	77	14	0
Stream salinity TDS mg/l		209	282	378	397	651	
Suspended sediment mg/l			51.6	86.3	86.6	74.5	
LEEUWIN							
Rainfall mm	88	82	39	39	17	17	5
Streamflow m^3/ha	483	1019	571	224	48		
Stream salinity TDS mg/l		111	82	125	125		
Suspended sediment mg/l			61.5	83.6	81.9		

Note (1) Streamflow is expressed as a water yield in cubic metres per hectare of catchment area.

raintall data × 2.6

Sediment loads in the three streams were very close in value. Stream salinity was higher in Iffley coupe, a result to be expected from the relatively high salt loads in the soil profile.

5. DISCUSSION

One year is an inadequate period for measurement for all the factors associated with ground water tables, soil moisture, rainfall, and streamflow. Discussion of these values is therefore avoided until a further year's data become available.

The results of core analysis from groundwater bores (Table 2) have yielded useful data. The variation in salt loads between bores within a coupe was very high. Bore no.7 in Iffley for example, had a lower salt level than most of the bores in Crowea, the coupe with the least salt load.

A common characteristic of Crowea, Poole and Leeuwin, all coupes with low salt loads, is their occurrence in the Pemberton soil association of McArthur and Clifton (1975). Iffley and Mooralup, with relatively high salt loads, occur on the Balbarrup and Nyamup associations respectively. These latter associations are characterised by a gentler topography and less deeply incised valleys than the Pemberton association.

The large variation in salt loads between bores within a coupe demands that the salinity risk of the coupe must be based on the mean figure for salt load. The data suggest that boring to determine salt loads to a reasonable degree of accuracy over a large area would be prohibitively expensive. Other studies of stream baseflow salinity have indicated this parameter to be a more realistic measure of salinity risk.

McArthur, W.M. and Clifton, A.L. (1975) - Forestry and Agriculture in relation to soils in the Pemberton area of Western Australia. Divn. of Soils, C.S.I.R.O. Soils and Land Use Series No. 54.

GROUNDWATER STUDIES IN CSIRO

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ABSTRACT

The effect of land use on stream salinity is dependent on a large number of processes, most of which have an effect on the dynamics of the catchment groundwater system. A catchment under steady state conditions can be shown to be divided into areas having two distinctly different characteristics, namely one of net recharge to the groundwater system and the other of net discharge. The definition of these areas is important in considering proposals for the clearing of selected areas within a catchment in order to minimise the flow of highly saline groundwater to the stream.

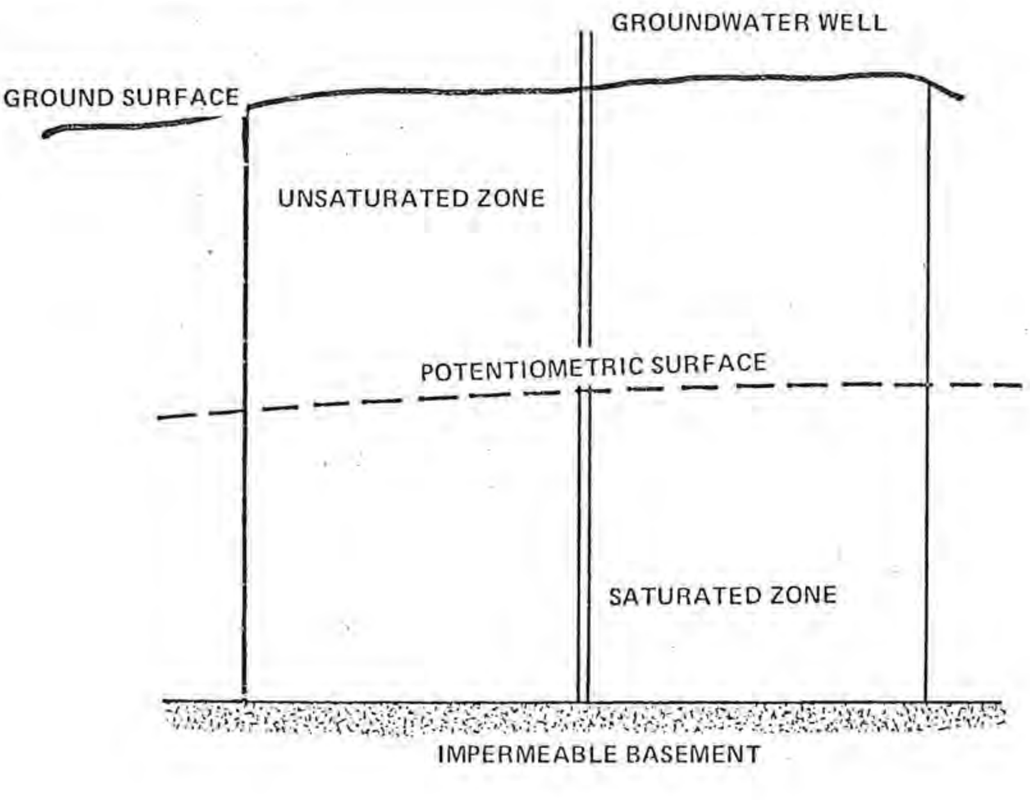
A simplified method of determining these areas of recharge and discharge in catchments under steady state conditions is proposed and applied to two experimental catchment areas.

1. METHOD OF ANALYSIS

For the analysis a fixed volume of soil, bounded from below by an impermeable basement is considered.

This element of soil contains a saturated zone of groundwater which is bounded from above by the potentiometric surface (see Fig. 1).

Fig. 1 SOIL ELEMENT



Then the balance of water flow in this element is given by

$$s \frac{\partial h}{\partial t} \quad = \quad \nabla.(T\nabla h) \quad + \quad R\,(x,y,t)$$

time rate of change of storage = fluxes through the element in the saturated zone + Recharge through the unsaturated zone

in the transient regime.

If it is assumed that the element is in steady state, then this equation reduces to

$$R(x,y) = -\nabla.(T\nabla h) \qquad (1)$$

where s = specific yield
h = hydraulic head
T = transmissivity
R = recharge rate

Definition of Recharge and Discharge

Recharge $R(x,y)$ positive

Recharge refers to water that percolates down through the unsaturated zone to the water table and enters the dynamic groundwater flow system.

Discharge $R(x,y)$ negative

Discharge is water that is removed from the dynamic groundwater flow system by means of springs, surface seepage areas, discharge to streams and evapotranspiration.

If we consider a catchment having a square grid of groundwater wells on it then the steady state flux balance equation may be approximated in finite difference form as follows.

Consider any one of the elements of the grid having (at most) four neighbouring elements (Fig. 2). If the elemental boundary is of length Δx then the flux of water from element N to element C can be approximated by

$$q_{NC} = K_{NC}\, \bar{h}_{NC}\, \Delta x \frac{\left[h_N - h_C\right]}{\Delta x}$$

$$= K_{NC}\, \bar{h}_{NC} \left[h_N - h_C\right] \qquad (2)$$

where K_{NC} is the hydraulic conductivity at the elemental boundary

and $\bar{h}_{NC}$ is the average depth of flow at the elemental boundary.

Using this method to determine all fluxes to element C we find that the recharge at element C is given by

$$\begin{aligned} R_C = \; & K_{NC}\,\bar{h}_{NC}\,[h_C - h_N] \\ & + K_{SC}\,\bar{h}_{SC}\,[h_C - h_S] \\ & + K_{WC}\,\bar{h}_{WC}\,[h_C - h_W] \\ & + K_{EC}\,\bar{h}_{EC}\,[h_C - h_E] \end{aligned} \qquad (3)$$

Note that for elements on the catchment boundary it is assumed that there is zero groundwater flux across this boundary.

This procedure is carried out for each element (i) of the grid to determine the recharge (or discharge) value R_i.

2. DATA USED FOR DETERMINING R_C

h_C, h_N, h_S, h_W, h_E - values of hydraulic head measured above a datum at wells C, N, S etc.

$\bar{h}_{NC}$, etc. - average depth of flow between element C and element N. This is approximated by $\bar{h}_{NC} = \frac{d_N + d_C}{2}$

where d_N = depth of flow at well N

d_C = depth of flow at well C

K_{NC}, K_{SC} etc. Hydraulic conductivities have been determined for each well on the grid by means of a well recovery test. Since small scale variation of this parameter was seen to be very large (see Fig. 3) it was decided to use the geometric catchment mean value for the calculations of each flux.

Fig. 2

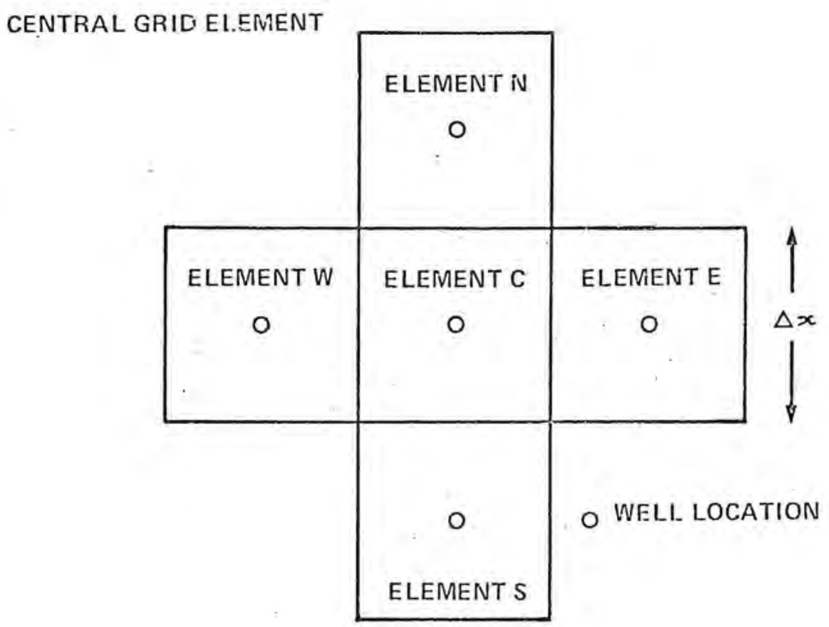
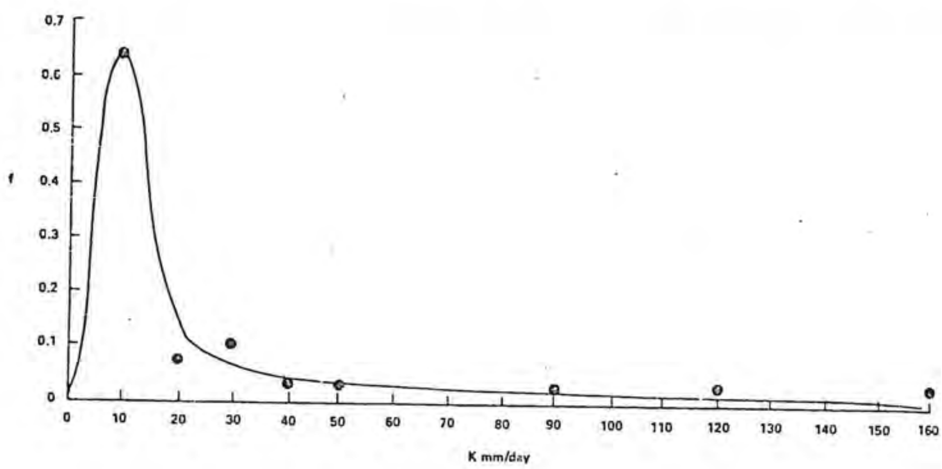


Fig. 3

FREQUENCY DISTRIBUTION OF HYDRAULIC CONDUCTIVITIES ON WIGHTS CATCHMENT



3. CATCHMENTS EXAMINED

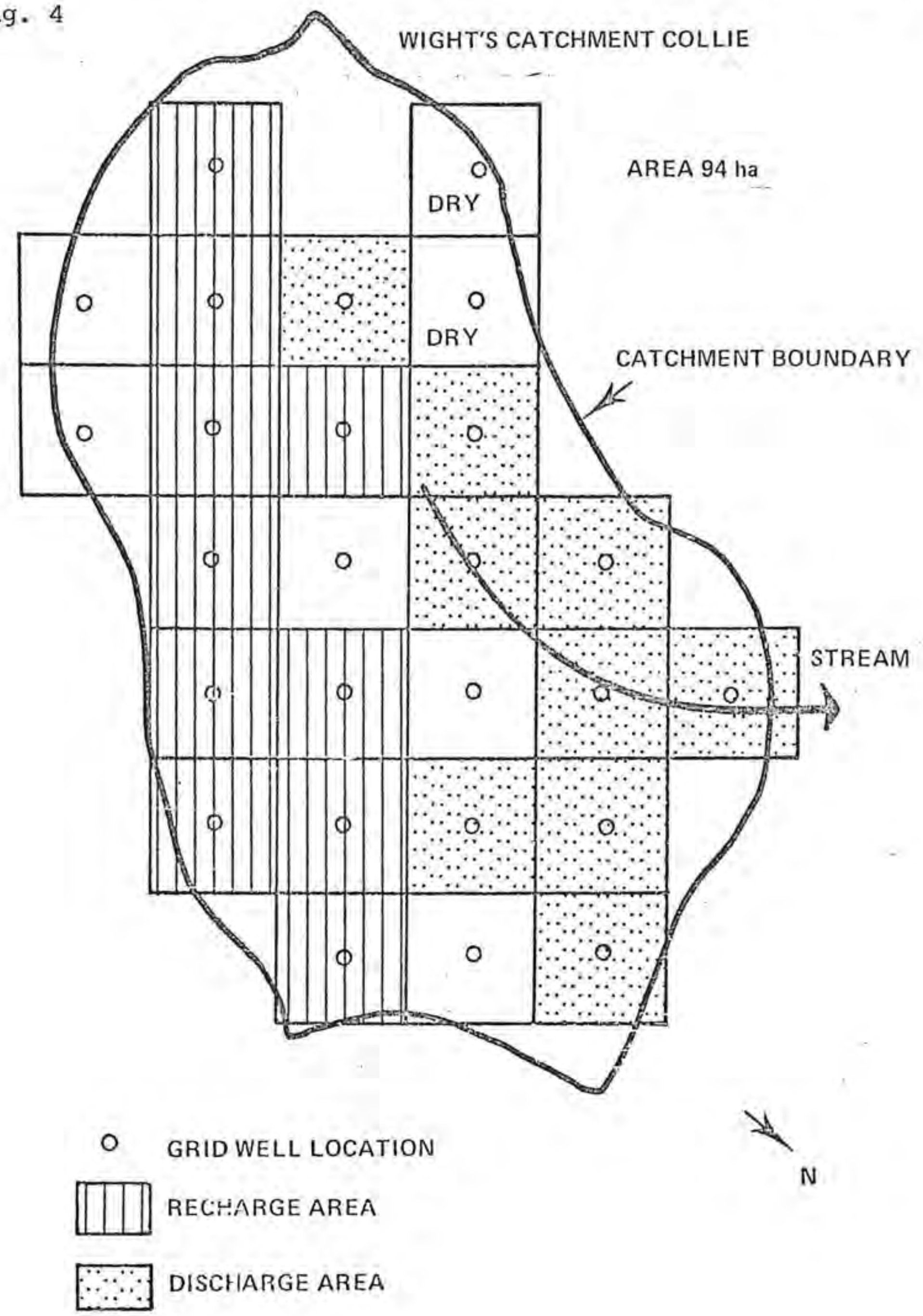
Using this method, recharge and discharge areas have been determined for Wights Catchment, Collie and for Del Park Catchment, Dwellingup, using data collected in December 1975.

Wights Catchment, Collie (see Fig. 4)

The analysis shows that on this catchment the recharge and discharge areas are confined to two major areas within the catchment. The recharge areas being on the more gravelly upslope parts of the catchment while the discharge occurs mainly in the down slope areas adjacent to the stream line.

Areas which have not been classified are due to either no groundwater being detected at the site or that the recharge value calculated was considered smaller in magnitude to the errors in the analysis (i.e. less than 5 mm/yr).

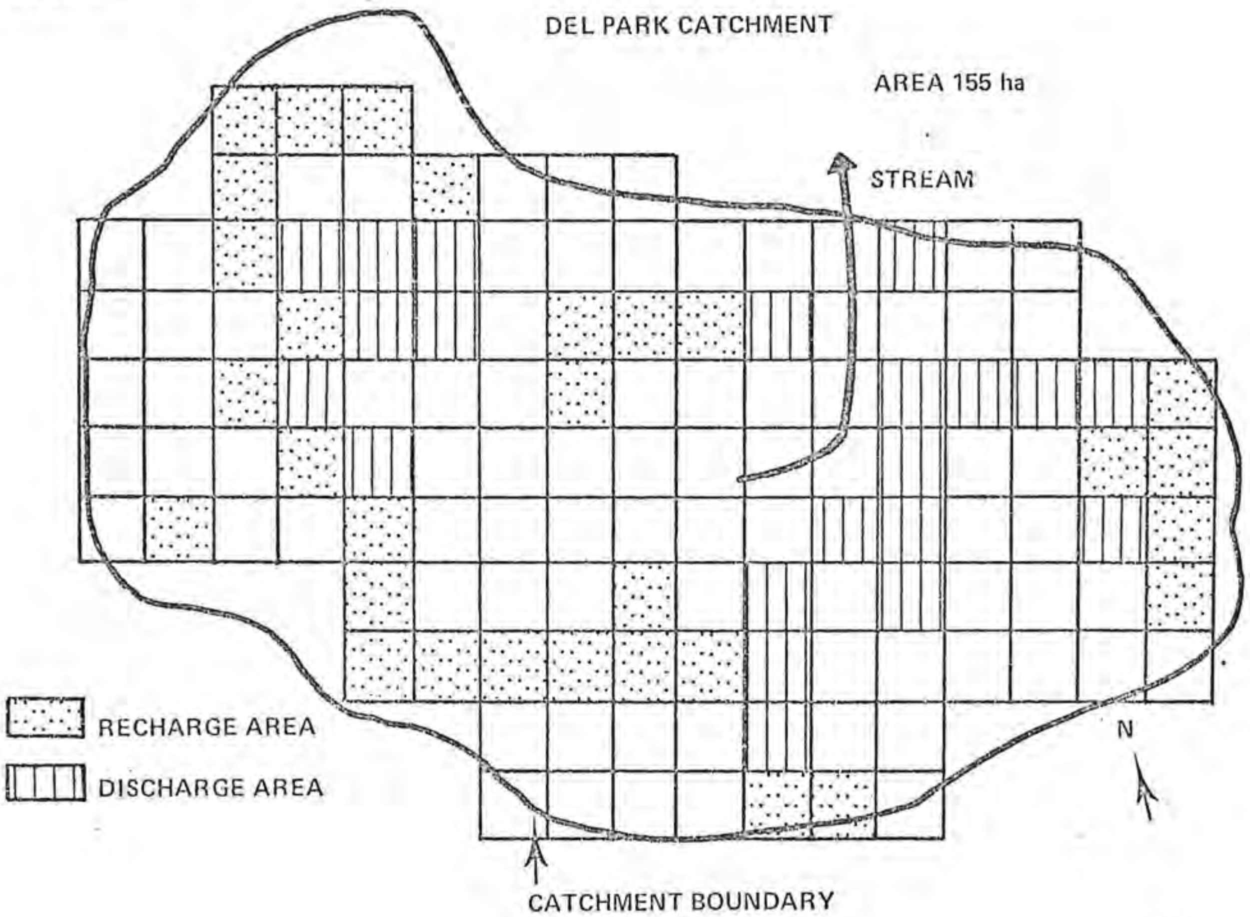
Fig. 4



Del Park Catchment, Dwellingup (Fig. 5)

The Del Park catchment is being monitored in order to determine the effects of bauxite mining on the dynamics of the groundwater system.

Fig. 5



Applying the steady state analysis to this catchment shows a similar pattern of recharge and discharge areas. However in this example it can be seen that the recharge areas tend to fringe the catchment boundaries, whereas the discharge areas appear to be more central within the catchment in a few separate units as well as adjacent the stream.

Hydraulic conductivities have not yet been measured in this area and consequently the average value used in the Wights analysis has been used here. This may lead to greater errors in estimating the transmissivities for this catchment.

4. DISCUSSION OF ERRORS

It can be seen that the transmissivity values used in this analysis will lead to the greatest source of error in estimating the net recharge or discharge.

This will of course be determined by the error in estimation of the hydraulic conductivity K since the depth of flow is not subject to great errors. Other errors will occur due to the assumptions of homogeneity of the aquifer across the elemental boundaries and this is proportional to the grid spacing used. Reduction in well grid spacing however would be extremely more expensive.

5. CONCLUSIONS

The method described gives satisfactory distinction between groundwater recharge and discharge areas in catchments under steady state conditions, and this information may be used for modelling the effect of clearing selected areas within the catchment on the dynamics of the groundwater system.

The accuracy of the determinations is dependent mainly on the estimation of hydraulic conductivities and on the well grid spacing.

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SMALL STREAM SALINITY SAMPLING, POTENTIAL BAUXITE MINING AREAS OF THE ALWEST LEASE

by C. Shedley,
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ABSTRACT

Project 7 was initiated to carry out a study of variation in stream salinity, and the effects of changed land use on stream salinity in potential bauxite mining areas of the south-west of W.A., particularly in the Alwest lease. These objectives have been pursued by means of a stream sampling programme in the Mount Saddleback area, and by collecting extensive data on the land use changes which have occurred in the catchments of the sampled streams during recent years. Future work in the project will involve treatment of the data already collected to determine the effects of changed land use on stream salinity in this area.

OBJECTIVE

The objective of the project is to carry out a study of variation in stream salinity, and the effects of changed land use on stream salinity in potential bauxite mining areas within the Alwest mining lease area.

INTRODUCTION

During 1975 a stream sampling programme was undertaken in the area around Mt Saddleback (in the 600 mm to 900 mm rainfall zone of the Murray-Williams-Hotham river system). Mean flow weighted salinities for fully forested catchments in this region varied from 524 mg/l to 720 mg/l T.D.S. Mean flow weighted salinities for catchments in which other land uses occurred varied from 798 mg/l to 5991 mg/l T.D.S.

These figures clearly demonstrate two important points:

i) One would need to be an extreme optimist to expect to point up differences in salinity of different forested catchments within the area studied by measuring the salinities of their streams.

ii) Clearing natural forest from catchments in this area can have a profound influence on the salinity of the associated streams.

With these two points established, and with the knowledge that water resources for the Perth Metropolitan Area are rapidly becoming less than adequate to satisfy the increasing demand for water, there exists a strong incentive to devise a means of classing catchments according to their sensitivity (in terms of salinity increases) to changes in land use on their catchments. A knowledge of this sensitivity would give decision makers some basis on which to decide land use management strategies consistent with the goal of minimising salinity increases. This project will attempt to provide such a sensitivity classing method by collecting stream salinity data, and relating this to measured land use and geomorphologic characteristics of the stream catchments.

DATA COLLECTION

Salinity data

Stream sampling was confined to an area within a 30 km radius of the proposed centre of initial mining by Alwest (Mt Saddleback). This area constitutes the lower Hotham and Williams and upper Murray River catchments.

Streams sampled covered as wide a range of magnitude, geomorphology and land use as possible, giving as good a coverage of the study area as was feasible within the given time and labour restrictions. Although the programme started with 80 stream sampling points, only 63 of these were sampled throughout due to problems of inaccessibility during winter.

Sampling was carried out fortnightly from April 17, 1975 to January 6, 1976. Samples were taken in one litre plastic bottles from as close to the centre of the stream as possible.

Flow rates were assessed at each sampling by estimating cross sectional area (average depth by width) and surface velocity of the stream. It should be stressed that these estimates were used for weighting salinities. Consequently, accuracy in estimation of magnitude was not as important as obtaining the correct relativities of flow measurements through time. Therefore these estimations were always made on exactly the same section of the stream bed.

Each water sample was analysed in the laboratory for Total Dissolved Solids (by evaporation), Electrical Conductivity (on a Phillips Resistivity Bridge) and for NaCl concentration (with a Metrohm Semi-automatic Chloride Titrator).

The relationship of NaCl and T.D.S. to E.C. was determined by quadratic regression analysis, both after each fortnightly sampling and for the whole year's data.

Flow weighted mean salinities were calculated from T.D.S. measurements and flow rate estimations. Also calculated were arithmetic mean salinities, base flow salinities (mean salinity of flows less than 10 per cent of maximum flow rates recorded), and peak flow salinities (mean salinity of flows greater than 80 per cent of maximum flow rates recorded). The relationships between these variables was determined to ascertain whether flow weighted salinities could be estimated from some more easily measurable quantity.

Catchment data

From previous salinity studies in this area (Shedley 1975a), it was shown that the majority of variation in salinity of streams could be accounted for by the amount of clearing for agriculture which had occurred in the stream's catchment. Other catchment characteristics which have been indicated, or may be expected to influence salinity, and which have therefore been measured or estimated for the catchments studied include landform distribution, catchment shape, catchment size, stream gradients, maximum catchment relief, position of the catchment in the landscape and rainfall.

For the purposes of this study, it is not useful to consider present clearing as an homogeneous variable, as this would severely limit the management alternatives which could be formulated. Rather, it would be better to differentiate present clearing by identifying its different time, position and fragmentation components.

Time

To measure the age of different parcels of clearing within a catchment, a combination of aerial photograph measurements and ground survey was used. Aerial photography of the area was available for 1958-60, 1965-66 and 1971-72. Areas cleared between 1972 and 1975 were mapped by a ground survey in December 1975.

Positioning

Areas cleared at the different dates were transposed onto landform maps prepared from those made by McArthur and Churchward of CSIRO. This enabled the measurement of the area of each landform unit cleared at each date in each catchment studied. However this generated 32 variables for each catchment, which was considered excessive, so similar landform units were grouped. Those units grouped were:

- Murray, Williams and Boddington valley types (all Major Valley Units).
- Yarragil, Pindalup and Coolakin valley types (all Minor Valley Units).
- Michibin type (slope unit).
- Exposed Rock type.
- Laterite.

The latter three were thought to be rather distinct landform types which could not be meaningfully grouped with others, so were left as individual types.

Fragmentation

Fragmentation of clearing in each catchment was measured in two ways:

- Dividing the total length of the boundary between forested and cleared area by the area of cleared land.
- Dividing the total perimeter of the cleared area by the area of cleared land.

The total area of each landform "group" in each catchment was measured from the landform map mentioned.

The ratio of catchment perimeter to catchment area was used as a measure of catchment geometry (Abrahams 1972). Previous work (Shedley 1975b) had shown a high correlation between this parameter and the E index (Jarvis 1972), indicating that it may also be a good measure of stream network configuration.

The areas of catchments were measured from aerial photographs.

Measurements of mean stream gradients were made from 10 metre contour maps (scale 1:50 000) of the area. All streams within a catchment which were of a length greater than 25 per cent of the length of the longest stream were identified. The sum of the change in height of all these streams was measured, and then divided by the sum of the lengths of these streams. The resultant number was then taken as a measure of the mean stream gradient of the catchment.

Maximum catchment relief was measured as the height difference between the highest point on the catchment perimeter, and the point where the stream was sampled.

Position in the landscape is the height difference between the point where the stream was sampled, and its point of confluence with the river into which it flows.

Annual rainfall was calculated using the Bureau of Meteorology isohyet map in "Climatic Survey, Region 11 and 16 of Western Australia".

Rainfall during 1975 was calculated from rainfall records taken at Bureau of Meteorology and Public Works Department rainfall stations in the area.

DATA SUMMARY

Data collection has recently been completed, but because there are 63 catchments on which 50 measurements are made, the raw data is too extensive to present here. Following is a summary of the range and distribution of some of the more important data groups studied.

Salinity data

Salinity of streams measured varied during the year in the typical pattern of highest salinities at the commencement of flow, lowest salinities at peak flow (which occurred for nearly all streams in the middle of August), with increasing salinities as flow decreased into the summer. Variation in Flow Weighted T.D.S. is as follows:

Range: 117 mg/l - 5991 mg/l

Distribution:

Salinity range	Number of streams
0 mg/l - 1000 mg/l	15
1000 mg/l - 2000 mg/l	14
2000 mg/l - 3000 mg/l	21
3000 mg/l - 4000 mg/l	7
4000 mg/l - 5000 mg/l	2
5000 mg/l - 6000 mg/l	4

Clearing data

The amount of clearing in each catchment varied considerably, ranging from nil per cent to 55.2 per cent of catchment area, with less than 30 per cent clearing occurring on 85 per cent of catchments, and less than 20 per cent clearing occurring on 63 per cent of catchments.

The data collected on the distribution of clearing with respect to land form types shows that in 1975, 78 per cent of catchments studied had less than 20 per cent of their clearing located on laterite. This contrasted strongly with the figures collected on the distribution of laterite in terms of total catchment area, which showed that 94 per cent of catchments studied had more than 30 per cent of their total area which was laterite. This demonstrates that farmers have been reluctant to clear laterite, but if clearing continues, there must be an increasing amount of laterite cleared in the future.

Other catchment data

Estimated annual average rainfalls varied from 635 mm to 916 mm, with a fairly even distributuion of catchments within this range. Rainfall figures for 1975 were slightly lower than these average rainfalls, but followed the same distribution pattern. Mean stream gradients ranged from 0.57 m/100 m to 3.88 m/100 m, with the majority of catchments having gradients at the lower end of the scale. Catchment size ranged from 197 ha to 22 470 ha, with 80 per cent of catchments having an area less than 10 000 ha. Position in the landscape (as measured by the height difference between sample point and point of confluence of the stream with its respective river) varied from nil to 90 m, while maximum catchment relief varied from 60 m to 406 m. Catchments were quite evenly distributed with respect to both parameters.

Fragmentation of clearing and catchment shape also varied considerably between catchments.

TREATMENT OF DATA

Having accumulated this data, there are two major objectives to be achieved:

i) The attribution of variation in salinity of streams to the various land use and geomorphic characteristics measured. This will be achieved both by subjective analysis of variation and postulation of causes, and by statistical curve fitting procedures.

ii) The development of a stochastic model for predicting salinity changes which would result from land use changes in the study area. It appears that ridge regression analysis (Hoerl and Kennard 1970) might provide a useful tool for the achievement of this objective.

VERIFICATION AND MODIFICATION OF CONCLUSIONS

Additional stream salinity data is being collected in the Mt Saddleback area during 1976. The area covered is not as large as that covered in the 1975 sampling programme, but coverage is more intensive, in that in addition to the sampling points from the 1975 programme, many new, small streams are being sampled, particularly in the proposed mining area. Sampling frequency has been reduced to one week in an attempt to increase the accuracy of flow weighted mean salinity estimations on these small streams.

The data collected from this sampling programme will be used for several purposes:

- To check whether the conclusions concerning relationships between catchment characteristics and stream salinity hold from year to year, or whether these relationships need to be modified by introducing more weather parameters.
- To provide additional base data on the pre-mining salinity of streams in the area.
- To provide new salinity data from this area which was not used in the formulation of the stochastic model, and which can therefore be used to test its accuracy.
- To provide a more complete salinity data coverage of the area which could be involved in future mining activities, so that the maximum potential salinity threat of the region can be assessed.

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INFLUENCE OF LAND USE ON STREAM SALINITY IN THE MANJIMUP AREA, WESTERN AUSTRALIA*

by C.V. Malcolm

SUMMARY

A review of the history of land use and stream salinity in the Marri Wood Chip Licence Area in the Manjimup district of Western Australia has been made. There is a general paucity of data for years before 1940, but sufficient was obtained to allow general trends to be clarified and areas of particular concern to be pin-pointed.

Statistics for land use show that major land use changes from forest to agriculture occurred before 1929. Subsequent changes have involved cleaning up the initial 'clearing', a surge of clearing in the driest parts of the Tone River catchment since 1945 and a general overall increase of about 10 per cent since the late 1920s.

Forestry methods have changed from exploitation as a preparation for agriculture in the early days to cutting programmes aimed at long term forest improvement and production.

There is evidence that changes in land use have caused changes in stream salinity in the Licence Area. For two part-cleared catchments, East Brook and Lefroy Brook, receiving 1260 and 1320 mm/a average rainfall stream salinity levels indicated by available data are below 200 mg/l NaCl. An early but low peak in salinity probably occurred following clearing in about 1913 and there is evidence of a drop in salinity to a new equilibrium for East Brook.

By contrast, for a part-cleared catchment (Wilgarup River) receiving 1000 mm/a average rainfall, there is evidence of considerable increases in salinity.

Modelling of water and salt balances for the Wilgarup River catchment indicates that if all alienated land is cleared for agriculture or if 4000 ha of forest is cut for wood chips the weighted average stream salinity is likely to increase. Agricultural development alone is predicted to produce a larger increase than cutting for wood chips but the two effects are cumulative.

Further studies of the salt and water balances of streams in 1000 to 1200 mm/a rainfall zones should be made and an attempt should be made to study the integrated effect of all possible clearing and wood chipping on the Warren River. Salt and water balance studies do not suffer the serious time limitations of monitoring programmes as they can be based on current data.

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* This paper reports the results of a joint study by officers of the Departments of Agriculture, Forests and Public Works, the Geological Survey of W.A. and the Government Chemical Laboratories. A full report of the study is contained in the West Australian Department of Agriculture Technical Bulletin No. 27.

Rivers with mean catchment rainfall less than 1200 mm/a and significant areas of uncleared alienated land in their catchments are the Donnelly, Wilgarup, Perup, Tone and Warren. Of these the Donnelly, Wilgarup, Perup and Warren have appreciable areas listed for possible cutting for wood chips. In addition, the Deep River catchment has significant areas of possible cutting for wood chips but an insignificant area of alienated uncleared land and a mean rainfall of 1180 mm/a.

It is most unlikely that cutting forest for either wood chips or agricultural development will cause a significant change in the salinity of the Carey, Fly, Treen, Lefroy, Dombakup, Shannon, Gardner and Weld rivers.

The possible vulnerable area from the point of view of the wood chip project can therefore be narrowed down to those parts of the catchments of the Donnelly and Warren rivers receiving less than a rainfall level somewhere between 1000 and 1200 mm/a. (The Wilgarup and Perup rivers are in the drier section of the Warren catchment.) The Deep River can probably be excluded on the basis of high rainfall, and for the other rivers agriculture on uncleared alienated land represents a greater hazard per unit area than cutting for wood chips. Cutting of wood chips on private land as a preparation for agriculture may represent a hazard.

Multiple regression analysis of catchment parameters relative to stream salinity offers a useful means of rating the factors contributing to stream salinity. With refinement the regression equation may be useful for predicting changes in stream salinity following clearing.

HISTORICAL SURVEY

The earliest indications of the existence of salinity problems in South Western Australia were encountered by the Railways Department. Data for sample sites at Collins (East Brook), the Pemberton railway area and the Manjimup railway area indicate that salinity levels were, in general, low. The general trend of the March figures between 1927 and 1949 was downwards and may be an indication of the re-establishment of salt balance following heavy clearing of forest for agricultural settlement which commenced in the East Brook catchment about 1913. Calculations of characteristic time for the re-establishment of chloride balance after clearing indicate that streams such as East Brook are likely to take between 30 and 40 years. The lowest March value in the W.A. data at East Brook occurs 33 years after the commencement of clearing.

The history of land use in the Manjimup area is reviewed in the main article. Large scale forest utilisation commenced around 1910 and utilisation of both karri and jarrah was heavy in the 1920s and 1930s. The pressure of utilisation was reduced in the following two to three decades but increased in the late 1960s and early 1970s. Heavy forest utilisation was used initially as a preparation for agricultural development to prepare the way for settlement. Data for agricultural land use are unfortunately not available for the Manjimup Shire (which comprises 74 per cent of the wood chip Licence Area) before 1930 by which time 59 per cent of the 100 432 hectares of alienated land in the Shire had been cleared. In the following 42 years to 1972 the area of alienated land in the Manjimup Shire dropped to a low of 68 401 ha in 1939 and rose steadily to 128 425 ha in 1971. The area of cleared land dropped to its lowest level (23 960 ha) in 1944 and only passed the 1930 level in 1967 rising to a peak of 72 064 ha by 1971. The major impact on stream salinity from agricultural clearing can therefore be expected to have occurred in the Manjimup Shire by 1930. However, it is likely that the nature of the cleared land has changed considerably since then owing to the advent of heavy land clearing machinery and the availability of money from the Dairy Farm Improvement Scheme. Irrigated agriculture in the Manjimup Shire accounted for only 2401 ha in 1972 and is therefore not a significant land use overall, although in the catchments of certain streams such as Smith's Brook it has a significant influence.

In general, a search of the literature and departmental records has failed to reveal a substantial salinity problem on farms in the Manjimup district in areas receiving more than 1150 mm/a average rainfall. Interviews with farmers confirm this conclusion. There are some reports of salt patches in saline streams in areas receiving between 1000 and 1150 mm/a average rainfall and in areas receiving less than 1000 mm, salt patches and saline water supplies are commonly reported to result from land clearing. These areas tend to remain saline for many years.

The records of the Railways and Forests Departments include examples of saline groundwaters encountered in exploratory drilling. Forests Department data for the Yornup area from 1959 to 1966 indicate a range in groundwater salinity from 304 to 7480 mg/l T.S.S.

SALINITY TRENDS IN RIVERS

Salinity data for a number of streams in the Licence Area are available from the records of the Public Works Department and the Government Chemical Laboratories. Data for the Warren, Donnelly and Lefroy rivers are available over a 30 year period. The Lefroy and Donnelly appear to have changed little between 1940 and 1970. However, there appears to have been a steady rise in the salinity of the Warren. Data are available for a shorter period for the Carey, Deep, Dombakup, Gardner, Shannon and Weld rivers. All of these rivers have catchments with 1180 mm/a or more average rainfall. The data cover the period 1966 to 1971 and show a marked inverse relationship with annual rainfall. The highest salinity peak for all but one of the rivers occurs in 1969 which was a drought year. The lowest salinity figures occur in 1963, a year of high rainfall. Data for rivers with catchments receiving less than 1200 mm/a average rainfall are available for the Perup, Tone, Wilgarup, Warren, Millstream and Tanjannerup. The level of salinity in these rivers except for Millstream and Tanjannerup are at least three or more times higher than the levels for the rivers in higher rainfall areas. A peak in salinity for these rivers is evident in 1968 while in the drought year 1969 there is a reduction from the peak.

SALINITY THREATS TO LAND AND STREAMS

The main causes of salinity in Western Australian streams and soils are:-

1. *Saltfall*

   Hingston (1958) has produced a graph from which the approximate saltfall with points at a given distance from the coast may be determined.

2. *Rainfall*

   If the rivers in South Western Australia are ranked according to average rainfall they are found to be in approximately the reverse order of their salinity levels.

3. *Salt storage*

   CSIRO workers have shown that the saltfall is stored in the soil profiles in the landscape especially where profiles are deep and fine textured.

4. *Land use changes*

   Changes in land use disturb the hydrological equilibrium, causing salt stored in the soil profiles to be leached into the groundwater. It may then appear in the form of salt patches where the groundwater is forced to the surface or may contribute to the salinity of streams.

MEASURING THE SALINITY HAZARDS

Using the salt balance approach to those streams for which flow and salinity data are available, Peck and Hurle (1973) have calculated various characteristics for forested and farmed catchments in the Darling Ranges south of Perth. The same techniques were used in the present study to calculate the chloride balance and equilibrium times for the streams for which data are available in the wood chip Licence Area. In general, the streams in the present study had less of their catchment areas cleared than those studied by Peck and Hurle. Forested catchments in the present study tended to be higher in saltflow/saltfall ratio than the forested catchments in the Peck and Hurle study. The farmed catchments in the present study were in reasonable agreement with the relationship established by Peck and Hurle except for the Warren, Wilgarup and Perup rivers. The saltflow/saltfall ratios for these catchments were higher than expected.

An attempt was also made to relate the saltflow/saltfall ratio to mean catchment rainfall. In general, the catchments in the present study were in reasonable agreement with the results of Peck and Hurle. Once again, the Perup, Wilgarup and Warren rivers appeared excessively saline. If streams with similar mean annual rainfall in the Manjimup area and the area studied by Peck and Hurle are compared it is found that those in the Manjimup area tend to have higher saltflow/saltfall ratios. It may be that Hingston's data for chloride in rainfall provide an underestimate for the Manjimup area. Estimates of equilibrium time for catchments in the Licence Area were calculated. Catchments in high rainfall areas had equilibrium times in the vicinity of 20 to 35 years.

WATER AND SALT BALANCES

As a second approach to interpreting the available data on salinity of streams in the Licence Area an attempt was made to calculate water and salt balances. Rainfall data and stream gauging data were compared and storage ignored to obtain an estimate of consumptive use. The salt balance was also used to give an estimate of consumptive use using formulae derived by Peck and Hurle from the leaching factor concept. Finally consumptive use indices were ascribed to the various forms of land use and direct estimates made of the amount of water used. These methods were checked against one another in an attempt to devise a means of predicting the effect of land use changes on stream salinity. The approach was applied in particular to the Wilgarup river whose catchment lies in that zone where the effects of clearing for agriculture or cutting for wood chips most need clarification. The salinity levels obtained in the predictions were not believed to be of value as such but rather for their relative values. A greater effect would be expected on the salinity of the Wilgarup by clearing for agriculture rather than by woodchipping but the effect of the two together would be still greater. It was concluded that it was not possible to make balanced decisions on a particular form of land use in isolation. It was considered desirable to estimate the proportion of currently alienated but uncleared land likely to remain in forest. Landholders could be encouraged not to clear umpromising land and the sale of wood chips by private landholders could be discouraged.

REGRESSION STUDIES

Salt and water balance studies can only be performed on streams for which gauging data are available. In the Licence Area 254 small streams were sampled for salinity and a regression analysis was conducted to determine the contribution of factors such as land clearing, rainfall and catchment area to the variability in stream salinity. For a subsample of 98 streams with catchments of 500 hectares or less, 55.8 per cent of the variation in salinity was accounted for using five factors; 51.8 per cent of the variation in stream salinity was accounted for by the factors, proportion of the catchment cleared and the interaction between proportion of clearing and mean rainfall. It may be possible to refine the analysis by testing the importance of other catchment parameters such as age of clearing and land form.

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WATER QUALITY MONITORING OF MAJOR STREAMS IN THE WOODCHIP LICENCE AREA.

K.L. Barrett, P.D.K. Collins.

ABSTRACT

Water quality measurement stations have been established on the nine major streams in the woodchip licence area to monitor the quantity, salinity and sediment content of flow. Approximately 80% of the area to be cut over for woodchips in the first 15 years of operation is within the catchments of these rivers.

This paper briefly discusses the establishment and operation of these stations and the handling of the information being collected.

INTRODUCTION

The woodchip industry licence area covers a greater part of the Shannon, Warren and Donnelly River Basins in the deep south of Western Australia.

As well as having timber, farming, environmental and recreational values these three River Basins provide a very valuable water resource which must be protected for the future. The basins have a combined yield of 1550 $m^3 \times 10^6$ (31% of the estimated yield of the South West Coast Drainage Division) and an estimated exploitable yield of fresh and marginal water of 720 $m^3 \times 10^6$. This resource will be required in the medium term and is substantial as it represents nearly 40% of the estimated exploitable surface water resources of the South West Region.

To ensure that the woodchip industry will not unknowingly have an adverse affect on this water resource, a number of research projects have been established. This paper discusses the project to monitor the water quality of the major streams in the Woodchip Licence Area.

OBJECTIVE

The aim of this project is to monitor runoff from the area over which the woodchip industry is to operate so that if there are any changes in the quality of flow in the major streams resulting from this industry, these changes will be detected.

For this project quality of water is considered to include those factors that could effect the potential use of the water, or aquatic life in the stream. Suspended as well as dissolved solids must therefore be considered.

As this was to be a long term project it was desireable that it be integrated into the general water resources measurement program.

PROJECT DESIGN

The design of this project was controlled by

(a) the need to distinguish any small quality changes caused by the intensified logging practice from within the normal variations of quality that occur through and between seasons,

(b) the need to monitor turbidity and sediment discharge in addition to dissolved solids and,

(c) the desireability of using readily available proven equipment.

To satisfy the first requirement it was necessary to have a good quality continuous flow record at the monitoring site and for the quality to be sampled at intervals of sufficient frequency to allow the salt flow to be calculated with reasonable reliability.

Manual weekly sampling was known to be inadequate for the precision required. Variations of flow and salinity over seven days are such that to obtain salt yields with weekly sampling it is necessary to develop salinity flow relationships and apply these to the flow records. However there is normally an appreciable scatter in the points defining this relationship. Figure 1 is an example for a relatively undisturbed catchment and the scatter of points is generally greater for disturbed catchments.

The availability of equipment then dictated the selection of the locally developed pumping sampler. This is an automatic device which can collect up to 64 one litre samples. The sampling sequence is initiated by a clock assembly and when the unit is activated the intake line is flushed with water from a supply tank, the sampling nozzle automatically positioned over the correct bottle inlet and water then pumped from the river to replenish the supply tank and to fill the sample bottle.

ESTABLISHMENT

Automatic pumping samplers were installed at nine existing river gauging stations in the Woodchip Licence area. These stations collectively monitor runoff from some 80% of the area to be cut over for woodchip in the first 15 years of operation.

These monitoring stations are shown located in map figure 2 and listed below.

NAME	STATION No.	RECORD STARTS	PUMPED SAMPLES START	CATCHMENT AREA $(km)^2$	AVERAGE RUNOFF		SALINITY - NaCl (mg/l)			PRIVATE LAND OR CLEARING
					$(m^3 \times 10^3)$	mm	max	mean	min	
Deep River	606001	MAY 75	1·8·75	550	—	—	—	—	—	nil
Shannon River	606185	MAY 64	7·8·75	337	94 750	281	840	151	80	< 5%
Weld River	606195	APR 64	4·8·75	258	60 900	236	925	126	75	nil
Gardner River	606218	AUG 66	31·7·75	414	124 600	301	415	130	75	35%
Wilgarup River	607144	FEB 61	29·7·75	427	37 730	88	5 340	600	143	40%
Dombakup Brook	607155	MAY 61	31·7·75	115	47 430	413	680	101	52	20%
Warren River	607220	MAY 66	5·8·75	3 870	348 800	90	3 950	520	150	—
Barlee Brook	608001	JUN 72	1·8·75	165	—	—	775	119	90	} < 5%
Barlee Brook	608148	6/62-1/74	—	165	33 900	206	400	99	52	
Donnelly River	608151	JAN 61	4·8·75	805	156 900	195	300	151	90	30%

The runoff and water quality data provided in this table are based on all records to 1974. The water quality summary coming from the results of the routine monthly sampling program that is carried out at all river gauging stations in the South West.

The catchments of all these monitoring stations have already been disturbed by timber cutting and five of the catchments have an apprecialbe percentage of cleared land.

OPERATION

A daily sample is collected by the pumping sampler at each station. These samples are collected every four to six weeks and to date have been analysed for NaCℓ, conductivity and sediment. Turbidity and colour measurements will be added in the near future.

At each visit a sediment discharge measurement is to be taken with an additional pumped sample. It is hoped to develop a correlation between the sediment concentration in the sample collected by the pumping sampler and the concentration of sediment finer than 63 microns obtained from the comprehensive sediment discharge measurement.

The gauging stations are all of good quality and produce an accurate and reliable flow record. The catchments have adequate rainfall networks.

Early teething troubles were experienced with the pumping samplers but these have now been overcome.

DATA PROCESSING

The river stage and pluviograph records for these gauged catchments can be readily processed through the computer based processing systems of the Water Resources Section. A system for handling the water quality data is now under development and could be in operation by December 1976.

The system under development is a computer based data processing, storage and retrieval system designed to handle the large quantities of water quality and bore level data now being collected from land use research catchments and the general water quality assessment program.

The essential features of the system are as follows:

(a) each monitoring site is registered with details of its location and a unique station number allocated,

(b) information input is referenced by station number, sampling authority, and time and date of sampling,

(c) data must be of a known standard to be included in this data base,

(d) there will be a dictionary of parameter codes with a code number for each type of measurement or chemical analysis required,

(e) for input the appropriate parameter code and quality tag will be assigned to each value.

RESULTS

This is a long term monitoring project and other than noting that the required information is being collected there is little to report at this stage.

Figures 3 and 4 show flow and salinity patterns through the 1975 winter for Barlee and Wilgarup Brooks. Most of the samples through this period were collected manually at three to seven day intervals while awaiting the installation of the pumping samplers. These salinity plots therefore indicate general trends only and miss out on the short term fluctuations in quality.

From other work it is becoming apparent that daily sampling will not be adequate during flood periods. It is therefore proposed to modify the pumping samplers to collect samples every three hours during periods of high flow.

Of the catchments being monitored by this project only the Warren has been subject to timber cutting for the woodchip industry at this stage. There is appreciable clearing for agriculture on this catchment so there is little possibility of detecting any changes that would be attributed to the woodchip industry.

INSTANTANEOUS FLOW - NaCl SALINITY RELATIONSHIP FOR HARRIS R.
FROM WEEKLY SAMPLES COLLECTED BETWEEN MARCH 1968 - FEB 1969

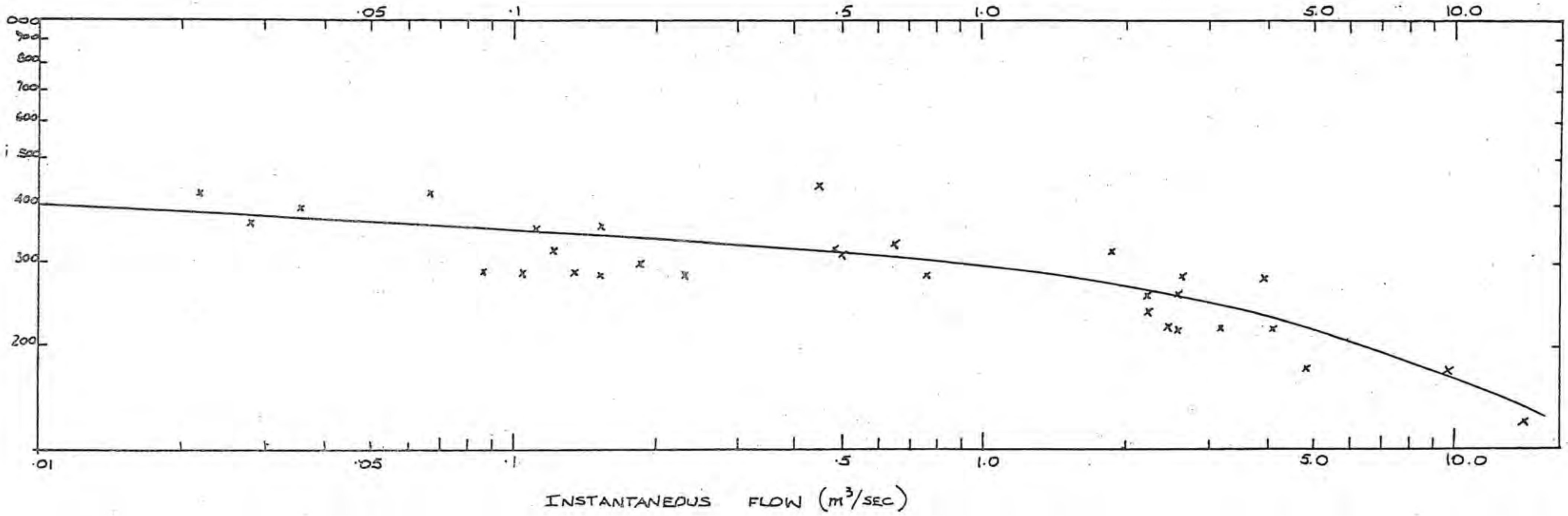
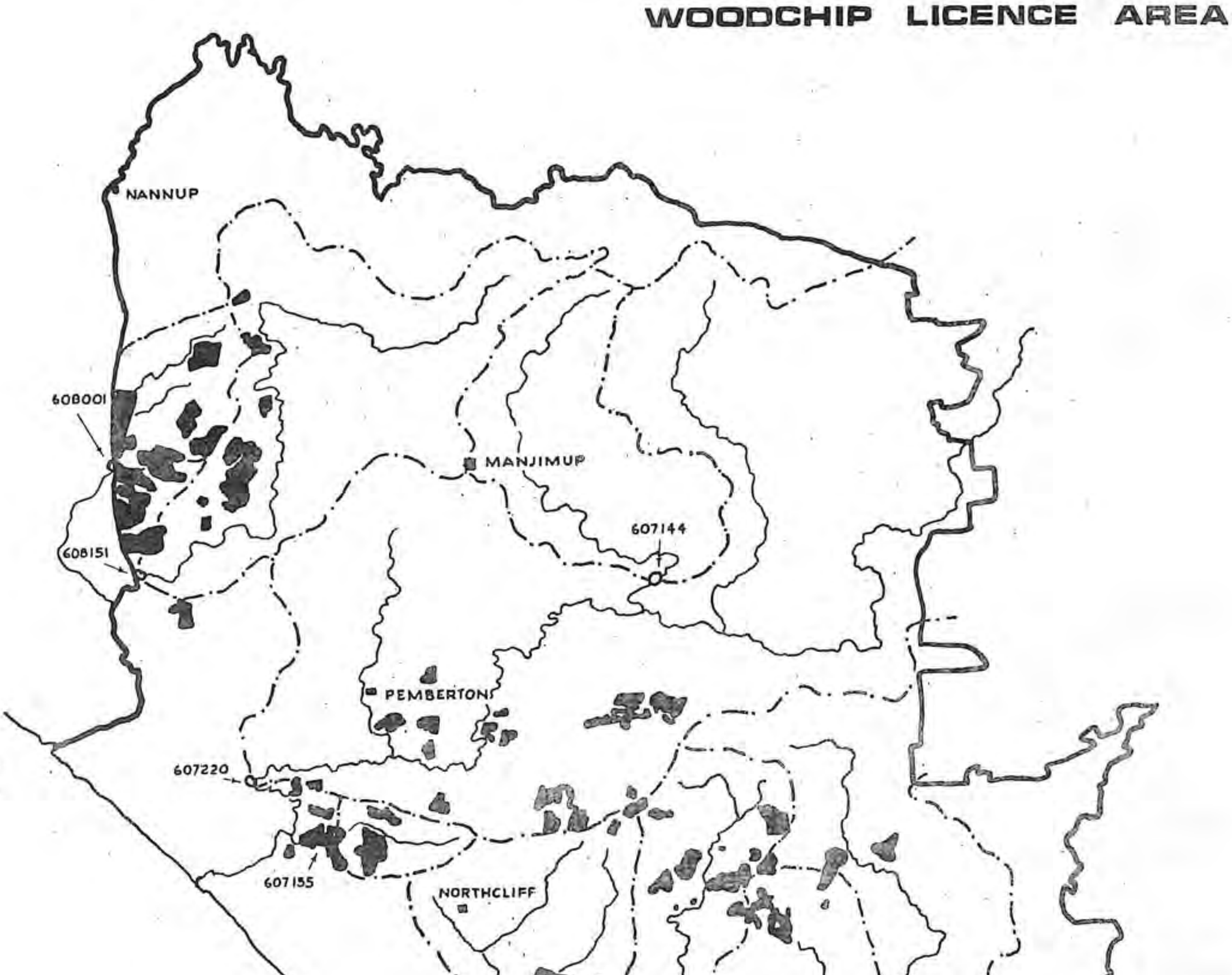


FIG. 1

FIG. 2



STREAMS MONITERED IN PROJECT 3.

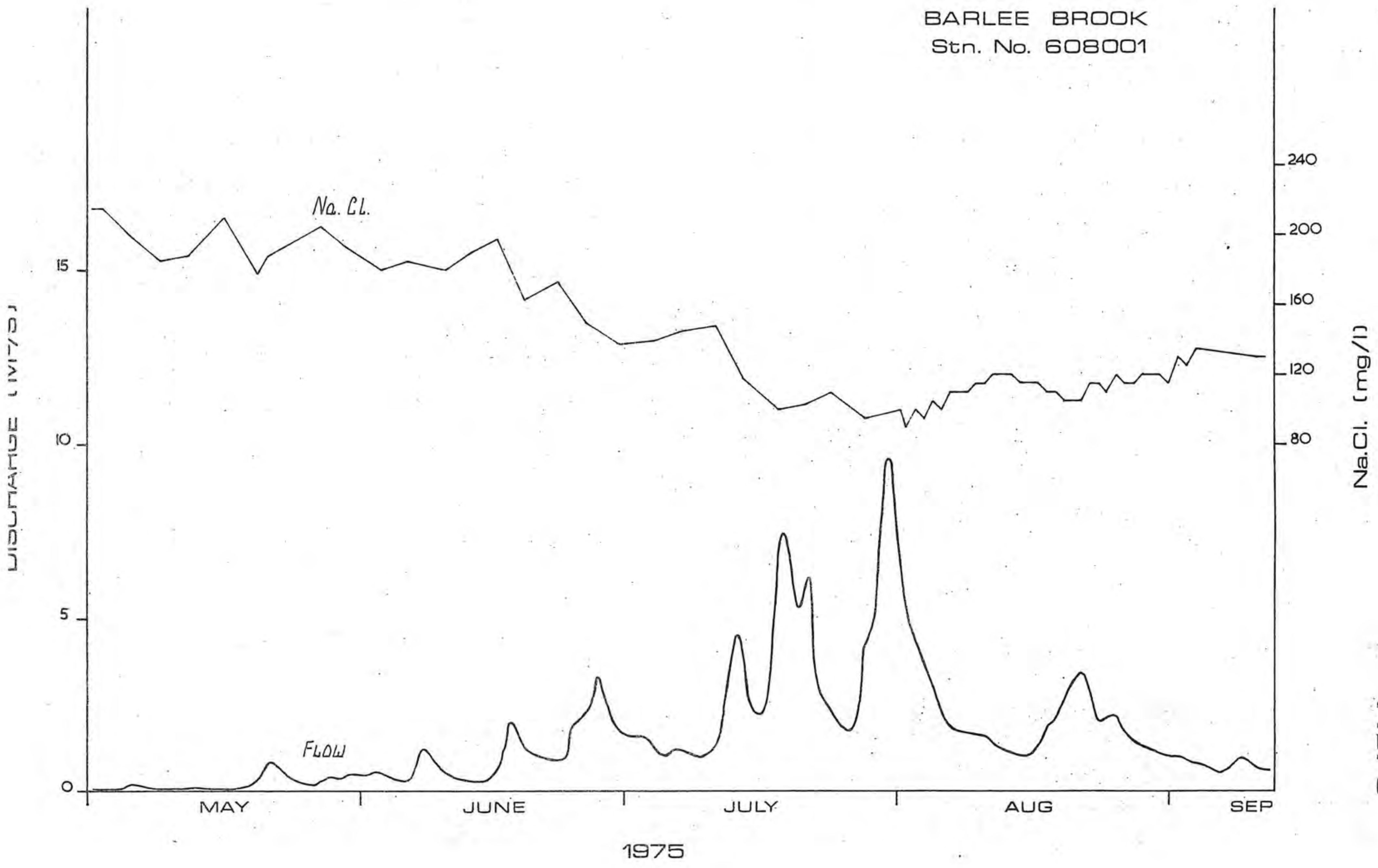

BARLEE BROOK
Stn. No. 608001
Na. Cl.
FLOW
15
10
5
0
240
200
160
120
80
Na.Cl. (mg/l)
MAY
JUNE
JULY
AUG
SEP
1975

FIG. 3

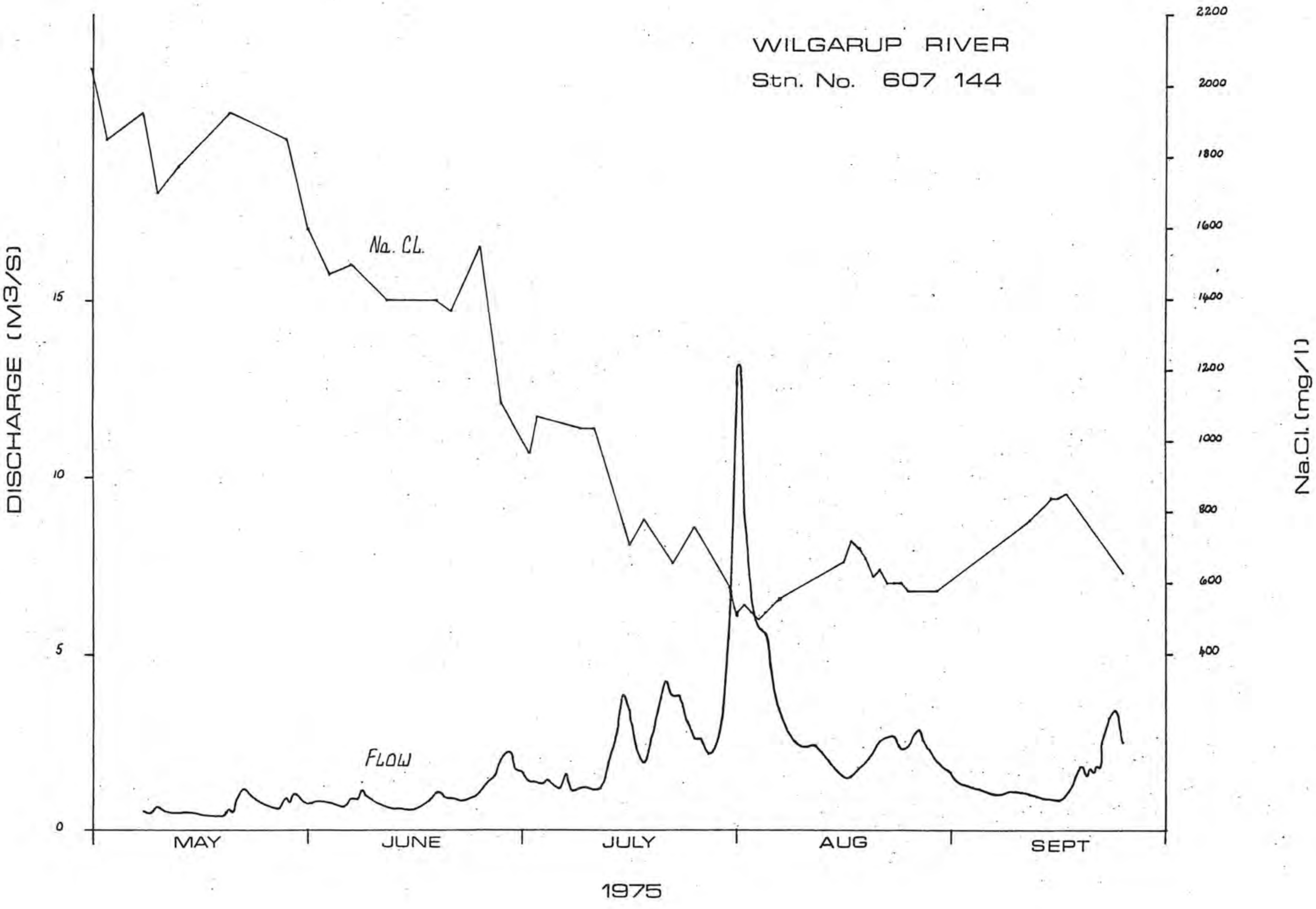

WILGARUP RIVER
Stn. No. 607 144
Na. CL.
FLOW
DISCHARGE (M3/S)
0
5
10
15
Na.Cl. (mg/l)
400
600
800
1000
1200
1400
1600
1800
2000
2200
MAY
JUNE
JULY
AUG
SEPT
1975

FIG. 4

SALINITY SAMPLING, HELENA CATCHMENT, WESTERN AUSTRALIA.

by

must consider evapo. transpiration of different areas and its likely effect on salinity

F.E. BATINI and A.B. SELKIRK.

SUMMARY

AT 117 sites within the Helena catchment, stream sampling for salinity commenced during autumn 1974 and continued, at weekly intervals, until summer 1975. For a restricted number of sites, samples were collected for a further year. The observed differences between years were not great and it appears that reasonable inferences can be drawn even from one year's data.

As the season progressed into spring and summer, so the percentage of flowing streams decreased rapidly and the proportion with higher values for total dissolved solids increased. In half the samples, the calculated value for base flow exceeded the currently acceptable potability standard (500 mg l^{-1} T.D.S.).

The data show that land use activities have a considerable influence of the base flow salinity of small streams. The greatest effects are associated with farm clearing and, in order of decreasing magnitude, with clearing for pine plantations, ringbarking, jarrah dieback and cutting. On these data, no part of this catchment is free from a potential salt problem.

Although the sampling technique is useful when comparing the effects of alternative land uses, its value as an indicator of the groundwater salinity and thus as a predictive tool is questionable.

Base flows for ephemeral streams do not accurately gauge the salinity of the adjacent aquifers and underestimates of 10 to 50 fold were observed.

Of the major streams which feed the reservoir, the weighted average salinity of the Helena river exceeds the current potability standards. That for Rushy creek approaches the standard. The current average salinity at the reservoir wall is 400 mgl^{-1} and flushing of the reservoir has become less frequent since the fitting of the gates in 1959. The flushing effect during 1974 (when the weir overflowed for 86 days) was relatively short lived, and the salinity has risen by 160 mgl^{-1} (to 380 mgl^{-1}) during the past 18 months.

About half of the privately owned land on the catchment has not yet been cleared (4300 ha). It is estimated that clearing could raise the salinity of the Helena and Darkin rivers by between 350 and 400 mgl^{-1}. Values in the reservoir could rise by 200 mgl^{-1}.

Given the current salinity levels and the strategic importance of this reservoir, action is recommended on the following aspects.

1. All cleared areas under the control of the crown (930 ha) should be revegetated with a deep rooted perennial crop.
2. A moratorium should be placed on the further clearing of privately owned land.
3. Any proposed new forestry practice should be closely investigated before it is implemented on an operational scale.
4. There is need to obtain further data to enable the accurate appraisal of alternative reservoir management strategies.

TABLE 1

CLASSIFICATION OF SAMPLING POINTS BY THE SALINITY CLASS OF THE BASE FLOW AND THE PREDOMINANT LAND USE ON THE UPSTREAM CATCHMENT

	PREDOMINANT LAND USES							TOTALS
	FARMLAND		PINE PLANTATIONS	HARDWOOD FOREST			MIXTURE OF USES	
	PARTLY CLEARED	REPLANTED		RINGBARKED	DIEBACK AFFECTED	LOGGED		
FRESH < 500*	3	Nil	Nil	1	2	53	Nil	59
MARGINAL 501-1000	Nil	Nil	1	5	3	12	5	26
BRACKISH 1001-3000	3	1	6	2	3	2	4	21
SALINE > 3000	7	1	1	1	Nil	Nil	1	11
TOTAL	13	2	8	9	8	67	10	117

* Total Dissolved Solids (T.D.S.) expressed as mgl^{-1} and calculated from electrical conductivity data.

Research Paper No.

1976

SALT CONTENT OF SOIL PROFILES IN THE
HELENA CATCHMENT, WESTERN AUSTRALIA.

by

F.E. BATINI, A.B. SELKIRK and A.B. HATCH

SUMMARY

Soil cores from 20 deep bores in the Helena Catchment were examined for electrical conductivity, total soluble salts, sodium chloride, pH, bulk density and moisture content. Within an area of a few square kilometres, considerable differences in the store of soluble salts were observed. Bores less than 300 m apart differed by a factor of 40. The quantity of salt stored per unit of landscape appears to be related to site type. Types J, F/J and M/G were generally non-saline; Y types had a saline band between 3 and 11 metres, and H/G types tended to be saline at depth. The data for A types were inconclusive. In finer-textured soils, the store of salts was concentrated in the region above the water rest level and below the surface soil horizons.

FIGURE 2

Vertical distribution of salt (g/100g) and pH for bores in the Wellbucket Catchment.

(WRL : Water rest level 24 hours after piezometer installation. +++ : Hard rock).

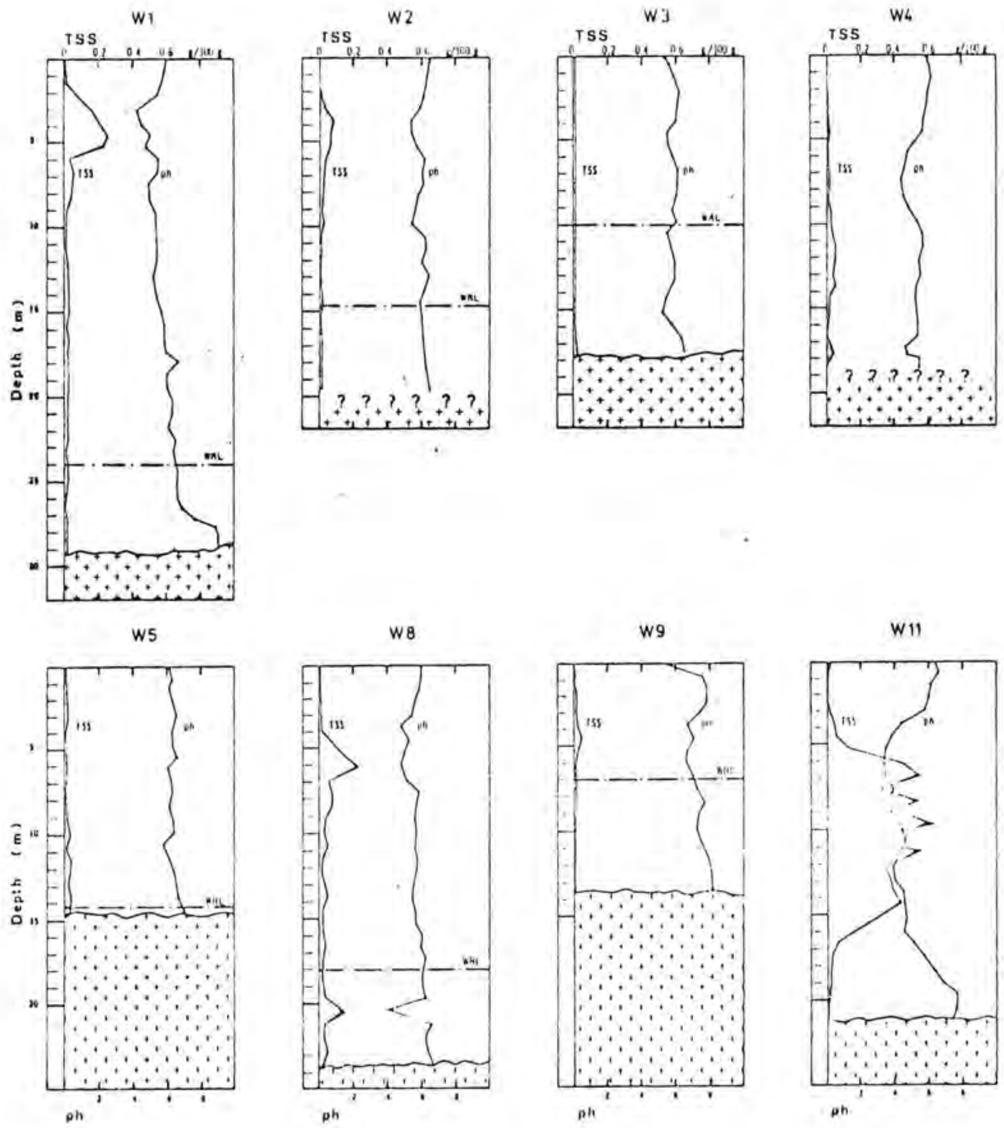


TABLE 3

COMPARISON OF THE SALINITY CHARACTERISTICS OF DEEP BORES

WITH THE DATA OF DIMMOCK ET AL

(Mean $\pm$ standard deviation, with range shown below).

	NO. OF BORES	DEPTH TO ROCK (m)	SALT CONTENT (g/100 g)	SALT STORAGE ($x10^5$ kg ha^{-1})
Helena Catchment	20	17.5 $\pm$ 5.3	0.07 $\pm$ 0.10	2.1 $\pm$ 2.2 [A]
(800-850 mm p.a.)		8.4 - 29.3	0.005 - 0.40	0.14 - 8.13
Dimmock et al	4	21.6 $\pm$ 11.3	0.13 $\pm$ 0.15	2.9 $\pm$ 1.7 [B]
(800-1000 mm p.a.)		7.1 - 33.6	0.03 - 0.19	1.1 - 4.5
Dimmock et al	29	20.6 $\pm$ 9.9	0.22 $\pm$ 0.10	8.1 $\pm$ 5.3 [B]
(800 mm p.a.)		5.4 - 42.1	0.05 - 0.49	0.5 - 19.2

A Assuming average bulk density of 1750 kg m^{-3} for profile

B Assuming average bulk density of 1700 kg m^{-3} for profile

VARIATIONS IN THE DEPTH TO AND THE SALINITY OF SHALLOW AND DEEP GROUNDWATER TABLES, HUTT AND WELLBUCKET EXPERIMENTAL CATCHMENTS, WESTERN AUSTRALIA.

by

F.E. BATINI and A.B. SELKIRK.

SUMMARY

The depth and salinity of perched and of semi-confined groundwater tables were monitored by installing groundwater wells ranging from 3 to 29 metres in depth. Position of the groundwater table was recorded weekly (perched) and monthly (semi-confined), using a weighted tape measure. The water column was thoroughly stirred and a 200 ml. sample bailed and tested for electrical conductivity.

Perched groundwater tables responded quickly to rainfall inputs, reached maximum levels between July and September and were dry in summer. The responses in the semi-confined aquifers were smaller in amplitude and more gradual with respect to rainfall. Maximum levels were observed between October and December

and minima between March and May. Wells either contained water all year, or were always dry. In every case where a shallow and deep well were adjacent, a considerable difference was observed between the relative levels of the two water tables. Hydraulic conductivities for most wells appear to be unusually high.

Data show that the conductivities of samples collected before or after stirring or sludge pumping were very similar. The groundwater salinities form a complex pattern. Often, those from bores located close to each other are markedly different (deep W2, W3; shallow W1, W2). The base flow salinities of the streams which drain these catchments underestimate the salinity of the perched and semi-confined groundwater tables by a factor 3 and 10 respectively.

TABLE 1

REDUCED LEVELS (IN METRES) OF WATER
TABLES IN DEEP AND SHALLOW WELLS

BORE NUMBER	REDUCED LEVELS (DEEP BORES) m		REDUCED LEVELS (SHALLOW BORES) m*	
	SEPTEMBER 1975	MARCH 1976	SEPTEMBER 1975	MARCH 1976
W1	249.06	249.14	263.91	DRY
W2	250.56	250.66	264.74	DRY
W3	255.54	255.12	260.02	DRY
W4	DRY	DRY	283.74	DRY
W5	258.92	258.93	270.64	DRY
W6	262.14	262.23	281.80	DRY
W8	249.55	249.22	N.A.	N.A.
W9	250.45	250.50	256.28	DRY
W11	DRY	DRY	N.A.	N.A.

* Shallow wells are 3m deep.

N.A. - data not available

TABLE 2

MAXIMUM AND MINIMUM SALINITY* OF WATER FROM SHALLOW AND DEEP WELLS

BORE NUMBER	DEEP BORE			SHALLOW BORE		
	MAXIMUM	MINIMUM	RANGE	MAXIMUM	MINIMUM	RANGE
W1	2650	2355	295	5860	1231	4629
W2	3732	3098	634	278	94	184
W3	421	317	104	593	91	502
W4	329	329	Nil+	248	156	92
W5	439	318	121	235	116	119
W6	761	690	71	261	91	170
W8	1718	1572	146			
W9	891	826	65	960	551	409
W11	Dry	Dry	Dry			

* Salinity expressed as the electrical conductivity in microSiemens (uS)

\+ One reading only.

REHABILITATION OF BAUXITE MINE SITES IN THE NORTHERN JARRAH (Eucalyptus marginata) FOREST

S.R. Shea & J.R. Bartle

ABSTRACT

Bauxite mining rehabilitation techniques have largely been developed from ad hoc applied research. Until 1974, the principal objective of rehabilitation was establishment of trees on bauxite sites which would replace the timber production function of the native forest. A number of different tree species have been successfully established on bauxite mine sites. Ripping to a depth of 1.5 to 2 metres and fertilization improve growth and survival of trees during the establishment stage of development. Initial growth rates during the establishment phase have been rapid, but it is impossible to predict the future development and survival of the trees. Preliminary root development studies have shown that root development on bauxite sites is almost entirely restricted to the overburden soils.

The mine pit surface is subject to erosion, and water running off the mine pit surface is turbid. A variety of mechanical treatments (for example, ripping and contour banks) have reduced but not eliminated erosion. Native recolonization of the pit surface is minimal, and the absence of a shrub layer has contributed to the instability of the mine floor. Native shrub species have been successfully established on mine pit surfaces using direct seeding techniques, and form a complete cover by the second year after mining. Clover establishes more rapidly, but markedly reduces growth and survival of native species.

Trials are currently being established to determine whether it is possible to achieve a succession from agricultural species to native species while monitoring overburden stability.

Preliminary data indicate that transpiration demand on rehabilitation bauxite pits will be returned to pre-mining levels 7 to 10 years after establishment of tree species. However, the data base for this conclusion is limited.

Nutrient levels in water running off fertilizer pits has been monitored for 1 year, and is not significant.

A study of the scale of change in vegetative cover due to mining and jarrah dieback suggests that rehabilitation should be carried out on a total catchment basis.

INTRODUCTION

Bauxite mining operations commenced at Jarrahdale in 1966 and at the Del Park mine site west of Dwellingup in 1971. Rehabilitation research was commenced in the first year following mining. In 1973, a formal but limited research programme was initiated by the Forests Department. In 1975 a comprehensive research programme under the direction of the Hunt Steering Committee was undertaken. This paper summarises the information on rehabilitation which has been gained from both operational experience and research projects in the period since bauxite mining commenced, outlines current and proposed research projects and identifies major problem areas requiring further research.

THE MINING PROCESS

Bauxite mining involves definition of the ore bodies by surveying and drilling crews, clearing of forest from the defined mine sites, removal and storage of the top 10-30 cm of the overburden soil, blasting of the concreted bauxitic layer and removal of bauxite ore down to approximately the pallid zone of the laterite profile (the average depth to which bauxite is removed is 4.5 metres). The economically viable bauxite ore bodies are restricted to upland jarrah forest sites, and the quality of the bauxite material is variable. Hence, a mined-over forest area consists of a mosaic of mine pits and forest. In addition to the area of forest cleared for mining, an additional 20% of forest is cleared for roads, conveyor belts, buildings etc.

INTERACTION BETWEEN MINING AND JARRAH DIEBACK

The effect of bauxite mining cannot be evaluated without consideration of jarrah dieback. This is a disease caused by an introduced soil-borne fungus Phytophthora cinnamomi Rands (Podger, 1968). The end product of the introduction of the fungus is,in the long term, the almost complete irreversible destruction of the forest vegetation on most jarrah forest sites.

The disease is widely distributed throughout the forest, but is concentrated on the western edge of the Darling Ranges, and occurs primarily in moisture-gaining sites. Natural uphill spread is slow, but when infections are established on upland sites, by movement of infested soil, spread downslope can be rapid (Shea, 1975).

Bauxite mining will increase the spread and intensification of the disease by the movement of infested soil and the creation of more favourable environmental conditions for fungal activity. The spread of the disease in the forest has been caused primarily by movement of infested soil on logging or road-making equipment. The bauxite mining operation, because it involves movement of large quantities of soil throughout the year (spread is less likely in the summer months because the fungus is killed by prolonged drying), is incompatible with forest hygiene techniques. Bauxite mining operations cause disruption of drainage, resulting in accumulation of water on previously freely drained sites, which in turn favours P. cinnamomi survival and pathogenicity.

No objective measurements of the effect of bauxite mining on P. cinnamomi spread and intensification have been made. However, there are numerous examples throughout the forest area of the association between disease occurrence and earthmoving activities. Thus, it is reasonable to assume that a large proportion of the forest adjacent to the mine pits will in the long term (20 years?) become infected with the fungus.

THE OBJECTIVES OF REHABILITATION

The objectives of rehabilitation have varied since mining commenced and are still not clearly defined in current and proposed mining areas. This is a consequence of both the change in the scale and location of mining and the absence of a land use plan for the forested area which defines the priority of land uses on different sites within the forest.

Rehabilitation techniques have changed as the result of research and in response to changing objectives. The initial objective of rehabilitation was to rehabilitate with trees capable of producing commercial timber. In the period 1966-1969 rehabilitation consisted of planting a variety of tree species in the topsoil which had been replaced on the mine surface. Following the occurrence of windthrow and erosion of the topsoil, ripping to a depth of 1.5 metres was carried out. By 1970 it was evident that erosion was a particularly serious problem, and increased emphasis was placed on water catchment protection although timber production was still a primary objective of rehabilitation. By 1974 the principal objectives of rehabilitation. in order of priority, were defined as water catchment protection, aesthetics and recreation and timber production.

TREE GROWTH AND DEVELOPMENT

1. SPECIES

As already indicated, the principal objective of rehabilitation in the initial years following mining was timber production. Hence, the criteria for selection of species was resistance to P. cinnamomi and potential timber production. Eucalyptus saligna, Eucalyptus microcorys, Eucalyptus resinifera and Pinus pinaster were the major species used, although a large number of potential timber-producing species were established in trial plots. As the timber production objective declined in priority, tree species which were not necessarily suitable for timber production were used. For example, Eucalyptus wandoo and Eucalyptus calophylla have been used in broadscale planting. Currently, no single species is favoured for replanting.

A comprehensive species trial is currently being established at the Del Park mine site. In this trial, the criteria for species selection has been widened from timber production potential to include hydrological characteristics (e.g. rooting depths and transpiration capacity) and aesthetics.

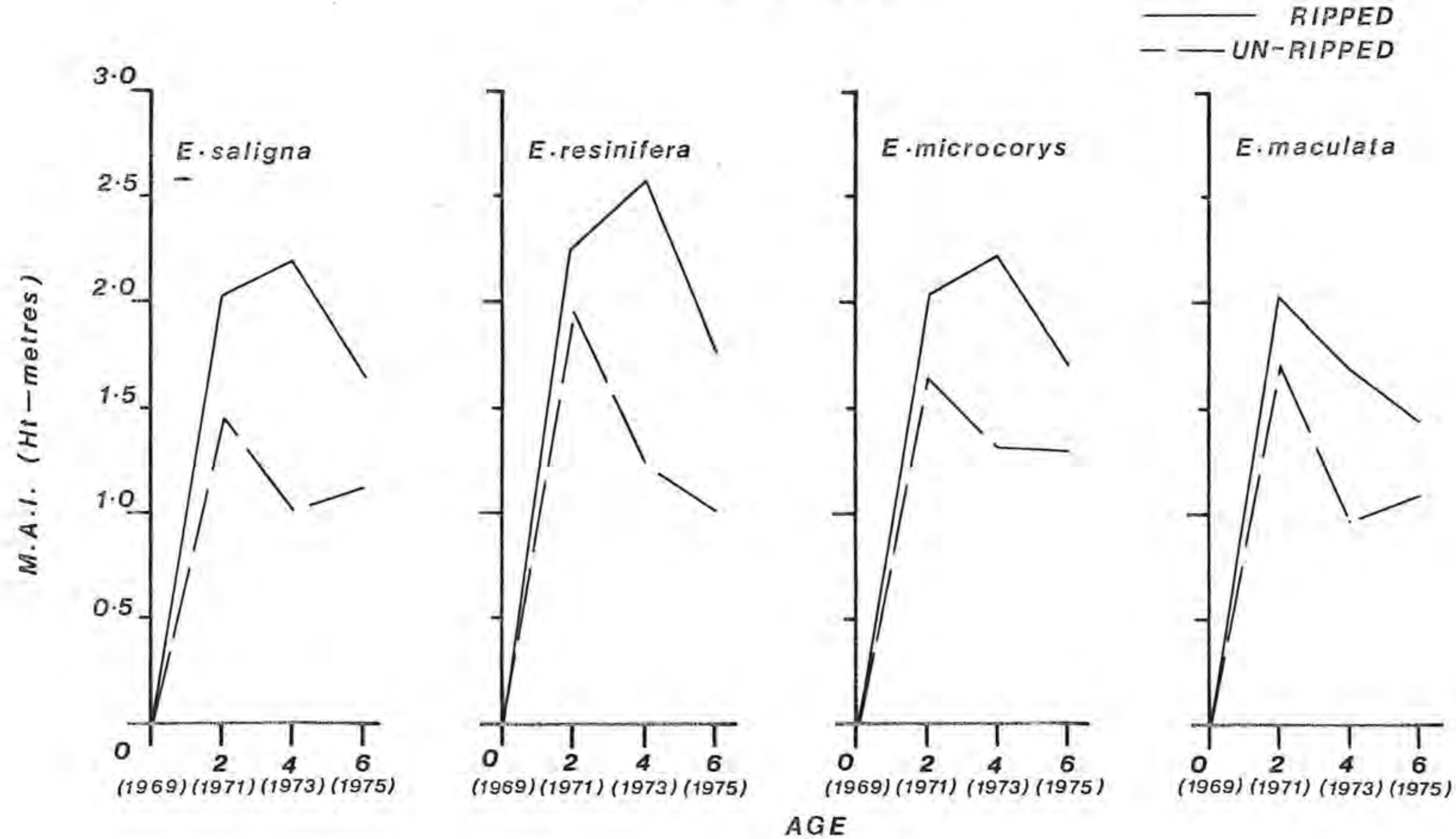
2. ABOVE-GROUND GROWTH

Initial growth rates of almost all tree species planted have been rapid. In Figure 1, mean annual height increment surves are plotted for 4 species planted in 1968 on ripped and unripped sites on the Jarrahdale No. 1 site. This site was ripped to a depth of 1.5 metres. The data suggest that ripping (which reached a depth of 1.5 metres) significantly increases height growth. A more comprehensive ripping trial was established in 1976. Preliminary results from this trial indicate that ripping has no significant effect on height growth in the first 8 months after establishment (Tacey pers. comm.).

There is some evidence to suggest that there has been a reduction in the rate of height growth during the last 2 years (Fig. 1), but this could be due to climatic factors. It is impossible to predict the future development (the pattern of growth over time) of the trees planted on bauxite sites, but initial rapid growths are often not conducive to long-term survival. For example, Eucalyptus microcorys was planted extensively on dieback sites and initially grew rapidly. However, in 1969 there was widespread mortality of E. microcorys.

Fig I

MEAN ANNUAL HEIGHT INCREMENT RIPPED vs UN—RIPPED SITES JARRAHDALE



3. BELOW-GROUND GROWTH.

The root development of 6 species (Eucalyptus resinifera, Eucalyptus maculata, Eucalyptus saligna, Eucalyptus globulus, Eucalyptus microcorys and Pinus pinaster) which had been planted on mine sites were studied. Thirty-four root systems were exposed by excavation and washing. The fine-root distribution was determined by taking cores of the vertical face of the soil pit located adjacent to the trees.

Interpretation of the results of this study was difficult because of the heterogeneity of the soil profile and the early stage of development of the trees (maximum age 7 years). Ripping had been carried out prior to planting of all but 5 of the excavated trees, but its effectiveness was variable.

Root development was almost entirely restricted to the overburden soils. One E. microcorys tree had a number of descending roots, but these were located in old jarrah root channels. Where ripping to 1.5 metres was carried out, vertical roots occurred in the ripped channel but terminated at the bottom of the ripped zone. The fine-root system of all trees was almost entirely restricted to the overburden soil.

This study demonstrated that there is a severe imbalance between the above and below-ground growth of trees planted on bauxite sites. Trees whose height exceeded 5 metres had root systems which were restricted to the top 0.5 metres of overburden soil. This imbalance is not conducive to long-term survival. As the maximum age of the trees was only 7 years, it is possible that vertical root development could occur at a later age.

A further, more comprehensive study of root development is currently being carried out at the Jarrahdale No. 2 mine site.

4. FERTILIZATION

Until 1973, fertilization regimes were based on a number of simple fertilizer trials. In 1973, comprehensive factorial fertilizer trials were initiated using Eucalyptus microcorys and Eucalyptus globulus as test species. The results of the E. globulus trial are shown diagrammatically in Figure 2. In both trials, tree height increased with increasing levels and frequency of application of nitrogen and phosphate.

An experiment which was aimed at determining the effect on vertical root development of fertilizer placement at different depths in the soil profile was initiated in 1975. Preliminary results indicate that E. globulus seedlings do not derive significant benefits from fertilizer placed at a depth of 70 cm (Tacey pers. comm.).

5. STAND DEVELOPMENT

No research has been carried out to determine the optimum thinning regime necessary to maintain the health of trees planted on bauxite sites. Forests Department research on Pinus radiata stands has shown that it is necessary to reduce stand density markedly at a stage of development comparable to that achieved by the trees planted on bauxite sites at ages between 7 and 10 years.

FERTILIZER RESPONSE — E.GLOBULUS

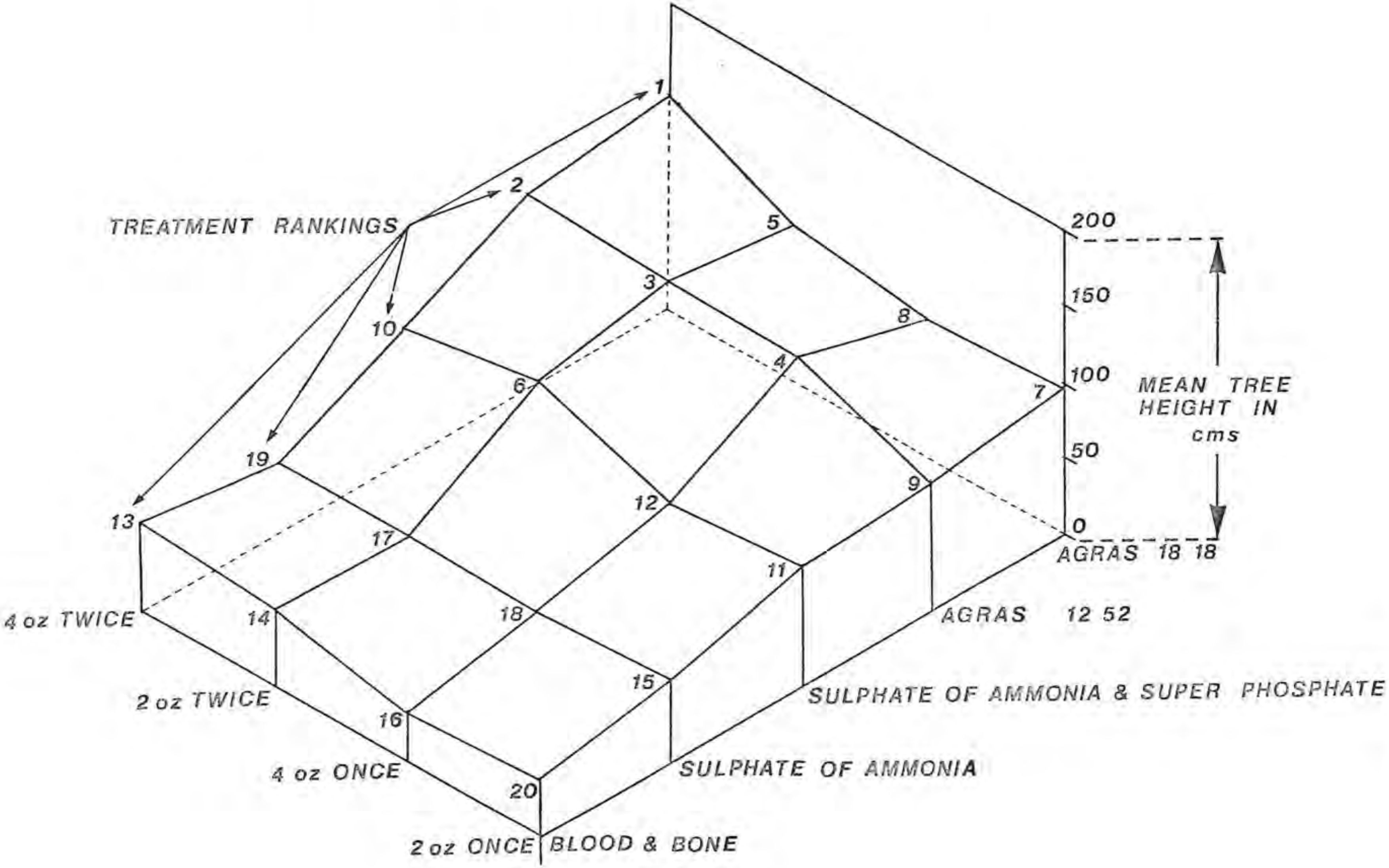


Fig 2

A trial is currently being established at the Jarrahdale site to demonstrate the potential for varying the stand structure of trees planted on bauxite sites. Two different types of forest are being established: (i) parkland - random planting of trees and shrubs in a woodland formation with a ground cover of clover; (ii) mixed forest - random plantings of trees and shrubs in a forest formation.

EROSION CONTROL

Overland flow rarely occurs in unmined forest areas, but on mine pit surfaces it can be observed after less than 50 mm of rainfall. Erosion in some pits has been severe, and the water discharging from freshly mined pit surfaces has a high sediment load and is turbid.

1. MECHANICAL EROSION CONTROL TECHNIQUES

Ripping to a depth of 1.5 to 2 metres along contour lines has been introduced to aid infiltration in addition to root penetration. There have been no quantitative studies of the effect of ripping on infiltration, but it has been assumed that it has a positive effect. However, where the rip lines depart from the contours, water has been concentrated and the effect has been to intensify scouring.

In 1971, following the occurrence of significant erosion, ALCOA adopted a policy of complete landscaping of the mine pits. This involved battering of the vertical pit walls and the construction of drains, silt traps, and concrete and rock spillways. This reduced erosion, but the water discharging off the mine pits still carried a considerable sediment load, and the water discharging into the forest in some areas was still turbid. Consequently, the policy of discharging the water run-off from the bauxite pits was discontinued. Water was confined to the mine area by the construction of embankments along contour lines on the lower side of the pits. Large contour drains were constructed at intervals on mine pits in an attempt to improve infiltration and reduce erosion on the pit surface.

Design of the contour banks was subjective. Riches (pers. comm.) has made a preliminary study of the capacity of the contour banks to contain overland flow. He concluded that, even with an overflow depth of 1.4 metres, the storage capacity of the contour drains will be exceeded in "wet" years.

Retention of surface run-off in the pits is possible in areas where there is no salt present in the soil profile. However, in saline areas this could increase the saline groundwater component of the yield (see below). Even in non-saline areas the use of mechanical techniques to limit erosion and turbidity will be limited because of:

(i) the high cost of construction of banks which will ensure retention of the water in very high rainfall years;

(ii) mechanical treatments such as large contour banks, ripping etc. place constraints on future management of the pits. For example, large contour drains present a major access problem to most vehicles used for fire control.

2. VEGETATIVE TREATMENT OF MINE FLOOR

(a) Native Recolonization

Recolonization of mine pits by native shrub and understorey species has been minimal in most mine pits. It has been assumed that the absence of regeneration of shrub and understorey species on the mine pits has been caused by destruction of the soil and lignotuberous material during the overburden storage phase of the mining operation. Tacey (pers. comm.) has examined the effect of soil storage on regeneration, and preliminary results are shown below.

Soil Treatment	Number of Plants/m^2	
	Spring	Late Summer
Stock-piled soil ($>$12 months)	0.25	0.50
Overburden soil replaced immediately on mine pit	0.80	-
Top 5 cm of overburden soil placed on mine pit	3.45	6.93

These preliminary results indicate that native shrub recolonization can be markedly improved by avoiding stockpiling of overburden soils. However, this practice presents severe logistical problems for the mining company (White, pers. comm.).

(b) Direct Seeding

In 1974 a number of trials were established to determine whether shrub species and agricultural grasses and clover could be used to stabilize the mine pit surfaces.

In the initial trials, native shrub species (primarily legumes) were sown singularly and in combination with Woogenellup clover and Wimmera rye grass in 40 metre square plots. Seeding rates were as follows:

native legume seed = 300 seeds/m^2
clover = 8.9 gms/m^2
grass = .56 gms/m^2

All plots were fertilized at a rate of 1 tonne/ha of superphosphate.

In a separate trial, 4 tree species (Eucalyptus bicostata, Eucalyptus camaldulensis, Eucalyptus saligna and Eucalyptus propinqua) were planted in plots direct seeded with clover and rye grass and clover and native shrub species.

Clover establishment was more rapid than that for native species, but clover was primarily restricted to the furrows of the ripped lines. The growth of legume species was variable, but 12 months after sowing, Acacia extensa, Acacia myrtifolia, Acacia strigosa and Acacia distachya had formed 100% canopy cover. By the second year after seeding, the legume plots had formed dense and vigorous stands (Figure 3). Clover had a marked effect on survival and growth of native shrub species (Figures 3 and 4) and tree height and survival. Mean tree height two years after establishment of the 4 species was 40.4 cm in the non-clover plots and 27.3 cm in the clover plots.

Fig 3

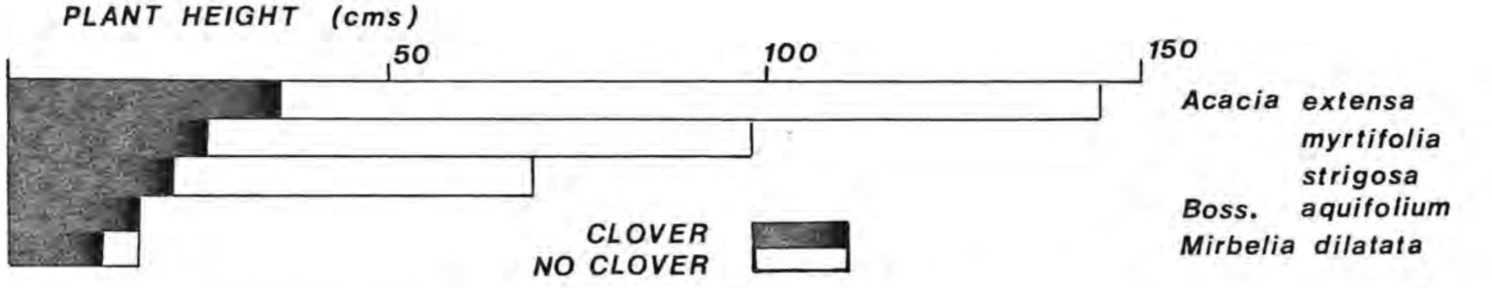
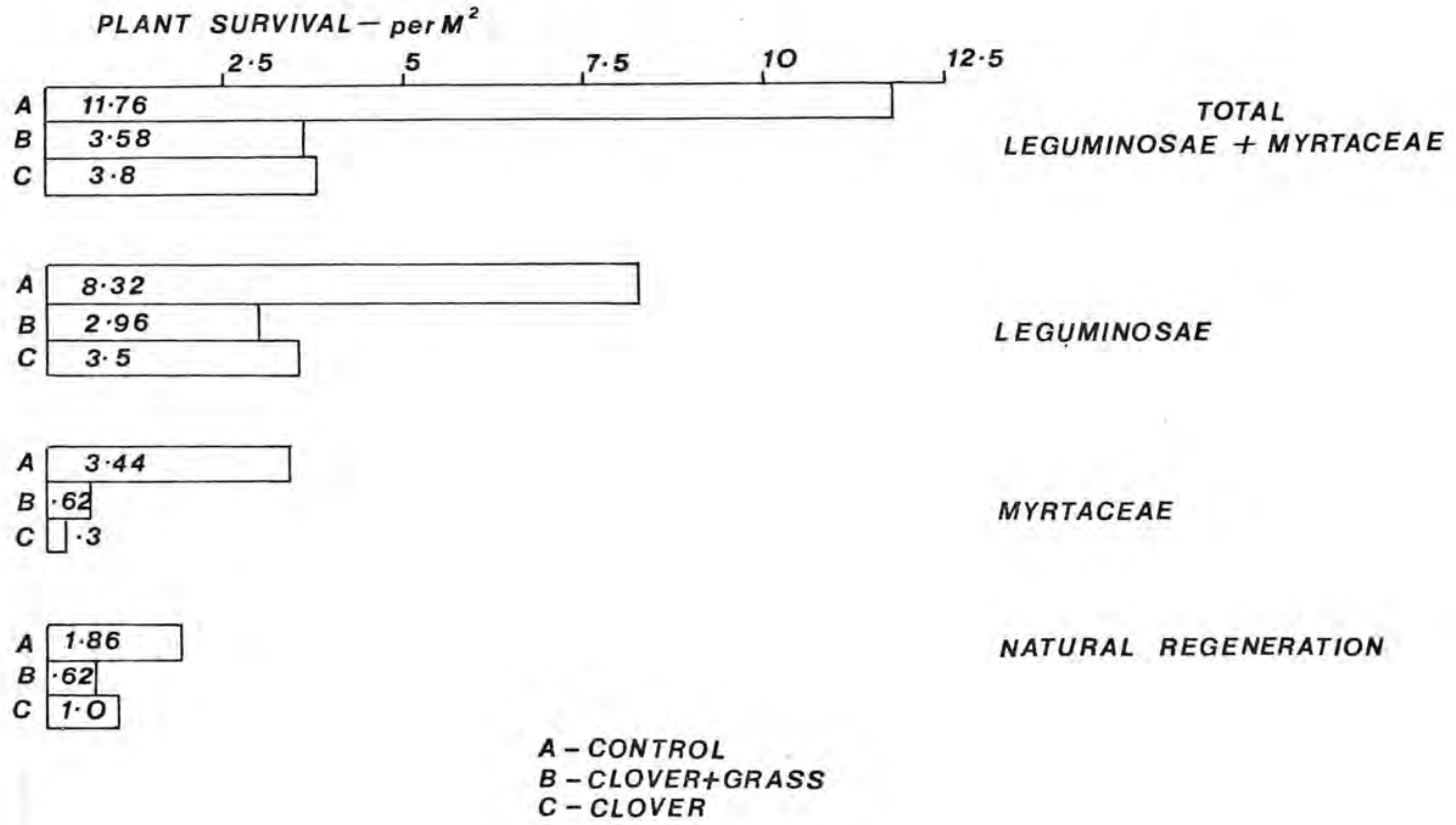

PLANT HEIGHT (cms)
50
100
150
Acacia extensa
myrtifolia
strigosa
Boss. aquifolium
Mirbelia dilatata
CLOVER
NO CLOVER

Fig 4


PLANT SURVIVAL — per M²
2·5
5
7·5
10
12·5
A 11·76
B 3·58
C 3·8
TOTAL
LEGUMINOSAE + MYRTACEAE
A 8·32
B 2·96
C 3·5
LEGUMINOSAE
A 3·44
B ·62
C ·3
MYRTACEAE
A 1·86
B ·62
C 1·0
NATURAL REGENERATION
A – CONTROL
B – CLOVER+GRASS
C – CLOVER

In an attempt to obtain quantitative data on the relative effect of different vegetative treatments on the quantity and quality of water discharged from the surface of the pits, a detailed small plot run-off trial has been established. Twelve carefully constructed 3.6 x 30 metre plots have been established. Each plot is self-contained, and the quantity of water and its turbidity and nutrient load are being recorded after each rainfall event. The total sediment yield from each plot will be determined after 12 months.

In addition to the detailed plot studies, direct seeding of native shrub species and tree species has been attempted in a broadscale trial. A mixture of native seed and tree seed was applied using a "hydroseeder" on a pit 2.5 hectares in area. Mulch was applied following seeding. Distribution was variable, but 12 months after seeding there was an average 20 plants (shrub + trees) per square metre.

The trials conducted to this date indicate that it will be possible to stabilise the overburden soils by the second year after direct seeding with native species. It is unlikely, however, that infiltration will be significantly improved by vegetative cover. Current research is directed at developing vegetative techniques which will stabilize the overburden soil during the first year following mining. A variety of agricultural species are being tested. However, the use of agricultural species is incompatible with the establishment of native species. Current trials are being established to determine if it is possible to achieve a succession from the agricultural species to native species while maintaining overburden stability. If the turbidity of water flowing from the bauxite pits can be reduced to acceptable levels,it is planned to discharge the overland flow directly into the stream channels.

SALINITY

The presence or absence of salt and its distribution in the soil profile will have a major influence on rehabilitation procedures. Data from Projects 3 and 4 and Forests Department stream salinity sampling indicate that it is unlikely that there are significant accumulations of salt west of the 1150 mm isohyet. Current bauxite mining operations occur west of this isohyet. However, comparison of groundwater levels under mine pits and adjacent forest have shown that a groundwater mound has developed. This is attributed to the "absence of transpirative loss from the water table and only in minor degree ..... to greater infiltration" (Projects 3 and 4. State of Knowledge Report, 1976). There is thus a potential for bauxite mining operations to increase stream salinity if it occurs in sites where there has been significant accumulation of salt in the soil profile.

The type and density of vegetative cover necessary to return the transpiration demand on bauxite sites to previous levels is unknown. Carbon (pers. comm.) compared the transpiration rates of leaves of trees planted in the No. 1 Jarrahdale Site to those in adjacent forest and concluded that there was no significant difference. As leaf area on the bauxite sites exceeded that in the native forest he concluded that after the initial establishment phase the transpiration demand would be at least equal to that of the native forest. Preliminary studies of the groundwater levels in the Jarrahdale No. 1 Site suggest that a "groundwater trough" is forming below a pit rehabilitated with *Pinus pinaster* (Project 4 - State of Knowledge Report, 1976). These preliminary studies suggest that, even though root development on bauxite pits is limited to the overburden soils, water consumption is comparable to that of the original native forest. However, the above studies were preliminary, and more detailed research on the effect of species and stand density on water consumption is currently being initiated. This includes:

(1) Transpiration studies.

(2) Measurement of the overland flow component of the hydrological cycle on bauxite pits.

(3) Paired catchment studies in eastern potentially saline areas where bauxite mining will be simulated.

(4) Measure of soil moisture withdrawal pattern of trees planted on bauxite sites, using neutron probes.

(5) Root excavation.

NUTRIENT DISCHARGE

Nutrient levels in water running off plots fertilized with Vigran 999 (9% N, 9% P, 9% K) at a rate of 500 kg/ha were monitored weekly during 1975 at the Del Park site. Total dissolved solids (TDS) levels rarely exceeded 50 ppm, and none exceeded 100 ppm. Approximately 50% of the T.D.S. content was NaCl. The bulk of the remainder was accounted for by K^{+}, Ca^{++}, Mg^{++} and HCo_3^{-}. Higher T.D.S. levels were recorded in the collector contour streams at the base of the pit, but they did not exceed 150 ppm. These preliminary data suggest that nutrient discharge is unlikely to be significant. However, more detailed monitoring of heavily fertilized agricultural legume pasture is currently being carried out.

TOTAL CATCHMENT REHABILITATION

Currently, rehabilitation is restricted to the bauxite pit surfaces. However, jarrah dieback infection which preceded mining operations, and new infections originating from mining and other forest operations, will ensure that the forest area requiring rehabilitation will exceed the mine pit surface. Bartle (1976) examined the current and projected forest cover on the catchment of the Seldom Seen.

The projected vegetation status of this catchment is shown below.

Vegetation Type	Area Hectares	% of Total
Protectable Healthy Forest	84	12
Mine Pits and Roads	189	27
Projected Dieback Infection	177	26
Advanced Dieback	244	35
TOTAL	694	100

The Seldom Seen study clearly demonstrated that bauxite mining rehabilitation must be placed in the context of total catchment management.

ACKNOWLEDGEMENTS

The bauxite mining rehabilitation research which is summarized in this paper is the product of the effort of numerous officers from the State Government Departments and ALCOA.

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PAIRED CATCHMENT STUDIES INTO THE EFFECTS OF BAUXITE MINING AND THE WOODCHIP INDUSTRY

R. A. HEWER

ABSTRACT : This paper essentially, describes the work being done in relation to the bauxite and woodchip paired catchment studies, with emphasis on the involvement of the P.W.D., Water Resources Section. Some of the problems encountered are discussed and salt storage values for a number of boreholes are presented. Preliminary work on catchment calibration is also briefly discussed.

INTRODUCTION

The ultimate objective of all research related to the effects of changing land-use is to be able to predict the behaviour of catchments that may be affected by changes in land-use. It is essential that these predictions can be made using readily obtainable, short term information. Long term catchment studies such as the bauxite and woodchip paired catchments experiment contribute to this objective in two ways. Firstly, they help in identifying the important variables and secondly, the long term data obtained can be used in validating prediction models.

There are basically 3 experimental methods available for studying the long term effects of changes in land-use:-

(i) Calibration of a single catchment.

(ii) Paired Catchments.

(iii) Multiple Catchments.

The first of these methods is less costly as it only involves one catchment, however, it relies entirely on calibrating the catchment using climatological data such as rainfall and evaporation. The paired and multiple catchment methods overcome this problem by having a "control" catchment (or catchments) hydrologically similar to those to be treated.

The technique of using paired catchments in studying the effects of land management on water resources was first used in 1911 in the United States (Boughton 1970). Since then the technique has been widely used throughout other parts of the world, but has only been adopted in Western Australia during the past five years. Apart from the bauxite and woodchip experimental catchments, there are catchments at Yallambee and Collie for studying the effects of agriculture, and at Mundaring where converting native forest to pines is being studied. As all of these projects are still in the calibration stage, it will be at least 5-10 years before they attain their objectives. Considering the length of time that the problem has been identified, it is surprising that these projects are the first to be carried out on the long term effects of changes in land use.

Results from a number of studies outside Western Australia have shown that the ratio of flows on paired catchments varies considerably, making them difficult to calibrate. We do not consider this to be a major problem in our studies because of the slow response of streams in the South-West compared to other parts of the world. With recent developments in mathematical modelling and improvements in the quality of data, we are confident of adequately calibrating the catchments.

This paper briefly discusses the work carried out on these projects over the past 18 months. Major problems are outlined and preliminary results presented.

CATCHMENT ESTABLISHMENT

The bauxite and woodchip projects consist of 11 catchments costing from $30,000 to $40,000 each to establish. Establishment commenced towards the end of 1974 and is progressing satisfactorily. By the winter of 1976 all of the catchments will have been commissioned, except for a pair located in the intermediate rainfall area of the northern jarrah forest, which will be established during 1976/77 summer. Details of establishment are considered below under :- catchment selection, surface and groundwater monitoring.

Catchment Selection

In selecting research catchments it is essential that they represent characteristics of the areas to which their data are to be applied. With paired catchments it is important that both catchments have similar 'hydrological' features such as climate, size, shape, vegetation, topography and surface geology. Selecting catchments with similar climate and size is reasonably easy, however, matching the other features is difficult to accomplish. The catchments selected range in size from 100 to 250 ha.

In the Bauxite Lease areas, the high rainfall zone (1250 mm) along the scarp is represented by the single CSIRO catchment at Del Park, the low rainfall area (750 mm) by a pair of catchments at Mt. Saddleback, and the intermediate zone (1000 mm) will be represented next summer by a pair to be established 5km south east of the South Dandalup Dam.

At Mt. Saddleback there were only a few suitable catchments and final selection was dictated by the location of the proposed crusher site, because of the need to mine the catchments following calibration. The selected catchments have steep headwaters descending from Mt. Saddleback with a marked change of slope mid-catchment. The vegetation is mainly jarrah with wandoo present in lower valleys.

In the intermediate rainfall zone, the selected catchments have high quality jarrah on the laterite uplands with wide swampy lower valleys. It is unlikely that these catchments will be mined thus simulation of mining will be necessary.

In the Woodchip Licence Area, the jarrah-marri vegetation community is represented by two pairs of catchments, one in the low rainfall zone (900 mm - Warrup Block) and one in the medium-high rainfall zone (1150 mm - Lewin Block). The karri-marri forest is represented by a set of three catchments in the med/high rainfall zone. (1150 to 1250 mm - Sutton Block).

The Warrup Block pair (Figure 4) are moderately dissected with laterite divides and podzolic soils on the valley slopes. The vegetation is typical low rainfall scrubby jarrah.

The Lewin Block pair (catchments C and D - Figure 5) are more deeply dissected with laterites on the divides, podzols on the slopes and reddish loams in the valleys. The higher rainfall is reflected in the more luxuriant vegetation of mixed jarrah/marri and some karri in valleys.

The Sutton block triple (catchments E, F, and G - Figure 6) represent the range of soils and vegetation types observed in repeated patterns across the whole transect of the karri/marri forest from the high to the medium rainfall zones. Catchment E is moderately incised with laterite divides, podzolic soils on the slopes and loams in the main valley, marri and karri dominate the vegetation with only a small area of jarrah/marri on the southern divide. Catchment F has a rather flat gradient and swampy flat uplands with grey sandy soils. Laterite is confined to the southern edge. Jarrah is dominant along the divides with karri on the north facing slopes and marri on the south facing ones. Catchment G has a moderate gradient. Jarrah dominates the lateritic headwater divides, and marri/karri covers the podzolic soils in the valley and on the slopes.

After investigation it was thought that this 'set' of catchments in the 1150 - 1250 mm rainfall zone gave a better overall representation of the karri/marri forest than two pairs situated over a wider rainfall range would have done.

Surface Water

The surface water monitoring comprises measurement of the quantity and quality of rainfall and streamflow. The instrumentation for measuring the rainfall and streamflow is basically the same for all of the catchments.

At the discharge section of each catchment a V-notch weir with a floatwell has been constructed and equipped with a Leupold and Stevens A35 graphical recorder which continually records stage height. A pumping sampler collects samples from the stilling basin of the gauging weir at 0900 hours each day. These samples are analysed for T.D.S., NaCl and turbidity. The amount of sediment deposited in the stilling basins is measured at the end of each winter and the stilling basin emptied.

Rainfall is measured by a Leupold and Stevens Q.A.C. pluviometer located at the top of each catchment and a tilting bucket pluviometer adjacent to each gauging station recording onto the A35 recorder.

In the Warrup Block, near Manjimup and at Mt. Saddleback, climatological stations have been established. These stations are instrumented to measure rainfall, evaporation, wind run, solar radiation and temperature onto a Rimco digital event recorder.

Ground Water

The groundwater system is monitored by approximately 15 bores distributed uniformly throughout each catchment, plus 3 bores located at the discharge section of the catchments to assess the groundwater flow beneath the gauging station. On some of the catchments additional boreholes have been drilled alongside the 3 bores at the discharge section to determine if flow within the bedrock is significant. These bedrock bores have proved difficult and costly to install, the main problem being to adequately seal off the overburden from the bedrock.

On one of the bedrock bores at Mt. Saddleback, the P.W.D. have conducted permeability tests using a "Packer Test", a test which is used extensively in dam site investigations. The test is carried out during drilling and involves pumping water, under a known pressure, down the diamond drill rods which are sealed off around the outside by an inflatable rubber seal (packer) located above the section of hole being tested. Results of these tests will not be available for inclusion in this paper, however, it is hoped to be able to present them at the workshop. Because of the expense of the bedrock bores no more will be drilled until it is proven from existing bores that significant flow takes place within the bedrock.

The Mines Department are responsible for drilling the woodchip bores and the P.W.D. for the bauxite bores. Only a few of the woodchip bores remain to be drilled, however, it is hoped to re-drill some of the bores in the low rainfall jarrah-marri catchments where core recovery was poor. The drilling program for the bauxite catchments will not be completed until next year.

Cores from the drilling are analysed for bulk density, moisture content, pH, T.D.S. and NaCl by the Forests Department.

Seismic surveys are being carried out by the Mines Department to determine the profile of the bedrock across the discharge section of each catchment. This technique is proving very successful except at Mt. Saddleback where the bauxite layer is too hard and deep.

COLLECTING AND PROCESSING DATA

Collecting and processing of surface water data presents no serious problem. Streamflow and rainfall are handled by existing Water Resources Section procedures and climatological data can now be handled with the recent development of a computer system for processing digital event recorder information. In the near future another computer system will be developed for handling the large amount of water quality information which is rapidly accumulating as a result of increased involvement in water quality over recent years. The proposed system will also handle borehole data including soil salinity information.

A major problem presently confronting the Water Resources Section is the measurement of salinity profiles in boreholes. Last year the section was responsible for measuring profiles six weekly in approximately 40 boreholes. This has been a considerable burden to our hydrographers and with the number of bores increasing to approximately 130 this year, it is unlikely that the section can handle the increased work load.

Another disturbing aspect of this work is the equipment available for taking the measurements. The conductivity meter being used is the only meter available for recording both temperature and conductivity down boreholes. This instrument continually loses calibration and at times has been as much as 150% in error. The instrument is checked against a laboratory conductivity meter and standard solutions before and after measuring each borefield, however, the large variations that occur in this time makes the data very suspect. Under these circumstances we begin to wonder if the information is worth the effort involved in obtaining it. Maybe the time could be better spent on more important aspects of the research.

SALT STORAGE RESULTS

Salt storage values for a number of boreholes have been calculated and are presented in Table 1. The salt storages are shown for each 2 metre interval as well as for the total depth of the borehole. The data is presented in this form to give some idea of the vertical distribution of the salt, and a more meaningful comparison between boreholes with differing depths and boreholes which may not have reached bedrock.

These results have not yet been evaluated to any extent and are only presented to allow comparison with other data.

There are in excess of 150 bores associated with the bauxite and woodchip paired catchments. To manually analyse and plot this data would involve a great deal of time and effort. Realising the amount of work involved, we have developed some small computer programs for calculating salt storages and plotting soil salinity profiles. Plotting facilities are very poor at present, however, with new facilities imminent it is expected that the programs will save a considerable amount of time and effort.

CALIBRATION OF CATCHMENTS

There are a number of hydrological models of varying degrees of complexity that may be used for calibrating a catchment. These models can be classified into basically two categories :-

- those which predict the outputs of a catchment (i.e. streamflow, salt load groundwater levels etc) from measured inputs (i.e. rainfall, evaporation etc)
- those which rely on obtaining a relationship with a nearby catchment which is hydrologically similar (control catchment)

Very little has been done so far in calibrating the bauxite and woodchip catchments, however some time has been spent in calibrating the Collie experimental catchments using a rainfall runoff model known as the "Sacramento Model" (Burnash et.al 1973). This model belongs to the first category as it predicts streamflow from rainfall and evaporation. The model, is very similar to the more commonly known "Stanford Watershed Model". The "Sacramento Model" does not predict water quality and cannot be used for predicting changes following disturbances within a catchment. It is only being used until C.S.I.R.O. have completed the model they are presently developing.

The model should give an indication of when sufficient information has been collected to confidently predict the behaviour of the catchment and hence when the catchments can be treated.

Calibration of the Wight's catchment using the "Sacramento Model" with 1974 data is complete. The flows predicted by the model are compared in Fig. 8 with the observed flows. The coefficient of determination (r^2) between the observed and predicted flows is 0.971. Calibration of the catchments using additional data from 1975 is continuing.

In order to obtain a quick appreciation of the standard of calibration to be expected for Wight's catchment using streamflow from Salmon catchment, which is alongside, a simple linear regression model was tried (second category). The flows predicted by linear regression are compared in Fig. 7 to the observed flows for Wight's ($r^2 = 0.975$). This method compares favourably with predictions by the "Sacramento Model" except in the low flow range where it overestimates. This inadequacy using simple linear regression should be overcome by using other techniques such as non linear regression or autoregressive integrated moving average models.

CONCLUSIONS

1. Establishment and operation of the woodchip and bauxite paired catchments has progressed satisfactorily.

2. The equipment available for measuring salinity profiles in boreholes is unreliable to the extent that the data being collected is of doubtful value.

3. Consideration is being given to terminating salinity profile measurement in boreholes until such time as a reliable instrument becomes available and would only continue then if the work can be justified in terms of the projects' objectives.

4. A computer program developed for plotting soil salinity profiles is expected to save considerable time and effort over manual plotting.

5. Work being carried out on the calibration of the CSIRO catchments using the "Sacramento Model" is sufficiently encouraging to extend the work to other experimental catchments.

6. The limitations of the "Sacramento Model" are realized and will only be used until better models become available.

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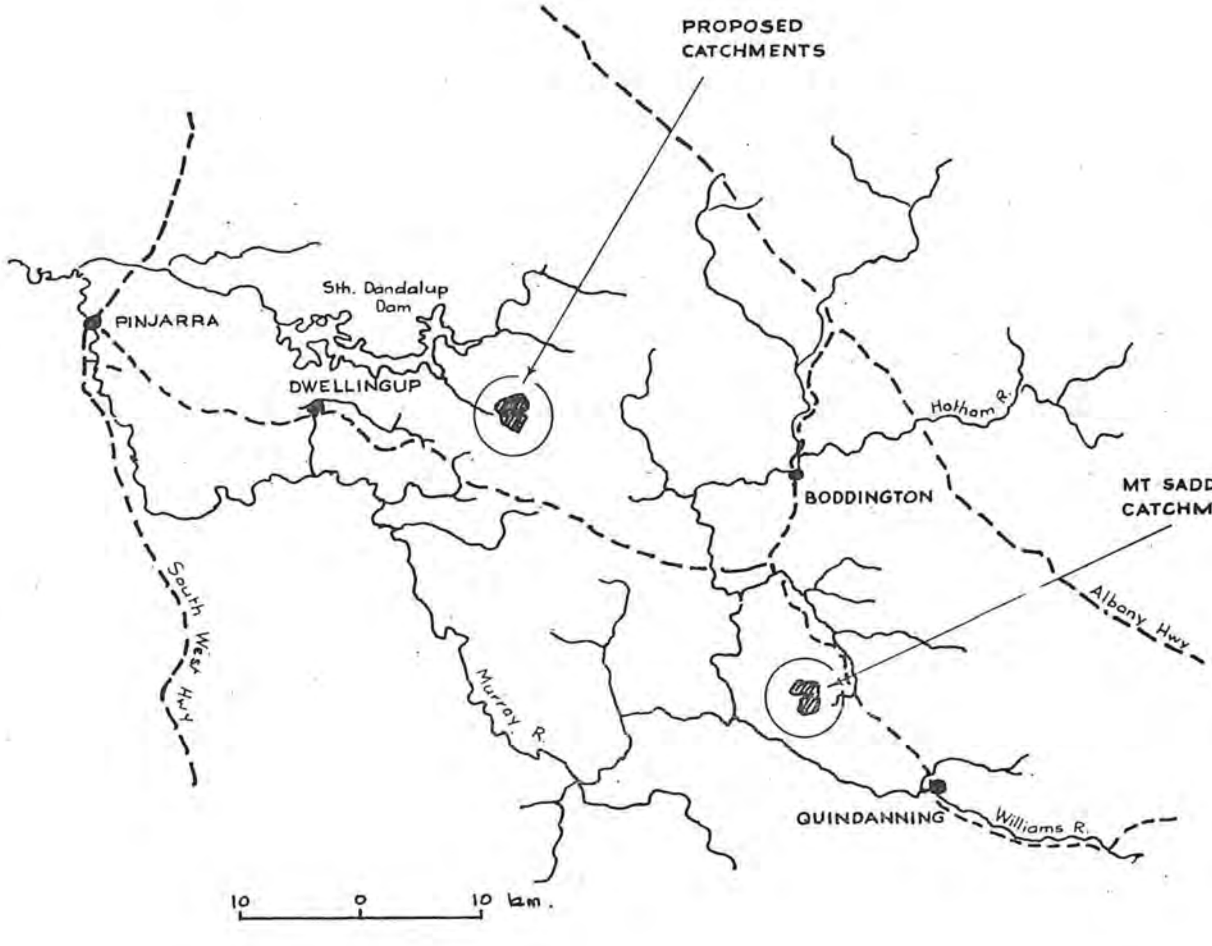
2. R.J.C. Burnash, R.L. Ferrel and R.A. McGuire, A Generalised Streamflow Simulation System, Co-operatively developed by the joint Federal-State River Forecast Centre, March 1973.

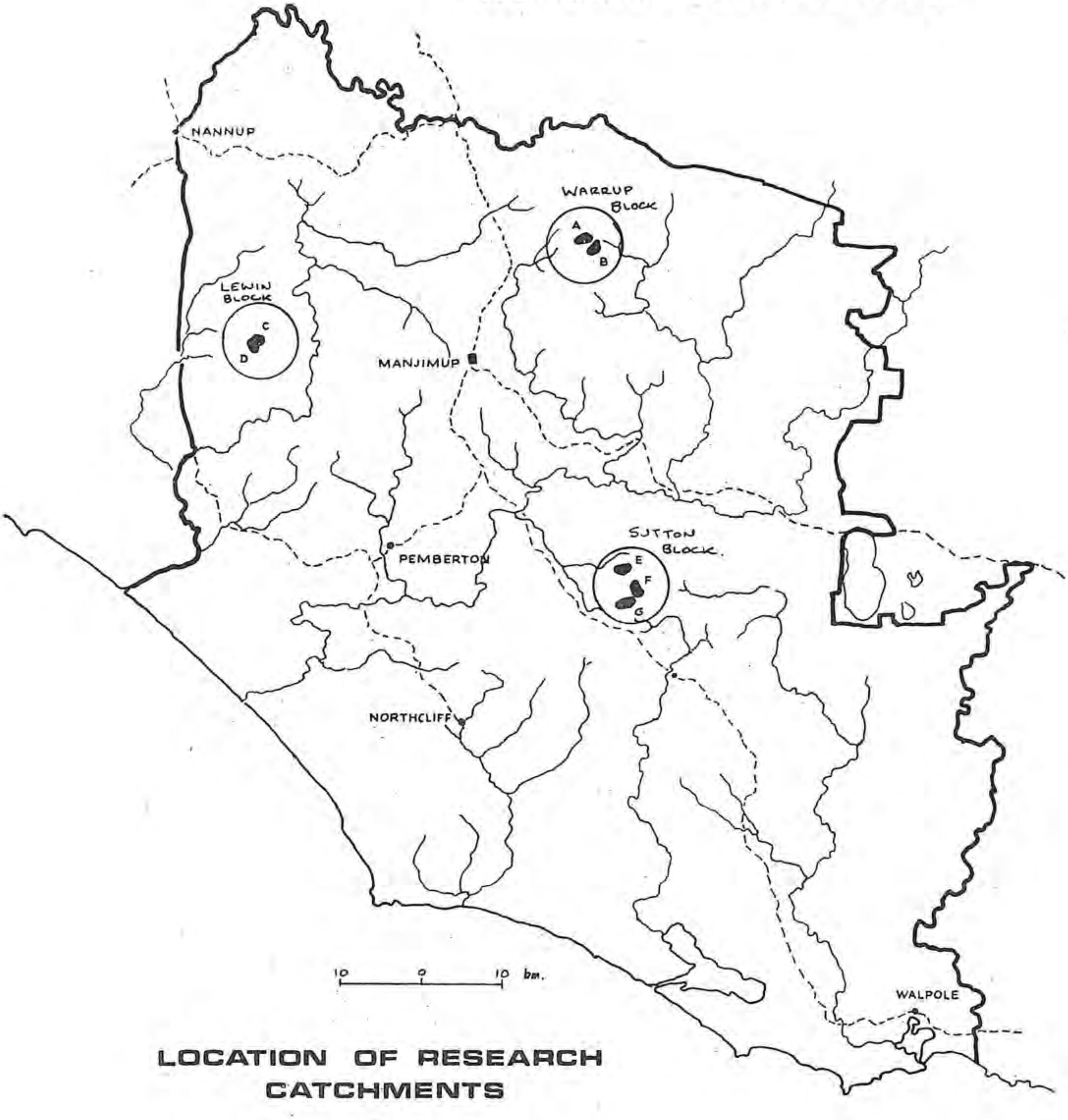
FIG. 1



LOCATION OF BAUXITE CATCHMENTS

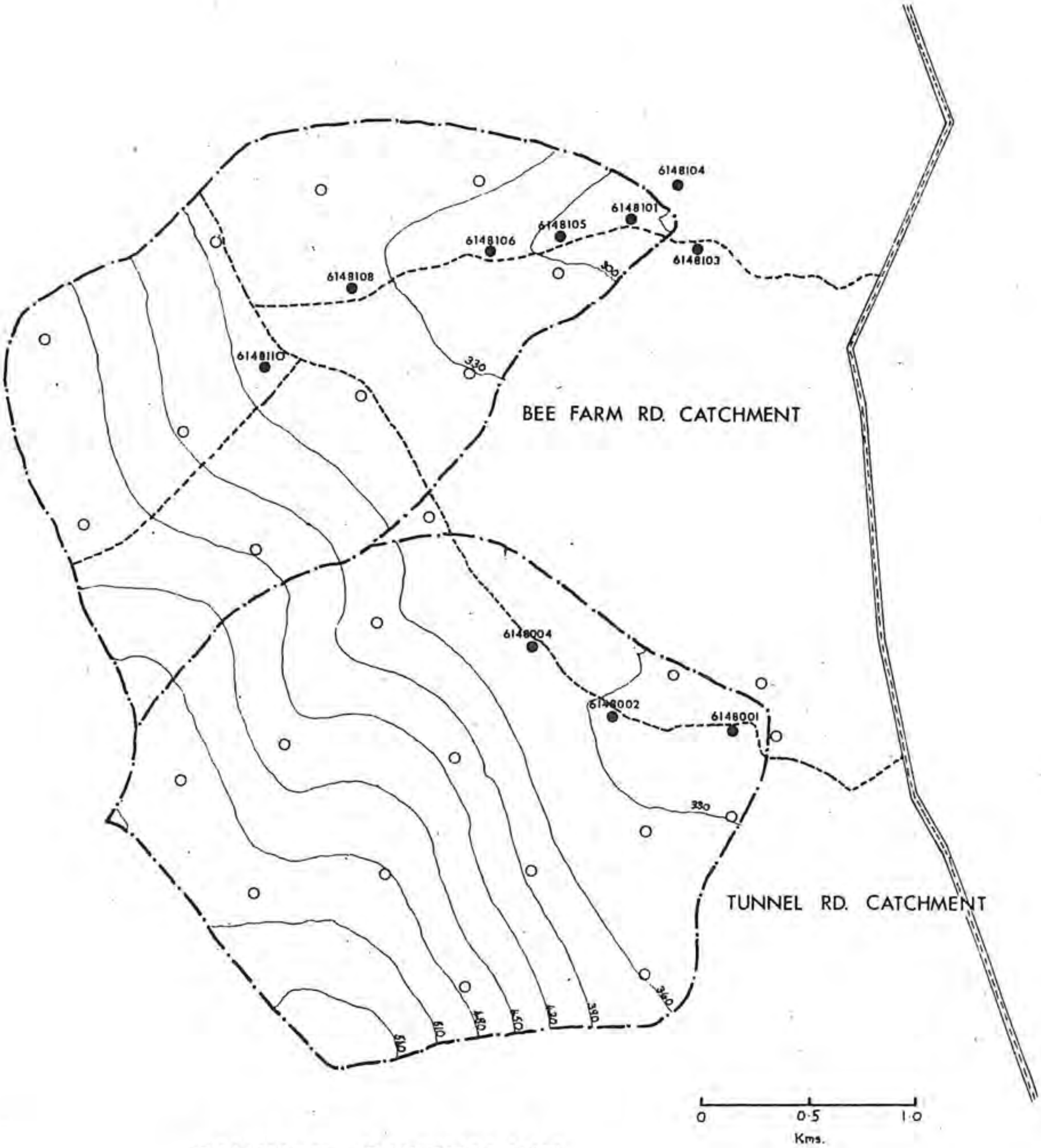
FIG. 2

WOODCHIP LICENCE AREA



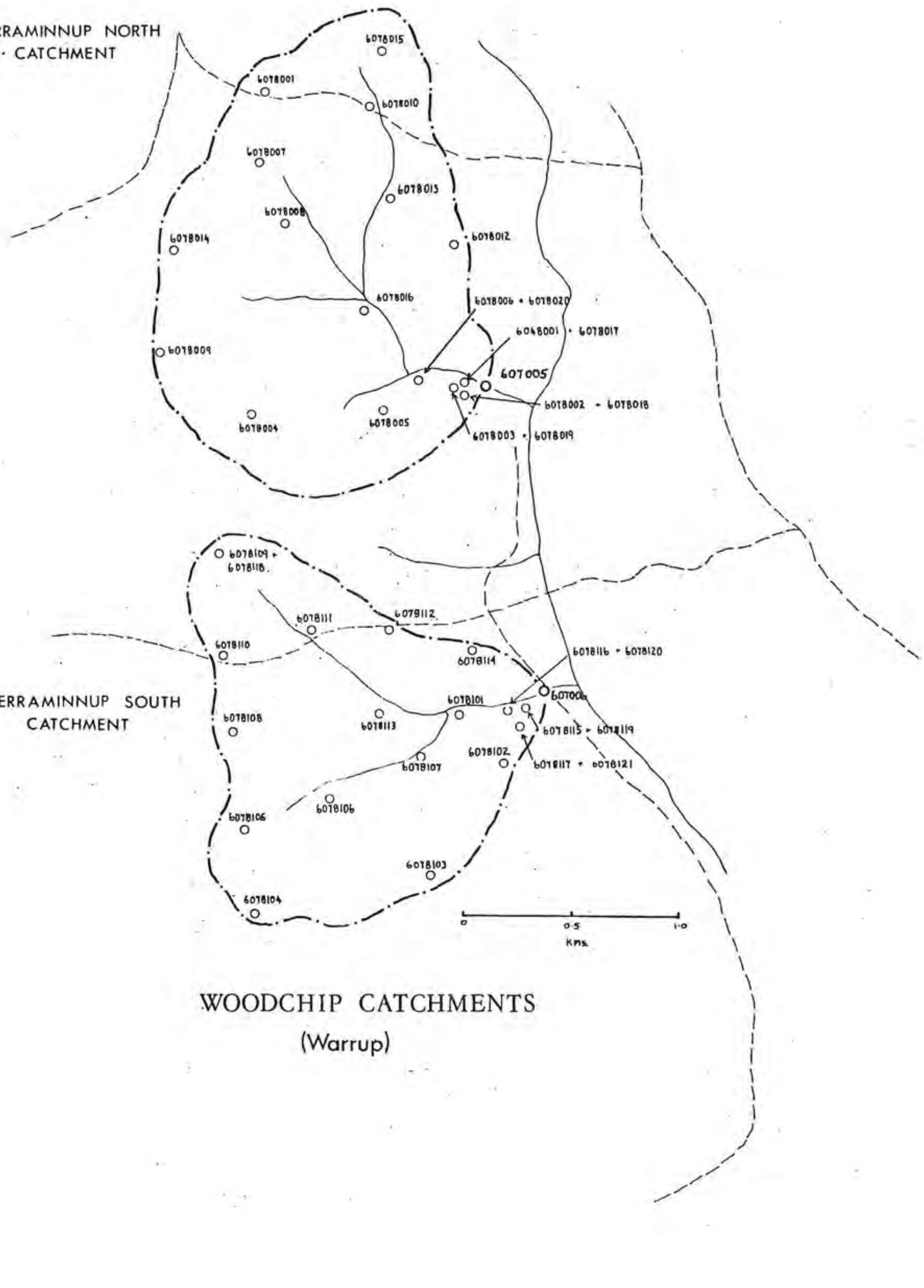
LOCATION OF RESEARCH CATCHMENTS

FIG. 3



BAUXITE CATCHMENT
(Mt. Saddleback)

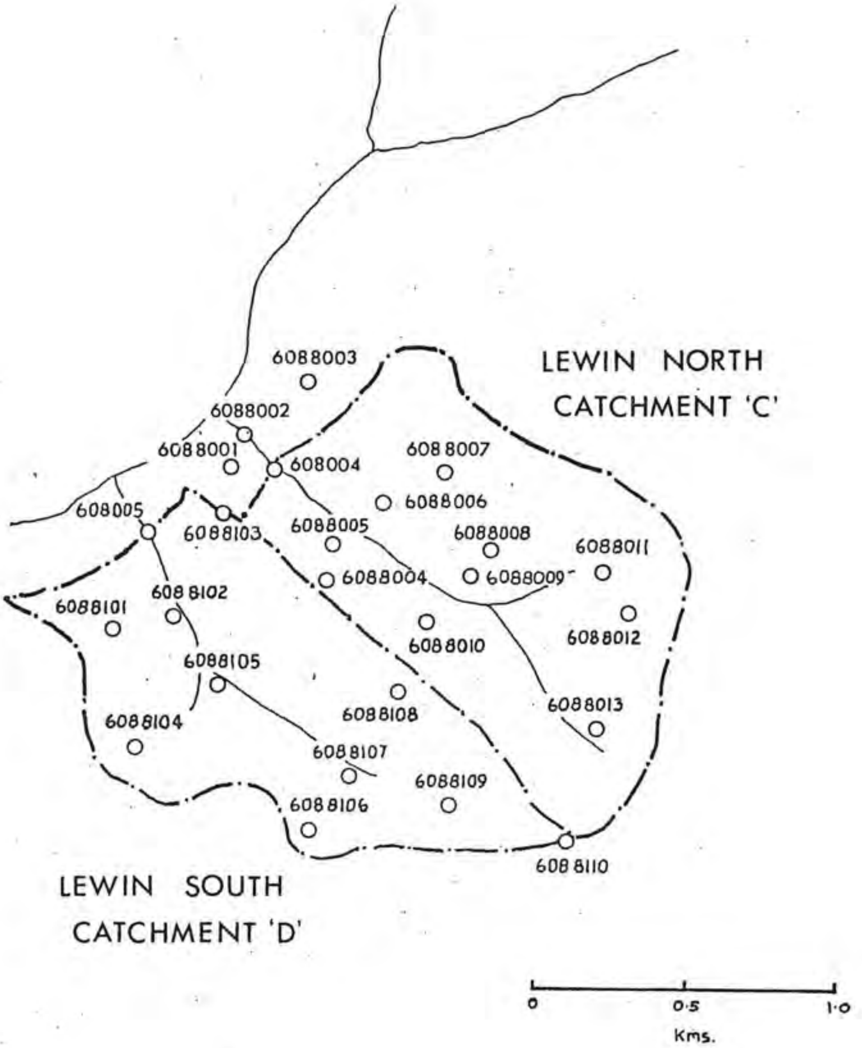
FIG. 4



WOODCHIP CATCHMENTS

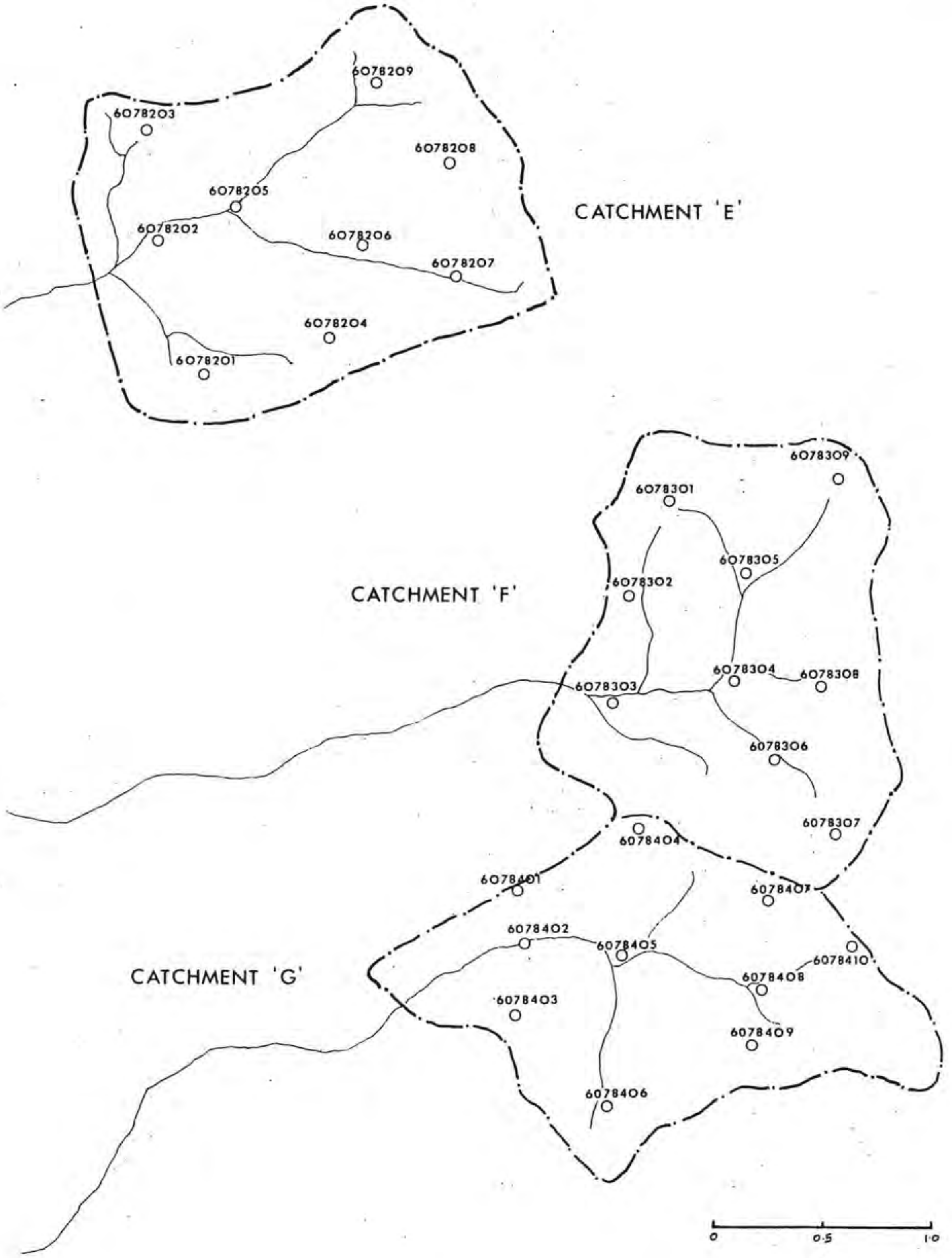
(Warrup)

FIG. 5



WOODCHIP CATCHMENTS
(Lewin)

FIG. 6



WOODCHIP CATCHMENTS
(Sutton)

FIG. 7

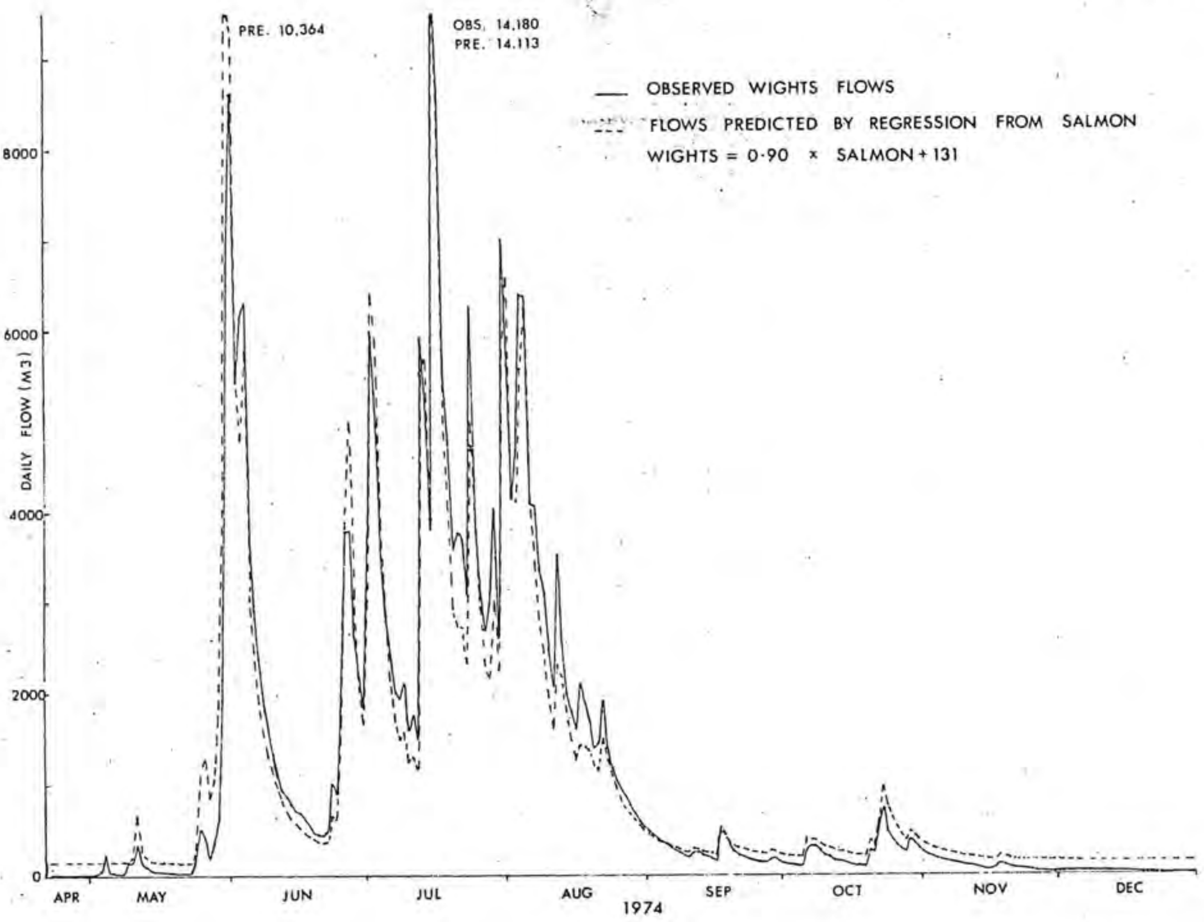

PRE. 10,364
OBS. 14,180
PRE. 14,113
OBSERVED WIGHTS FLOWS
FLOWS PREDICTED BY REGRESSION FROM SALMON
WIGHTS = 0·90 × SALMON + 131
8000
6000
4000
2000
0
DAILY FLOW (M3)
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1974

FIG. 8

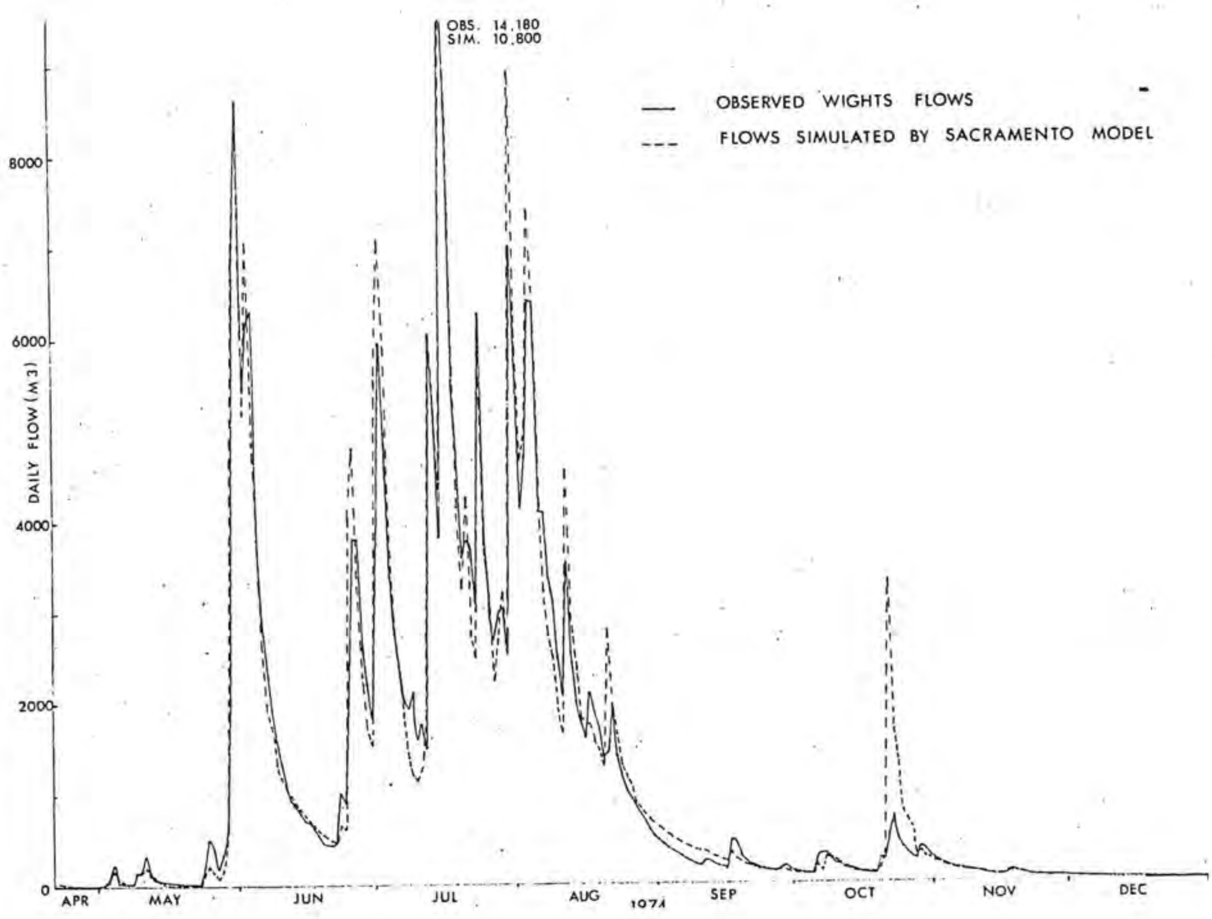

OBS. 14,180
SIM. 10,800
OBSERVED WIGHTS FLOWS
FLOWS SIMULATED BY SACRAMENTO MODEL
8000
6000
4000
2000
0
DAILY FLOW (M3)
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

TABLE 1

Depth Interval (m)	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	Total	Last core sample depth (m)
	SALT STORAGE (tonnes/hectare)											
Bauxite Saddleback												
6148101	22.6	111.1	328.7	135.5	24.5	17.0	8.8				648	12.95
103	2.8	5.2	52.4	60.3	19.4	13.6	7.1	6.2			167	17.52
104	2.0	9.8	8.2	11.5	10.7	10.0	10.3	8.0	7.1	3.5	81	19.05
106	1.1	0.9	0.6	3.4	8.8	12.3	1.0				28	12.19
108	4.2	0.4	1.2	4.4	11.4	54.0	36.0	10.1			122	15.56
Woodchip D. Catchment												
6088101	7.6	8.3	24.7	61.2	105.2	105.7	97.7	46.0			456	15.09
102	13.8	13.8	7.0	1.6	2.5	2.1	2.5	0.3			44	14.36
103	10.8	14.8	27.3	40.9	43.0	23.9					160	11.25
106	3.8	39.7	33.1	7.0	3.6	2.3					90	11.30
107	4.2	4.1	2.9	3.3	3.1	1.2					19	11.01
Woodchip F. Catchment												
6078301	30.0	14.3	4.4	3.4	1.7						54	9.61
302	2.8	7.3	32.7	33.3	20.1	23.0	8.8	7.4	5.2	4.2	145	20.2
303	7.0	34.0	47.2	12.7	4.2	2.7	.4				108	12.45
308	17.4	17.8	15.8	26.0	20.9	7.4	4.8				110	12.47
309	1.9	14.7	35.1	31.7	20.1	11.2	8.3	6.6	6.6	6.6	143	20.30
Woodchip G. Catchment												
6078402	58.80	52.9	13.0	12.9	10.8	10.3	1.2				160	12.23
404	6.0	4.8	6.0	4.5	4.5	3.1	2.2	1.9	0.2		33	16.17
407	2.4	6.3	11.3	15.0	22.3	32.0	32.8	5.7			128	14.48
408	3.2	17.0	12.2	8.1	5.0	0.8					46	10.41
409	3.1	4.1	3.4	2.8	4.6	3.9	3.3				25	14.97

Note : 1. Refer Figures 3, 5 and 6 for borehole location

2. The last value shown for each borehole extend from the start of the depth interval to the depth of the last core sample

FIELD EXPERIMENTATION FOR DETERMINING THE SALT AND WATER BALANCES FOR CATCHMENTS

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Abstract

Salt and water balances are being determined using three sets of paired catchments in different rainfall zones. The data will provide the basis for understanding the mechanisms of hydrologic change which induce changes in the salt content of streams. The measurements will also be the input data for models of the systems. Seven catchments are being used to study the land use change from forest to agriculture, and an eighth catchment is being instrumented to study the effects of bauxite mining. The quantity and quality of rainfall, groundwater flow, soil water and stream flow are being measured. The evaporation and change in salt storage are not being measured directly. The measurements have been made for some years and land use treatments either have been applied or will be during the next year.

1. Introduction

The determination of both the quantity and the flux of water and salt at the macro-scale in the natural environment, requires data to be collected from an area large enough to include the hydrologically significant features of the system being studied. For monitoring the effects of a change in land use on stream salinity there needs to be included in the area studied those landscape units expected to show significant changes due to salt and water redistribution.

The Division of Land Resources Management of CSIRO has a number of long-term catchment studies in the Darling Range of south west Australia. The broad objective is to establish the mechanisms and magnitude of the changes in the salt and water balances when the land use is altered. The research is aimed at developing methods to predict

(1) the stream salinity, and
(2) the time taken for the system to reach a new "steady-state" condition following the change in land use, in terms of physical characteristics of a catchment. The development of models has been discussed in papers by Luxmoore and Peck. The field experimentation to be described here is providing the data to be used to test the validity of the models.

The land use changes being studied are from jarrah-marri forest to agriculture, and jarrah-marri forest through bauxite mining to the rehabilitation phase using trees.

Experimental Method

The water balance for a catchment can be described in the equation

$$P = O + U + E - \Delta W \qquad (1)$$

where P is rainfall

O is the stream flow integrating both runoff and groundwater sources

U is sub-surface drainage across the catchment boundaries

E is evaporation

ΔW is change in soil water storage (initial minus final)

The solute balance for a catchment has the form

$$P c_p = O c_o + U c_u - \Delta(W c_w) - M \qquad (2)$$

where P. O, U, and W are as in equation (1) and c_p, c_o, c_u and c_w are the solute concentrations for rainfall, stream flow, sub-surface drainage and soil water storage respectively.

M is the solute contribution from the weathering process. For these catchment studies M is taken equal to zero.

The paired catchment technique is being used for the studies involving land use change to agriculture at "Yalanbee," Bakers Hill, in the Bingham River catchment east of Collie and in the Salmon Brook area west of Collie near the Wellington Dam. One catchment in each group is to remain uncleared to act as a control. The clearing treatment is a complete removal of natural vegetation to be replaced by grazed pasture.

A ten year period of measurement is planned at least three years of which is required for the calibration of the catchment response to the uncleared condition. For the study of land use change involving bauxite mining, only one catchment is being studied with the measurement of the soil water storage changes in the unsaturated soil zone being excluded. Only one year of studies of this catchment near Dwellingup have been possible prior to mining operation commincing. The land use change involves mining and rehabilitation of about 20% of the catchment.

Some features of the catchments are given in Table 1. The responsibility for the field data collection programme is divided between the Water Resources Section of the Planning Design and Investigation Branch of the Publice Works Department (stream flow, rainfall quantity) and the CSIRO Division of Land Resources Management (Rainwater quality, below ground level components, analysis of stream water samples). Financial assistance from the Australian Water Resources Council is acknowledged. (Project 71/31).

The spatial distribution of measurements for some components of the water and salt balance require prior knowledge of the variability of these measured quantities in the catchments. In the absence of local data, a statistical analysis using estimates of variability indicated the need for more measurements than was feasible with the available resources. This applies particularly to soil water storage.

Although the contours of the groundwater potentiometric surface will tend to follow the soil surface contour, the gradient of the water surface, which sets the spacing for groundwater wells, cannot be predetermined with any confidence. For ease of analysis of flux matrix and contour plotting the square grid of groundwater wells has been used at intervals of 100, 200 and 400m spacing using closer grids for the steeper land form catchments. Where the emphasis is on the groundwater behaviour such as in the bauxite mining catchment or at the mouth of a catchment, the closer spaced grid has been used. Each groundwater well has been used to make a measurement of hydraulic conductivity using a rate of recovery technique developed by Peck (Private communication).

Instrumentation for the Water and Salt Balances

With some minor differences only between the catchments at Bakers Hill and at Collie, a description of the instrumentation of one catchment, Lemon in the Bingham River area, is an adequate representation of all the catchments where the land use change to agriculture is being studied.

For the measurements of the water balance the input by rainfall is measured by storage gauges at three exposed sites (1300m apart) and by two recording gauges. At five other sites across the catchment, rainfall is measured by storage gauges exposed below the forest vegetation, the location being an estimate of average canopy opening.

Output through stream flow is measured with V-notch weirs of either 90° or 60° angle depending on the flow characteristics. For the broad valley type stream cross-section concrete stilling ponds have been installed.

The change in soil water storage is obtained by determining the soil water content using the neutron scattering method. From statistical analysis the most suitable arrangement of access tubes was in five groups of three tubes. The catchments were known to have four main soil types, one type being dominant in area. A site of a nominal 0.1 hectare size was selected in each soil type, with a second site selected in the dominant soil type. Each of these water balance sites was instrumented with three neutron access tubes, allowing measurement of soil water content to six metres. The problem of tube placement was solved by using an oversize hole technique.

The measurement of soil water changes between the six metre depth and the groundwater level has not been attempted. At each water balance site a hole has been drilled to obtain a core for the full depth to basement rock. This hole was lined subsequently with a plastic pipe to allow measurements of the groundwater level. To measure the perched groundwater in the gravelly or sandy surface soils, shallow wells to the clay interface have been installed in each water balance site.

The movement of groundwater is being studied with a grid of small diameter wells installed to basement rock where that is possible with the drilling equipment available. Only the catchments which will have a land use treatment are being instrumented in this manner. On all catchments in the Bingham River area, and at Bakers Hill, a close grid (100m by 100m) of wells has been installed at the mouth of the catchment to measure the groundwater flow from the catchment. A summary of the numbers of wells on each catchment is given in Table 2. (Note: The grid size on the Wellington Dam catchment, Wights is 200m; on the Bingham River catchments, Lemon and Dons, is 400m; and at Dwellingup there is a basic 200m grid with some areas closed to 100m spacing).

The major input component for the salt balance is the salt deposition in the rainfall measured by sampling of water collected in the storage gauges at the fully exposed sites. Salt output is obtained using daily samples of stream water and by regular (usually monthly) samples of the groundwater. No measure of the degree of salt stratification in the groundwater has been made. The core-holes, five per catchment, have provided the data for salt storage. Teh chloride ion is used as the prime measure of salt content. Electrical conductivity is also measured for stream and ground waters but a suitable conversion equation to obtain total soluble salts has not been established to date. Recently developed instrumentation for continuous measurement of electrical conductivity of stream water is being used to study the small time period fluctuations of total soluble salt.

For the land use change involving bauxite mining (Del Park catchment) the change in soil water storage in the unsaturated zone is not being measured. The instrumentation is to obtain data on the response of the groundwater in the saturated zone.

Catchment Characterisation

A map of the soils of each catchment has been prepared. The major soil types are being studied for hydrological characteristic relevant to the flow of water. Relationships between water content and hydraulic potential and hydraulic conductivity are being determined. The infiltration coefficient, sorptivity, has been measured for the gravel and red earth surface soils and the sub-surface mottled clay soil horizon. More in-field infiltration studies are planned.

At each deep groundwater well on the catchment saturated hydraulic conductivity has been measured using a method developed by A.J.Peck (personal communication) using the recovery of a bailed small diameter well. The method assumes that at any instant during recovery the well is a sink for purely radial flow. End effects of the slotted section of the well pipe are neglected and flow is assumed to be at steady state rate. It can be shown that the hydraulic conductivity, K, can be estimated by

$$K \simeq - \frac{10 \; r_w^2 \; S}{l} \qquad (3)$$

where r_w is the radius of the well assumed to be equal to the radius of the well casing S is the slope of the plot of

$$\log_{10} \left[\frac{h - ho}{h_1 - ho}\right] \text{ against time (t)}$$

where h is the depth from the reference level to the water level at time t

ho is the depth from the reference level to the water level at equilibrium before bailing commenced

h_1 is the depth to the water level from the reference level at time t = o

l is the length of the slotted section of the well casing.

The hydraulic conductivity is in the units of LT^{-1}. The recovery method was preferred to the injection (slug test) method because the wells are also used to monitor groundwater quality which would be disturbed by addition of water.

In practice, depth measurements are made with reference to the top of the well casing. A bailer is used to lower the water elevation in the well by several meters (one to four) and recovery is monitored until the ratio $\frac{h - ho}{h_1 - ho}$ is about 0.2.

The continuous soil care obtained at at least five sites in each catchment has been used to describe the soil profile characteristics from the soil surface to the basement rock. Profile element boundaries, colour, mottling, gravel content, structure, consistence fabric, texture, and field pH have been described for each core.

Maps have been prepared showing the contours at 2m intervals and the catchment boundary. The Forests Department have mapped the vegetation for each catchment.

Limitations of the Experimental Approach

The catchment pair at Bakers Hill have inadequacies related to size, topographical features and instrument location which limit their use as representative catchments. However, they serve a most useful purpose, in addition to the salt and water balance data, by being sites to experiment with experimental methods and experimental philosophy which assist the more definitive studies elsewhere.

Little decay of stream salinity can be expected for some time after clearing in representative catchment in lower rainfall areas such as the three Bingham River catchments. The Wellington Dam catchment apir have soil and rainfall characteristics which should result in a more rapid approach to a new salt balance after clearing. Though possibly not representative of the more common catchment type in the Darling Range, this catchment pair should provide the most useful data to test the validity of the land use models. The more representative catchment trio in the Bingham River area are essential both for model testing and because experience, soil survey and groundwater quality data lead us to expect a serious long-term salinity hazard when current land use practices are adopted.

For the forest, evaporation accounts for at least 75% of the water output from a catchment. In this type of field study, the "signal to noise" ratio is large. The magnitude of the errors involved in making a measurement of the actual evaporation from a catchment, would be at least as large as the changes in the other output components of the water balance which bring about the redistribution of salt in the landscape. Consequently, evaporation is obtained as the unknown in equation (1). Evaporation does not appear in the salt balance equation. Applying the same philosophy, every effort is being made to reduce the error in measurement of salt input and output rather than attempt to measure accurately the changes in salt storage in the catchment. The total salt storage has been found to be greater by at least a factor of 100 than the annual salt flow from a forested catchment.

Inherent in the objective of the studies is the need to relate the results to other catchments. Objective measurements are being made rather than pursuing all possible measurements in the hope that some may be useful, the aim of making direct physically based measurements is to provide data suitable for models of the mechanisms which control the effects produced by changed land use.

Data Acquisition

Table 1 shows the date when measurements were commenced on each catchment pair. Stream flow is measured on a continuous basis, with the Collie catchments recording stage height on two parallel but independent recording systems. The two recorders each receive a signal from the same rainfall sensor. Electrical conductivity of stream water and the level of the perched groundwater at one well are recorded continuously. The stream water is sampled daily by an automated system.

Other variables in the salt and water balances are much less time dependent and are measured at either time or magnitude-of-change based intervals. During the first and second years of measurements, data for ground water levels and salt content, soil water content to 6m, and salt content of rainfall were obtained on a time basis, usually every four weeks. As obvious patterns emerged, the data collection frequency was altered to a magnitude based change in variables.

One of the catchment pair at Bakers Hill was cleared in 1974 having had more than five years for calibration. Clearing for agriculture is planned for 1976 in each of Wights (of the Wellington Dam pair), and Lemon (of the Bingham River trio) which will have permitted collection of data sets for three winters. Dons catchment (in the Bingham River area) is to receive a modified clearing treatment to experiment with some strategies which may avoid unsatisfactory salt redistribution in catchments. The Del Park mining catchment was monitored for over a year before mining commenced at the end of 1975. There are three physically separated areas for mining in the catchment, only one of which is involved in the present mining operation. This situation is opportune as groundwater data from each may be treated as a sub-experiment both in time and space. The normal rehavilitation treatment will follow mining and data acquisition will continue while transient conditions can be observed.

D. WILLIAMSON
20th May, 1976.

TABLE 1

SOME FEATURES OF THE CATCHMENTS BEING STUDIED

IN SOUTH WEST WESTERN AUSTRALIA

Catchment Group	Catchment Name	Area (hectares)	Estimated Annual Rainfall (mm)	Commencement of Measurements
Land Use change - Forestry to Agriculture				
Bakers Hill	East Catchment	15	600	1969
	West Catchment	19	600	1969 (Cleared 1974)
Wellington Dam (Western Catchments)	Salmon	82	1100	1974
	Wights	94	1100	1974
Bingham (Eastern Catchments)	Dons	350	750	1974
	Ernies	270	750	1974
	Lemon	344	750	1974
Land Use change - Forestry through bauxite mining to Forestry				
Del Park	Del Park	150 (approx.)	1200	1974

Table 2. Numbers of groundwater wells installed in experimental catchments

CATCHMENT	Well types 1	2	3	4	5	6	7	TOTAL deep	TOTAL shallow
SALMON	5	5	-	-	-	2	1	12	1
WIGHTS	5	5	26	-	-	3	1	39	1
DONS	5	5	31†	8	10	2	1	51	11
ERNIE	5	5	-	10	10	6	1	26	11
LEMON	5	5	29†	9	20	4	1	52	21
DEL PARK	-	-	39	36	-	6	-	81	-
YALANBEE WEST	-	-	-	11*	-	10	-	19	2
YALANBEE EAST	-	-	-	16*	-	1	-	17	-
								297	47

† not all installed at May 1976
* a hemispherical grid

<u>Legend to Well Types</u>

1. Deep groundwater well at water balance site.
2. Shallow perched groundwater well at water balance site.
3. Deep groundwater well in 200m or 400m square grid over whole catchment.
4. Additional deep groundwater well in closer square grid than for type 3. Used for special purpose, e.g. at the mouth of the catchment.
5. Shallow groundwater well in square grid in selected parts of a catchment, e.g. sandy duplex soil types near stream flow gauging station.
6. Other wells including exploratory wells, wells not in the grid system, special purpose wells, etc.
7. Shallow groundwater well with continuous water level recorder.

MODELLING THE EFFECT OF A CHANGE IN LAND-USE ON STREAM SALINITY.

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ABSTRACT

Understanding of the effects of changes in land-use on stream salinity can be expressed as a model. Such a model may have many uses, e.g. to identify important parameters of the system, or to estimate the effects of land-use options. Detailed process models of salt leaching are not useful for management due to computer limitations and the cost of parameter estimation. A simplified model based on conservation of mass has been developed, but there are no data sets suitable for validation. Until it has been tested, predictions using this model must be viewed appropriately and may be used only with caution. Existing research programs will provide suitable test data, and may lead to further improvement of the model.

1. INTRODUCTION

Science aims to develop generalizations from sets of empirical observations. A proposed generalization is known as a hypothesis, and when this adequately accounts for the results of suitable experimentation the hypothesis is accepted as a useful theory.

Many of the problems faced today are associated with large and complex systems. There may be adequate theories for system components, but their integration and the quantification of system parameters presents new and difficult problems. It is this integration which I describe as modelling. In so far as modelling represents something more than a simple integration of established theories, it may be equated with the development of quantitative hypotheses.

The experimental testing of a model of a complex system is usually referred to as validation. But in some cases the expenditure of resources required to adequately test a model may so far exceed the potential benefits that validation cannot be funded, and it is quietly forgotten. Philip (1975) has drawn attention to such problems in water catchment studies.

A model can take many different forms, and may be developed for many different purposes. It may provide a structure for the orderly aggregation of our knowledge and understanding of some phenomenon, or it may be used to guide decisions in areas such as:

(i) Dominant parameters of a system;

(ii) Optimum sampling in space-time to quantify system parameters;

(iii) Desirable accuracy of measurement of system parameters;

(iv) Design of critical experiments to test the adequacy and reliability of a model; or

(v) System management for specified purposes.

In the case of a quantitative model which may be used to make predictions, there will be some relationship between the accuracy of the predictions and the costs of characterizing the system and running the model. Improved accuracy is usually possible only at greater cost, but cost may restrict the usefulness of a model.

This paper provides a brief description of a model of the effect of forest removal for any purpose on the salinity of a gaining stream. The objective of the model development was to provide a basic estimate of the change of stream salinity which would result from a proposed change of land-use within a catchment. The model sacrifices detail and accuracy in its representation of field processes for relatively low cost of operation and definition of system parameters. Many of the input data are tabulated results from stream gauging and sampling programs.

2. SOLUTE TRANSPORT IN POROUS MEDIA

The major processes contributing to solute transport in soils or permeable rocks are convection of the soil solution, and molecular diffusion in response to local solute concentration gradients. The spectrum of local solution velocities is a fundamental factor contributing to solute-solvent mixing, but molecular diffusion interacts with convection to affect the mixing process which is referred to as hydrodynamic dispersion (Peck, 1971).

When there is a significant interaction, such as physical adsorption or exchange of solute between the solution and solid particle surfaces, the solute is transported more or less rapidly than the average solution velocity. In many porous media the result is that cations travel less rapidly, and anions slightly more rapidly than the solution velocity (Biggar, & Nielsen, 1967).

As a basis for modelling solute transport in soil, it is first essential to develop a suitable model of water movement within the system.

3. REVIEW OF RELEVANT MODELS

Several models of solute transport in soils have been developed to aid understanding of the accumulation or leaching of salts in the root zone of irrigated plants (Gardner, 1967; Raats, 1974). Other research has been concerned with multidimensional water and solute transport to a tile drainage system (Mulqueen and Kirkham, 1972; Peck, 1973, Miyamoto and Warrick, 1974; Jury, 1975). An investigation relevant to the present objective is modelling the increase in salinity of a river passing through an irrigation area (Konikow and Bredehoeft, 1974).

While these models aid in understanding the catchment salinity problem, they demand input data sets to characterize soil and groundwater systems which are rarely available. Stephenson and Freeze (1974) concluded from a soil and groundwater modelling exercise that widespread application of detailed process models is unlikely for some time because of the cost of characterizing the system, and the capacity of present-day computers.

A completely different approach to stream water quality modelling has been developed by Betson and McMaster (1974). The empirically relate stream discharge and total dissolved salts concentration using a 2-parameter equation. Each of these parameters is then correlated with landscape parameters. Clearly the method relies on adequate data in the region to establish the local correlations.

4. BRIEF DESCRIPTION OF MODEL

The model developed for this project is based on conservation of mass, and inverts a well-known method for estimating amounts of groundwater discharge and surface runoff using stream chemistry data (Pinder and Jones, 1969). Details of the model have been reported by Peck (1975).

The model assumes that:

(i) The quantity and salinity of surface runoff is not affected by the change in land-use;

(ii) Increased recharge of groundwater in the area of changed land-use leads to increased discharge to the stream without lag in time or loss in volume.

The model takes the form of an algebraic equation which relates the increase of flow-weighted average stream salinity Δc_s to other factors:

$$\Delta c_s = \frac{\alpha}{\beta} \cdot \frac{A_m}{A_c} \cdot \frac{(c'_g - c_s)}{(1 + \alpha A_m/\beta A_c)} . \qquad (1)$$

The factors A_m, α and c'_g may be considered as functions of time, but usually each is treated as a constant.

5. INPUT DATA REQUIREMENTS

To estimate Δc_s in a specific situation it is necessary to know the area of land which may be subjected to some change of use (A_m) and the area of the catchment defined by a chosen point on a stream (A_c). The increase of groundwater recharge per unit area (α) must be known or independently estimated for the change of land-use. Similarly, data are required on the original flow-weighted average stream salinity (c_s) and discharge per unit area (β). This information may be obtained by stream gauging and frequent sampling for salinity analysis.

The final input data requirement is the salinity of groundwater discharging into the stream after the land-use disturbance (c_g'). In some cases this concentration may be assumed to be the same as that before the land-use change, and estimated by analysis of stream samples during a period of base-flow. However, when a change of land-use significantly disturbs the groundwater system(so that, for example, a stream changes from losing to gaining, or from ephemeral to permanent) the salinity of discharging groundwater may change too. Some experimentation (Mulqueen and Kirkham, 1972) suggests that, in this case, c_g' may be approximated by the ratio of salt to water storage in the hydrologically active part of the soil profile.

Equation (1) may be applied regardless of the size of the catchment, but c_g' must be related to the area of changed land-use. In a large catchment, for example, c_g' may be estimated from base-flow samples of the tributary which drains the disturbed area, or from salt and water storage data for this sub-catchment.

The sensitivity of Δc_s to errors in the input data may be estimated from equation (1) using conventional methods and specific values of the parameters. The most sensitive variable is always c_g'. There is always equal sensitivity to small errors in A_m, A_c, α and β, and this may be more or less than the sensitivity of stream salinity to an error in c_s.

6. MODEL LIMITATIONS AND TESTING

The model expressed by equation (1) is conservative in the sense that changes of land-use will often increase surface runoff, and some part of any increased recharge may be lost by increased transpiration between the disturbed area and the stream. Both of these processes will result in a calculated Δc_s which exceeds the actual change.

In application to Darling Range streams a considerable difference between base-flow salinity and average soil-water salinity is common. As a result of the uncertainty in c_g', which is the most sensitive variable, the numerical predictions must be interpreted with appropriate caution. After several comparisons of predicted and observed changes it may be possible to use the data and equation (1) with greater confidence.

The salinity model has been applied to the More Seldom Seen catchment for comparison of predicted effects of mining with actual stream salinity data. Assuming that all mining effects have been cumulative (although they have been spread over several years, and there has been an effective revegetation program), and using base-flow data to estimate c_g', the predicted Δc_s is 7mg/l. This increases to 195mg/l if c_g' is estimated from salt and water storage (data from three salt and water profiles provided by G. Slessor, Alcoa, for the Seldom Seen Catchment). Analysis of the stream salinity data reveals no significant trend in time, but a change of only 7mg/l could not be detected due to stochastic fluctuations. While an increase of order 200mg/l should be readily detectable, the second method for estimating c_g' appears to be inappropriate since More Seldom Seen is a permanent stream.

The prediction in this case is not inconsistant with the data, but it cannot be claimed that the model has been validated.

7. MANAGEMENT IMPLICATIONS

The model suggests methods for managing land uses to minimize the effect on stream salinity:

(i) The area cleared in any catchment at any time should be minimized;

(ii) Cleared areas should be revegetated with deeprooted perennial plants as soon as possible, or other steps taken to reduce changes to the groundwater system;

(iii) The broadest possible belt of forest should be left downslope of a disturbed area. This will reduce groundwater discharge to the stream;

(iv) Increased surface runoff from a disturbed area should be channelled into the stream if this is practicable without increasing stream turbidity;

In areas where a change of land-use has no significant effect on stream salinity, the best management for water resources may be to revegetate for erosion control and minimum evapotranspiration. The increased yield of good quality water from a disturbed area may be of considerable value.

8. FURTHER DEVELOPMENTS

Understanding of the groundwater hydrology of the deeply weathered Darling Range soils is increasing continually, and this may lead to a better salinity model. As data is collected the usefulness of the best available model can be tested.

A major limitation at present is the estimation of increased groundwater recharge beneath disturbed areas. We need both data from particular areas, and methods to predict this factor for the effects of agriculture, woodchipping or bauxite mining in previously forested land. A model of soil-plant-weather interactions developed by a group in the Oak Ridge National Laboratory, USA has been applied to simulate the removal of forest from one catchment in the Darling Range. This model will be described in the following paper by Dr. R. J. Luxmoore.

9. CONCLUSIONS

A detailed process model of salt leaching to streams in the Darling Range would be impractical for management due to the costs of characterizing the system, and the capacity of present-day computers. There are no suitable data sets to test the adequacy and reliability of a simplified model which has been developed. Until it has been tested, predictions based on the simplified model must be treated appropriately. Continuation of existing research programs will provide the test data.

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TERRESTRIAL ECOSYSTEM HYDROLOGY MODELING.

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SUMMARY

A brief outline of the models of terrestrial ecosystem processes developed by scientists at Oak Ridge is given. Hydrologic processes form the framework around which mineral cycling and carbon dynamics of vegetated land are structured. The coupled set of models has a flexible structure allowing application to a range of catchment investigations.

1. INTRODUCTION

A unified modeling approach to the simulation of water and material transport in catchment landscapes has been under development by a research group at Oak Ridge National Laboratory for several years. A collection of component models describing air, land and stream transport combine to form the Unified Transport Model (figure 1). This modeling approach has built in flexibility that permits application to a wide range of situations.

The physical, chemical and physiological aspects of water in any particular segment of a landscape are described with six models (PROSPER, SCEHM, CERES, DIFMAS, DRYADS and SUBSRF) that form the terrestrial ecosystem components of the Unified Transport Model (UTM). The terrestrial models are based on "simplified" principles and require measureable landscape properties for input values (Patterson et al 1974, Huff et al, 1976)

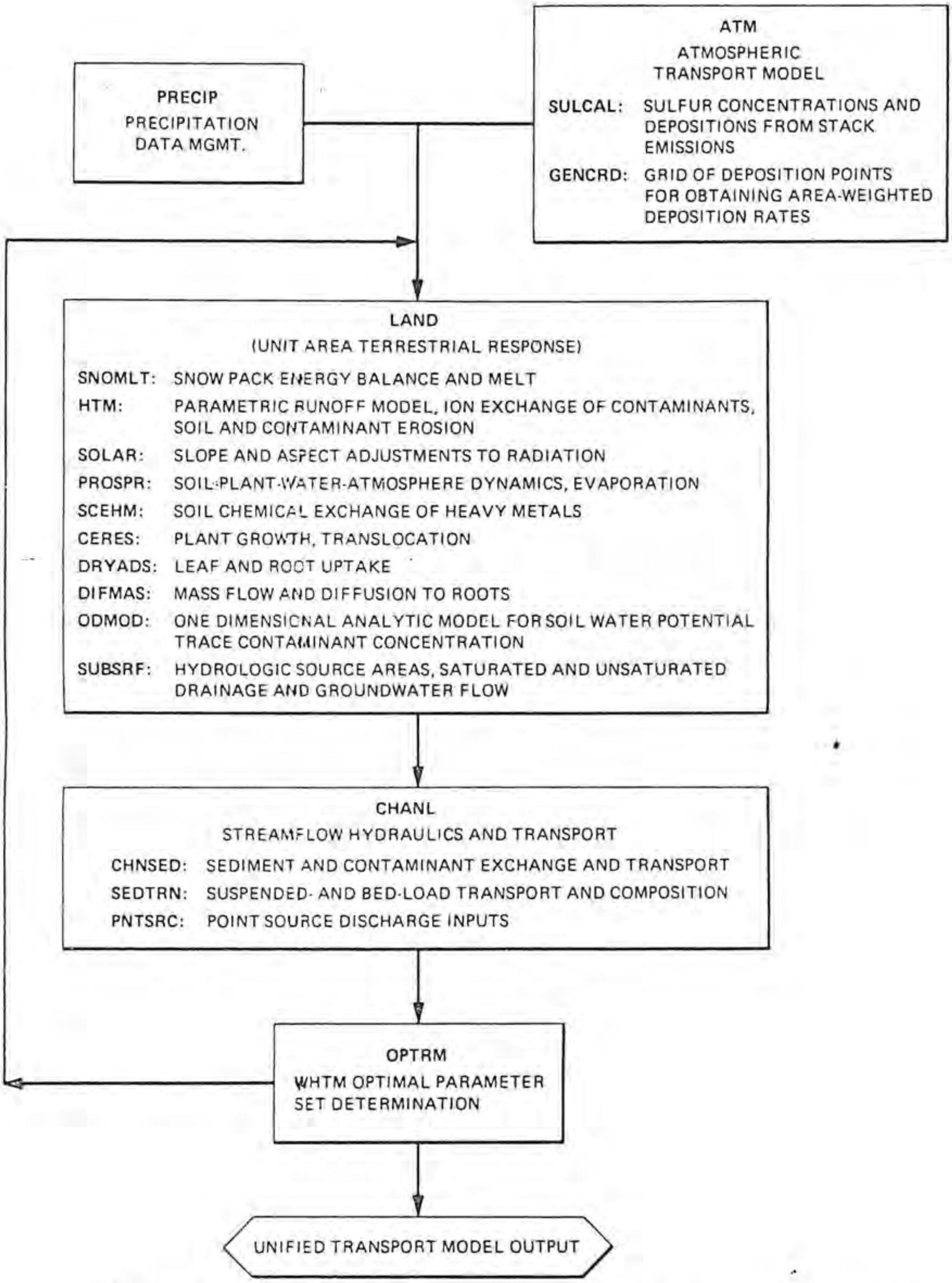

Figure 1. The submodels that may be linked to form a unified transport model.

Simulation modeling with the UTM is being used at Oak Ridge National Laboratory in conjunction with field investigations to assess the relative significance of transport processes in both the movement of trace contaminants deposited on watersheds (chronic and toxic levels) and the cycling of minerals and contaminants in terrestrial ecosystems.

Topographic maps and catchment area data are desirable starting points for deciding on an approach to model application. Surveys of soils, landscapes, geology and vegetation are very useful. A catchment is divided into segments having "uniform" soil, vegetation and landscape characteristics and reaches (channel sections) with "uniform" roughness and cross-section geometry. The main features of the terrestrial hydrologic processes applying to a segment (figure 2) are outlined, followed by brief descriptions of the channel routing subroutines and the subroutines describing terrestrial carbon and solute dynamics.

2. METEOROLOGICAL INPUTS

Subroutines PRECIP and GETSET read in the following meteorological data; hourly precipitation (inches), max and min air temperature ($^{\circ}$F), daily solar radiation (langleys), average daily wind speed (mph), average dew point temperature ($^{\circ}$F). The subroutine DTRSTR can take daily precipitation data and calculate hourly values proportionally to specified pluviometer records. Hourly air temperature is determined from a smooth curve fitted to the maximum and minimum input values. The daily solar radiation data are adjusted for slope, asimuth and latitude of the segment using methods of equivalent slope theory.

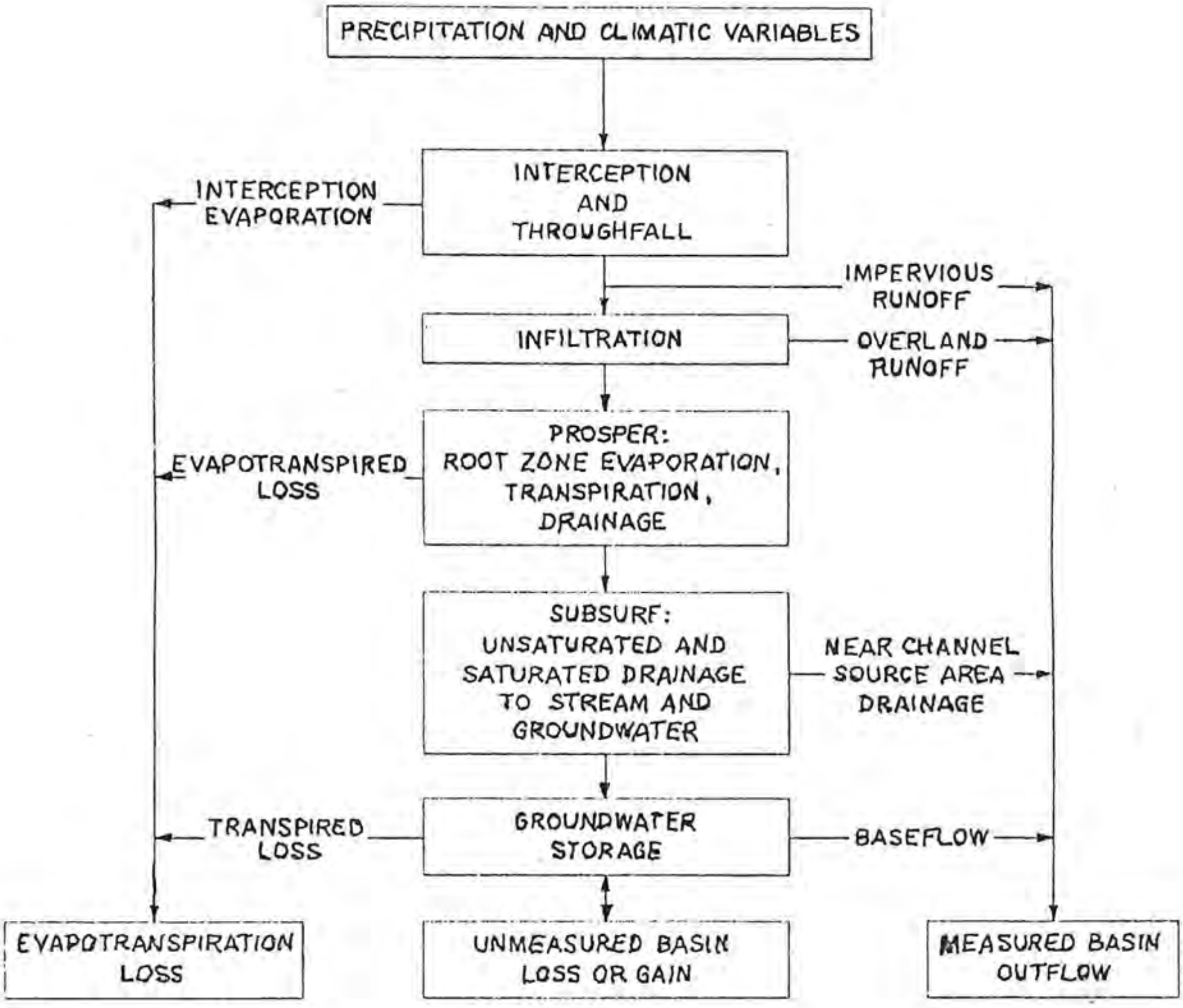

Figure 2. Diagram of hydrologic processes in the Terrestrial Ecosystem Hydrology Model (TEHM, Huff et. al., 1976).

Hourly radiation values may be calculated either by empirical functions or using equations based on solar altitude as a function of time.

3. TERRESTRIAL WATER FLOW

(a) Interception

An interception storage value is assigned to vegetation and litter that may be changed seasonally. Rainfall fills interception storage and the excess becomes input to the infiltration subroutine. Interception evaporation is calculated with the Monteith (1965) form of the combination equation having a surface resistance of zero.

(b) Infiltration

The infiltration characteristics of a land segment in the form of cumulative infiltration-time input data are used with the "time-compression" approximation outlined by Reeves and Miller (1975) to calculate infiltration and overland runoff.

(c) Soil-Plant-Water Relations

The PROSPER model of atmosphere-soil-plant water flow (Goldstein et al, 1974) describes soil evaporation, plant transpiration and soil drainage on a 15 minute basis during rainfall, otherwise hourly. A set of four main equations and four unknowns are solved (figure 3) and then water fluxes between soil layers are calculated along with the drainage from the bottom soil layer. Darcy flow equations describe water flow between soil layers based on input values of soil hydraulic properties. Up to eight soil layers may be considered, however roots are restricted to the upper two layers. The water status

Location	Properties	Structural Equations
Atmosphere	Environmental conditions (daily) Solar radiation Precipitation Dew point temperature Max. and min. air temperature Average wind speed	Vapor flux from surface $F_v = f(R_x)$ (1) Calculation uses combined energy balance-aerodynamic method
Boundary Layer	Resistance to vapor and heat flow	
Evaporating Surface	Resistance to vapor flow (R_x) Surface water potential (PSI)	Surface characteristic $R_x = f(PSI)$ (2)
Plant and Soil System	Plant and root resistances Root distribution in upper two soil layers Soil water characteristic for each soil layer Hydraulic conductivity vs water content for each soil layer Soil layer thicknesses	Liquid flux to surface $F_w = f(PSI)$ (3) Calculation uses electrical network equations
Whole System	Steady state	Vapor flux = Liquid flux $F_v = F_w$ (4)

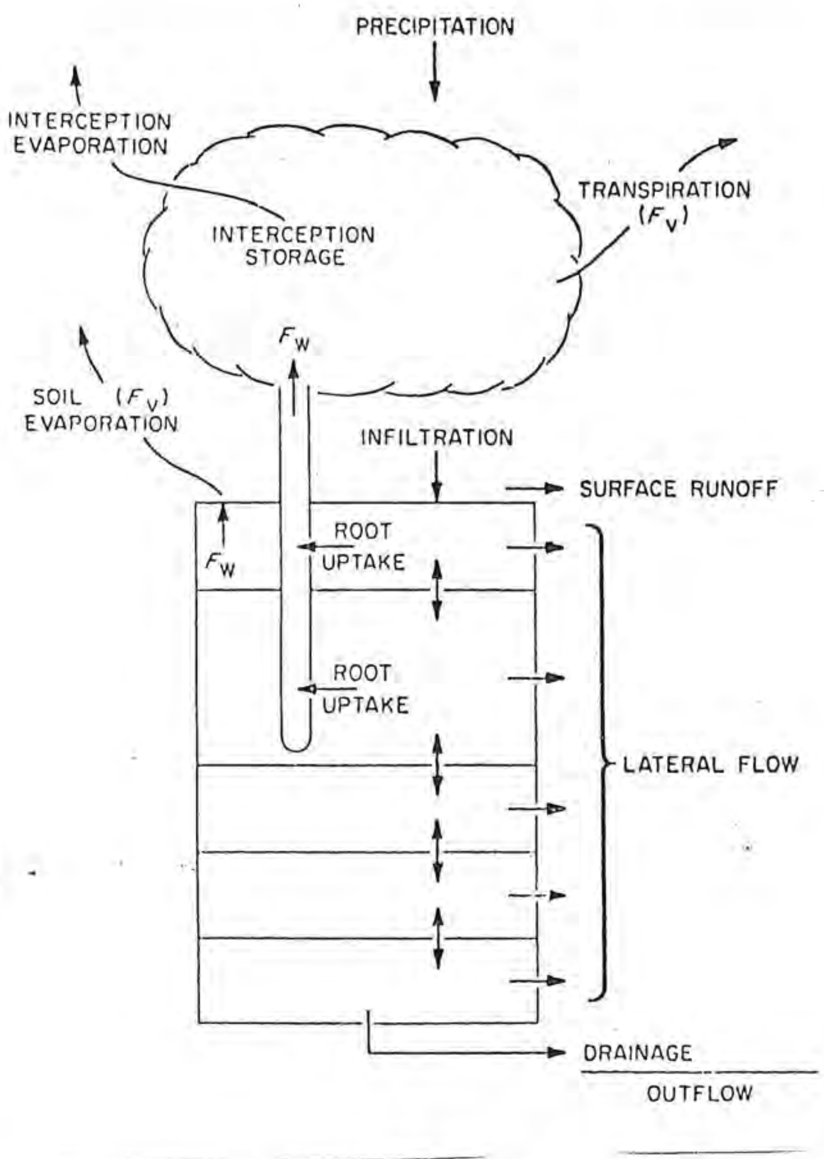

Figure 3. Basic structure and equations of PROSPER.

of the vegetation (stomatal resistance and leaf xylem water potential) are calculated and used in models of plant growth and solute uptake by vegetation (see section 6).

(d) Subsurface Flow

A specified fraction of each segment is considered to have quick hydrologic response that contributes water readily to a reach during a storm (figure 4). This quick response zone may increase in area (cannot exceed a specified maximum proportion) during a storm and decrease afterwards depending on an empirical relationship between the extent of the source areas and drainage rate through the root zone.

The transmission zone receives water from PROSPER drainage and transmits water to groundwater by Darcy flow according to input values for the hydraulic properties of the transmission zone and a gravitational gradient. Groundwater flow to a reach is proportional to the amount of storage with the storage constant being related to the daily recession constant obtained from stream flow data. This storage constant dominates baseflow response during and shortly after storms whereas between storms the baseflow is generally dominated by the drainage rate through the transmission zone.

4. CHANNEL HYDROLOGY

The channel system of a watershed is divided into uniform reaches that have double trapazoidal (figure 5) or circular cross sections (storm drains) and small dams may be included in the reach. Each reach connects to another downstream channel section (figure 6) and receives water flow from adjacent segments by overland flow, impervious flow, lateral

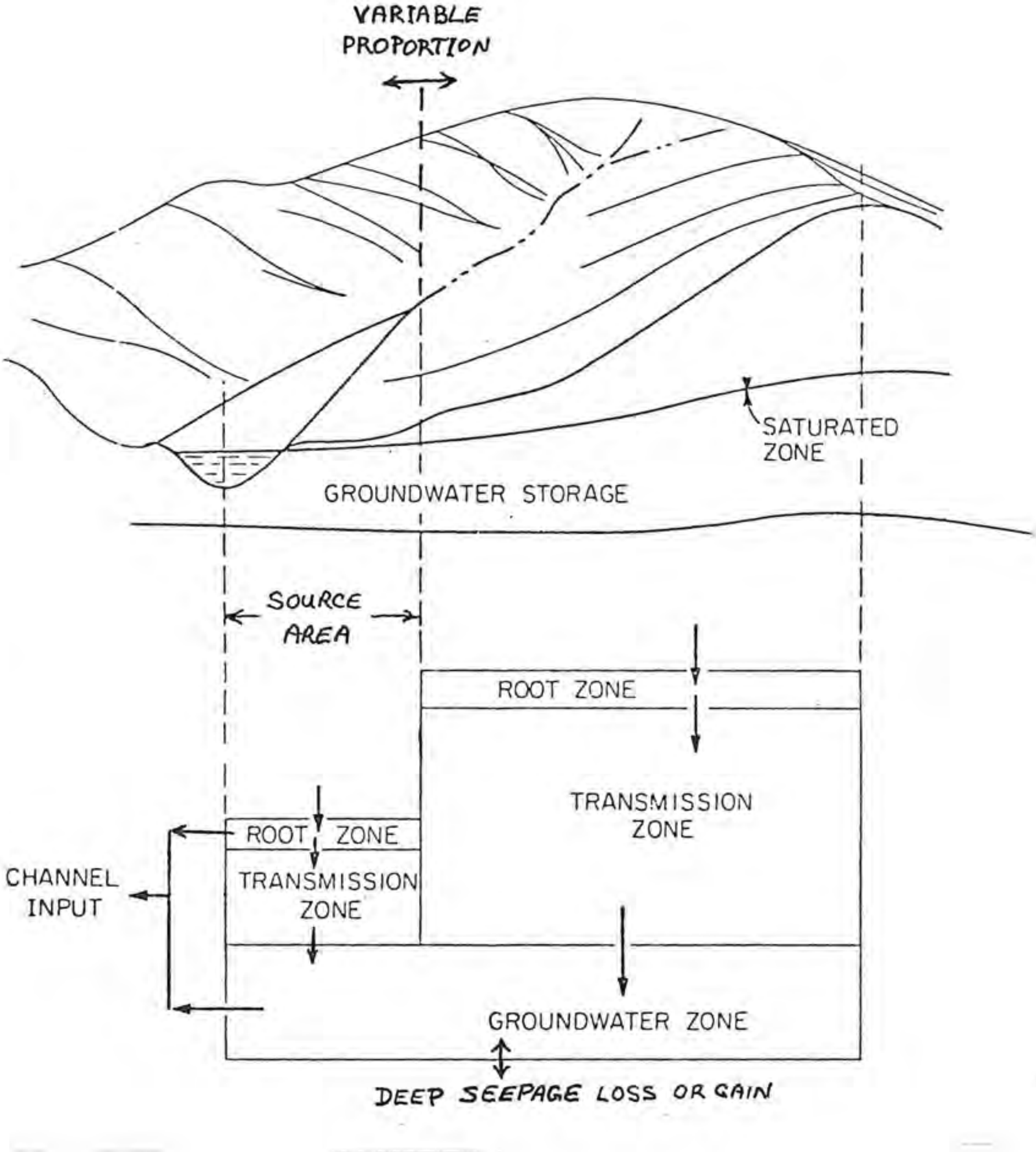

Figure 4. Variable source area, transmission zone and groundwater hydrology.

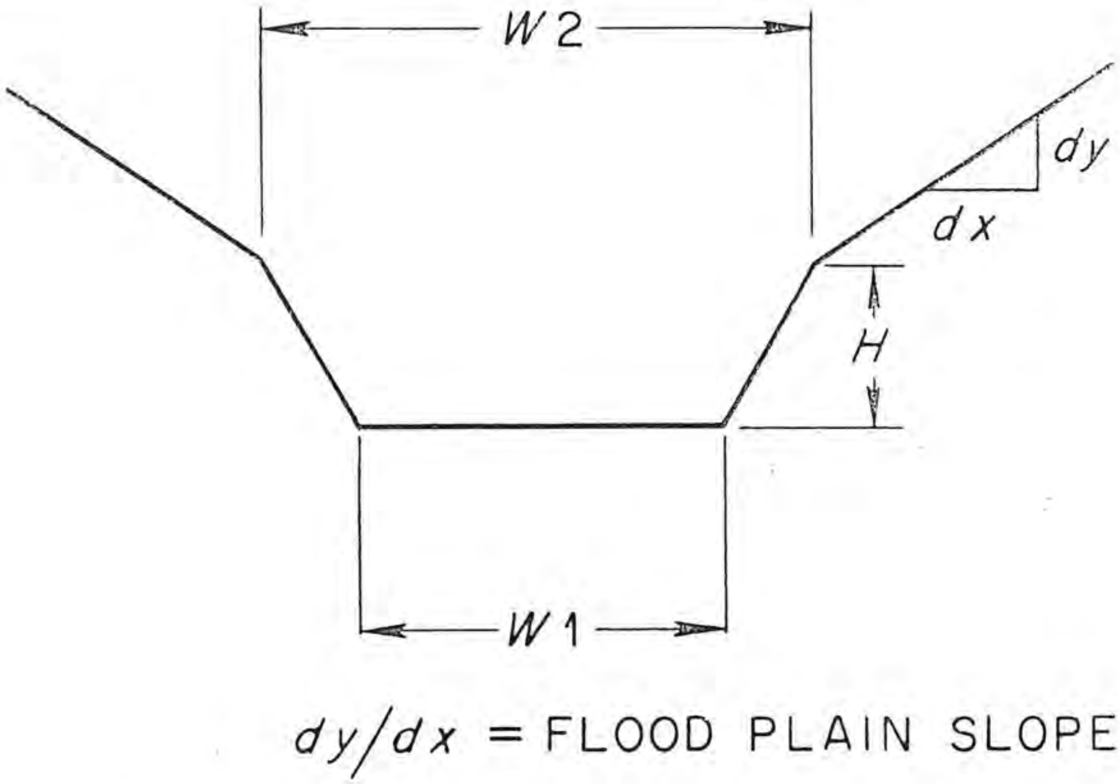

Fig. 5. Trapezoidal transverse cross-section for flow in the CHANL link.

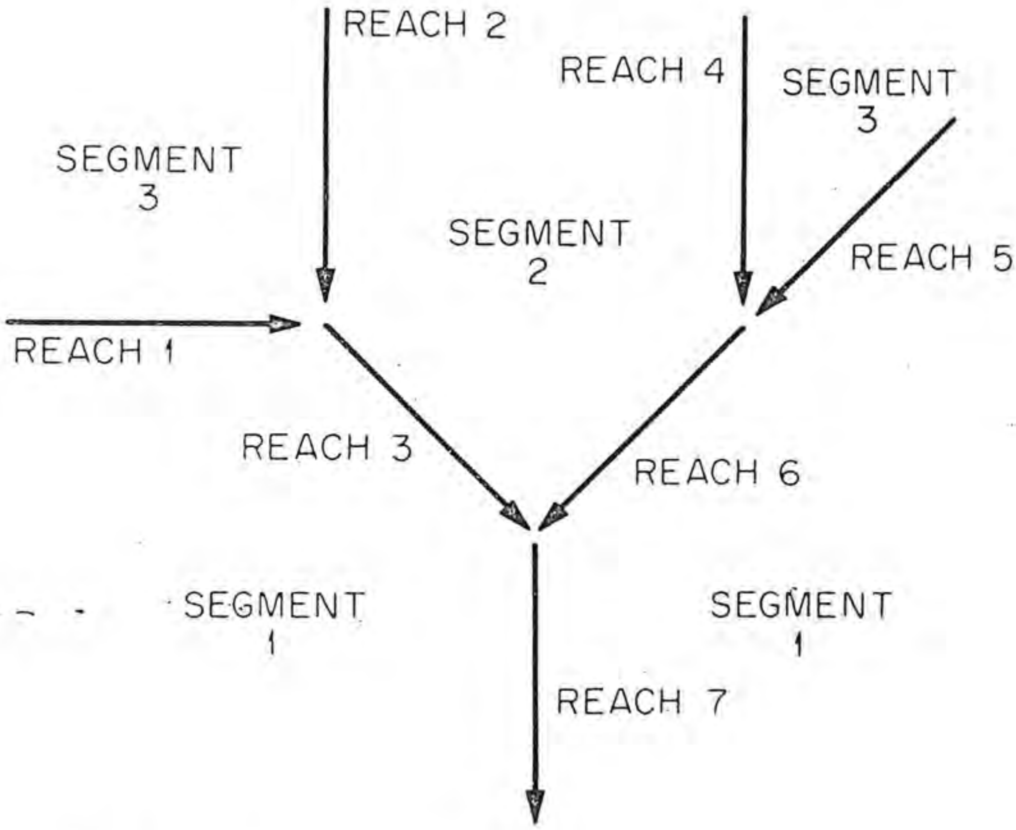

Fig. 6. Example of land areas (segments) and typical channel lengths (reaches).

drainage and groundwater flow. The travel time through the channel system is computed with the Chezy-Manning equation and integrated to generate a hydrograph at the watershed outlet. Subroutines describing soluble, suspended and bedload transport of materials couple with the channel hydrology (figure 1).

5. SOIL CHEMISTRY PROCESSES

The SCEHM code (Begovich and Jackson, 1975) is coupled to the PROSPER model to give a simplified soil chemistry simulation (figure 7). Wetfall and dryfall from the atmosphere is deposited on the canopy and litter and washed off during rainfall. Particulates deposited in the litter are dissolved and move with the infiltration water into the soil profile. Exchange between soil colloids and soil solution is calculated with a simple distribution coefficient (Kd) determined experimentally for the soil of interest. This coefficient is the ratio of the ug of chemical adsorbed on 1g soil per ug chemical in 1 ml of the equilibrium solution. Root uptake of chemical may also be considered by empirical (constant rate of uptake) or mechanistic methods (section 6). Drainage water conducts solutes into the transmission zone or laterally to the reach during storms from the variable source areas. Soil chemistry processes have not yet been introduced into the transmission zone or groundwater equations.

6. COUPLED LITTER AND VEGETATION MODELS

Models of the carbon dynamics of vegetation and litter (CERES) (Dixon et al, 1976), solute movement from soil solution to roots (DIFMAS) and solute dynamics in vegetation and

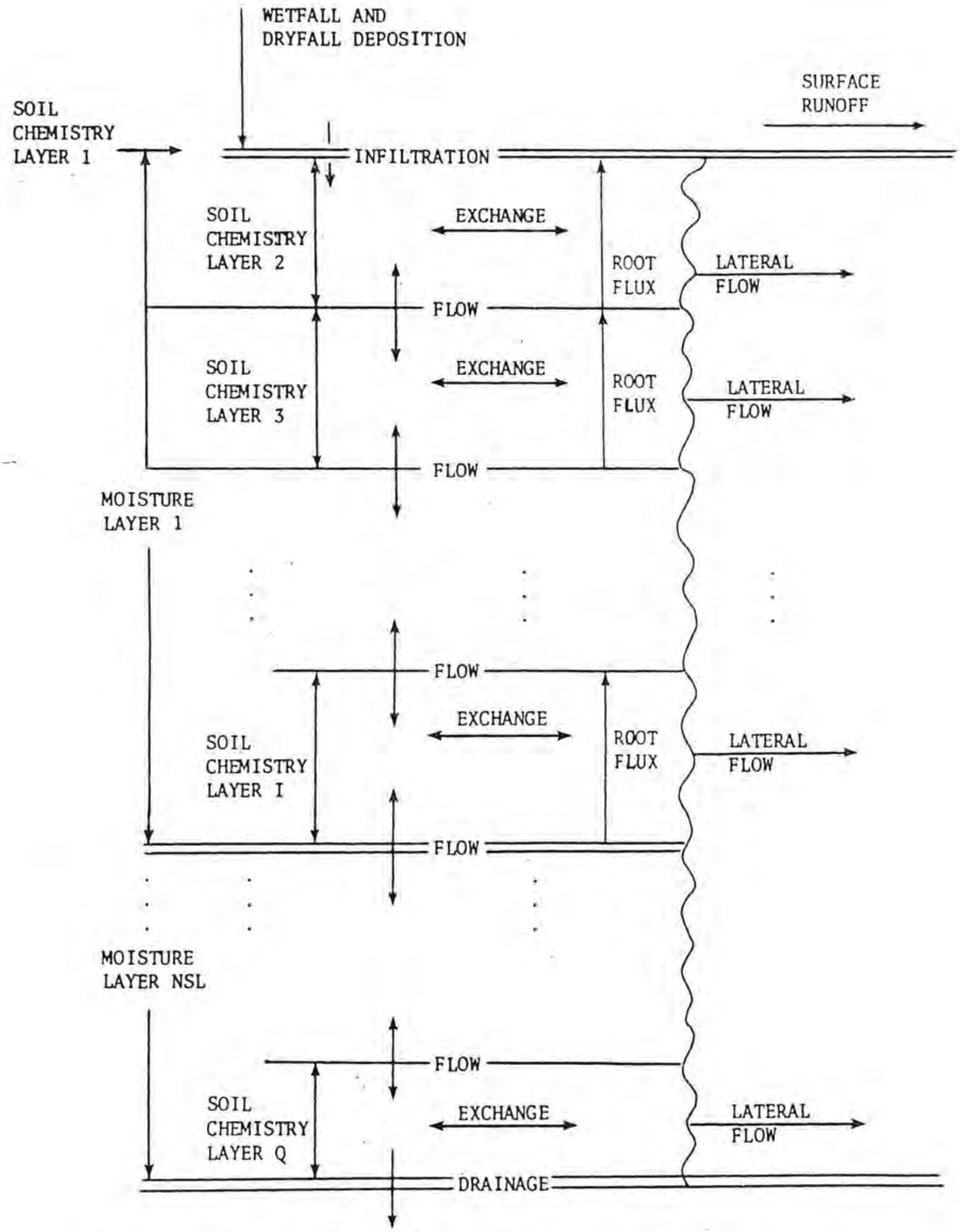

Figure 7. The sequence of deposition, infiltration, exchange, and flow of heavy metal contaminants considered in SCEHM.

litter (DRYADS) (Luxmoore et al, 1976) are coupled with the terrestrial water processes models (figure 8). Mineral cycling and carbon dynamics in the landscape may be investigated with this coupled set of models. Additional models will be developed to look at mycorrhizal-root associations and the competition between plants for environmental resources as part of the continuing terrestrial ecosystem analysis tasks at ORNL.

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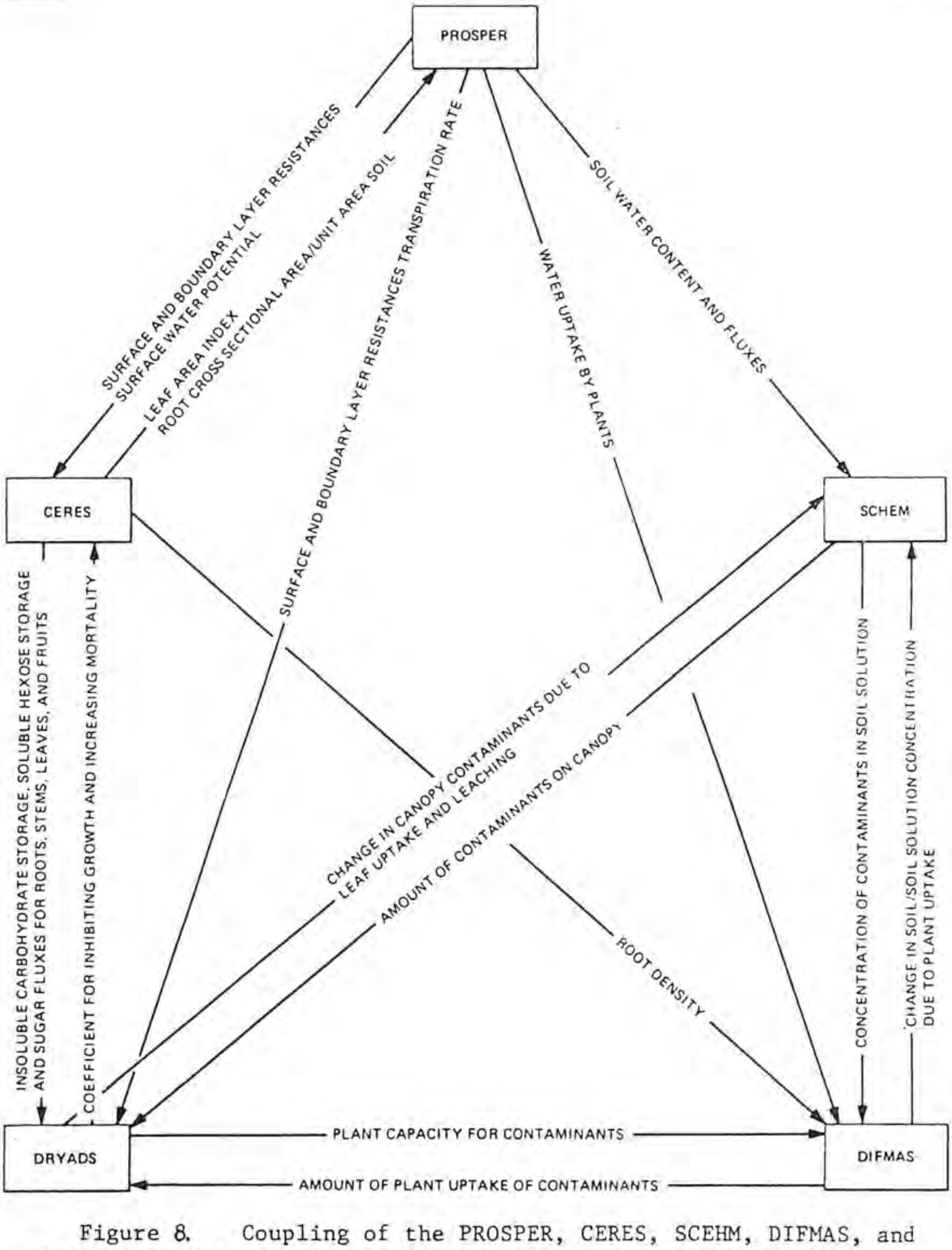

Figure 8. Coupling of the PROSPER, CERES, SCEHM, DIFMAS, and DRYADS submodels.

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MODELLING THE WELLINGTON CATCHMENT - RESERVOIR SYSTEM

I. LOH

ABSTRACT : Long term simulation procedures are used to model variations in the input to, and response of Wellington Reservoir under different operating policies and at two stages of the catchment's history. Speculations are also made about probable response in the future.

INTRODUCTION

Currently there are a large number of research projects investigating many specific aspects of different land use changes on stream salinity in south western Western Australia. Most, by necessity, are on a small experimental scale. However, planners and decision makers will have the difficult task of combining and interpreting the research findings of these projects into general land management policies on a broad scale. Studies on a large catchment on river basin scale must play a major role in bridging this gap between research and management policy.

Many previous studies of stream salinity in the region, also by necessity, have not considered the problem of salinity variations with streamflow. However, a knowledge of variations in both streamflow and salinity are essential to water supply planning and reservoir operational problems. This paper describes a broad scale study of the Wellington Reservoir Catchment system which investigates the effect of streamflow and salinity variability on reservoir operational policies at different stages in the catchment's history.

Three specific objectives were considered. Firstly, the study was to provide general (yearly) operating policies which maintain a balance between the quantity and quality of supply; secondly, to study time trends in salinity of the total input to the reservoir; and thirdly, to place the changes in salinity due to land use change in the context of natural variations caused by streamflow fluctuations.

Long term simulation procedures, commonly used in reservoir design investigations, were adopted for this study. Sequences of monthly streamflow input to the reservoir were generated to be statistically indistinguishable from the historic record. From flow - salinity relationships based on two sets of historic salinity data (1955 to 1960 and 1968 to 1974) and one set of probable future flow-salinity relationships, associated sequences of monthly salt load input to the reservoir were calculated and compared. The combined streamflow and salt load data, together with reservoir rainfall and evaporation formed the input to two reservoir simulation programs. Output from these programs provided the desired reservoir response for the comparison of different operational policies and input salinities.

STREAMFLOW GENERATION

Twelve log normal distributions were defined from 30 years of monthly streamflow at Wellington Dam. Based on these distributions sequences of 1000 years of monthly streamflow were generated which preserved the historic means, standard deviations and lag one serial correlations. Some limitations were noted in other statistics but generally the generation was considered satisfactory (Ref. 1, 2 and 3). Table 1 below lists the historic and generated annual statistics and compares streamflow and rainfall variability.

TABLE 1

ANNUAL RAINFALL AND STREAMFLOW FOR WELLINGTON DAM CATCHMENT

Statistics	Annual Streamflow		Catchment Rainfall (72 years)
	Historic (30 years)	Generated (1000 years)	
Max	648	1470	1240
Mean	201	199	810
Median	153	153	810
Min	29	19	448

Streamflow is in $10^6 m^3$

Catchment rainfall is in mm over a 2830 sq.km area

Note the symmetrical nature and lower variability of the rainfall distribution in comparison with the positively skewed (i.e. median less than the mean) and higher variability of the streamflow distribution. While the two orders of magnitude range of Wellington Reservoir inflow may be considered large, it represents only average variability when compared with other Australian streams (Ref. 4). With such large yearly streamflow variations and consequent salinity variations, the problem of distinguishing salinity trends caused by land use changes is extremely difficult.

SALT LOAD GENERATION

The determination of associated salt loads with the generated monthly flows was also difficult. To simplify the problem the catchment was divided into 4 sub-areas; two of which were predominantly forested and had stable relationships between flow and salinity. Clearing on other sub-areas has produced time trends in salinity (Ref. 5). Time varying behaviour was avoided by simply studying two different time periods during which relationships between salinity and flow were considered constant. Salt load - flow relationships were developed for the 4 sub-areas based on data from 1955 to 1960 and from 1968 to 1974.

Details of the relationships are given in reference 3. However the following general points should be made. Most flow-salinity relationships were of the form

$$C = \frac{So}{1+BQ^a}$$

where C is the salinity, Q the flow rate and So, a and B are constants. The same relationship occurs between the salinity and flow rate from a single mixing volume with a constant base salinity of So, subject to a varying and diluting inflow of zero or negligible salinity (Ref. 6). All relationships for streams issuing from partially cleared areas, showed large scatter. Deviations from average relationships for the mouths August to November were weakly correlated (negatively) with the previous months flow.

Monthly salt load inputs to the reservoir were calculated by first dividing the generated flow into sub-area flows, applying the various sub-area relationships, including random scatter, and recombining to form the total salt load input. Table 2 presents statistics of the generated inflow salinities for the two time periods. Note the increase in salinity between the two periods. The yearly rate of increase is approximately 15 mg/ℓ/year NaCℓ, three times larger than previous figures (Refs. 5 & 7). The pattern of monthly mean salinities reflect the general seasonal behaviour of the catchment. High salinities occur when the first winter flows from the two major Collie River tributaries reach the reservoir (June and August). Lower salinities occur through spring and early summer when surface salts have been removed from the catchment and when a larger percentage of flow comes from the forested western region of the catchment. High salinities occur again in the late summer when low flows are sustained from the saline southern tributary of the Collie River.

Also included in Table 2 are statistics of generated salinities based on speculations of probable flow-salinity relationships which are likely to develop as a result of previous clearing. The average annual salinity of 646 mg/ℓ NaCl (equivalent to 760 mg/ℓ TDS) represents the mid range of predicted average annual salinity for clearing to the end of 1971 (Ref. 5). Based on the above 15 mg/ℓ/year annual salinity increase, the speculated salinities would develop by the mid 1980's. However, there are a number of factors, principally the 1975 inflow salinities and the rapid rate of clearing in the late 1960's, that suggest the current rate of increase is far greater. If twice the rate of increase between the late 1950's and early 1970's is assumed then the speculated salinities would develop by the late 1970's.

RESERVOIR SIMULATION

Initial simulation runs were carried out by a general computer program which models a single reservoir subject to rainfall, streamflow and salt load input, and output from evaporation, scour, spillage and draws for both irrigation and water supply purposes. The program maintains a record of stored water and stored salt over time by adding and subtracting input and output volumes of water and tonnes of salt each month. An important but incorrect assumption of these calculations is that all inflowing water is completely mixed with the existing stored water. While this program was considered satisfactory for assessing the reliability of supply and the general fluctuations in reservoir salinity, the assumption of complete mixing precluded any valid evaluation of winter scour policies.

From both field work and modelling studies of Wellington Reservoir (A.W.R.C. Project No. 70/74) a large amount is now known about the dynamic mixing in Wellington Reservoir. A sophisticated daily simulation model has recently been completed (Ref. 8) which will be extremely valuable for short term operational decisions. However a simplified monthly model is required for long term policy decisions.

A monthly two layer model is being developed to specifically evaluate the benefit of winter scour policies in terms of salinity improvement. Currently the model places all inflow between May and September (usually cold and saline) into the bottom layer and places all inflow between October to April (usually warm) into the top layer. Complete mixing occurs between layers at the end of April when seasonal cooling from the surface commences. Improvements to these assumptions are planned.

RESULTS

Figure 1 shows the percentage of years (% failure) in which target draws could not be fully achieved for a variety of target draws and scour policies. Considering a 2% failure criteria, approximately $93\times10^6 m^3$ could be drawn if no scour were employed. Current draws are considerably less (approximately $70\times10^6 m^3$) as the full allocation for industrial and town water supply is not being used. Consequently at least $20\times10^6 m^3$ is currently available for scour. Figure 1, however, shows that a policy of scouring $35\times10^6 m^3$ in June in all non critical years (i.e. when storage is greater than $130\times10^6 m^3$ the previous October) results in a 2% failure draw of $79\times10^6 m^3$. Barring a rapid industrial development a base draw of $79\times10^6 m^3$ is unlikely to be exceeded in the next 5 to 10 years. To scour in every year regardless of storage causes excessive numbers of unrealistic failures during winter months.

Table 3 and Figure 2 indicate the general reservoir response to the three sets of inflow salinities. Table 3 clearly indicates that reservoir salinities are dominated by salinities of inflow. Other factors such as reservoir evaporation have little or no effect on reservoir salinity. Figure 2 emphasises the large range of reservoir salinities for one land use condition caused primarily by variations in monthly streamflow. Note that about 35% of the time salinities based on the 1968 to 1974 data were in the same range as salinities based on 1955 to 1960 data. Similarly about 70% of the time speculated salinities are in the same range as 1968 to 1974 salinities.

TABLE 3

MEDIAN VALUES FOR INFLOW AND RESERVOIR SALINITIES

Statistic	Annual Inflow Salinities	Monthly Reservoir Salinities	Monthly Reservoir Salinities (Scour $= 35\times10^6 m^3$)
MONTHLY MEDIAN			
55 - 60	250	250	-
68 - 74	450	425	375
SPECULATED FUTURE (78 - 86?)	660	600	530

Salinities are in mg/ℓ NaCℓ

Initial results from the two layer model suggest that improvements of about 10 to 12 percent can be expected from a scouring policy of $35\times10^6 m^3$. On current rates of salinity increase this improvement effectively delays salinity increases by only 3 to 5 years. While larger improvements in salinity are probable with further modelling and improved scouring policies, it is apparent that improved reservoir operation will only delay the inevitable salinity increase if clearing is allowed to continue.

Of considerable importance is the pattern of salinities in the reservoir over time. Periodically, major flood flows, often greater than the capacity of the reservoir, effectively flush the reservoir and dramatically reduce its salinity. To study this phenomenon a 'flush' was defined as any monthly flow which equalled or exceeded the reservoir capacity, or any sum of two successive months' inflow which equalled or exceeded 1.5 times the reservoir capacity.

Statistics from periods between flushes (flushing lengths) are included in Table 4. Also included in Table 4 for comparison are statistics of the distribution of times to reach critical salinities after a flush. Critical salinities were defined as being 300 mg/ℓ NaCl greater than salinities of the last flush.

TABLE 4

DURATION OF CRITICAL SALINITY RISES AND YEARS BETWEEN FLUSHING

Statistic	Years Between Flushes	Duration of Critical Salinity Rise (years)	
		68 - 74	Speculated Future
Maximum	52.4	35.0	8.5
Median	7.5	5.0	1.5
Minimum	1.0	1.8	1.0

Flushing lengths were highly variable ranging from 1 to 54 years. Similarly critical salinity rises for the 1968 - 1974 data were highly variable varying from 2 to 30 years. Note, however, that the median critical salinity rise was only 5 years in comparison with the flushing length median of 7.5 years. There was a marked decrease in the salinity rise periods from the 1968 - 1974 data to the speculated future salinity data. This indicates that as inflow salinities continue to rise it will only be in the infrequent flood years, and possibly one or two subsequent years, that reservoir salinities will drop to levels below the desirable limit of 500 mg/ℓ TDS.

CONCLUSIONS

In terms of the three objectives described in the introduction the following conclusions can be drawn.

1. A long term operating policy of scouring $35 \times 10^6 m^3$ during the initial winter flows maintains reliability of supply while having a beneficial effect on water quality.

2. From the late 1950's to the early 1970's the salinity of inflow to Wellington Reservoir has increased 80 percent.

3. Variations of up to two orders of magnitude in the annual streamflow input to Wellington Reservoir cause wide ranges of reservoir salinities which are larger than the average change in inflow salinity between the late 1950's and early 1970's.

Other implications can be drawn from speculated future flow-salinity relationships and resulting reservoir simulations. These, however, must be regarded with some caution.

4. The range of reservoir salinities will increase as the range of inflow salinities increase.

5. Critical salinities will develop in shorter and shorter times after major reservoir flushing (of the order of one or two years) as average inflow salinities continue to rise.

6. Initial winter scouring will continue to improve overall reservoir salinities but effectively only delay, for a relatively short period, the inevitable salinity increase if clearing is not controlled and corrective actions taken.

When the uncertainty of how quickly the salinity is increasing with time, and with clearing, is added to uncertainty of both the magnitude and distribution of future inflows, precise predictions of future reservoir salinities are impossible. Based on present trends, however, it is apparent that high quality water will be supplied only on infrequent occasions.

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TABLE 2

STATISTICS OF GENERATED SALINITIES OF INFLOW TO WELLINGTON RESERVOIR

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
an													
1968/74	704	841	802	779	447	544	479	503	435	405	414	399	455
1955/60	394	457	505	526	317	277	244	242	274	300	315	310	251
eculated Future	1093	1294	1274	1243	616	698	649	683	701	645	617	588	646
d. Dev.													
1968/74	263	171	159	148	124	145	188	240	104	89	91	131	139
1955/60	101	101	106	97	53	80	57	83	72	63	54	58	59
eculated Future	402	263	256	250	186	303	249	311	218	135	147	221	211
x.													
1968/74	1295	1270	1243	1163	1076	1021	1093	1247	770	730	1365	1104	790
1955/60	674	760	762	748	684	476	433	472	488	480	592	676	383
eculated Future	1893	1927	1922	1881	1707	1605	1320	1453	1354	1062	2166	1744	1147
n.													
1968/74	233	413	400	453	237	136	130	112	115	161	224	234	145
1955/60	234	242	262	272	218	101	106	76	106	131	177	229	104
eculated Future	353	552	574	620	353	130	143	120	120	211	357	313	168

Salinity values are in mg/ℓ NaCℓ

Speculated Future – salinities generated from probable future salt-load – flow curves

FIG. 1 - RELIABILITY CURVES FOR WELLINGTON RESERVOIR · WITH SCOUR POLICY

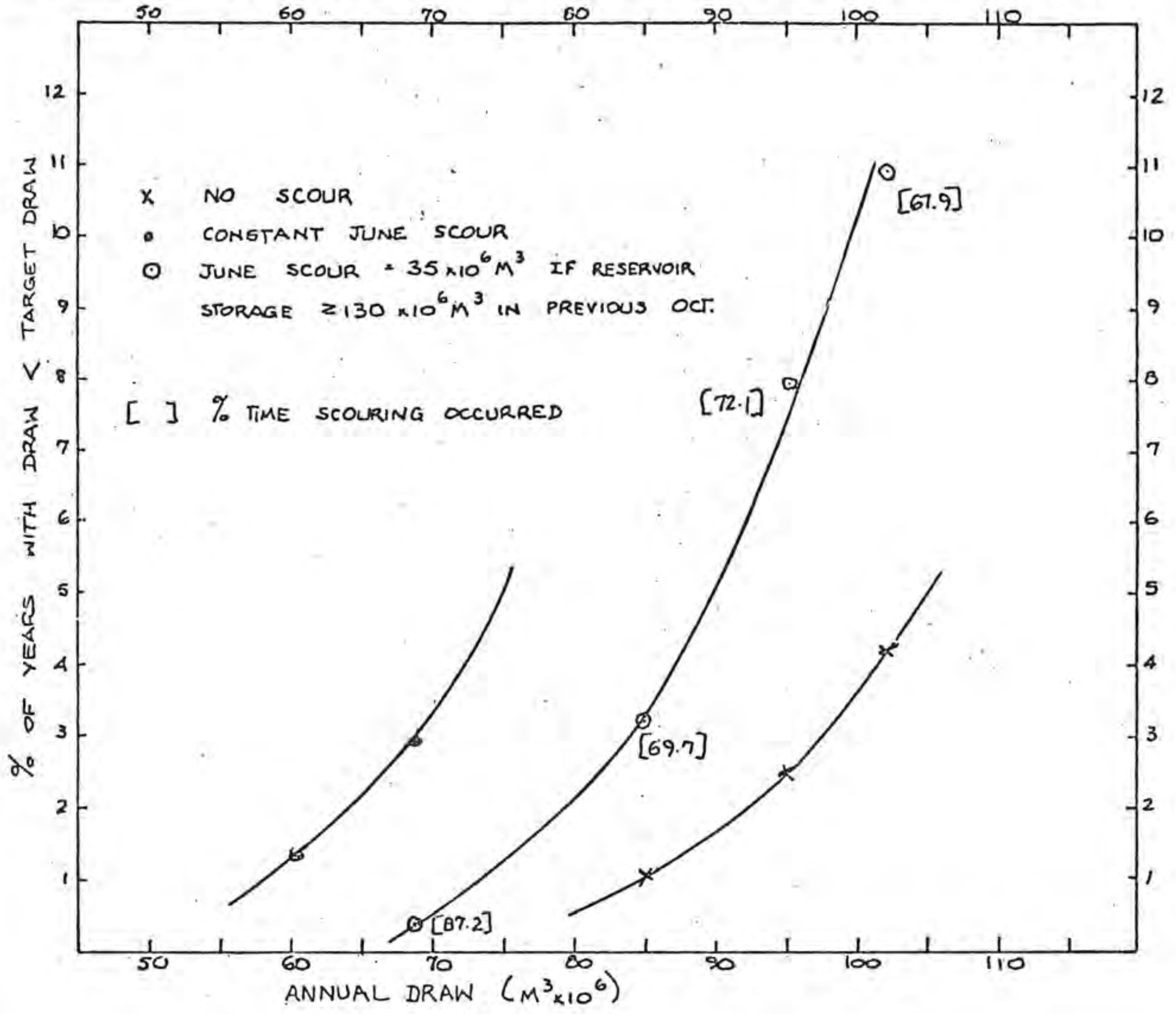

FIG. 2 · CUMULATIVE DISTRIBUTIONS OF WELLINGTON RESERVOIR SALINITIES