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Hydrological Studies in Soil Salinity

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Contents

1. Summary

Hydro geological investigations into the cause of soil salinity in the Western Australian wheat belt included installation of wells and piezometers for groundwater observation and excavation of pits to examine soil profiles and structures.

Investigations involved examination of near-surface indurated layers to investigate their role in saltland formation. It was found that groundwater could move readily through this layer due to the presence of macro-pores.

Close examination of apparently impermeable pallid zone clays, shows that decayed tree roots and large diameter voids provide a continuous pathway for the vertical transport of saline water from deeper aquifers.

Hydraulic, chloride ion and pH gradients suggest that groundwater moves in a vertical upwards direction below salt-affected land.

On hillslopes the presence of impermeable barriers such as a rock dykes may force groundwater to the soil surface resulting in a saline seep.

Shallow seepage was found to not be a dominant cause of salt-affected soil. Deep groundwater, under pressure was invariably the mechanism operating at the many sites, which were investigated.

2. Introduction

Hydro geological investigations into the causes of salt affected land were conducted by officers of the Western Australian Department of Agriculture throughout the cereal growing districts ("wheatbelt") of Western Australia in the period 1978 to 1981 (see Figure 1). Most wheat is grown in the area between the 300mm and 500mm rainfall isohyets.

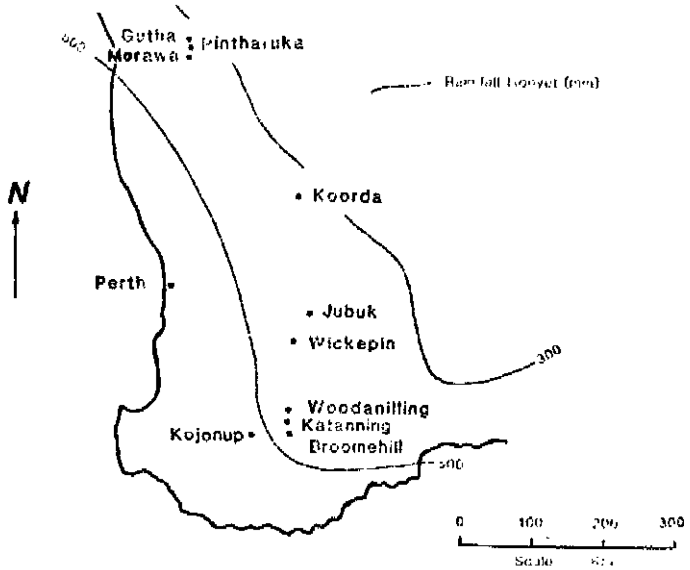

Figure1 - Sites of hydro geological investigations

In the wheatbelt, secondary soil salinity has been increasing since farmer surveys first began in 1955. According to farmers' estimates in 1979, there were 263,750 ha of land in Western Australia, which had previously been used for crops and pastures but was then affected by salinity. This represented 1.75% of all cleared land (Henschke 1980).

Madden (1974) carried out a study of soil salinity In the Morawa shire, and suggested that the Morawa region could be unique to the wheatbelt in having a rock-like hardpan material, which may have considerable influence on water movement and salt redistribution.

It was observed that the hardpan (also known as "coffee rock" or "cement") was relatively heterogeneous, containing quartz and ironstone gravel in a matrix of lime, silica, ferrous and aluminium oxides and clays. It was 0.15 to 1.20m below the ground surface in the valley floor and had a variable thickness.

Brewer et al. (1972) found that hardpan horizons in semi-arid Western Australia were formed in a colluvium derived largely by erosion of older lateritic profiles. The hardpans were formed by deposition of silica interspersed with periods of clay illuviation. Madden (1974) measured hardpan pore volumes of 1×10^{-4} m^3 kg^{-1} and although this was considered to be relatively high, it was found that 70 to 80 per cent of the pore volume was due to pores less than 10^{-4} mm in diameter.

Madden (1974) concluded that the hardpan was probably fairly impermeable to vertical movement of water, due to the difficulty of drilling through it. It was suggested that depressions in the hardpan may hold perched water for long periods, thus encouraging the accumulation of salts at the soil surface. Groundwater was probably confined by the hardpan and would not readily rise upwards through it, except where the hardpan was thinner or had cracks and root holes. It was recommended that more research should be done on the nature of the hardpan in this area and its influence on water movement.

During the middle to late 1970s, the theory that one of the main causes of saltland was the movement of water through shallow surface soils gained popular support by some members of the farming community. The theory was originally proposed by a Brookton farmer, Mr H.S. Whittington and promoted by the WISALTS* organisation ((Whittington, 1975, McMiles, 1981). They advocated interception of shallow throughflow by construction of large bulldozer banks, and claimed that in time, saline areas would improve to the extent that normal crops and pastures would again grow.

Many farmers tried the system and some thousands of kilometres of interceptor banks have been constructed in the wheatbelt.

It became apparent that there were differences between the Department of Agriculture and WISALTS supporters as to the nature and causes of saltland.

Both groups agreed that the removal of perennial deep-rooted native vegetation and its replacement by annual crops and pastures with shallow root systems, resulted in reduced plant water use. This increased the quantity of water, which, either percolates down through the soil and is added to the ground water, runs off and is discharged into streams, or produces waterlogging in low-lying areas.

The research work of the Department of Agriculture (Smith (1962) and CSIRO (Bettenay et. al 1964) has shown that the major cause of soil salinity problems which have developed following clearing in the agricultural areas, is the development of shallow saline watertables.

*Whittington Interceptor Salt Affected Land Treatment Society

Groundwater in the valleys exhibited upward vertical gradients and it was postulated that vertical leakage from the saline groundwater was the cause of salinity.

A controversy developed around the question as to whether a "rising watertable" could actually occur when the confining and indurated layer appeared to be impermeable. Drilling experiences often show that relatively dry layers of soil do exist between a shallow watertable and the deep aquifer in saline land.

The phenomena of groundwater travelling vertically through an apparently dry zone was raised by Holmes (1979). He questioned the widely held opinion that it is impossible for water to travel through relatively dry soil layers, and showed by calculation that, given a positive hydraulic head gradient and enough time, significant amounts of salt and water can be transported through apparently dry and slowly permeable strata.

In the period 1977 to 1979, the Department of Agriculture organised a series of field days at various locations throughout the wheatbelt in an attempt to demonstrate to farmers the hydro geological mechanisms involved in saltland formation. A total of 15 sites were examined in the period 1978 to 1981.

The objective of the investigations were:

1. Investigate the mechanisms, which cause secondary soil salinity.

2. Disseminate this information to the public via field days organised by district offices of the Department of Agriculture.

3. Monitor the effects of salinity control-treatments installed by farmers on their own properties.

The aim of this report is to document the information collected in this programme, as it relates to the nature and causes of the salinity problem at the sites studied, and the various corrective measures employed. Case studies are presented which cover a range of geographical locations in the wheatbelt.

3. Methods

The investigations at each site included some or all of the following:

1. Drilling holes with a powered rotary auger to various depths to describe soil and weathered material profiles.

2. Collection of soil samples from drilling for measurement of salt content, expressed as per cent chloride on a dry weight basis (% $C1^-$w/w). This was used to calculate salt storage in the profiles.

3. Installation and monitoring of piezometers and observation wells.

These were used to determine:

- watertable and potentiometric surface
- hydraulic gradients
- groundwater salinity, expressed as milligrams per litre of chloride (mg L^{-1} $C1^-$)
- groundwater pH
- seasonal and topographic variations of the above parameters.

4. Excavation of soil pits using a backhoe to study in-situ soil profiles and observe pathways of water movement through the soil.

At each site of drilling, a nest of piezometers and wells were installed. This included drilling holes to different depths (e.g. 1, 3 and 6 metres) and then placing a 40mm diameter PVC tube in the hole. For an observation well, the tube was fully slotted, to allow water to enter along the entire length. In the case of a piezometer, the PVC tube was slotted over the bottom one to two metres, and after placement in the hole, sand was tipped down around the outside of the tube to cover the slotted section, followed by bentonite clay to seal off vertical movement of water along the edge of the tubing. After installation, the bores were developed by manual bailing.

Static water levels in the tubes were measured with a sounding tape-measure and corrected to depth of water in metres above or below the ground surface.

Water samples were withdrawn with a hand bailer and placed in a plastic bottle. The first few bail-fulls of water were discarded to allow for stratification of water in the tube due to density differences. Samples were analysed in the laboratory for electrical conductivity (EC) and chloride ion ($C1^-$).

Pits were excavated with a backhoe, usually to depths ranging from one to three metres. The pit was then examined and the soil profile was described. Soil samples were sometimes taken from the pit-face for salinity and pH measurement. The movement of water into the pit was noted, and included the depths and horizons from which the water appeared to originate and the structures through which the water was moving.

The final rest level of water in the pit was noted, along with the approximate time for the water to reach this level after digging of the pit. A sample of inflow water was taken for salinity measurement.

4. Results

4.1 Role of a Shallow Indurated Layer in Saltland Development

Investigations were carried out on three catchments (Gutha, Pintharuka and Morawa) in the Morawa Shire. In the Pintharuka catchment the soils were neutral to alkali red earths (Gn2.1), (Northcote et al, 1967), with an indurated layer, or "hardpan", at depths of 0.5 to 1.5 metres below the ground surface. This horizon was up to 1.5m thick, and was a reddish-brown coarse sandy rock with gravel lenses cemented in the matrix. It had a vesicular structure, and some denser indurated layers. The hardpan was generally laminar and surfaces were often stained black with manganese. Channels of decayed roots were observed to penetrate this material vertically and horizontally (See appendix II for detailed description).

Drilling and pit excavation showed red-brown sandy loams overlying the hardpan. The hardpan was underlain by weathered parent material and bedrock, consisting of granite intersected by dolerite dykes. Bedrock was generally within 10m of the ground surface.

Figure 2 is a plan of the Pintharuka catchment. Outcrops of granite rock and lateritlc breakaways occur at the western end of the catchment. These would most likely be the recharge areas for groundwater (Bettenay et al, 1964). The salt-affected land of approximately four hectares is high in the catchment near the headwaters of the drainage line. Aerial photograph inspection and ground examination showed three dolerite dykes, in close proximity to the saltland.

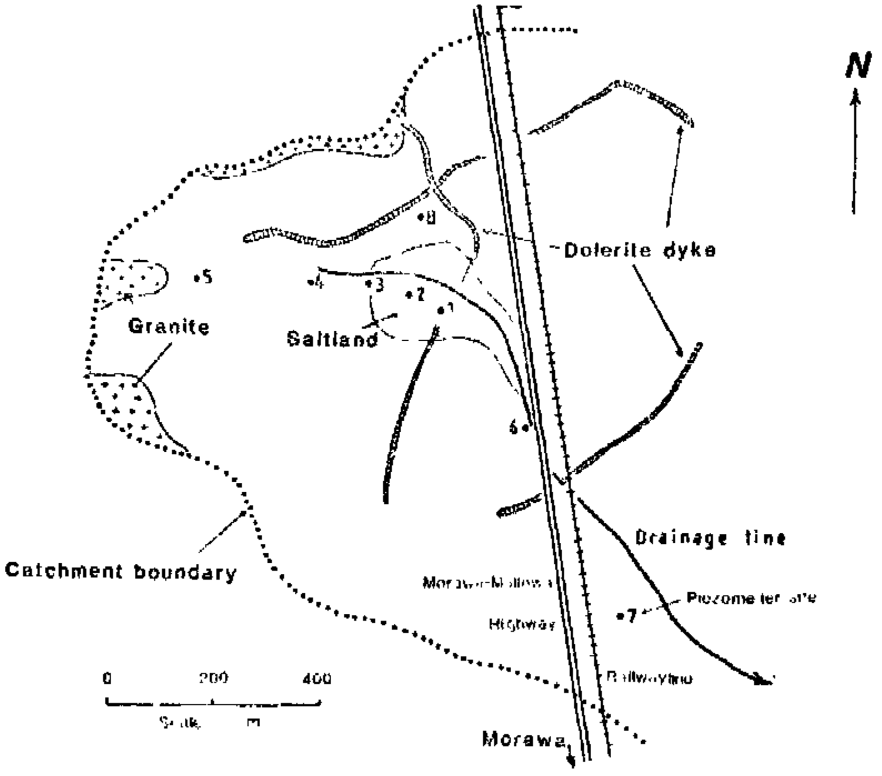

Figure 2: Plan of the Pintharuka catchment

Soil samples were taken during drilling and pit excavation at the Pintharuka and Gutha catchments. Results of analyses are summarised in Appendices I and III.

Piezometers were installed at each site. One piezometer rested on top of the hardpan, another was inserted below the hardpan into the upper parts of the weathered zone, and a third piezometer was inserted to bedrock. Water level measurements and sampling were carried out at infrequent intervals. Observations for a piezometer nest at Site 2 in the Pintharuka catchment, representative of the salt-affected area, are presented in Table 1.

Table 1 - Water Level Fluctuations For Piezometers At Site 2, Pintharuka

-	-		Depth to water level below ground level (m)					
Bore No.	**Bore Depth m**	**Screen Length m**	**15.8.78**	**28.11.78**	**14.3.79**	**23.4.80**	**20.8.80**	**21.9.81**
2A	0.9	0.9	0.66	T	D	D	0.81	0.77
2B	4.6	1.0	0.62	0.96	1.00	1.41	0.79	0.76
2C	9.8	2.0	0.46	0.54	0.35	0.70	0.73	0.36

T = trace of water In well D = dry well

Water levels in both shallow and deep piezometers fluctuate with time, reflecting changes in the amount of water stored in the aquifers or pressure changes. A vertical hydraulic gradient of -0.14 (The negative sign indicates an upwards direction) between piezometers 2B and 2C on 14/3/79 shows the potential for upwards flow. The horizontal gradient of the potentiometric surface between sites 1 and 3 is 0,004.

Ten pits were excavated with a backhoe from 0.8 to 3.3 metres deep in the Pintharuka and Gutha areas. In one pit at Gutha, Nulsen (1978) reported a 2mm diameter channel 1.6m below the ground surface, which was flowing at 9L hr^{-1} with a salt content of 19,500 mg L^{-1} C1^{-}. At Pintharuka, water movement was studied on a pit face immediately after excavation. Initially, water flowed down the face of the pit from sand above the hardpan. The salinity of this water was not measured, but was estimated by taste to be around 1,000 mg L^{-1} C1^{-}. This flow ceased after 15 minutes but flow continued from macro-pores and root channels lower down, and on the floor of the pit until it filled the pit to within 0.5m of the surface in less than two days. The salinity of this water was 10,920 mg L^{-1} C1^{-}. These data suggest that the horizontal gradient for groundwater flow is less than the vertical gradient and the main input of salt is from the deeper layers.

Figure 3 is a cross-section through the saltland at Pintharuka, showing that the watertable is very close to the ground-surface beneath the salt-affected area. A reason for saltland development in this particular position in the landscape may be due in part to Dolerite dykes acting as barriers to groundwater flow. Bettenay 1978 observed saline seep development adjacent to a dolerite dyke at Yalanbee near Bakers Hill. The potentiometric head was above ground level at the seep, but a piezometer to 5m depth was dry 20m downslope of the dyke at Yalanbee. Another cause may be the low surface gradients, which means that surface water was draining downwards and recharging the aquifers, eventually causing groundwater to come close to the ground surface.

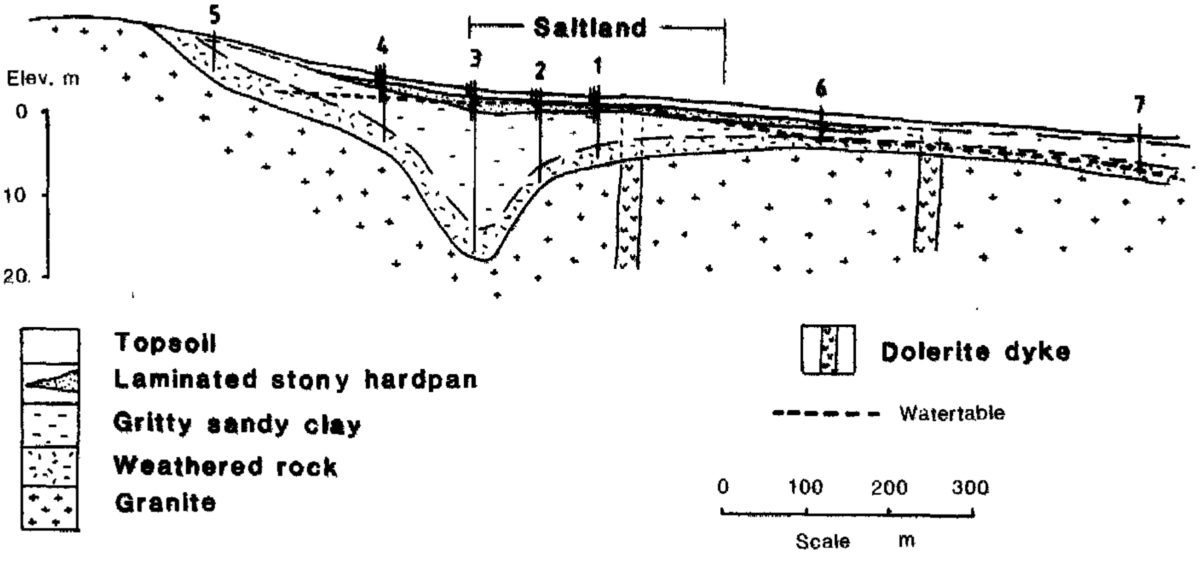

Figure 3: Cross-section through saltland at Pintharuka

4.2 *Examination of Routes of Water Movement in Subsoils*

On a broad saline valley at Jubuk, west of Corrigin, a bulldozer was used to strip back layers of earth to expose surfaces at 0.3, 0.6 and 1,0 metres below the ground surface. Table 2 outlines the soil profile.

Table 2 - Description Of Profile At Jubuk

Depth (m)	pH	% C1^{-}	Description
0.0 - 0.1	8.7	0.67	Dark brown to yellowish-grey sand
0.1-0.2	-	0.24	Bleached coarse sand
0.2 - 1.0	6.7	0.18	Mottled yellow-grey sandy clay with sub-angular blocky structure. Numerous decayed root channels varying from less than 1mm to 5min in diameter.
1.0 - 1.6	-	0.24	Mottled grey gritty sandy clay, slightly cemented with silica. Free water apparent in sandy lenses.
1.6 - 2.0	5.4	0.18	Mottled grey gritty clay, grading to red gritty sand, hard ferruginous cemented layer.

The soil was a solodized solonetz which Northcote et al (1967) describes as hard alkaline yellow soils (Dy2.4) and underlain by acid lateritic clays. Channels containing decayed tree roots were saturated while the surrounding clay matrix was only slightly moist.

Detailed examination of the clay surface when exposed at 1.0m showed that water was bubbling out of very small voids and root channel holes. Perspex tubes were sealed over the voids and water subsequently rose up inside the tubing until they either overflowed or leaked around the base.

The cylinders were graduated so that volume of water per unit time could be measured and discharge calculated. Results are given in table 3.

Table 3 - Measurement Of Water Flow In Four Individual Soil Macro-Pores

Calculated Pore Discharge (m^3 year^{-1})	C1^{-} (mg L^{-1})	Calculated Salt Load (kg C1^{-} year^{-1})
2.1	22,400	45
0.9	22,100	20
1.4	22,300	30
5.2	20,800	110

A grid was laid out on the clay surface and individual voids leaking water were mapped. Up to 70 per square metre were found showing that while the clay matrix overall is impermeable, the macro-pores have the capacity to transport significant amounts of water and salt.

Nulsen (1980) calculated that a 2mm diameter pore can transport the same quantity of water as 1.3m^2 of clay matrix, while a 4mm diameter channel is equivalent to 20.9m^2 of clay.

Twenty four hours after excavation, the soil surfaces exposed at 0.3m and 0.6m levels had glistening patches of white salt deposited, while the 1.0m level was covered with very saline water of 22,000mg L^{-1} $C1^{-}$. This indicates upward capillary rise of salt from a shallow saline watertable.

4.3 Examination of broad saline valleys at Wickepin and Woodanilling

On a catchment north-east of Wickepin a transect was drilled across a broad saline valley. The soils are hard alkaline red soils (Dr2) with acid lateritic strata common below 1.2 to 1.5 metres. Table 5 shows groundwater data at three sites, with site 1 being located on severely saline ground. Site 2 is located on moderately saline ground, 40m downslope of an interceptor bank constructed in the previous year according to the recommendations of Whittington (1975). Site 3 is at the margin of the saltland, 20m above the interceptor bank. Another site (site 4) was located further upslope. Lateritic strata was encountered during drilling at Sites 2, 3 and 4. The hardness and dryness of this material made drilling difficult, particularly at Site 2.

Table 4 - Piezometric Data At Wickepin (March 1979)

Bore No.	Bore Depth (m)	Screen Length (m)	Depth to water (m)	$C1^{-}$ (mg L^{-1})	pH
1A	0.7	0.7	0.57	22,900	7.8
IB	1.4	0.6	0.56	19,000	5.5
1C	2.8	1.0	0.49	18,800	3.9
ID	7.4	1.5	0.48	18,400	3.9
IE	16.9	2.0	0.42	18,600	4.2
2A	1.3	1.3	0.82	-	-
2B	6.7	6.7	0.68	18,400	4.4
3A	0.9	0.9	Dry	-	-
3C	9.8	1.5	0.72	18,900	4.5
4C	4.3	1.5	Dry	-	-

The data for the nest of piezometers at site 1 shows a vertical hydraulic gradient of -0.006 between piezometers A and E. This indicates a potential for groundwater to flow towards the soil surface. There is a groundwater salinity gradient throughout the soil profile as shown by the increasing salt concentration towards the ground-surface. The processes by which salt can be concentrated in the upper part of the saturated zone include concentration by evapotranspiration, and dissolution of salt by rising groundwater.

At Site 2, although very dry lateritic material was encountered during drilling, the wells eventually gained water after a few weeks. This suggests the presence of small channels conducting water through an otherwise relatively impermeable matrix.

Pits were excavated at Sites 1 and 2 to almost three metres deep. Cemented ferruginous boulders set in a gritty kaolinitic matrix were encountered, along with lateritised conglomerates, suggesting alluvial and colluvial deposits. Although this rock-like material presented difficult conditions for back-hoe operation, inflow of water through macro-pores on the floor and sides of the pit was clearly seen indicating once again the ability of macro-pores to transport significant amounts of water.

Because of the low acidity and high salinity of the water flowing into the pit, it was concluded that its origin was deep in the landscape, the water being subsequently forced to the surface through macro-pores in the confining clays in the valley.

The data in table 4 also shows that water occurs in the shallow wells at Sites 1 and 2 downslope of the interceptor bank. The watertable at well 1A is 0.57m below ground-level and has a salinity of 22,900mg L-1 C1-. The interceptor banks have been ineffective at this site in preventing the development of a shallow watertable.

A broad, saline flat with seepage spots occurs in the upper reaches of a stream known as Salt Creek in a catchment 6 km east of Woodanilling. Piezometers were installed and pits excavated in the saltland (Site 1), the margin of the saltland, (Site 2) and on the upper slope (Site 3). Table 5 summarises the data.

Table 5 - Piezometric Data At Woodanilling (February 1979)

Bore No.	Depth of Hole BGL* (m)	Screen Length (m)	Static level of Water in pipe BGL (m)	$C1^-$ (mg L^{-1})
1A	1.5	1.5	0.18	5,000
IB	4.3	1.0	0.36 above GL	4,300
1C	18.6	1.8	0.46	4,400
2A	1.3	1.3	0.78	14,700
2B	5.4	1.0	0.80	4,700
2C	11.3	1.8	0.80	1,100
3A	0.6	0.6	dry	-
3C	12.5	1.5	5.54	2,200

* BGL = Below Ground Level

These data, along with evidence from the pits, showed that a deep watertable on the slopes (5m at Site 3) comes close to the soil surface in the valley (0.2m at Site 1). The hydraulic gradient between piezometers A and B at Site 1 is -0.17.

Seepage spots in the saltland were excavated with a spade and these rapidly filled with water to the surface suggesting that these spots were underlain by paths of less resistance for upwards water flow from the aquifer. Seepage "eyes" which overflow would have even less resistance. Channels of decayed roots of large trees are likely pathways for flow of water to the surface seepage "eyes".

Soil chloride storages were and a storage of 6 x 1(P kg (assuming a bulk density of upwards flushes this stored concentrated by evaporation, preferred pathways, some of calculated from samples taken during drilling ha-1 to a depth of 18m was calculated 1,600 kg m~3) at Site 1. Water travelling salt to the ground surface and is then Assuming the majority of flow is through the salt would be remobilised rapidly, whilst other stored salt would move by the much slower process of diffusion.

4.4 Role of a Rock Dyke in Saltland Formation

On a catchment north-east of Woodanilling a transect was drilled (see Figure 4) across a mid-slope saline area. The soils are sandy yellow mottled soils (Dy5.4), (Northcote et al., 1967). An outcrop of gabbro occurs 50m downslope of the saltland. The section shows a large thickness (20m or more) of pallid-zone clay exists upslope, with a rock bar occurring immediately downslope of the saltland. The soil is severely saline upslope of the rock bar with bare ground encrusted with salt. Downslope of the bar the soil is less saline and is covered with sea barley grass (Hordeum marinum).

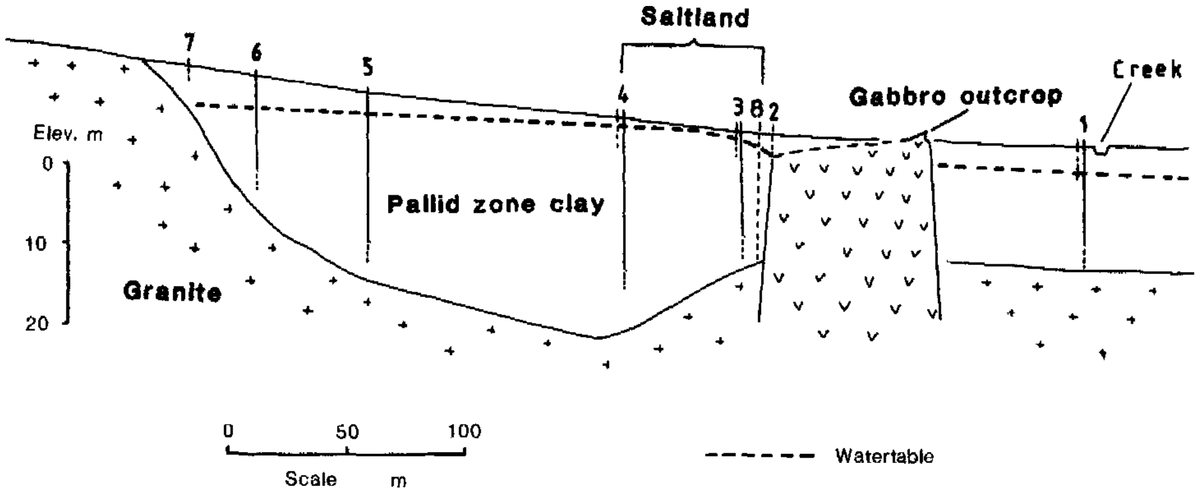

Figure 4: Cross-section through a rock dyke at Woodanilling

Large storages of salt existed in the pallid-zone clays and are shown in table 6 for the depths drilled.

Table 6 - Salt Storages In The Woodanilling Catchment

Site	Sampling depth (m)	Salt Storage (t ha^{-1} C1^{-})
1	15	380
2	3	40
3	15	260
4	21	540
5	21	270

There is probably more than 600 tonnes ha^{-1} C1^{-} stored from the surface to bedrock (assumed to be 25 to 30m deep) in this catchment.

Pits were excavated near Sites 1, 3 and 4 and within the gabbro outcrop. After 24 hours the pit at Site 4 filled with water to within 0.7m of the surface. However, the pit on the gabbro outcrop was excavated to a depth of 3m and had only a small amount of water at the bottom after two weeks. The pit at Site 1 had a waterlevel 2.7m below the ground surface.

Figure 4 also shows the position of the watertable as derived from both well and pit data. There is a sharp drop of 2m between sites 2 and 3, just upslope of the rock outcrop. The steeper horizontal gradients of the watertable and potentiometric surface immediately upslope of the rock outcrop may be due to either a decrease in hydraulic conductivity of the subsoil or a drainage effect due to the rock itself.

4.5 Saline seeps in higher rainfall districts

On a catchment at Punchmirup, west of Katanning, saline seeps spreading from mound springs or seepage "eyes" are found in the mid to lower slopes, with salinity generally absent in the main drainage channel downslope. Outcropping rock bars occur downslope of the seeps. Drilling transects also confirmed the presence of relatively shallow bedrock. The groundwater at depth is under considerable pressure upslope of the rock bars with potentiometric heads 1 metre or more above ground level. Downslope of the seep area the potentiometric head was about 1 metre below the ground surface.

On a catchment west of Broomehill, numerous outcrops of granite and basic rock occur on the valley sides. Saltland is confined to the valley bottoms and some isolated hillside seeps. Extensive areas (c. 100ha) of trees have been planted by the farmer during the past 10 years in and on the margins of the saline seeps. These include various species of Casuarina, Tamarisk and Eucalyptus.

A saline seep high in the valley with shallow bedrock immediately downslope, was chosen for study. An excavated pit on the upper boundary of the saline seep showed the water table was 1.8m below the ground surface. Drilling delineated an aquifer of decomposed rock at 3 to 5 metres depth (see Figure 5). The potentiometric head of water in this aquifer was 0.9m below the ground surface. The vertical hydraulic gradient was -0.23. It is possible that small increases of potentiometric head could force more water upward through the confining clay to cause a spread of the seep. However, the trees which are planted at spacings about three metres apart may help to keep the watertable at a static level, hence prevent further encroachment of salt.

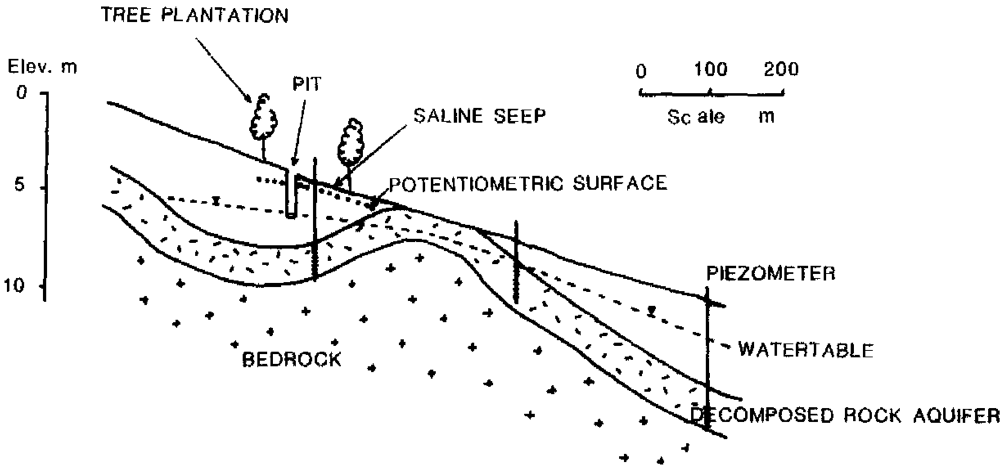

Figure 5: Cross-section of saline seep at Broome hill

A saline seep occurring on a 5 per cent grade hillslope was investigated on a catchment south-west of Kojonup. Drilling and a seismic survey conducted by the Geological Survey of Western Australia (Rowston, 1981) did not detect the presence of any rock bars or dykes, which might be forcing groundwater to the soil surface. A vertical hydraulic gradient of -0.03 occurred at the top of the seep where the potentiometric head was 0.5m above ground level. At the lower end of the seep, near the valley floor the potentiometric head was 1.9m above ground level. In March the phreatic surface was close to the soil surface and seepage "eyes" were discharging water, which was running down the slopes to the valley floor.

5. Conclusions

At many of the sites where hydrological investigations were carried out drilling showed a typical lateritic weathering profile up to 30 m deep. The bedrock surface was found to be quite undulating, and occasionally outcropping on the ground surface. The quartz-rich kaolinitic pallid-zone almost always contained an aquifer in its lower levels and in the valley floors was often found to be completely saturated throughout its entire profile.

At many sites in the wheatbelt, particularly in the drier northern areas, a hardpan was found at depths of 0.5 to 1.5 m. The hardpan varied from a fine-textured siliceous material to a cemented, conglomerate rock. It was often difficult to penetrate with either a power-drill or a back-hoe. However, in all cases, direct observation showed the existence of continuous macro-pores which in total had the capacity to transport large quantities of water vertically up or down through the hardpan at a rate dependant on the hydraulic gradient, and assuming a constant hydraulic conductivity.

Bedrock topography appears to play a dominant role in the formation of hillslope saltland, including seepage "eyes". Saline seeps often occurred upslope of an outcrop of impermeable strata. High potentiometric heads upslope of the impermeable strata usually dissipated at, or below the outcrop. These situations were found to be common in the more dissected country where rainfall exceeds 450mm.

In some broad saline valleys of the wheatbelt, highly acidic waters and soils (pHs ranging between 3 and 5) were encountered at depths below I.5m. A calcareous horizon with soil and water pHs of around 9 were occasionally found above this. The acidity of the groundwater is a useful tracer for identifying the origin of groundwaters seeping into pits, namely that the water comes from the deeper acid layers as opposed to the more alkaline near-surface horizons.

Many pits excavated on salt-affected land showed that although some water flow originated from the near-surface sandy horizon, this flow soon ceased to be obvious. However, channels containing decayed tree roots, planar voids and other macro-pores appearing at the walls and floor of the pits continued to flow until the pit filled to the phreatic surface.

Although most water reaching the lower lands is from surface run-off, its main affect is to increase waterlogging and consequently increase the area and duration of saturated conditions. The main source of salts is from deep subsoils and groundwaters, which transport this, salt to the surface. Surface drainage alone cannot significantly reduce shallow watertables and soil salinity, although they will remove some surplus water from rainfall and shallow seepage. On all saline flats and seeps investigated a deep saline semi-confined aquifer was present and hydraulic gradients indicated upwards movement of water from this aquifer, to cause salinity at the soil surface.

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8. List Of Terms

5. AQUIFER - A layer or zone below the soil surface, which transmits water more easily than surrounding layers.

6. SEMI-CONFINED AQUIFER - An aquifer bounded above and below by less permeable layers which transmit water very slowly. May also be known as an artesian aquifer if the water is under considerable pressure.

7. PALLID ZONE - A white or pale coloured kaolinitic clay subsoil, which often has a thickness of more than 10m.

8. GROUNDWATER - Water occurring in the soil or subsoil beneath the watertable.

9. WATERTABLE (also known as the PHREATIC SURFACE) - The upper free surface of water in the soil, where the pressure in the groundwater is the same as that of the atmosphere. It is measured by the elevation of water in wells, which penetrate only a short distance into the saturated zone.

10. PERCHED WATERTABLE - A local watertable, usually seasonal and separated from the groundwater body by an unsaturated and slowly permeable subsoil.

11. OBSERVATION WELL - A length of slotted tubing, which is lowered into a borehole and backfilled with sand around the outside of the tube. Water can freely enter the tube along its entire length, thus giving the position of the watertable in the soil.

12. PIEZOMETER - A tube inserted and sealed into the soil, with the bottom metre or so, slotted to allow entry of water. Water cannot travel along the outside of the tube and so the pressure of the water in the soil at the bottom of the tube may cause water to rise in the tube.

13. POTENTIOMETRIC HEAD (HYDRAULIC HEAD) - The elevation of the water level in a piezometer with respect to a reference level. The potentiometric surface is the imaginary surface through all the points to which the water rises in piezometers penetrating the aquifer.

14. HYDRAULIC GRADIENT - The change in hydraulic head per unit distance in the direction of subsurface flow.

15. HYDRAULIC CONDUCTIVITY (PERMEABILITY) - Expresses the ability of a soil to transmit water under a unit hydraulic gradient.

16. SECONDARY SALINITY - Areas where soluble salts, mainly sodium chlorides, have accumulated in the surface soil because of agricultural practices and/or the clearing of native vegetation. Primary salinity refers to areas, which were saline before agricultural development.

17. SALINE SEEP - Intermittent or continuous saline water discharge at or near the soil surface, which reduces or eliminates crop and pasture growth in the affected area because of increased soluble salt concentration in the root zone. It is

differentiated from other saline soil conditions by its recent and local origin, saturated root zone profile and shallow watertable.

18. THROUGHFLOW (SHALLOW SEEPAGE) - Water that has infiltrated the soil may encounter at shallow depth a layer of lower permeability and move laterally along it until it moves out to the surface again at a lower point.

9. Appendix I

9.1 Pit Studies In Saltland

On March 8, 1978, by arrangement with Mr Malcolm Henning of Koorda, several pits were dug with a backhoe on his property to investigate the salt problems. The exercise was part of the preparation for a salt seminar held at the request of 'Farmanco' of Dowerin. The pits were sampled and described at the time of digging and water levels were checked on March 20. During the seminar the pits nearest the house were visited. Details of all pits are as follows:

Pit K1 - Bare saline area in valley floor NW of homestead

Depth (m)	pH	% $C1^-$	Description
0 - 0.10	6.9	0.91	Dark brown sandy loam
0.10 - 0.25	7.8	0.33	Reddish-brown sandy clay loam
0.25 - 0.70	8.6	0.17	Yellowish-grey and light orange mottled sandy clay; somewhat cemented from 0.60 -0.70m
0.7 - 1.20	8.7	0.16	As 0.25m but no cementation (Water apparent at about 1.12m)
1.20	8.5	0.21	Grey sandy clay with mottles of orange and red cemented material

Pit K2 - Saline area in valley floor with some grass cover

Depth (m)	pH	% $C1^-$	Description
0 - 0.05	6.4	0.25	Grey sand
0.05 - 0.30	7.7	0.13	Yellowish-brown loamy sand
0.30 - 0.90	8.0	0.13	Yellowish-light brown and yellowish-grey mottled sandy clay with some cementation
0.90 - 1.58	8.5	0.08	Orange and light grey mottled sandy clay with less cementation (Water seeping in via root channels and possible termite galleries at 1.58m)
1.58 - 2.40	8.6	0.07	Grey sandy clay with red and orange mottles
-	(7.6)	-	(Water seeping in pit floor via root channels)

Pit K3 - Non-saline rise, south of pits 1 and 2

Depth (m)	pH	% $C1^-$	Description
0 - 0.10	6.2	0.06	Dark grey-brown loamy sand
0.10 - 0.25	7.5	0.06	Reddish-brown sandy loam
0.25 - 0.50	8.6	0.13	Yellowish-grey sandy clay
0.50 - 0.95	9.3	0.11	Yellowish-grey sandy clay with orange mottles and nodular lime
0.95 - 1.33	6.7	0.10	Yellowish-grey and dull orange mottled sandy clay
1.33 - 2.10	5.2	0.10	Mottles redder and soil harder with depth
-	(3.9)	-	(Water bubbling in root hole with bark at 1.65m and in root holes in bottom of pit)

Pit K4 - Non-saline paddock

Depth (m)	pH	% $C1^-$	Description
0.0 - 0.1	6.7	< 0.01	Grey loamy sand
0.1 - 0.25	6.7	< 0.01	Reddish-brown sandy loam
0.25 - 0.5	8.6	0.02	Yellowish-grey sandy clay
0.5 - 1.25	9.4	0.07	Calcareous nodules in sandy clay
1.25 - 2.2	5.4	0.12	Red and grey mottled sandy clay
2.2 - 3.0	-	-	Grey mottled sandy-clay, increasing moisture

Pit K5 Non-saline area in patchy saline paddock

Depth (m)	pH	% $C1^-$	Description
0 - 0.10	6.6	0.04	Grey loamy sand to sandy loam
0.10 - 0.25	7.4	0.02	Yellowish-brown sandy loam
0.25 - 0.50	8.1	0.08	Yellowish-grey sandy clay
0.50 - 1.18	9.1	0.07	Yellowish-grey sandy clay with lime including nodules
1.18 - 1.48	7.4	0.10	As above
1.48 - 2.25	4.9	0.13	Red and grey mottled sandy clay cemented and with root channels evident to bottom of hole
-	(3.5)	-	(Damp spots evident in pit up to 1.73m. 0.60m auger hole sunk in pit bottom made water)

Pit K6 - Bare saline area in patchy saline paddock

Depth (m)	pH	% $C1^-$	Description
0 - 0.10	7.2	0.91	Brown sandy loam
0.10 - 0.30	8.1	0.29	Reddish-brown sandy clay loam
0.30 - 0.45	8.4	0.38	Yellowish- brown sandy clay
0.45 - 1.23	8.6	0.31	Yellowish-brown sandy clay with lime nodules
1.23 +	5. 1	0.28	Red and grey mottled sandy clay with red mottles increasing with depth
-	(3,8)	-	(Made water quickly through obvious root channels at 1.80m. Root activity evident at all depths)

9.2 Comments

All of the pits were excavated to red and grey mottled clay, and with the exception of the first two pits, the mottled material was penetrated sufficiently for its acidic nature to be evident in the pH analyses. The groundwater flowing into pits 3-6 were highly acidic (average pH = 3.8) indicating an origin deep in the landscape, rather than through the alkaline subsoils above.

Obvious root channels, some with root remains, were observed to be carrying water in most pits. In the saline areas (pits 1, 2 and 6) groundwater in the pits rose to within 1.5m of the ground surface after 12 days.

The following 6 pits were excavated in the Morawa area in July 1978

Pit M1 - B. North, Pintharuka, Bare saltland

Depth (m)	pH	% $C1^-$	Description
0 - 0.15	7.5	0.21	Dark red-brown sandy loam
0.15 - 0.40	7.5	0.21	Red-brown sandy clay loam
0.40 - 0.50	7.6	0.18	Grey-brown sandy clay loam
0.50 - 1.00	-	-	Red-brown sandy clay loam, cementation increasing to 1,0m. Large pores flowing water at 0.5 to 1.0m. Diameter of pores about 0.05m.

Pit M2 - B. North, Pintharuka. Edge of bare Saltland

Depth (m)	pH	% C1^{-}	Description
0 - 0.15	6.6	0.01	Orange gritty sandy loam
0.15 - 0.30	-	-	Red-brown gritty sandy loam
0.30 - 0.50	7.3	0.01	Reddish yellow brown gritty sandy clay loam
0.5 - 0.95	7.2	0.02	Grey-brown sandy clay loam. Patchy iron cemented area with manganese. Cementation intense at 0.50m.
0.95 - 1.30	8.8	0.02	Variably cemented horizon.
1.30 - 1.50	8.2	0.03	Patchy cemented sandy clay with manganese deposits. Tendency to be layered.
1.50 - 2.50	7.8	0.02	Grey-orange gritty cemented clay. Root holes are saturated.
2.50 +	6.3	0.10	Red-grey-orange mottled gritty clay.

Pit M5 - J. Stephens, Gutha. Non-saline site

Depth (m)	pH	% C1^{-}	Description
0 - 0.10	8.0	-	Orange-brown sandy loam
0.10 - 0.80	5.4	-	Red-brown friable sandy clay loam
0.80 - 1.00	6.1	-	Sandy clay loam with ironstone gravel increasing with depth to 1.0m
1.00 - 1.10	6.4	-	Strong cementation at 1.10m, manganese staining.

Pit M6 - J. Stephens, Gutha. Saline site supporting bluebush

Depth (m)	pH	% C1^{-}	Description
0 - 0.60	7.4	0.22	Dark red-brown sandy loam
0.60 - 1.10	8.0	0.29	Red-brown cemented horizon. Cementation increases with depth and impenetrable at 1.10m. Extensively fractured, with water flowing into pit through fractures.

Pit M7 - J. Stephens, Gutha. Bare saline site.

Depth (m)	pH	% C1$^-$	Description
0 - 0.02	-	-	Red brown sandy loam
0.08 - 1.00	-	-	Blue-grey friable clay with orange and yellow mottles. Cemented and layered. Substantial root holes.
1.65	-	-	Water spurring from sides of pit at nearly 9 litres per hour. If this continued for one year, the channel would produce 79m3 of water.

Pit M8 - K. & M. Tubby, Gutha. Saline site

Depth (m)	pH	% C1$^-$	Description
0 - 0.15	7.5	0.05	Dark red brown loamy sand
0.15 - 0.25	7.3	0.20	Light brown sandy clay loam
0.25 - 0.70	8.8	0.24	Light brown sandy clay with large lime nodules at 0.25m. Cementation and manganese at 0.70m.
0.70 - 1.30	-	-	Cemented horizon.
1.30 - 2.00	7.9	0.36	Light grey friable clay with some manganese concretions

10. Appendix II

Description Of Cemented Alluvial/Colluvial Material From Pits At Morawa

Colour:	Red Brown	
Mineralogy:	Quartz	70%*
	Feldspar	20%
	Ironstone	5%
	Manganese	3%
	Limestone	' 2%
Texture:	Gravel	35%
	Sand	50%
	Silt	15%
	Clay	
Textural maturity:	Quartz	Angular to sub-angular, <0.02mm - 7mm
	Feldspar	Angular to sub-angular, <0.02mm - 9mm
	Ironstone	Sub-angular to rounded, 1mm - 12mm
Structures:	Porous, vesicular	
	Wavy layerings of clay around pebbles	
	Manganese laminations	
	Lime concretions Kaolinite lenses	

* Visual observation only

11. Appendix III

Summary Of Soil And Water Salinity Data From Excavated Pits And Piezometers

			Soil		**Water**	
Site	**Depth (m)**	**pH**	**% C1-**	**Total chloride storage in soil (t ha^{-1})**	**Depth to watertable (m)**	**Salinity of watertable (mg L^{-1} C1^{-})**
Gut ha						
1	0	6.5	0.08	-	-	-
-	1	5.7	0.18	-	-	-
-	2	8.8	0.19	70	1.1	15,400
3	0	6.8	0.15	-	-	-
-	1	8.5	0.16	-	-	-
-	2	8.5	0.18	-	-	-
-	3	8.8	0.12	90	1.5	21,000
Pintharuka						
1	0	8.1	0.11	-		-
-	1	8.3	0.15	-	-	-
-	2	8.3	0.08			
	3	8.3	0.05			
	4	8.6	0.07			
	5	7.9	0.10			
	6	8.4	0.07			
	7	7.8	0.05	100	1.0	8,000
2	0	8.5	0.04			
	1	8.0	0.11			
	2	8.9	0.12			
	3	9.0	0.08			
	4	9.4	0.10			
	5	9.2	0.07			
	6	9.1	0.13			
	7	8.8	0.13	110	1.3	5,800

			Soil		Water	
Site	**Depth (m)**	**pH**	**% C1-**	**Total chloride storage in soil (t ha^{-1})**	**Depth to watertable (m)**	**Salinity of watertable (mg L^{-1} C1^{-})**
3	0	6.9	0.02			
	1	7.7	0.04			
	2	8.7	0.07			
	3	6.8	0.05			
	4	5.8	0.08			
	5	5.6	0.15	60	1.7	6,300
4	0	7.2	0.02			
	1	8.1	0.05			
	2	8.7	0.07			
	3	9.5	0.06			
	4	9.3	0.07			
	5	9.5	0.06			
	6	9.2	0.12			
	7	9.4	0.10			
	8	8.2	0.22			
	9	8.9	0.21	150	2.6	3,300
Pintharuka						
M3 (pit)	0	-	0.13			
	0.3	-	0.14			
	0.7	-	0.12			
	1.1	-	0.08			
M4 (pit)	0	-	0.05			
	0.3	-	0.02			
	0.6	-	0.02			
	0.8	-	-			
	1.2	-	0.05			
	2.0	-	0.05		1.6	5,100

			Soil		**Water**	
Site	**Depth (m)**	**pH**	**% C1-**	**Total chloride storage in soil (t ha^{-1})**	**Depth to watertable (m)**	**Salinity of watertable (mg L^{-1} C1^{-})**
Koorda						
K1 (pit)	0	6.9	0.91			
	0.2	7.8	0.33			
	0.5	8.5	0.17			
	1.0	8.7	0.16			
	1.4	8.5	0.21		1.2	13,100
K2 (pit)	0	6.4	0.25			
	0.2	7.7	0.13			
	0.6	8.0	0,13			
	1.2	8.5	0.08			
	2.0	8.6	0.07		1.5	6,900
K3 (pit)	0	6.2	0.06			
	0.2	7.5	0.06			
	0.4	8.6	0.13			
	0.7	9.3	0.11			
	1.1	6.7	0.10			
	1.7	5.2	0.10	2.1		15,200
K4 (pit)	0	6.7	<0.01			
	0.2	6.7	<0.01			
	0.4	8.6	0.02			
	0.9	9.4	0.07			
	1.7	5,4	0.12	2.7		12,500
K5 (pit)	0	6.6	0.04			
	0.2	7.4	0.02			
	0.4	8.1	0.08			
	0.8	9.1	0.07			
	1.3	7.4	0.10			
	1.9	4.9	0.13	2.0		17,700

			Soil		Water	
Site	**Depth (m)**	**pH**	**% C1-**	**Total chloride storage in soil (t ha^{-1})**	**Depth to watertable (m)**	**Salinity of watertable (mg L^{-1} C1^{-})**
P6	0	7.2	0.91			
	0.2	8.1	0.29			
	0.4	8.4	0.38			
	0.9	8.6	0.31			
	1.5	5.1	0.28	1.6		21,300
Jubuk						
1	0	8.4	0.64			
	0.1	9.1	0.21			
	0.3	7.8	0.40			
	0.7	5.6	0.12			
	1.2	5.0	0.21			
	1.5	6.2	0.27			
	1.8	5.1	0.16	70	0.4	17,700
2	0	7.1	0.10			
	0.2	7.4	0.08			
	0.3	7.9	0.24			
	0.5	7.9	0.24			
	0.8	6.9	0.21			
	1.0	6.1	0.18			
	1.2	5.1	0.17			
	1.5	5.0	0.15			
	1.8	5.3	0.15	50	0.5	16,600
3	0	4.9	0.19			
	0.3	6.1	0.02			
	0.5	6.9	0.04			
	0.6	6.8	0.05			
	0.9	5.2	0.04			
	1.1	5.0	0.04			
	1.3	4.9	0.05			
	1.6	5.0	0.06			
	1.9	4.8	0.08	20	0.8	8,800

			Soil		Water	
Site	**Depth (m)**	**pH**	**% C1-**	**Total chloride storage in soil (t ha^{-1})**	**Depth to watertable (m)**	**Salinity of watertable (mg L^{-1} C1^{-})**
Wickepin						
4	0	6.8	<0.01			
	1	7.2	0.02			
	2	6.2	0.02			
	3	5.4	0.03			
	4	5,1	0.03			
	4.5	5.4	0.02			
	5	6.0	0.02	20	4.3	
Woodanilling						
1	0	7.6	0.14			
	1	8.3	0.06			
	2	6.1	0.02			
	3	7.3	0.25			
	4	7.6	0.15			
	4.5	8.1	0.15			
	5.5	7.9	0.03			
	6.5	7.8	0.15			
	7	7.8	0.13			
	8	9.5	0.12			
	12	9.1	0.13			
	14.5	9.2	0.25	370	2.0	6,700
2	0.5	8.0	0.08			
	2	7.7	0.11			
	3	8.6	0.04	30	3.0	
3	0	8.1	0.15			
	1	8.8	0.08			
	2	8.7	0.05			
	3	7.1	0.27			
	4	8.5	0.07			
	4.5	7.8	0.10			
	6.5	8.5	0.09			
	11	7.8	0.12			

			Soil		Water	
Site	**Depth (m)**	**pH**	**% C1-**	**Total chloride storage in soil (t ha^{-1})**	**Depth to watertable (m)**	**Salinity of watertable (mg L^{-1} C1^{-})**
	14.5	9.2	0.12	260	0.5	4,600
4	0	8.4	0.87			
	0.5	7.9	0.11			
	1	8.0	0.10			
	2	8.3	0.08			
	3	8.2	0.12			
	4	7.8	0.18			
	8	8.4	0.22			
	16.5	7.9	0.08			
	21	7.8	0.30	550	0.7	8,800
5	1	7.1	0.04			
	4	8.2	0.04			
	5.5	8.7	0.05			
	7	8.3	0.02			
	9	7.6	0.05			
	11	9.3	0.05			
	13	8.8	0.03			
	17	9.5	0.08			
	13	8.8	0.03			
	20	8.2	0.28	270	2.5	3,800
Salt Creek, Woodanilling						
1	0	9.7	1.03			
	1	9.6	0.09			
	2	9.6	0.09			
	3	8.1	0.13			
	8	7.9	0.44			
	19	8.3	0.26	860	0.2	5,100
2	1	8.8	0.12			
	2	8.6	0.10			
	3	7.8	0.25			

			Soil		**Water**	
Site	**Depth (m)**	**pH**	**% C1-**	**Total chloride storage in soil (t ha^{-1})**	**Depth to watertable (m)**	**Salinity of watertable (mg L^{-1} C1^{-})**
	4	7.6	0.09			
	5	8.9	0.05			
	8	7.8	0.27			
	11	7.3	0.03	260	0.8	11,400
3	2	5.5	0.02			
	3	5.9	0.02			
	4	5.3	0.02			
	6.5	5.1	0.06			
	9	8.8	0.25			
	13	6.2	0.24	290	5.5	2,200
Broomehill						
1	0	-	0.02			
	1	_	0.04			
	2	-	0.05			
	3	_	0.03			
	4	-	0.02	20	1.5	
4	0	_	0.42			
	1	_	0.09			
	2	-	0.04			
	3	-	0.03			
	4	_	0.05	30	0.2	5,300
6	1	_	0.03			
	2	-	0.03			
	3	-	0.03			
	4	-	0.04	20	5.5	3,600
Ongerup						
4	0.5	6.4	0.09			
	1	5.7	0.12			
	2	5.0	0.44			
	3	5.1	0.73			
	4	5.3	0.66			
	5	5.0	0.74	420	2.0	