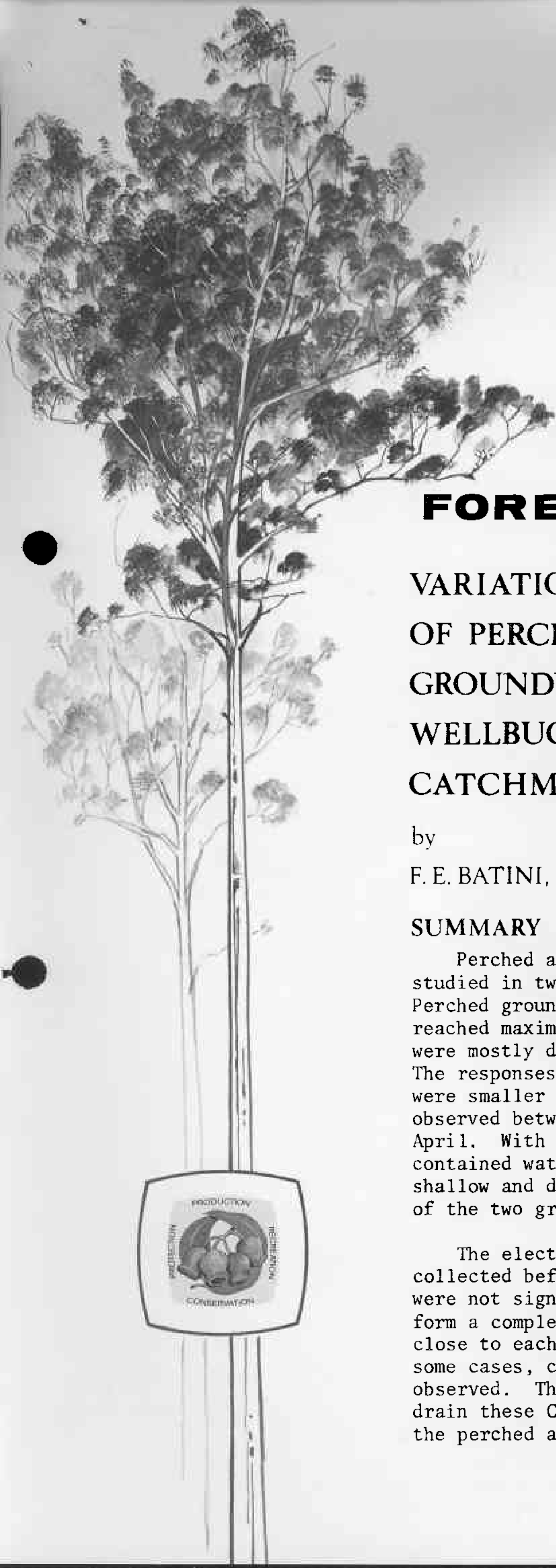

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VARIATIONS IN LEVEL AND SALINITY OF PERCHED AND SEMI-CONFINED GROUNDWATER TABLES, HUTT AND WELLBUCKET EXPERIMENTAL CATCHMENTS

by

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SUMMARY

Perched and semi-confined groundwater tables were studied in two experimental catchments by means of bores. Perched groundwater tables responded quickly to rainfall, reached maximum levels in winter (July - September), and were mostly dry in summer and autumn (November - May). The responses of the semi-confined aquifers to rainfall were smaller and more gradual: maximum levels were observed between October and December, and minima in April. With one exception, the deep bores either contained water all year or were always dry. Where a shallow and deep bore were adjacent, the relative levels of the two groundwater tables differed considerably.

The electrical conductivities (EC) of water samples collected before and after agitating the water column were not significantly different. The groundwaters form a complex pattern. Often the EC values of bores close to each other were significantly different. In some cases, considerable within-bore changes were observed. The base flow EC values of the streams which drain these Catchments were lower than the EC values of the perched and semi-confined groundwater tables.

INTRODUCTION

In the eastern portion of the Helena Catchment, there are large areas of land suitable for heavy firewood-cutting operations and the establishment of pine plantations. However, before undertaking either programme, the possible effects of these changes in land use on salt and water yield of the streams need to be assessed (Batini et al., 1977).

Two Catchments, (Hutt and Wellbucket), each of about 500 ha, in cutover forest 22 km east of Mundaring Weir (Figure 1) were mapped for soil and site-vegetation types, according to the system of Havel (1975). Rainfall, saltfall, streamflow and saltflow are currently being measured. In addition, a drilling programme in 1975 yielded data on the salt content of 17 soil profiles within these Catchments (Batini et al., 1976).

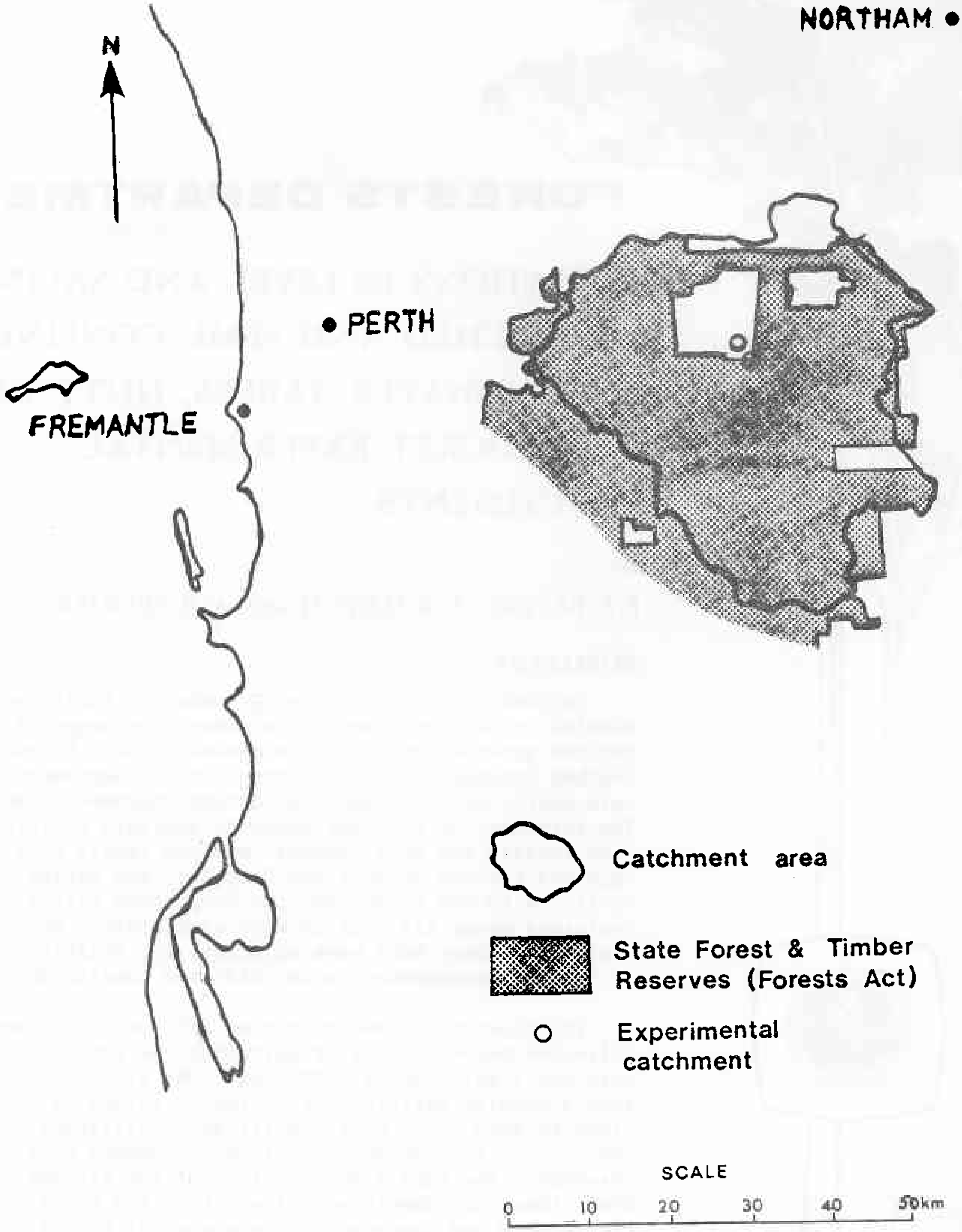


FIGURE 1: Location of experimental Catchments in relation to the Helena Catchment and to the capital city (Perth).

METHOD

Since the salinity of groundwater and fluctuations in water level of the groundwater table are important to the understanding of salt accumulation and saltflow, several bores were installed to monitor these factors. This paper discusses the results of the first 12 months' observations.

The locations of bore holes were selected on the basis of site-vegetation type, with a greater proportion of holes drilled in the lower topographic positions where the effects of land use changes are likely to be greatest. Eighteen deep (>8 m) (Table 1) and 12 shallow (< 3 m) bores were drilled.

TABLE 1

Location and description of deep bore holes

Hole no.	Map reference	Depth (m)	Topographic situation	Dominant tree species	Soil types	Site type
W1	AT8057	29.30	lower slope	wandoo (Eucalyptus wandoo)	loam (1 m) over clays	Y
W2	AT8064	19.76	mid slope	jarrah (Eucalyptus marginata) marri (Eucalyptus calophylla)	grey sands (1 m) over laterite band and clays	J
W3	AU8093	17.48	lower slope	jarrah banksia (Banksia attenuata)	white sands (3 m) over clays	J
W4	AU8099	18.10	mid slope	wandoo, marri, jarrah powderbark wandoo (Eucalyptus accedens)	lateritic gravel (3 m) over clays	M/G
W5	AU8159	14.44	lower slope	jarrah, marri, banksia	grey sands (3 m) over laterite band and clays	J
W6	AT8152	31.40	mid slope	jarrah, marri	grey sands (3 m) over clays	J
W8*	AT8059	23.56	lower slope	wandoo, marri	lateritic gravel (1.5 m) over clays	M/G
W9	AT8094	13.81	swamp	very open, occasional wandoo	grey sands (0.5 m) over laterite band and clays	A
W11*	AU8117	21.08	saddle	wandoo, marri	lateritic gravels (3 m) over clays	M
...3	AV8258	16.16	mid slope	jarrah, marri	yellow sands (3 m) over clays	F/J
H14	AV8227	9.12	swamp	open, occasional wandoo	sandy clay (0.5 m) over compact clays	A
H15	AV8255	15.16	lower slope	banksia, Christmas tree (Nuytsia floribunda), jarrah	white sands (3 m) over clays	J
H16	AV8214	15.96	lower slope	wandoo	grey sand (0.5 m) over laterite band and clays	Y
H18	AW8299	13.68	saddle	jarrah, marri	yellow sands (3 m) white sand, then laterite band and clays	F/J
H19*	AV8354	19.76	upper slope	jarrah, marri	laterite (4 m) on mottled clays	H
H20*	AV8340	8.36	upper slope	jarrah, marri	lateritic gravel (1 m) over clay	H/G
H21*	AW8199	20.52	upper slope	jarrah, marri	lateritic gravel (0.5 m) over clay	H/G
H22*	AV8294	17.39	mid slope	jarrah, marri	lateritic gravel (3 m) over clay	H/G

* no shallow bore drilled

The deep bores were drilled with a Gemcodril H13 mounted on a Bedford Truck, and fitted with hollow flight augers, wire-line, split-barrel and press-shoe. Where possible, drilling continued to bedrock. In each hole a length of 48 mm internal diameter PVC piping with slits below the groundwater table (or for a minimum of 6 m) was installed. Between the pipe and the wall the hole was backfilled with coarse sand to about 1 m above the slitted section, a cement grout was added, and the remainder was backfilled with drilling spoil. Above ground the pipe was capped and protected with a length of asbestos pipe.

Shallow bores were drilled using a hand auger 55 mm in diameter. Most of the holes were 3 m deep but in two instances (W2 and W9) it was not possible to penetrate beyond 1.5 m. On several rocky, lateritic or gravelly sites (W8, W11, H19, H20, H21, H22) shallow bores were not attempted. A length of 48 mm internal diameter PVC piping with slits throughout was installed in each hole. The space between the pipe and the hole wall was backfilled with coarse sand and a cement grout was added at the soil surface. Above ground the pipe was capped and protected with an asbestos pipe.

Depth to the groundwater table was recorded weekly for shallow bores and monthly for deep bores, using a weighted tape measure. Weekly measurements at two deep bores showed that the changes in level were gradual, and that monthly sampling was adequate. After each measurement, the column of water was agitated, and a 200 ml sample collected for testing using a bailer. Electrical conductivity (EC) of each sample was measured using a Phillips Measuring Bridge and a flow-through conductivity cell (Hatch, 1976). Standard potassium chloride (0.01 M) was used as a reference, and all values were measured at or corrected to a standard temperature of 25°C. Total dissolved solids (TDS) was estimated from the regression:

$$Y = -36.515 + 0.705X$$

where Y = TDS ($mg \cdot l^{-1}$)
and X = EC ($\mu S \cdot cm^{-1}$)

On several occasions samples were collected at the groundwater table without agitating the water column. The EC values of these samples were compared with those obtained after agitating the water column.

A 200 ml sample was collected weekly from each of the two streams which drain these Catchments. Samples were collected just below the gauging weirs installed by the Public Works Department, and streamflows were measured at each date of collection by reading the staff gauges. EC values of these samples were measured as described above.

RESULTS

Depth to groundwater table

Data for the 12 months are presented in Tables 2 and 3.

TABLE 2

Reduced levels (m) of groundwater tables in deep and shallow bores in Wellbucket Catchment

Bore no.	Deep bores				Shallow bores			
	June 1975	Sept. 1975	Dec. 1975	March 1976	June 1975	Sept. 1975	Dec. 1975	March 1976
W1	249.03	249.06	249.07	249.14	260.82	263.91	dry	dry
W2	250.61	250.56	250.57	250.66	265.41	264.74	dry	dry
W3	254.95	255.54	255.64	255.12	dry	260.02	dry	dry
W4	dry	dry	dry	dry	dry	283.74	dry	dry
W5	258.84	258.92	258.99	258.93	dry	270.64	dry	dry
W6	262.06	262.14	262.06	262.23	dry	281.80	dry	dry
W8	249.18	249.55	249.48	249.23	N.A.	N.A.	N.A.	N.A.
W9	250.20	250.45	250.77	250.50	256.71	256.28	dry	dry
W11	dry	dry	dry	dry	N.A.	N.A.	N.A.	N.A.

N.A. - data not available

TABLE 3

Reduced levels (m) of groundwater tables in deep and shallow bores in Hutt Catchment

Bore no.	Deep bores				Shallow bores			
	June 1975	Sept. 1975	Dec. 1975	March 1976	June 1975	Sept. 1975	Dec. 1975	March 1976
H13	276.97	277.42	277.47	277.24	dry	284.27	dry	dry
H14	dry	dry	dry	dry	dry	273.08	dry	dry
H15	279.99	281.29	281.44	280.55	280.49	282.74	282.19	281.59
H16	265.16	265.06	265.41	265.43	dry	277.34	274.86	dry
H18	286.54	287.88	288.09	287.63	dry	dry	dry	dry
H19	dry	dry	dry	dry	N.A.	N.A.	N.A.	N.A.
H20	dry	dry	dry	dry	N.A.	N.A.	N.A.	N.A.
H21	dry	dry	dry	dry	N.A.	N.A.	N.A.	N.A.
H22	dry	dry	dry	dry	N.A.	N.A.	N.A.	N.A.

N.A. - data not available

Shallow bores - The perched groundwater table of the shallow bores showed a greater variation in height and a more rapid response to rainfall than the semi-confined aquifer of the deep bores. In a number of holes the groundwater table was either at or very near the soil surface during winter (July to September)(Figures 3 and 4). From late October, the depth to the groundwater table increased rapidly so that most of the bores were dry by early December. One bore, H18, in deep sand on a saddle, was dry all year round. In contrast, H15, also on deep sand but on a lower slope, contained water at each sampling date.

Deep bores - In the deeper bores the variations in the semi-confined groundwater table had a maximum range of 1.80 m (Figure 3). Depths to the groundwater table were at a minimum from October to December, after the winter rains. Maximum depths were observed in April (autumn). With the exception of W4, where only one reading was possible, the remaining bores either contained water all year round or were always dry.

Adjacent deep and shallow bores - In all cases where a deep and a shallow bore were adjacent, there was a considerable difference between the two groundwater levels. In an extreme case, H14, the deep bore remained dry all year whereas in the shallow bore water rose to within 0.27 m of the soil surface. Further examples of this difference are shown in Tables 2 and 3, and in Figures 3 and 4. The data indicate perched and semi-confined aquifers within the test Catchments; they also suggest that the grout seals prevented substantial leakage from one zone to the other.

Conductivity

Results are shown in Tables 4 and 5, and in Figure 2.

TABLE 4

Maximum, minimum and mean conductivity of water from deep and shallow bores in Wellbucket Catchment

Bore no.	Deep bores				Shallow bores			
	Maximum	Minimum	Range	Mean	Maximum	Minimum	Range	Mean
W1	2650	2355	295	2475	5860	1231	4629	2990
W2	3732	3098	634	3488	278	94	184	133
W3	421	317	104	371	593	91	502	190
W4	329	329	nil+	329	248	156	92	206
W5	439	318	121	350	235	116	119	148
W6	761	690	71	724	261	91	170	125
W8	1718	1572	146	1640	N.A.	N.A.	N.A.	N.A.
W9	891	826	65	859	960	551	409	730
W11	dry	dry	dry	dry	N.A.	N.A.	N.A.	N.A.

+ one reading only

TABLE 5

Maximum, minimum and mean conductivity of water from deep and shallow bores in Hutt Catchment

Bore no.	Deep bores				Shallow bores			
	Maximum	Minimum	Range	Mean	Maximum	Minimum	Range	Mean
H13	2680	252	2428	1473	2427	917	1510	1308
H14	dry	dry	dry	dry	598	311	287	418
H15	467	122	345	283	478	69	409	258
H16	4088	3643	445	3832	946	125	821	324
H18	555	332	223	467	dry	dry	dry	dry
H19	dry	dry	dry	dry	N.A.	N.A.	N.A.	N.A.
H20	dry	dry	dry	dry	N.A.	N.A.	N.A.	N.A.
H21	dry	dry	dry	dry	N.A.	N.A.	N.A.	N.A.
H22	dry	dry	dry	dry	N.A.	N.A.	N.A.	N.A.

N.A. - data not available

Shallow bores - Considerable differences in maxima (range 5625 $\mu S \cdot cm^{-1}$), minima (range 1162 $\mu S \cdot cm^{-1}$), and mean values (range 2865 $\mu S \cdot cm^{-1}$) occurred between sites. Often bores close to each other (W1 and W2, H13 and H15) had very different EC values. Three bores (H13, H16, W1) had a within-bore range exceeding 750 $\mu S \cdot cm^{-1}$; the highest range was 4629 $\mu S \cdot cm^{-1}$ for W1. The maxima for most bores occurred towards the beginning (July-August) and end (November-December) of the winter cycle: the minima for most bores occurred during August-September. The differences in EC between shallow bores were highly significant ($p > 0.001$) whereas the differences between sampling dates were not significant. The interaction (bores x dates) could not be analysed since it is the error term.

Deep bores - Within the semi-confined groundwater tables, there were also considerable differences in EC values. Between-site variations were 3759 $\mu S \cdot cm^{-1}$ (maxima), 3521 $\mu S \cdot cm^{-1}$ (minima) and 3549 $\mu S \cdot cm^{-1}$ (mean values). Again, bores close to each other (W2 and W3, H15 and H16) had very different EC values. With the exception of H13 (2428 $\mu S \cdot cm^{-1}$), the within-bore variations were not great (< 750 $\mu S \cdot cm^{-1}$). There was no consistent relationship between time of year and minimum or maximum EC values. However, most of the minima were recorded between July and November (winter-spring) and maxima were more common during December to February (summer). The differences between bores were highly significant ($p > 0.001$) whereas the differences between sampling dates were not significant. The interaction (bores x dates) could not be analysed since it is the error term.

Adjacent deep and shallow bores - Where a perched and semi-confined groundwater table could be compared, the EC values in the semi-confined groundwater table were slightly higher (with W1 the only exception). In most cases, the EC values between the two aquifers were not greatly different (< 750 $\mu S \cdot cm^{-1}$). However, for H16 and W2, the semi-confined groundwater tables had considerably higher EC values (3508 and 3355 $\mu S \cdot cm^{-1}$ respectively).

Comparisons of adjacent deep and shallow bores were possible on five separate occasions between July and December. Analysis of variance showed a similar pattern for both Catchments : the interactions groundwater table x bores were highly significant ($p > 0.001$), and the main effects groundwater tables and bores were also highly significant. The differences between sampling dates were not significant. The data show that the EC values for deep and shallow groundwaters were similar, except for W2 and H16 where the EC values of the deep groundwaters were significantly greater than those of the shallow groundwaters.

Topography - Figure 2 shows the spatial distribution of the bores, and the mean EC of the perched and semi-confined groundwater tables at each site. The higher EC values were generally found in the lower topographic positions towards the mouths of the Catchments. Most of the bores in the higher topographic positions were dry, though some were drilled to bedrock and others were more than 20 m deep.

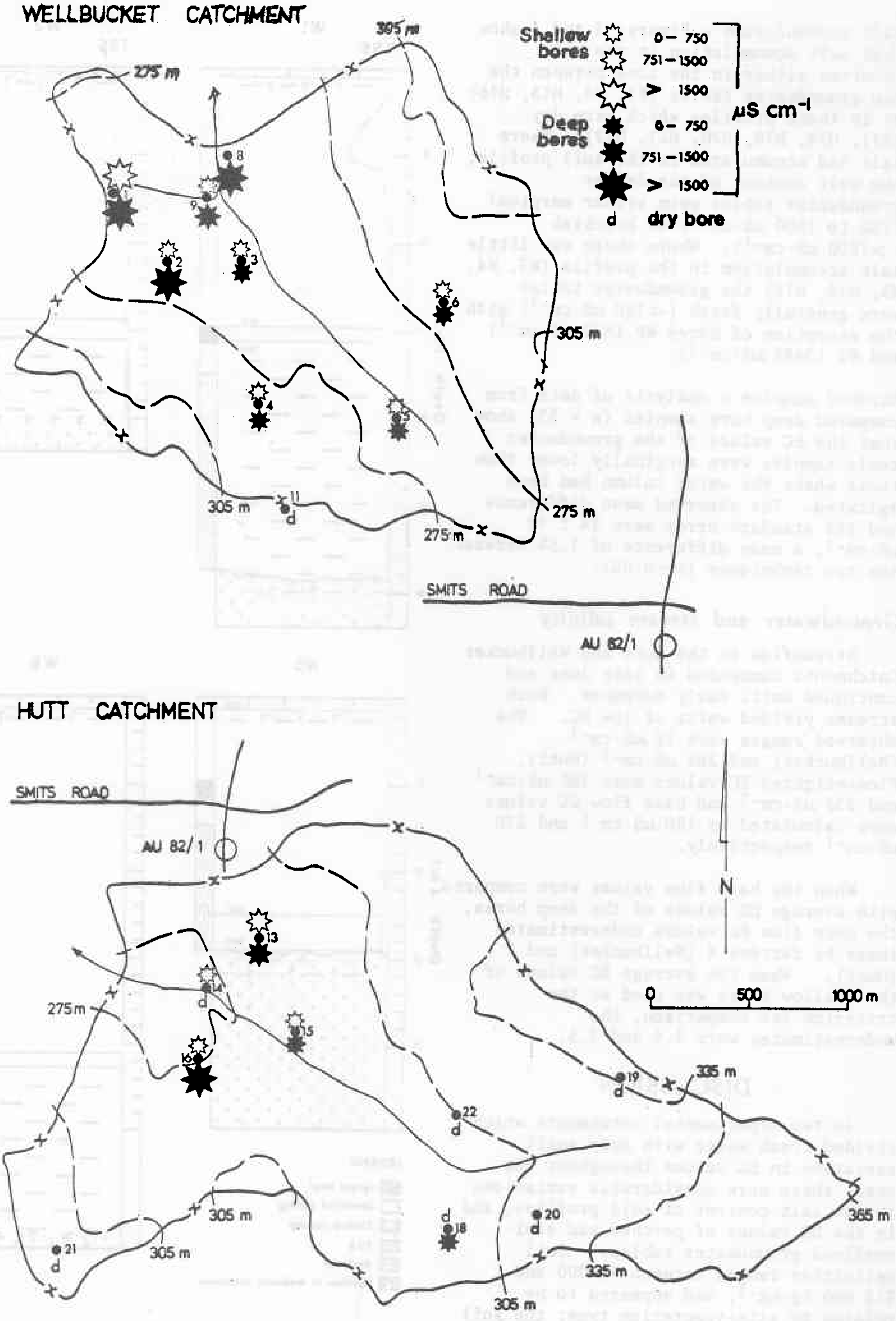


FIGURE 2: Bore number, position and mean EC values of perched and semi-confined groundwater tables.

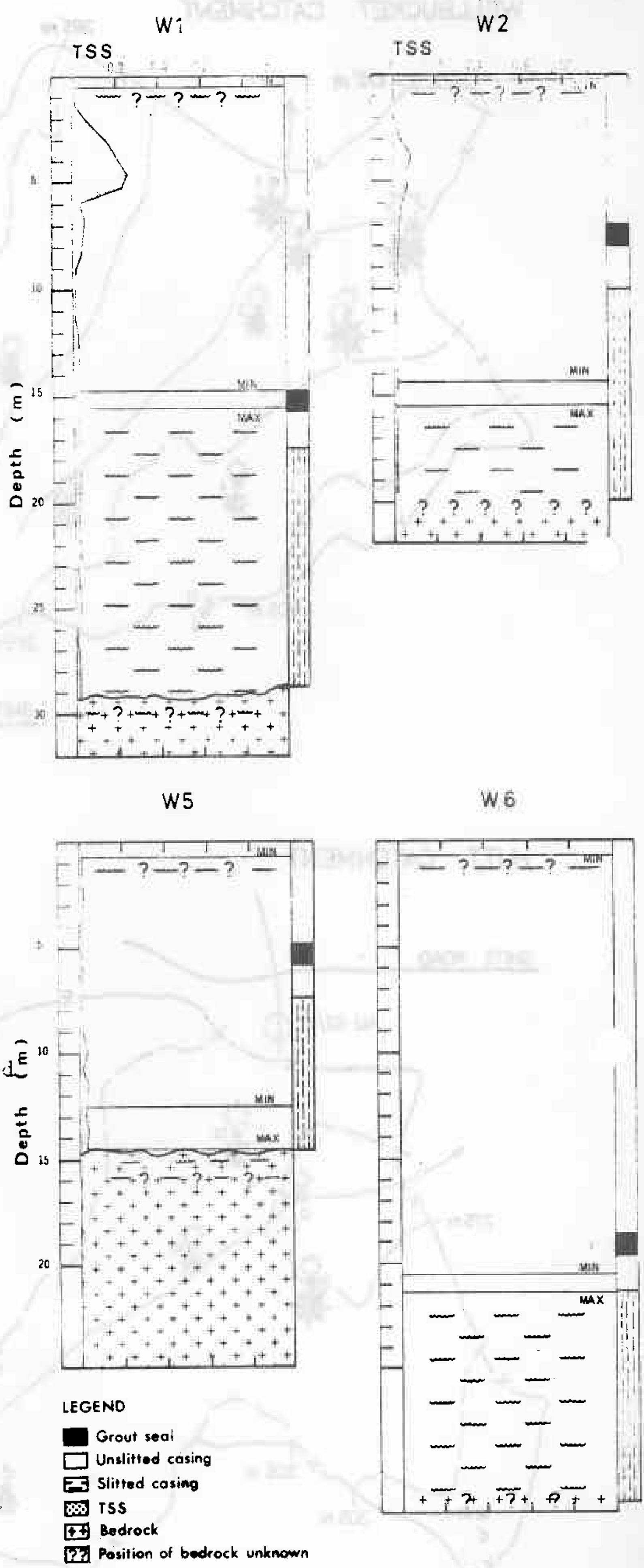
Salt accumulation - Figures 3 and 4 show that salt accumulation in the soil occurred either in the zone between the two groundwater tables (W1, W8, H13, H16) or in those profiles which were dry (W11, H14, H19, H20, H21, H22). Where salt had accumulated in the soil profile, the salt content of the deeper groundwater tables were either marginal (750 to 1500 $\mu S \cdot cm^{-1}$) or brackish (>1500 $\mu S \cdot cm^{-1}$). Where there was little salt accumulation in the profile (W3, W4, W5, H15, H18) the groundwater tables were generally fresh (<750 $\mu S \cdot cm^{-1}$) with the exception of bores W9 (859 $\mu S \cdot cm^{-1}$) and W2 (3488 $\mu S \cdot cm^{-1}$).

Matched samples - Analysis of data from compared deep bore samples (n = 33) show that the EC values of the groundwater table samples were marginally lower than those where the water column had been agitated. The observed mean difference and its standard error were 24 ± 10 $\mu S \cdot cm^{-1}$, a mean difference of 1.5% between the two techniques ($p < 0.05$).

Groundwater and stream salinity

Streamflow in the Hutt and Wellbucket Catchments commenced in late June and continued until early November. Both streams yielded water of low EC. The observed ranges were 75 $\mu S \cdot cm^{-1}$ (Wellbucket) and 285 $\mu S \cdot cm^{-1}$ (Hutt). Flow-weighted EC values were 160 $\mu S \cdot cm^{-1}$ and 230 $\mu S \cdot cm^{-1}$ and base flow EC values were calculated as 180 $\mu S \cdot cm^{-1}$ and 370 $\mu S \cdot cm^{-1}$ respectively.

When the base flow values were compared with average EC values of the deep bores, the base flow EC values underestimated these by factors 4 (Wellbucket) and 7 (Hutt). When the average EC values of the shallow bores was used as the criterion for comparison, the underestimates were 1.5 and 3.5.



DISCUSSION

In two experimental catchments which yielded fresh water with only small variation in EC values throughout the year, there were considerable variations in the salt content of soil profiles, and in the EC values of perched and semi-confined groundwater tables. Soil salinities ranged between 14 000 and 813 000 $kg \cdot ha^{-1}$, and appeared to be related to site-vegetation type; the soil

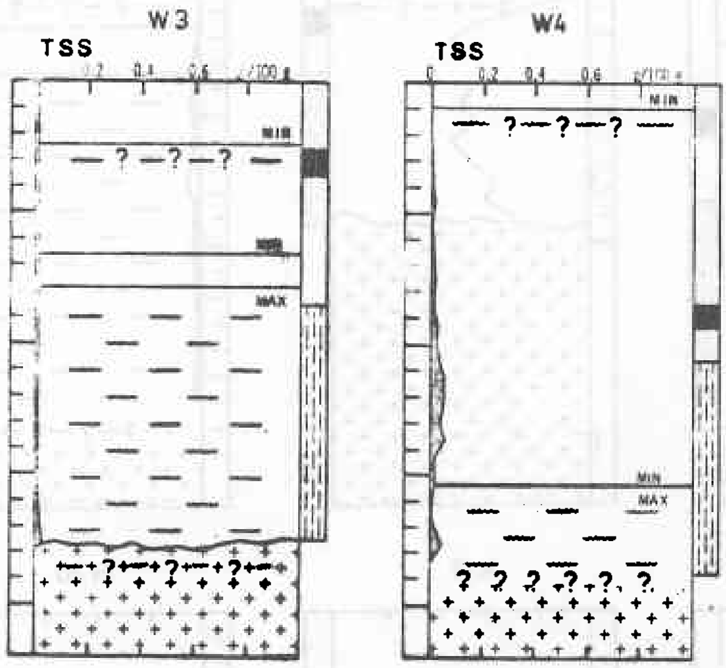


FIGURE 3: Bore number, depth and soil salinity profile (Wellbucket Catchment) with details of the position of the grout seal and the length of slitted bore casing. Positions of perched and semi-confined groundwater tables are shown.

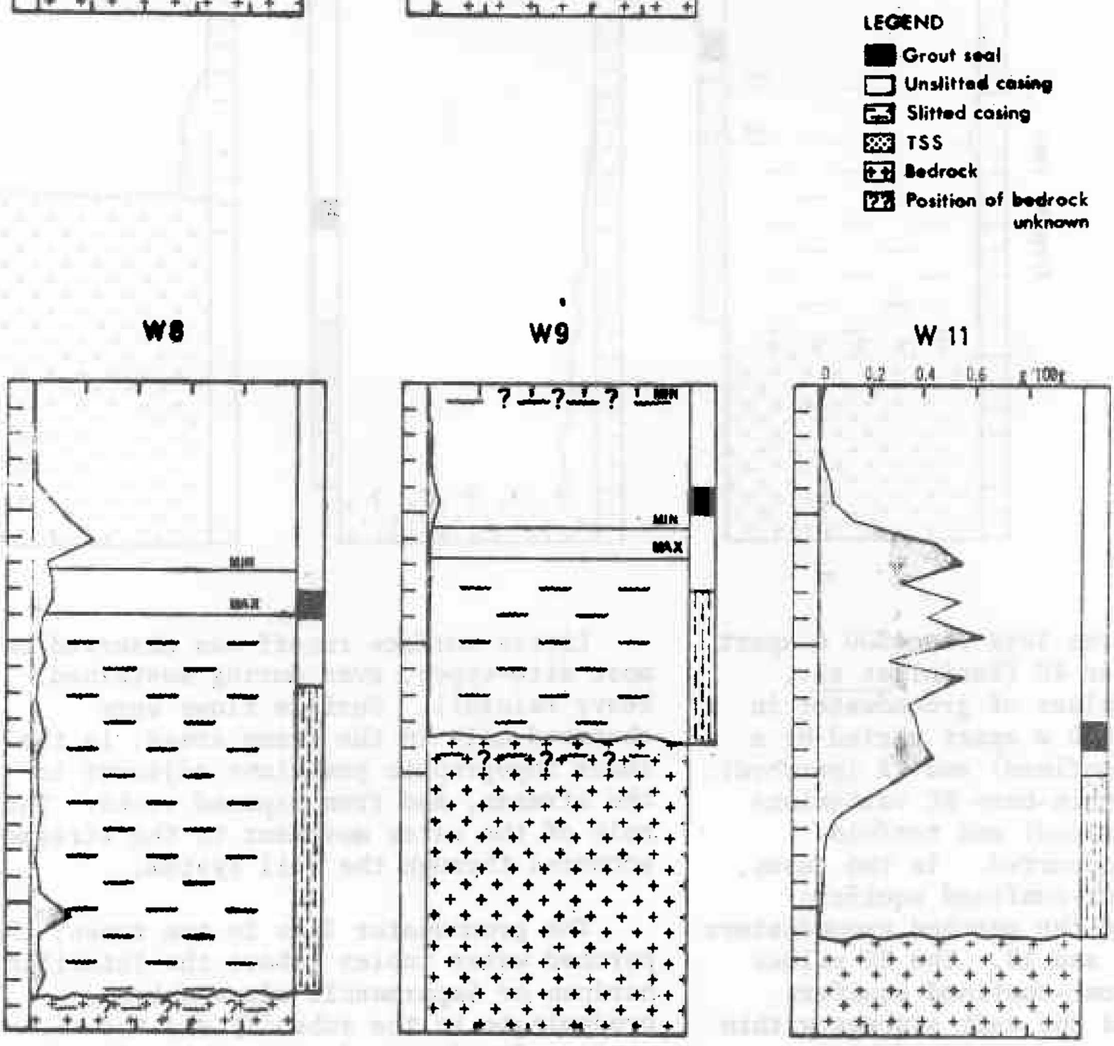
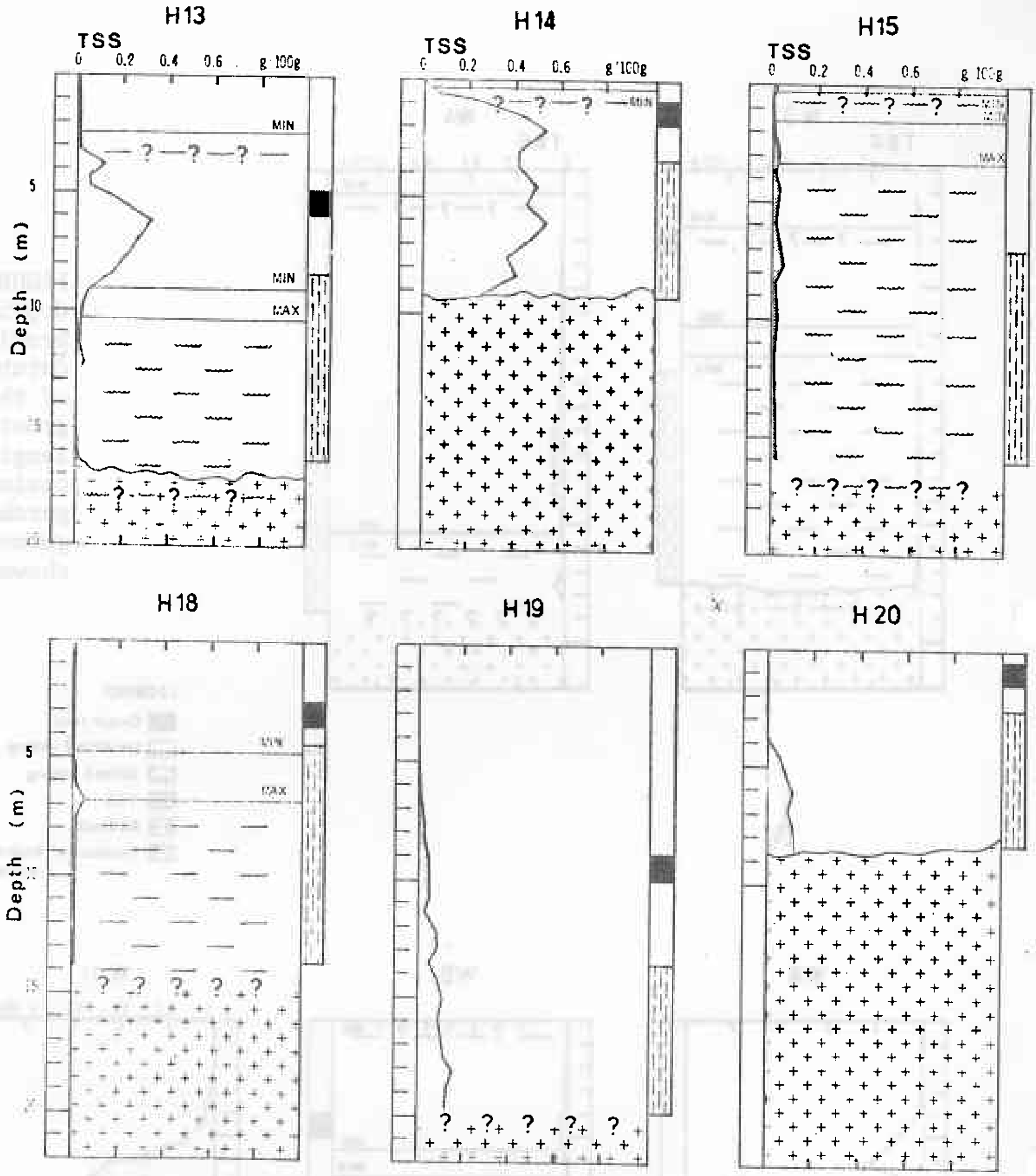
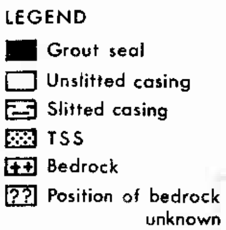


FIGURE 4. Bore number, depth and soil salinity profile (Hutt Catchment). Details of the position of the grout seal and the length of slitted bore casing. Positions of perched and semi-confined groundwater tables.

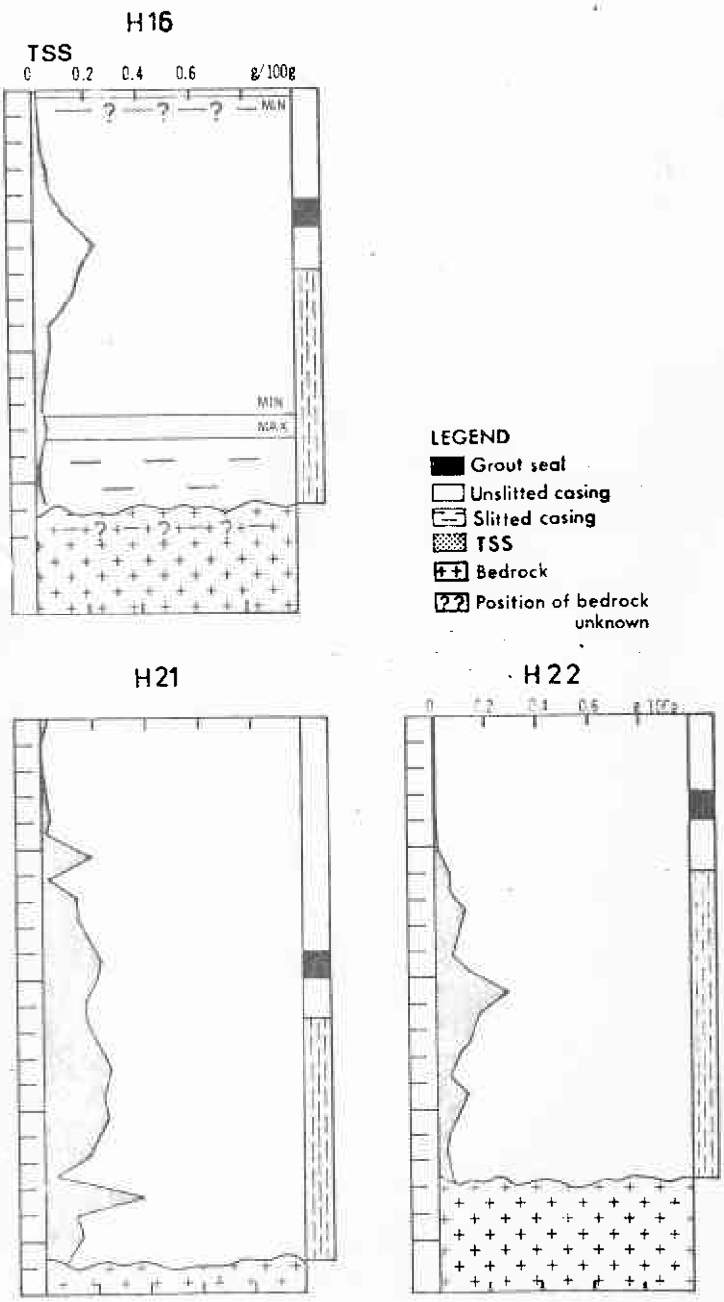




salinities of bores less than 300 m apart varied by a factor 40 (Batini et al., 1976). The EC values of groundwater in bores less than 500 m apart varied by a factor 9 (semi-confined) and 22 (perched). In some cases within-bore EC variations of eightfold (perched) and tenfold (semi-confined) occurred. In two cases, the EC of the semi-confined aquifers exceeded those of the perched groundwaters by factors of 12 and 19. The EC values of perched and semi-confined aquifers usually reflected the salt storage within the profile, but some exceptions were noted. There was no substantial storage of salt in the soil below the position of the semi-confined groundwater table.

Little surface runoff was observed on most site-types, even during sustained, heavy rainfall. Surface flows were observed only in the swamp areas, in the lower topographic positions adjacent to the streams, and from exposed rocks. The bulk of the water movement to the streams occurred through the soil system.

The groundwater lies in two zones: the perched water tables (above the lateritic hardpan or impermeable clays which predominate in the subsoil) and the semi-confined groundwater tables (at depths ranging from 5 to 20 m below soil surface). The former responded rapidly to rainfall whereas the responses in the latter were



delayed and less pronounced. Atypical responses to rainfall observed in the shallow bores H18 and H15 can be explained by their soil type (deep sands) and topographic positions (saddle and lower slope respectively). H14 is the only deep bore which is in a low topographic position and is dry; this bore may be on a granite dome which is higher than the level of the groundwater table in that area.

CONCLUSION

The data suggest that the groundwater is not uniform throughout the two Catchments, but exists in pockets. The higher values for EC were usually found in the lower topographic positions near the mouths of the Catchments. At the time of testing, the EC values of the stream water were lower than those of the groundwater.

Problems in forest management could occur in these areas. Firstly, the drilling data indicated that there were considerable reserves of salt in some profiles and secondly, groundwaters with high EC values were present in certain parts of the Catchments.

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