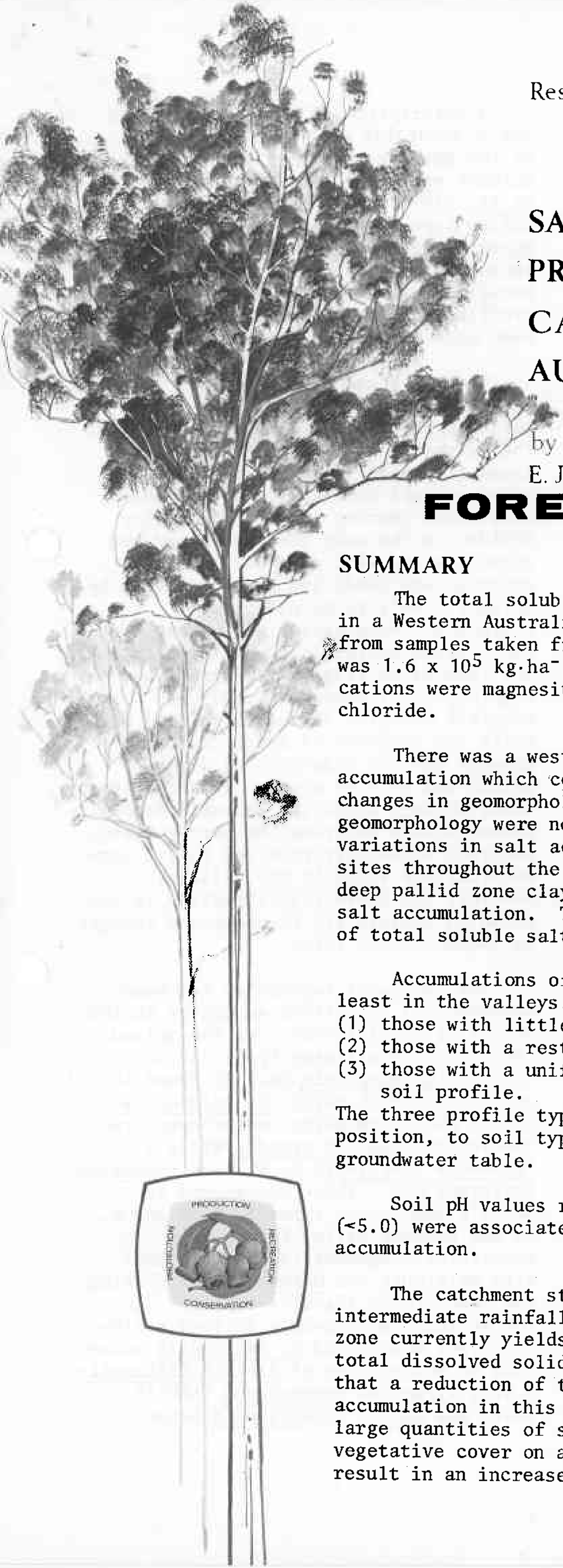

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SALT CONTENT OF LATERITIC PROFILES IN THE YARRAGIL CATCHMENT, WESTERN AUSTRALIA

by

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SUMMARY

The total soluble salt content of lateritic soil profiles in a Western Australian jarrah forest catchment was estimated from samples taken from 27 cored bore holes. The mean value was 1.6×10^5 kg$\cdot$ha^{-1} of total soluble salts. Dominant cations were magnesium and sodium and the dominant anion was chloride.

There was a west to east gradient of increase in salt accumulation which coincided with decreasing rainfall and changes in geomorphology. However, variations in rainfall and geomorphology were not sufficient to explain the large variations in salt accumulations observed between and within sites throughout the catchment: physical characteristics of the deep pallid zone clays were also an important factor affecting salt accumulation. The maximum salt concentration equalled 7 kg of total soluble salts per m^3 of soil.

Accumulations of salt were greatest on upland sites and least in the valleys. Three salt profile types were identified:
(1) those with little salt;
(2) those with a restricted zone of salt;
(3) those with a uniform distribution of salt throughout the soil profile.
The three profile types appeared to be related to topographic position, to soil types and to the presence or absence of a groundwater table.

Soil pH values ranged from 3.3 to 8.9. The lower values (<5.0) were associated with the zones of higher salt accumulation.

The catchment studied is representative of catchments in the intermediate rainfall zone of the northern jarrah forest. This zone currently yields water of acceptable quality (< 500 mg total dissolved solids). The results of this study indicate that a reduction of the vegetative cover on areas of high salt accumulation in this zone could result in the discharge of large quantities of salt via streamflow, but a reduction in vegetative cover on areas where salt accumulation is low could result in an increased yield of potable water.

N.B. The general terms 'salinity' and 'salt' mentioned in this paper refer to the concentration of total soluble salts (TSS).

Definition of soluble salts:
(1) they are calculated from electical conductivity measurements;
(2) they are composed predominantly of magnesium, sodium and chloride.

INTRODUCTION

The objective of this study was to estimate the salt content of soil profiles by direct analysis of soil samples. The Yarragil Catchment was selected because it is representative of the intermediate rainfall zone and because the water quality and yield throughout the Catchment is being intensively monitored (Shea et al., 1975; Herbert and Ritson, 1976).

The intermediate rainfall zone has considerable significance in catchment management. In terms of water yield it is intermediate between the high yield of the western high rainfall zone, and the low yield of the eastern low rainfall zone. Whereas the danger of deterioration of water quality through leaching of salt out of the subsoil is minor in the former, and acute in the latter zone, it requires clarification in the intermediate zone. The intermediate zone is a major source of fresh water, but the catchments in this area are potentially saline. It has a relatively high rainfall excess (excess of rainfall over evaporation during the winter months) and is therefore sensitive to changes in canopy cover. Maintenance of the groundwater component of the yield in potentially saline catchments at a level which maintains high water quality is theoretically dependent on evapotranspiration of the rainfall excess (Shea and Hatch, 1976). Disturbance to canopy cover may result from changes in land use or from the effects of jarrah dieback (Podger, 1972).

Description of the Catchment

The Yarragil Catchment is 13 km south-east of Dwellingup in the intermediate rainfall zone (800-1000 mm per annum) of the northern jarrah forest (Fig. 1). It covers an area of 72.5 km^2 comprising a range of geomorphological and vegetational types typical of the zone.

A description of the landforms and soils occurring on an adjacent part of the Darling Range has been made by Mulcahy et al. (1972) whilst McArthur et al. (1977) have defined the major valley types and soils occuring in the Murray River catchment area, which includes the Yarragil Catchment. A detailed description of lateritic soil profiles characteristic of the area has been made by Gilkes et al. (1973).

The soils and landforms vary with increasing dissection from the broad valley systems in the east and centre of the Catchment with sandy and gravelly loams (Yarragil type), to the steep-sided valleys in the west with reddish, clay loams (Murray type). The valley divides in the east are also broad and often covered with detrital lateritic material and sands and are considered by Mulcahy (1967) to be old plateau residuals. Progressing westwards, the old plateau residuals (Dwellingup type) are reduced to ridges with ironstone capping, their slopes covered with detrital material derived from it. Such soils are composed of sandy or loamy gravels and are underlain at depth by pallid and mottled clays. In the western zone, through which the Yarragil Brook passes before entering the Murray River, outcrops of country rock and pallid zone material are found in the valleys. However, the above classification is too broad to explain all the observed changes in landforms and soils.

The Catchment vegetation has been surveyed and classified according to the system of Havel (1975). On the uplands (McArthur's Dwellingup type) jarrah (Eucalyptus marginata Sm.) is found in association with marri (E. calophylla R.Br.) while the major understorey tree species are Banksia grandis Willd., Persoonia longifolia R. Br. and Casuarina fraserana Miq. These correspond to Havel's vegetation types T, S, O and P. On the eastern valley floors the overstorey component is E. rudis Endl. with Melaleuca and Hakea species forming the understorey (Havel's type A). In the western, more deeply incised valleys E. patens Benth. and E. calophylla occur with an understorey of Banksia littoralis R.Br., Trymalium spathulatum (Labill.) Ostf. and Agonis linearifolia Schau.

(Havel's types W, Q and C). There are isolated occurences of wandoo (E. wandoo Blakely) and bullich (E. megacarpa F. Muell.) which correspond to Havel's types Y and C respectively.

The base flow salinity levels of micro-catchment streams in the Yarragil and adjoining catchments frequently exceed 500 mg total dissolved solids (TDS) per litre (Shea et al., 1975).

Groundwater salinity levels have been determined for the adjacent South Dandalup Catchment, which also lies in the intermediate rainfall zone. The figures ranged from 250 to 1000 mg·l^{-1} TDS (Shea and Hatch, 1976).

METHOD

Twenty-seven bore holes were drilled in locations selected to sample the main geomorphological features of the Catchment. Sampling covered the major differences between strongly dissected, narrow erosional valleys in the south-west and the broad, weakly dissected valleys with depositional fill in the east. Within each major valley type, bore holes were located on ridge, mid-slope and valley floor respectively.

The methods of drilling, sampling and analysis used were those described by Batini et al. (1976) and Hatch (1976). A Gemco rotary drill using hollow-flight augers, wire-line retrieval gear and core barrels was used to obtain core samples from the soil profile at 0.76 m intervals. From these samples specific electrical conductivity (EC), total soluble salts (TSS), sodium chloride (NaCl) content, pH values, gravimetric moisture content and bulk density were calculated. The methods used to estimate the concentration of soluble salts and pH

FIG 1

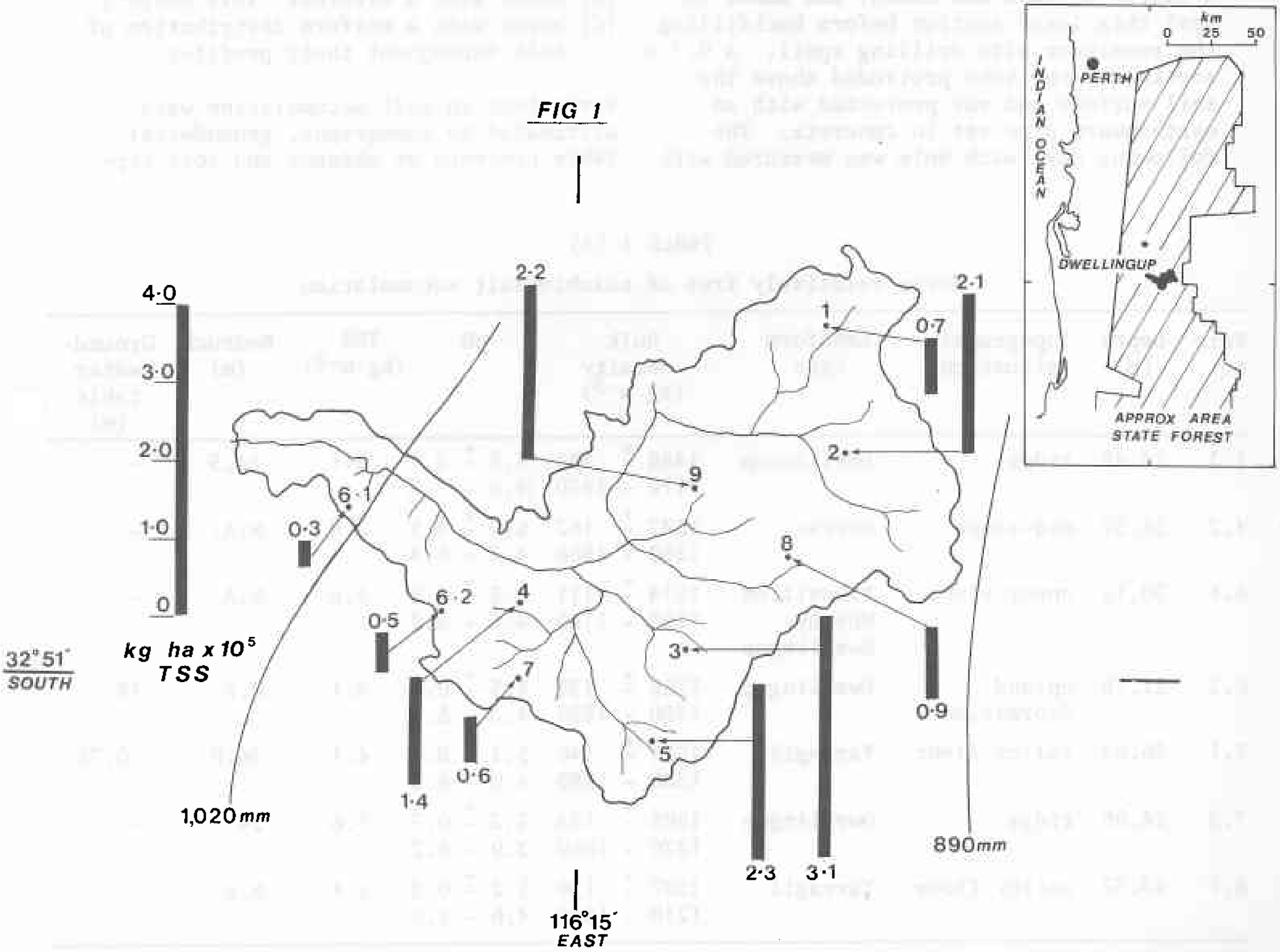


FIGURE 1: Location map of the Yarragil Catchment showing bore hole positions and mean salt storage values (kg·m^{-2} TSS). Rainfall is in millimetres.

of the soil samples are described in detail by Hatch (1976). Salt accumulation per unit of landscape was estimated by integrating the salt profile data by means of the trapezoidal rule. Data from profiles which did not terminate in bedrock because of excessive depth (> 44m) or drilling difficulties were used in the integration but were not extrapolated.

On completion of drilling, each bore hole was fitted with a piezometer made from 42 mm internal diameter poly-vinyl chloride (PVC) tubing. The lower end of each piezometer had longitudinal slits spiralling the tubing for a length determined by the position and anticipated fluctuation of the groundwater table. Where there was no groundwater table, only the bottom 6 m of tubing had slits. Bore holes were backfilled with coarse sand (0.001-0.002 m diameter) to at least one metre above the top of the split section. A slurry of sand and cement was added to seal this lower section before backfilling the remainder with drilling spoil. A 0.7 m section of the tube protruded above the soil surface and was protected with an earthenware pipe set in concrete. The following day, each hole was measured with a Tamam salinity/temperature meter to determine the water rest level (WRL) and any salinity stratification within the groundwater table. The soil cores were examined and stored for further analysis.

RESULTS

Bore locations and mean total salt accumulation per unit of landscape are shown in Figure 1. Site descriptions, mean bulk density, mean pH values, total salt storages, groundwater table and bedrock depths are shown in Table 1. A summary of the data in the form of salinity and pH profiles together with groundwater table (WT) levels is presented in Figure 2.

For ease of discussion the results have been divided into the following broad categories (Table 1):

(A) bores relatively free of salt accumulation;
(B) bores with a distinct "salt bulge";
(C) bores with a uniform distribution of salt throughout their profiles.

Variations in salt accumulation were attributed to topography, groundwater table presence or absence and soil type.

TABLE 1 (A)

Bores relatively free of soluble salt accumulation

Bore no.	Depth (m)	Topographic situation	Landform type	Bulk density ($kg \cdot m^{-3}$)	pH	TSS ($kg \cdot m^{-2}$)	Bedrock (m)	Ground-water table (m)
1.3	24.45	ridge	Dwellingup	1488 ± 191 1110 - 1970	5.5 ± 0.7 4.6 - 7.3	6.1	24.5	-
4.2	26.39	mid-slope	Murray	1537 ± 162 1260 - 1860	5.0 ± 0.5 4.3 - 6.4	2.8	N.A.	-
6.1	30.14	upper slope	transition Murray-Dwellingup	1514 ± 111 1250 - 1740	5.5 ± 0.5 4.5 - 6.2	4.6	N.A.	-
6.2	21.78	upland depression	Dwellingup	1559 ± 137 1250 - 1820	5.5 ± 0.6 4.3 - 6.5	3.1	N.A.	18
7.1	36.04	valley floor	Yarragil	1521 ± 146 1280 - 1980	5.1 ± 0.5 4.0 - 6.2	4.1	36.0	0.75
7.3	24.06	ridge	Dwellingup	1595 ± 138 1270 - 1860	5.3 ± 0.7 3.9 - 6.2	3.6	24	-
8.1	43.32	valley floor	Yarragil	1507 ± 130 1210 - 1840	5.2 ± 0.3 4.6 - 5.9	5.4	N.A.	-

TABLE 1: Description of bore holes (Mean ± standard deviation, range below)

TABLE 1 (B)

Bores with a distinct salt bulge

Bore no.	Depth (m)	Topographic situation	Landform type	Bulk density ($kg \cdot m^{-2}$)	pH	TSS ($kg \cdot m^{-2}$)	Bedrock (m)	Ground-water table (m)
1.1	15.75	valley floor	Yarragil	1519 ± 390 1000 - 2350	5.4 ± 0.9 3.4 - 7.5	6.3	N.A.	6.0
1.2	33.44	mid-slope	Yarragil	1446 ± 186 1040 - 2030	4.8 ± 0.7 3.5 - 6.5	8.7	33.4	23.0
2.1	32.88	valley floor	Yarragil	1556 ± 176 1130 - 2050	6.3 ± 0.4 5.7 - 7.1	8.9	N.A.	6.5
2.2	43.32	mid-slope	Yarragil	1537 ± 134 1300 - 1860	5.7 ± 0.8 3.5 - 6.7	24.7	N.A.	14
2.3	42.56	ridge	Dwellingup	1580 ± 141 1320 - 2180	5.3 ± 0.6 3.6 - 6.4	41.6	N.A.	22
2.4	41.34	upper slope	Dwellingup	1540 ± 276 1040 - 2300	5.0 ± 0.9 3.4 - 6.8	25.6	N.A.	15
2.5	24.72	valley bottom	Yarragil	1549 ± 192 1240 - 2030	5.6 ± 0.4 4.7 - 6.3	5.7	N.A.	6
3.2	44.08	mid-slope	Dwellingup	1660 ± 116 1450 - 1950	5.3 ± 0.5 4.5 - 6.5	38.9	N.A.	-
5.1	27.55	valley bottom	Yarragil	1674 ± 257 1050 - 2160	5.6 ± 0.5 4.4 - 6.2	14.2	27.5	7
5.2	35.32	upper slope	Yarragil	1716 ± 174 1360 - 2000	5.3 ± 0.3 4.0 - 6.1	33.9	N.A.	13.5
5.3	44.08	ridge	Yarragil	1602 ± 215 1150 - 2170	5.9 ± 0.5 4.0 - 7.1	20.5	N.A.	19.5
7.2	27.36	mid-slope	Dwellingup	1502 ± 258 1140 - 2030	4.9 ± 0.8 3.4 - 6.3	8.9	N.A.	18
8.2	32.04	mid-slope	Yarragil	1481 ± 165 1160 - 1840	5.4 ± 1.0 3.6 - 8.9	7.3	32	10
8.3	18.72	ridge	Yarragil	1649 ± 147 1400 - 1940	4.9 ± 1.1 3.3 - 6.5	15.7	18.7	10.75
9.1	21.55	valley floor	Yarragil	1613 ± 174 1310 - 2100	5.3 ± 0.3 4.9 - 6.2	30.0	21.5	7

TABLE 1 (C)

Bores with a uniform distribution of soluble salt throughout their profiles

3.1	32.63	valley floor	Yarragil	1703 ± 150 1460 - 2030	6.0 ± 0.6 5.2 - 7.8	10.1	32.6	6
3.3	35.72	plateau	Dwellingup	1646 ± 104 1400 - 1820	5.3 ± 0.6 4.5 - 7.1	43.6	N.A.	-
4.3	37.24	plateau	Dwellingup	1570 ± 149 1240 - 1860	5.4 ± 0.5 5.2 - 7.8	24.5	N.A.	Nil
9.2	27.45	mid-slope	Dwellingup	1626 ± 200 1200 - 2340	5.3 ± 0.6 4.4 - 6.4	8.6	27.4	Nil
9.3	38.98	plateau	Dwellingup	1574 ± 168 1070 - 1960	5.1 ± 0.6 4.4 - 7.0	28.2	39	Nil

N.A. Information not available,
Bedrock not intersected.

TABLE 1: Description of bore holes (Mean ± standard deviation, range below).

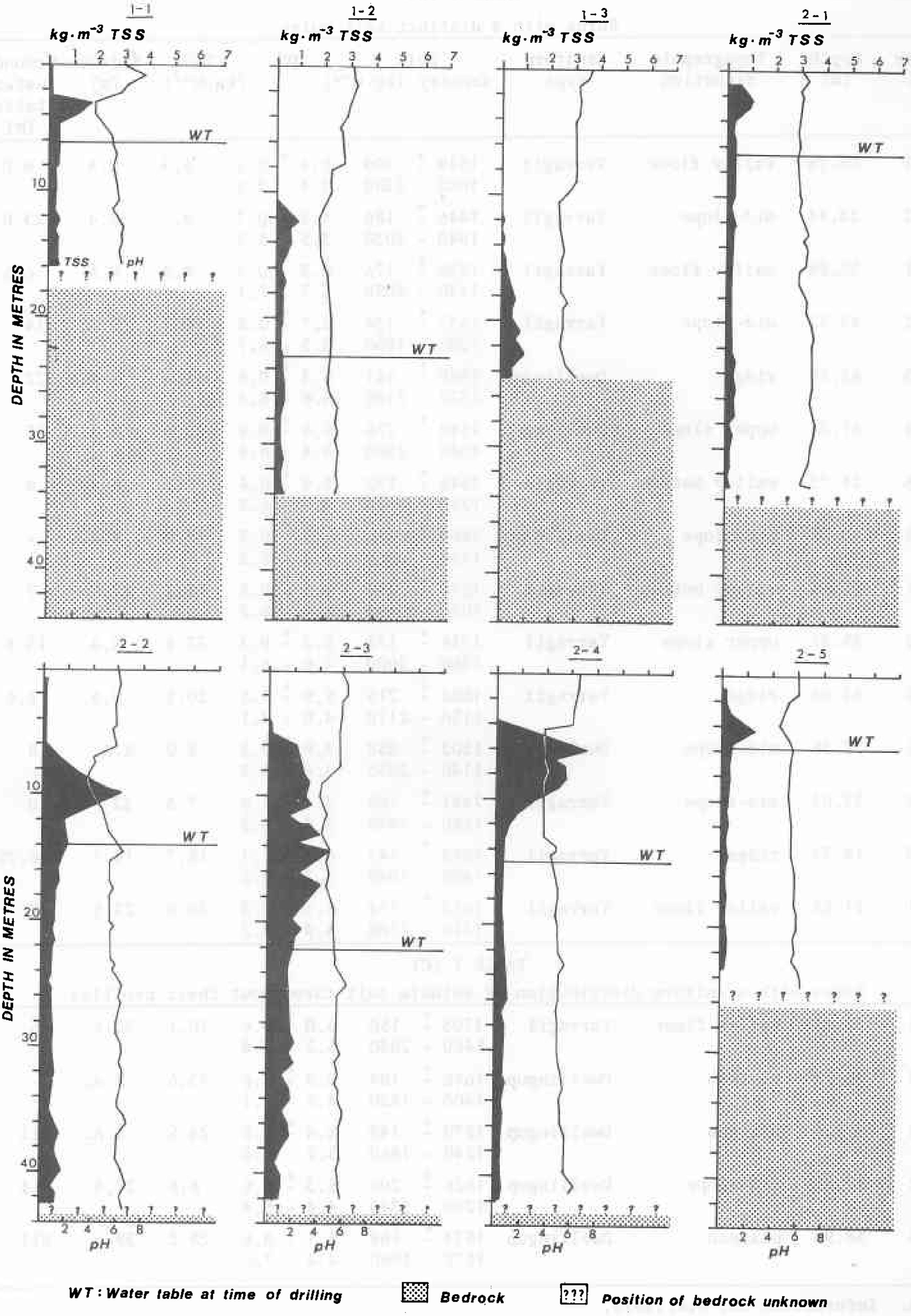
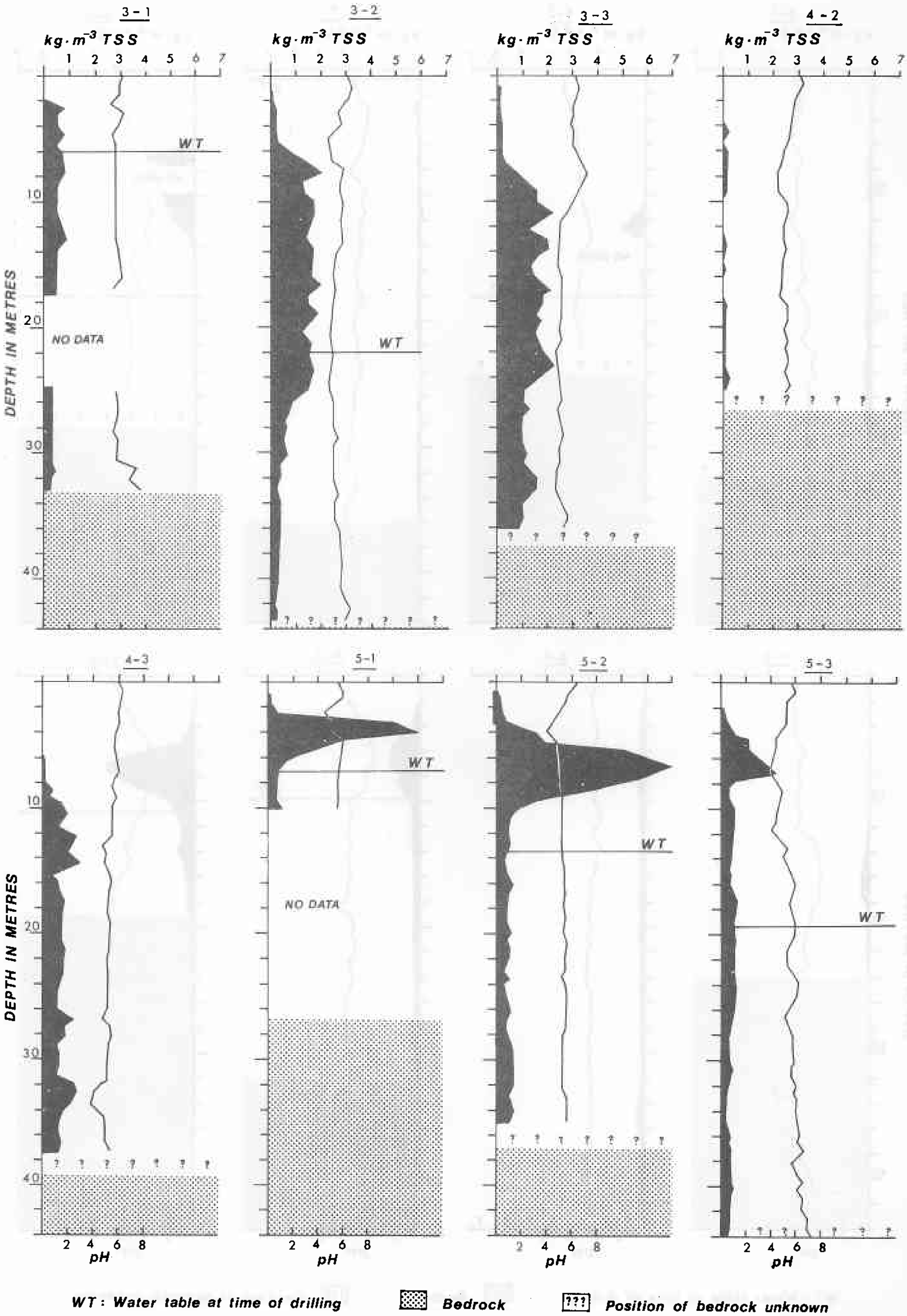


FIGURE 2: Vertical distribution of salt ($kg \cdot m^{-3}$ TSS) and pH for bores in the Yarragil Catchment.



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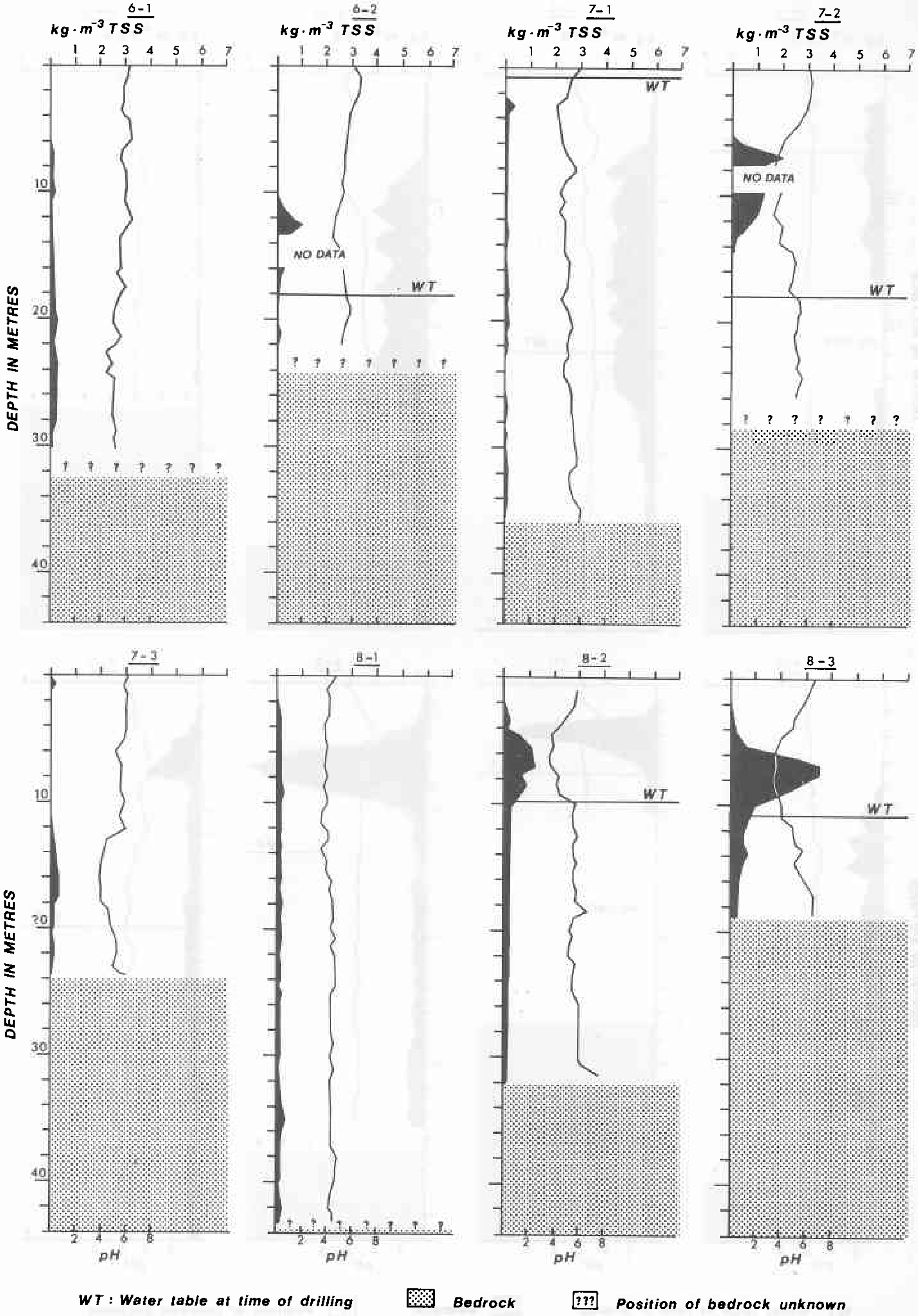

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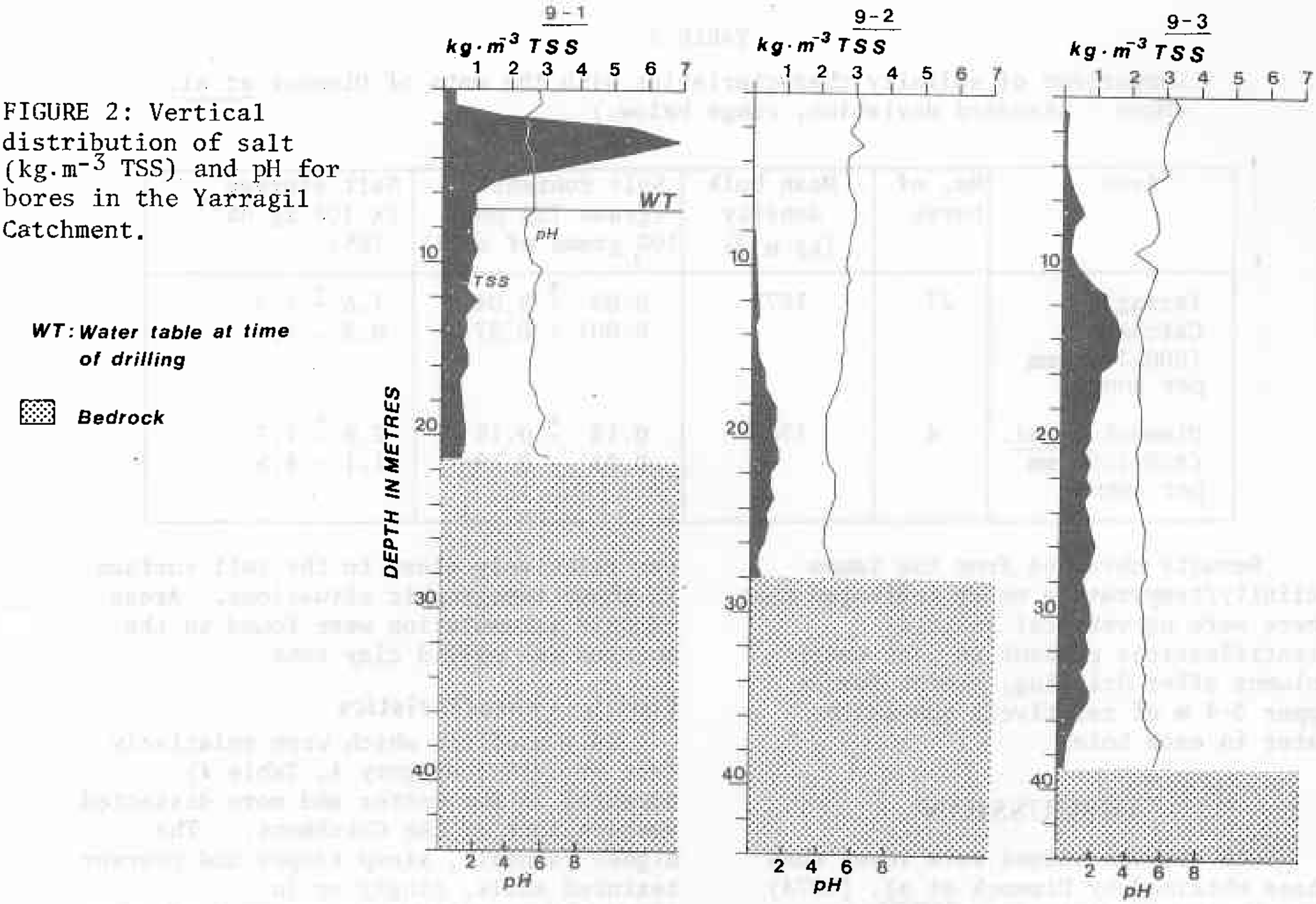

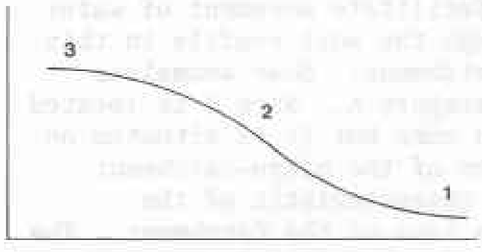

TOPOGRAPHIC LOCATION OF BORE HOLES

Eighty-one per cent of the total salt observed in the Catchment was confined to the upper slopes and valley divides. Profiles in the incised valleys in the western part of the Catchment contained less salt per unit landscape than the broader valleys in the east (Fig. 1). The depth of maximum salt concentration varied with topographic position, being closer to the soil surface in valley sites. Concentrations ranged from less than 0.01 kg.m^{-3} TSS soil to 7.0 kg.m^{-3} TSS soil. The proportion of exchangeable cations present in the deeper soil horizons was: calcium 9%, magnesium 72%, potassium 1%, sodium 18%. Chloride was the dominant soluble anion present. This is in marked contrast to the soil water when sodium is the dominant cation (72%) and chloride the dominant anion present. Those bores which had a distinct zone of salt accumulation were generally associated with an underlying groundwater table. The mean salt storage value was 1.6 x 10^{5} kg.ha^{-1} and the mean bulk density was 1572 kg.m^{-3}. These and other salt characteristics are compared with those of Dimmock et al. (1974) in Table 2.

Soil texture encountered in the bore samples varied from coarse-textured clayey sands (bore hole 8.1) to dense fine-textured clays (bore hole 5.2). Each profile, though varying in soil type, had the characteristic of an in situ weathered granite-gneiss (Harley, personal communication). Space limitation does not permit the inclusion of the soil core descriptions but they are available from the authors upon request.

Observed pH values ranged from 3.3 to 8.9, the lowest values occurring where concentrations of salt were greatest and the highest values occurring in the top metre of soil and immediately above bedrock. Similar trends were noted by Batini et al. (1976).

TABLE 2

Comparison of salinity characteristics with the data of Dimmock et al. (Mean ± standard deviation, range below.)

Area	No. of bores	Mean bulk density ($kg \cdot m^{-3}$)	Salt content (grams TSS per 100 grams of soil)	Salt storage (x 105 $kg \cdot ha^{-1}$ TSS)
Yarragil Catchment (800-1000 mm per annum)	27	1572	0.03 ± 0.04 0.001 - 0.37	1.6 ± 1.3 0.3 - 4.4
Dimmock et al. (800-1000 mm per annum)	4	1700	0.13 ± 0.15 0.03 - 0.19	2.9 ± 1.7 1.1 - 4.5

Results obtained from the Tamam salinity/temperature meter indicated that there were no vertical salinity stratifications present in bore water columns after drilling, except for an upper 3-4 m of relatively non-saline water in each hole.

DISCUSSION

Salt storage values were lower than those obtained by Dimmock et al. (1974) for the intermediate rainfall zone (Table 2). The pattern of salt distribution observed in the Yarragil Catchment was variable but there was a general trend of increasing salt accumulation occurring concomitantly with an increase in distance from the western border of the Catchment (Fig. 1). Although there is a decline in rainfall (1000-800 mm per annum) along the west-east gradient (Public Works Department, unpublished data), this factor alone does not explain the variations in salt accumulation observed between and within the sites studied: soil texture, valley shape and position in the landscape also influence salt storage and distribution within the profile.

The largest accumulations of salt were found in the uplands areas. Of the total salts measured from all bores, ridge and plateau bores contained 44%, mid-slope bores contained 37% and valley floor bores contained 19%. The lower percentages of the mid-slope and valley floor bores were probably caused by the flushing of the groundwater table, which was relatively close to the soil surface in these topographic situations. Areas of salt accumulation were found in the mottled and pallid clay zone.

Profile characteristics

Soil profiles which were relatively free of salt (category A, Table 1) occurred in the wetter and more dissected western zone of the Catchment. The higher rainfall, steep slopes and coarser textured soils, singly or in combination, facilitate movement of water and salt through the soil profile in this zone of the Catchment. Some anomalies occurred in category A. Site 1 is located in the eastern zone but it is situated on a steep section of the micro-catchment which is more characteristic of the wetter western zone of the Catchment. The low salt content in profile 8.1, located in a generally high salt accumulation zone, was associated with highly permeable soils of clayey sand interspersed with layers of fractured quartz rock. At this site, salt accumulation increased as the distance from the valley floor became greater and was associated with increased clay content and a decrease in depth to bedrock (profiles 8.2 and 8.3) (Fig. 2).

In contrast, at site 4, which is located in a generally salt-free zone, profile 4.3, situated on the ridge, had a relatively high salt content. The difference in salt content between profiles 4.3 and 4.2 could not be explained by differences in soil texture. However, the valley in which this site was located was moderately dissected which probably results in more rapid water movement through soils located on the mid-slope and valley floor situation.

Profiles with a distinct salt bulge (category B, Table 1) (Fig. 2) were associated with a permanent groundwater table. The "bulge" or zone of concentration usually occurred below the permeable laterite horizon (3-5 m) and extended to the groundwater table. These profiles had large salt accumulations (Fig. 1, Table 1). The depth of maximum salt concentration varied with topographic position. Depths of maximum concentration ranged from 7-14.5 m on ridge sites, 6-12 m on mid-slope sites and 2-4.5 m on valley floor sites. Similar observations were reported by Dimmock et al. (1974). Low pH values were associated with zones of high salt concentration.

The profiles with a uniform distribution of salt had no permanent groundwater table (category C, Table 1) (Fig. 2). Except for bore 3.1 they occurred only on upper slopes and plateau areas and thus water flow would be almost entirely vertical. Sites with uniform salt distribution had a dense vegetative cover and deep soil profiles. This, together with the absence of lateral water movement, probably accounts for the absence of a permanent groundwater table.

Salt accumulation mechanisms

The three categories of salt accumulation which have been observed can be at least partially explained by the presence or absence of factors which affect water movement through the soil profile. In profiles where salt accumulation is low (category A) valley shape, soil texture and to a lesser degree rainfall facilitate water movement through the profile. In soils with significant salt accumulation (categories B and C) these factors effect a reduction in water throughflow.

In general, most valley sites were relatively non-saline due probably to the flushing effect of the groundwater table. Notable exceptions were bore holes 5.1 and 9.1 which had large salt accumulations above their groundwater tables. The clays at these depths were observed to be exceptionally dense and fine textured. The slight bulge at holes 1.1 and 2.5 can be explained similarly while the uniform distribution of salt below the groundwater table at hole 3.1 is probably caused by the dense impermeable clays.

Where salt accumulation occurred the pattern of distribution of salt within the profile was associated with the presence or absence of a groundwater table. It is possible that the presence of a permanent groundwater table is responsible for the formation of a distinct salt bulge. If it is assumed that salt accumulation results from the action of tree roots extracting fresh water and hence concentrating salt in the soil, a relatively stable groundwater table would tend to concentrate root proliferations in a relatively narrow zone through time. Kimber's (1974) preliminary studies of the root system of jarrah suggest that root proliferation does occur above the groundwater table. In contrast, where no permanent groundwater table is present, there would not be a distinct root zone formed and hence both roots and salt would be distributed more uniformly with depth. The occurrence of a more permanent groundwater table determines the lower limit of salt accumulation in these profiles (similar observations were made by Batini et al., 1976). This would probably be caused by lateral flushing as suggested by Dimmock et al. (1974).

It is not fully understood how tree roots can live and extract non-saline water from these highly saline soils (maximum observed soil water concentrations equalled 18000 $mg \cdot l^{-1}$ TSS). Low pH values, which were observed to be associated with zones of high salt accumulation, would add to the adversity of the root environment.

The presence of preferred soil water channels together with soil physical mechanisms which partition salt may explain the above phenomena. Such a mechanism has been outlined by Blackmore (1976). His results support the hypothesis that salt is constrained within large interior clay pores by a process of salt sieving in the narrower pores. However, a detailed discussion of the factors involved in the partitioning of salt from the soil-water-plant continuum is beyond the scope of this paper.

An attempt to correlate salt accumulation with ecological type as defined by Havel (1975) was undertaken (Table 1). This will be dealt with in a separate paper (Herbert, Ward and Havel, in preparation).

Catchment management

The Yarragil Catchment currently yields water of acceptable quality but has a relatively high weighted average salinity of 342 $mg \cdot l^{-1}$ TSS (Public Works Department, 1972). Peck and Hurle (1975) found that the saltflow/saltfall ratio was 1.3 which indicates that the Catchment is not in equilibrium. Although the Catchment vegetation has been disturbed, principally by jarrah dieback disease (Phytophthora cinnamomi), the disturbance is restricted to the valley systems. These have been replanted with dieback-resistant tree species. Most of the Catchment is forested with relatively dense mixed-age jarrah stands.

The data presented in this paper indicate that in a considerable proportion of the Catchment large quantities of salt are present in the soil profiles. Although some of this stored salt is currently being discharged, it is insignificant in relation to the total amount retained. The relation between quantities of salt discharged and degree of canopy disturbance is not known. However, it is evident that there are two hydrological systems operating in the Catchment:

(1) the valley and slope system which is currently the major source of water and salt;
(2) the closed system of the plateaus and valley divides which are contributing minimal amounts of water and salt.

Any disturbance of the forest in those micro-catchments which have large salt storages has the potential to cause large discharges of salt into streams. This applies to both of the above systems but because the uplands contain the largest amount of salt they have the potential to cause the most significant increases in stream salinity.

A reduction of canopy cover in micro-catchments where salt accumulation is minimal would result in an increase in water yield without a corresponding increase in stream salinity. To produce potable water from micro-catchments which contain salt in their uplands but have salt-free lower slopes and valleys a reduction in canopy could be tolerated only in the lowlands.

If the existing forest were destroyed as a consequence of changes in land use or disease, re-establishment of pre-disturbance water quality levels by replanting with P. cinnamomi resistant trees could be difficult: replanted dieback-resistant trees would have to penetrate dense, saline and acid clays and in this relatively high rainfall zone it would be necessary to rehabilitate with a dense forest cover.

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