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Climate, Physiography Geology, Hydrology and Land Use in the North Stirlings Area — A Precursory Report

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Resource Management Technical Report No.126

Disclaimer

Forward

This report was compiled in October 1985, but was not prepared for publication until August 1991. The report was complied to collate existing data on the North Stirlings Basin preliminary to the start of a major investigation in the area supported by the National Soil Conservation Program. Understanding of the hydrogeology of the area increased significantly between 1985 and 1991. Where appropriate, data from the National Soil Conservation Program project have been in the Figures, however the text is based largely on the 1985 data.

In the period between compilation and publication the North Stirlings Soil Conservation District changed to the North Stirlings Land Conservation District.

The authors would like to thank the farmers in the area for their co-operation and assistance during collection of the data. We also thank John Moncrieff of the Geological Survey of Western Australia, Jack Lorimer of Western Collieries and John Pringle of CRAE for their helpful discussions. Assistance provided by T. Doney, S. Fairhead, J. Hardy, D. Imrie, T. Lacy, F. Lewis, G. Scrase, P. Smith, E. Solin, S. Taylor, P. Tipping and B. Wren in assembling some of the available data is gratefully acknowledged.

Table of Contents

1. Introduction

The North Stirlings Land Conservation District (NSLCD) includes land within the Shires of Cranbrook and Tambellup. It lies within the Lower Great Southern statistical area (W.A.) north of the Stirling Range National Park and east of Cranbrook. Figures 1 and 2 indicate the location of the District in relation to other such districts as of June, 1985.

The District encompasses some 70, 000 hectares of land of which approximately *50%* is subject to deterioration due to secondary salinization, waterlogging, flooding and wind erosion.

The intention of this report is to summarize our present understanding of the area and to suggest methods which could be used to delineate the hydrology more fully. Precursory groundwater investigations within the District have already been made at one of the worst salt-affected areas. When these investigations are extended, a workable land management strategy could be developed to alleviate the serious land degradation problems of the area.

2. Climate

The belt of land extending eastward from Cranbrook (Fig. 2), which embraces much of the North Stirlings Land Conservation District, is drier than would otherwise be expected due to the rainshadow effect of the Stirling Range. For this reason it is best categorised as a dry Mediterranean type climate, with relatively long, dry and hot summers and short, wet and cold winters. The wettest six monthly period in the District is generally from May to October, although in the east this period can often be from April to September. The length of the growing season decreases eastwards from Cranbrook being approximately seven months at Cranbrook to about six months east of Camel Lake (Fig. 2) (Bureau of Meteorology, 1962).

Table 1 shows the mean monthly rainfalls at Cranbrook (record of 65 years) and Amelup (record of 52 years) located just to the east of the Land Conservation District. Detailed rainfall analyses of the area have not been done and it is recommended that isohyetal and Thiessen polygon methods be employed using rainfall stations within and outside the District, to enable a clearer definition of rainfall variation. The extent of unofficial rainfall records by local farmers also needs to be ascertained.

Table 1 indicates that during the winter months of May to October 360 mm of rain falls at Cranbrook while at Amelup 277 mm falls in the same period (74% and 71 % of the average annual rainfall respectively).

The mean annual potential evaporation at Cranbrook is approximately 1070 mm. Within the Lower Great Southern evaporation increases from west to east and northwards (Bureau of Meteorology 1962). Therefore traversing east from Cranbrook the potential evaporation (Ep) (as measured by a Class A pan, with standard bird

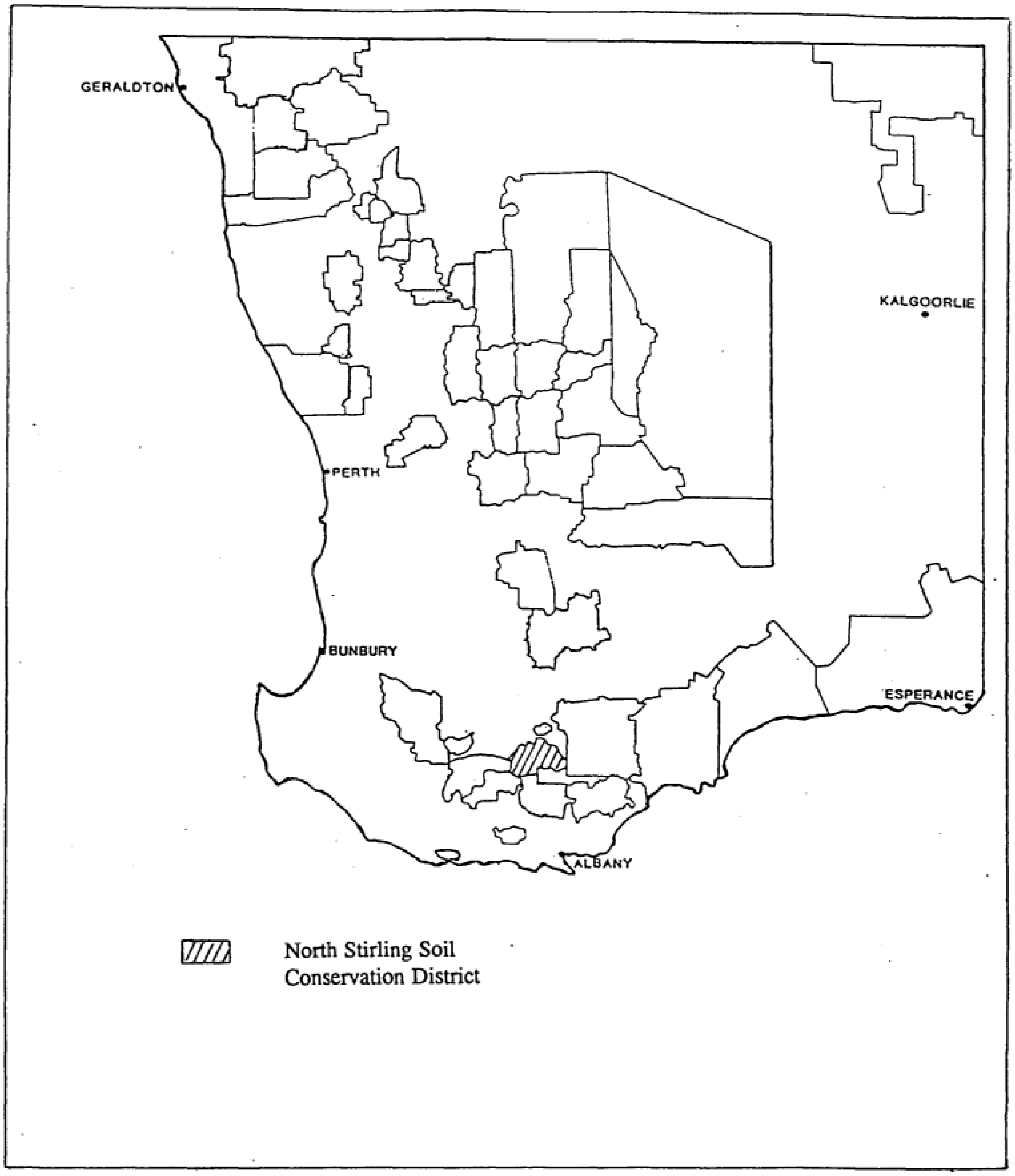

Figure 1. Soil Conservation Districts as at June 1986 Showing the Location of the NSSCD, (now the NSLCD).

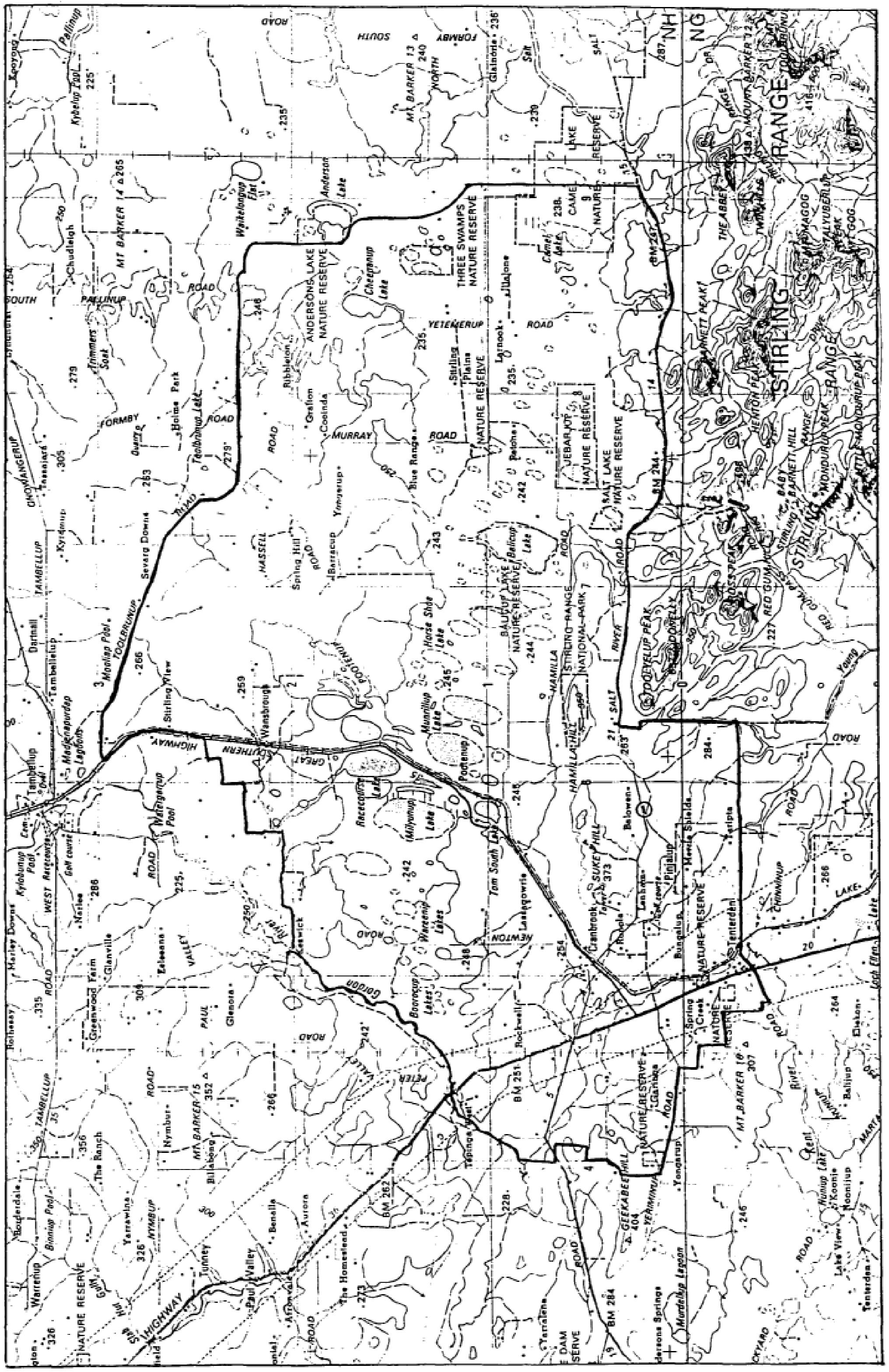

Figure 2. Location of the NSLCD   Boundary of NSLCD = ———————

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Table 1 Rainfall Data for Cranbrook and Amelup

Month	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
Cranbrook Mean Rainfall (mm)	14	18	25	35	63	76	77	66	52	46	25	17	514
Amelup Mean Rainfall (mm)	14	14	21	33	50	55	55	47	36	34	20	13	392

The mean annual potential evaporation at Cranbrook is approximately 1070 mm. Within the Lower Great Southern evaporation increases from west to east and northwards (Bureau of Meteorology 1962). Therefore traversing east from Cranbrook the potential evaporation (Ep) (as measured by a Class A pan, with standard bird guard) increases gradually and at the extreme east of the NSLCD Ep is about 1100 mm. Monthly evaporation in the region varies from less than 25 mm in winter to perhaps 200 mm in summer.

Storms intermittently cause flooding within the region, and if the flooding is excessive waters flow westward to the Gordon River, (Fig . 2) although, on one occasion waters were reported to flow from the river to the east. After such inundation low lying areas remain waterlogged for many weeks.

3. Physiographical And Geological Setting

The area of land north of the Stirling Range is predominantly flat with scattered dune ridges and salt lakes. The Stirling Range rises abruptly up to 800 m above the surrounding countryside. To the north of the District the land rises gradually. Figure 3 indicates the topography of the more easterly section of the NSLCD.

The Proterozoic basement is part of the Stirling Range Formation which unconformably overlies the Archaean granite. Archaean basement rocks crop out to the north and Proterozoic ones to the south. The greatest depth to basement occurs in the vicinity of Balicup Lake where drilling has found fresh Archaean granite at up to 50 metres (Ellis 1984). This tendency of basement depths to increase in this locale and diminish to the north, south, east and west has led to the area being informally termed the Tambellup Sub-basin (Ellis 1984).

The Sub-basin comprises friable, poorly consolidated sediments of the Plantagenet Group which overly bedrock unconformably and are overlain by superficial Quaternary units. The Plantagenet Group consists of the Werillup Formation and the Pallinup Siltstone.

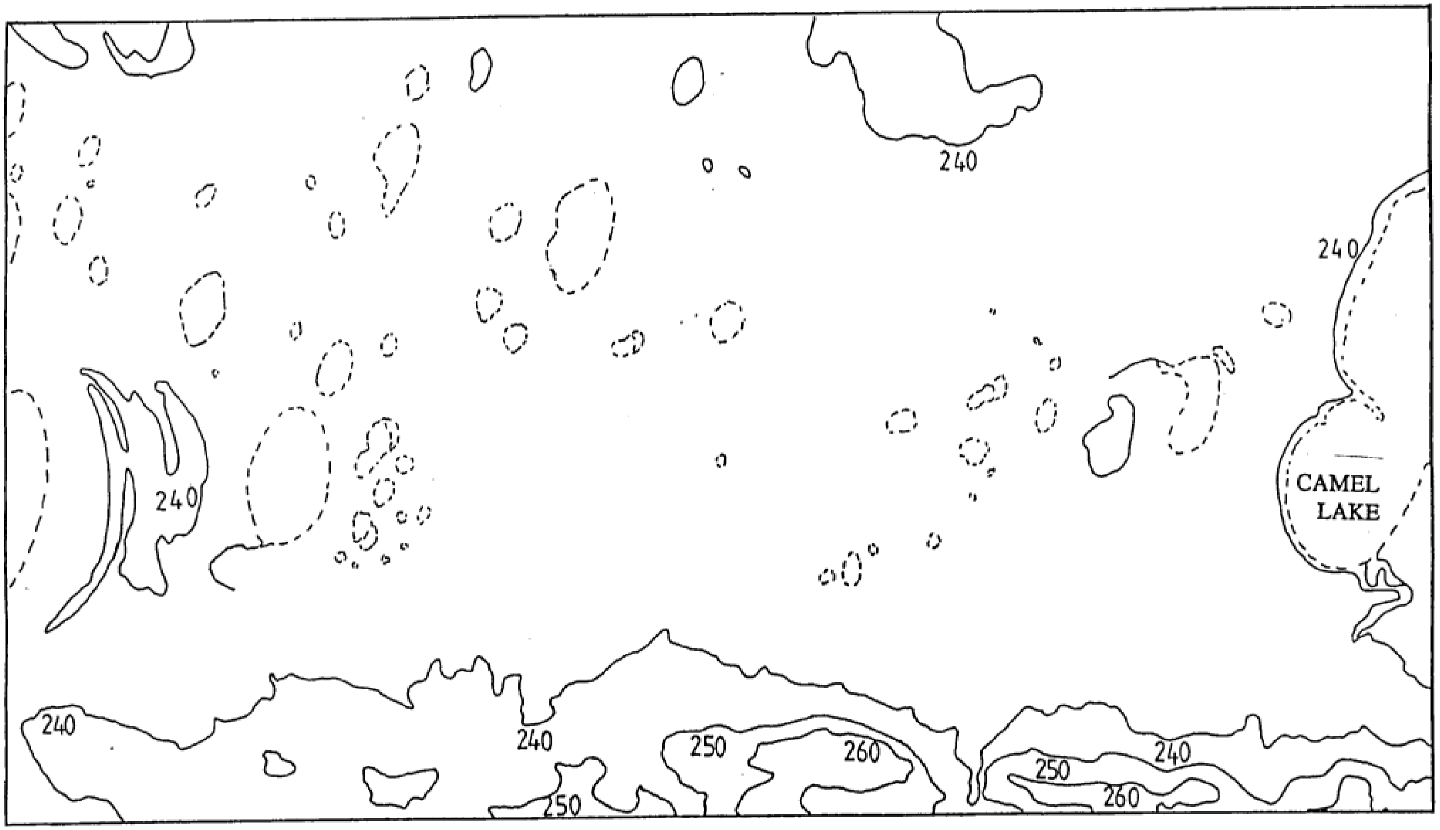

Figure 3. Topographic Contour Map of a Section of the NSLCD.

The Werillup Formation conformably underlies the Pallinup Siltstone which is a light-coloured, sandy siltstone or spongolite of late Eocene age. There is a transitional silty sandstone between the two formations (Moncrieff, 1977).

During the late Eocene there was a major marine transgression onto a landscape of low relief. It was at this time that the dark-coloured siltstones, sandstones, carbonaceous siltstone and lignites of the Werillup Formation were deposited.

The presence of various large foraminifers and type of algae indicate shallow, warm, marine conditions, while the lignite and non-marine clays point to regional deposition within coastal swamps (Muhling and Brakel, 1985).

Ellis (1984) assigns the carbonaceous intervals intercepted in various boreholes drilled by CRA Exploration Pty Ltd within the Tambellup Sub-basin to the Werillup Formation and classifies the overlying sediments as ‘undifferentiated’ Tertiary or Quaternary. Thus on present evidence it is not possible to say whether the Pallinup Siltstone occurs north of the Stirling Ranges. A Tertiary, medium grained, friable sandstone crops out to the north of the District but has not been allocated to any particular geological formation. It is illustrated on the Mt Barker-Albany 1:125,000 Geological Map (Muhling and Brakel, 1985).

The area within the District is thought to represent the most northern extension of the Eocene sea (J. Moncrieff; W. Lorimer pers. comm.). The Stirling Range probably was an island or peninsular in the sea, as were the Porongurups to the south. This view contrasts with that of Muhling and Brakel *(1985)* who state -

“The Pallinup Siltstone was deposited in a shallow transgressive sea with a coastline along the southern Stirling Range....”

It may be better to consider the area north of the Stirlings in late Eocene times as consisting of coastal swamps and so giving rise to the Werillup Formation only. Quaternary deposits unconformably overlye the Plantagenet Group and consist of alluvium, colluvium and saline and/or gypsiferous lake material. Sand dunes marginal to the scattered salt lakes are surrounded by sands, silts and clays derived from alluvium and lake deposits. These dunes may also be gypsiferous. Colluvial deposits occur as skirts around cropping out basements in the north and south of the District. Towards the centre of the Sub-basin pre-Quaternary alluvial and colluvial sand, silt and clay predominate. Massive and pisolitic laterites hem the Ranges proper and are also found to the north-east on higher country. They are commonly overlain by sand containing ironstone pisoliths.

Dunes are up to 5 m high and trending north in general, and often occur on the eastern and south-eastern side of lakes and thus can be more correctly termed lunettes.

4. Vegetation And Soils

The original natural vegetation of the region was described by Beard (1972 and 1979). It is summarized in Figure 4 which is taken from Beard's (1979) 1:250,000 vegetation survey map of Albany and Mt Barker. To the west of the Land Conservation District was a Eucalypt woodland of wandoo *(Eucalyptus wandoo),* York Gum *(E. loxophieba),* and flat-topped or swamp yate *(E. occidentalis).* In the east was a mallee-heath dominated by tallerack *(E. tetragona)* immediately north of the Stirling Range; further north black marlock *(E. redunca)* dominated. The swamp yates occurred in swampy areas and marginal to lakes.

All lakes between Balicup Lake and Lake Milyunup (Fig. 2) were surrounded by low woodlands of paperbark (Melaleuca cuticularis). Camel Lake, to the east, was, and still is surrounded by tea trees *(Melaleuca spp.)* and samphires *(Halosarcia spp.).*

About 85% of the land in the North Stirlings Land Conservation District is alienated for agricultural use (the rest is designated for parks etc) and is held under conditional purchase title or freehold. A large proportion of the District is cleared and thus Figure 4 does not represent present day vegetation. Only roadside verges and uncleared areas (e.g. reserves) represent the original vegetation.

Beard (1979) places the area north of the Stirlings in the Eyre Botanical District and within the Qualup vegetation system. In this system, mallee-heath grows on plains of sand overlying clay (often with ironstone gravel). Deeper sands, such as those around Camel Lake, are associated with a scrub-heath where the mallee-form eucalypts are absent; mallee formations occur on the lunettes of the lakes. Figure 5 is based on an enlargement of the CSIRO (1967) 1:2,000,000 Atlas of Australian Soils, Sheet 5. The original 1:250,000 compilation sheets of Sheet *5* do not show any greater detail for the area.

The predominant soil types in the NSLCD are duplex with mottled yellow subsoils and friable sandy surface soils which are not hardsetting. A2 horizons are conspicuously bleached and subsoils are pedal. The soils generally have an alkaline reaction trend and are classified as Dy5.43 soils (Northcote, 1979).

The Dy5.43 soils occur on the flatter regions north of the Ranges; lunettes and ridges consist of sandy alkaline red soils and hard alkaline red soils, (Dr4.43, Dr5.43 and Dr2.43). Areas with bedrock at shallow depth but still on gently sloping land (i.e. land at the edge of the basin) have various hard and sandy yellow, yellow-mottled and red duplex soils.

Shallow sandy soils (Uc4. 11) occur over the metasediments of the Stirling Range. Further north towards Tambellup, Dy soils are again evident but they typically have apedal subsoils (Dy3.82).

No detailed soil survey of the area has been done, although Poutsma *(1953)* carried out a soil and salinity survey to the east of the NSLCD He noted most of the soils in this locale (north and east of 118°W, 34015'S) were duplex with sandy A horizons less 30 cm deep. B horizons were mostly yellow or brown and A-B horizon boundaries were distinct; many soils showed a clear differentiation between a dark A1 and a lighter A2 horizon. He concluded that the soils of the area fell into five groups; residual laterites (i.e. any soil with ironstone gravel in the profile), solonetz, solodized solonetz, solods and deep undifferentiated sands.

The loose sandy A horizon of these soils makes them very susceptible to wind erosion, especially when vegetation has been killed by ponded water and/or high soil salinities. Conventional agricultural practises have also increased the susceptibility of soils with sandy A horizons to wind erosion. The soils are also highly prone to waterlogging.

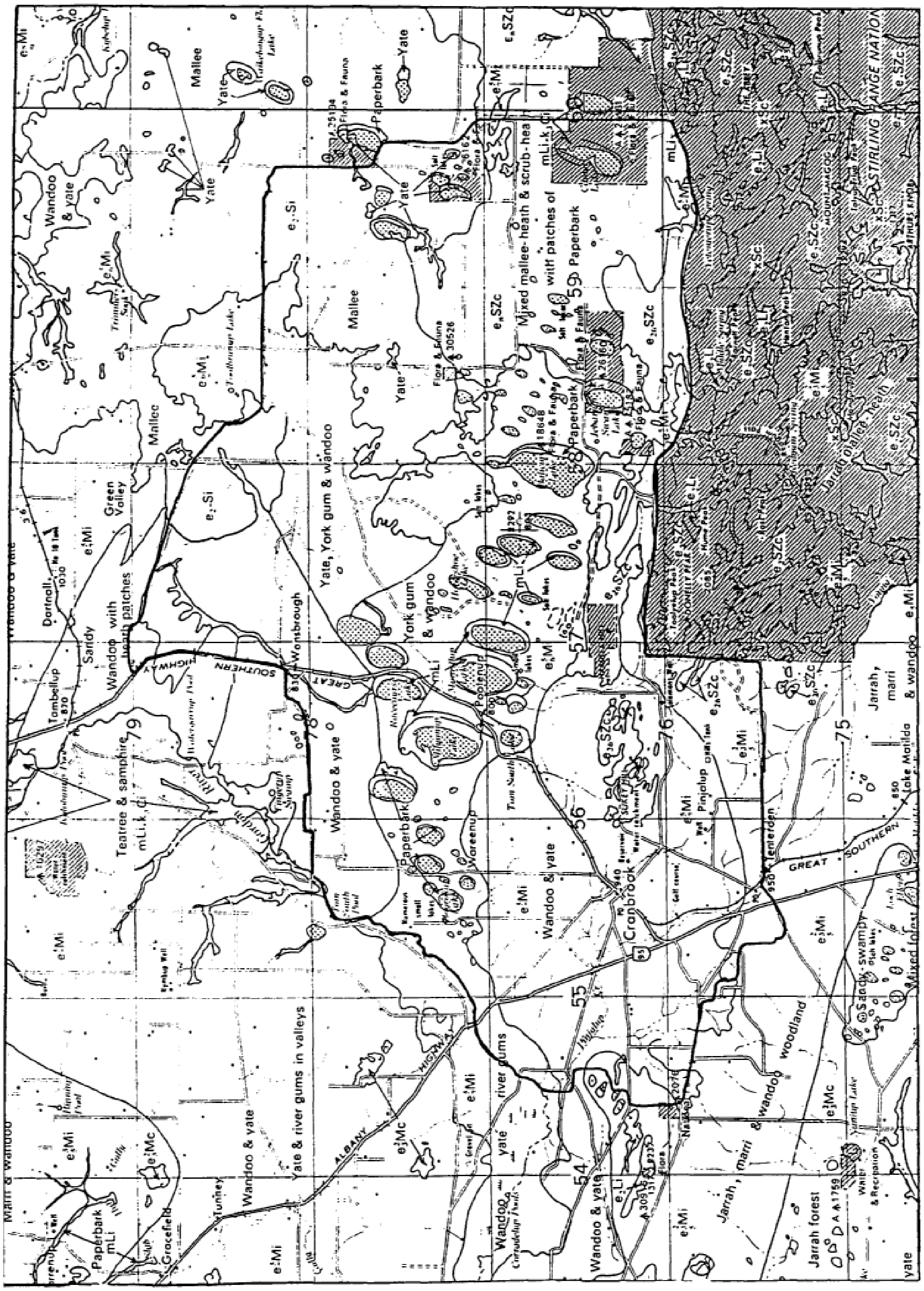

Figure 4. Vegetation Map of the Area. Boundary of NSLCD = ----------- SCALE 1:250 000

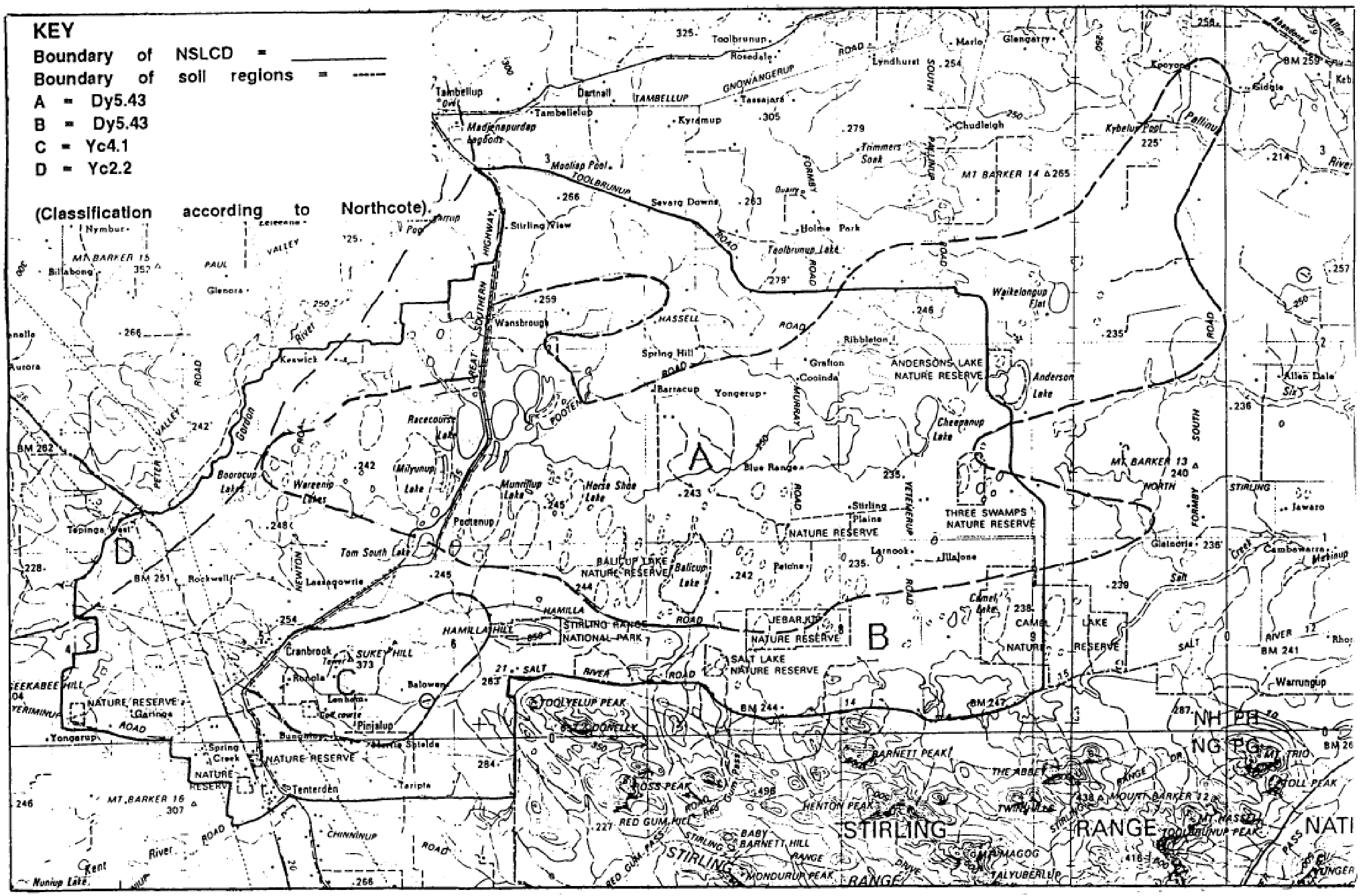

Figure 5. Soils Map of the Area.

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5. Land Use

Various location numbers within the NSLCD had their survey lines surveyed in during the late sixties. Many blocks were released and taken up in this period and clearing has progressed since then. Within the Great Southern Region there was a rapid expansion in clearing between 1965/66 and 1970 (Great Southern Regional Development Advisory Committee, 1985) after which clearing proceeded at a reduced rate. Clearing within the NSLCD is likely to have followed this pattern.

Farming within the NSLCD is mixed cereal grain - sheep production. The ratio of coarse grain (barley and oats) to wheat decreases eastwards in the district. There are some piggeries and a small number of beef cattle in the area.

Apart from the Stirling Range National Park at the southern boundary of the NSLCD there are numerous Flora and Fauna Conservation Reserves mostly around lakes such as Balicup and Camel. Any water management strategy for the region would need to take into account the effect of such a strategy upon the flora and fauna within these reserves.

No significant mining occurs within the District but various companies are, or have been, interested in lignite in the area. CRA Exploration Pty Ltd has relinquished its exploration license application for the Tambellup Lignite Prospect which it termed as inferior. Western Coffieries are currently pursuing investigations east of Cranbrook (Cranbrook Lignite Prospect) which may be more promising.

6. Drainage

Surface drainage within the District is poorly defined. During periods of substantial rain, runoff occurs via ephemeral streams to various salt lakes (e.g. Camel Lake) and other low points in the topography. Water flows both from the higher land to the north and from the Stirling Range in the south into the central portion of the Sub-basin. Farmers have reported water flowing from the north and south then flowing eastward or westward depending on small scale nuances in relief.

The chain of salt lakes in the Sub-basin centre are discharge areas for groundwater which is recharged on the higher land of the Stirlings and northern slopes of the District.

The region has been designated as part of the Frankland River Basin (see Figure 6) (Public Works Department 1977) with the eastern divide of the catchment being just east of Camel Lake. It is true that in flood years water flow has been noted towards the Gordon River (which flows into the Frankland) but more investigation is needed to determine if the Tambellup Sub-basin is wholely closed or is open to the west. Do salts slowly build up within the basin or are they periodically flushed to the Frankland system and thence to the Southern Ocean?

Some anomalies with this scenario are evident. The surface of Camel Lake, in the east, is at a lower elevation than that of Balicup lake, to the west, by perhaps 5-10 m (on topographic map evidence) and this seems inconsistent with flooding to the west. In the region between these two lakes the surface and sub-surface drainage is ill defined and the salinity problems are probably very largely due to the poor drainage. Cyclic and connate salts are transported to the area, which is essentially a large sump, and concentrate by evaporation. Land clearing has exacerbated the situation by perturbing any quasi-steady state which may have once existed.

7. Results of Preliminary Investigations

7.1 Groundwater Hydrology

The salinity problems within the NSLCD are attributed to the clearing of native vegetation causing a rise in the saline water table and a subsequent accumulation of soluble salts at the soil surface. Many areas inside the District were saline before agricultural development and indicated the potential serious salt problems that would occur with the onset of clearing. As deep drainage, aquifer pumping, revegetation or a combination of these. Saline areas should be revegetated with halophytes (Malcolm, 1983). Before treatments can be effectively implemented, an accurate picture of the sub-surface hydrogeology must be obtained. Preliminary groundwater studies were initiated by the Department of Agriculture and a series of boreholes drilled in a badly salt affected area west of Camel Lake. The location of the bores is shown in Figure 7 and details of drilling logs are given in Appendix 1. Approximate depth to bedrock at each site is shown in Table 2.

Table 2. Depths (m) to bedrock in bores west of Camel Lake

Borehole No.	1	2	3	4	5	6	7
Depth (mBGL)	25.50	17.0	18.8	22.0	20.2	22.7	>27.0
Borehole No.	8	9	10	11	12	13	14
Depth (mBGL)	>27.0	>6.3	6.2	>18.2	6.7	>22.0	4.5

(mBGL = meters Below Ground Level).

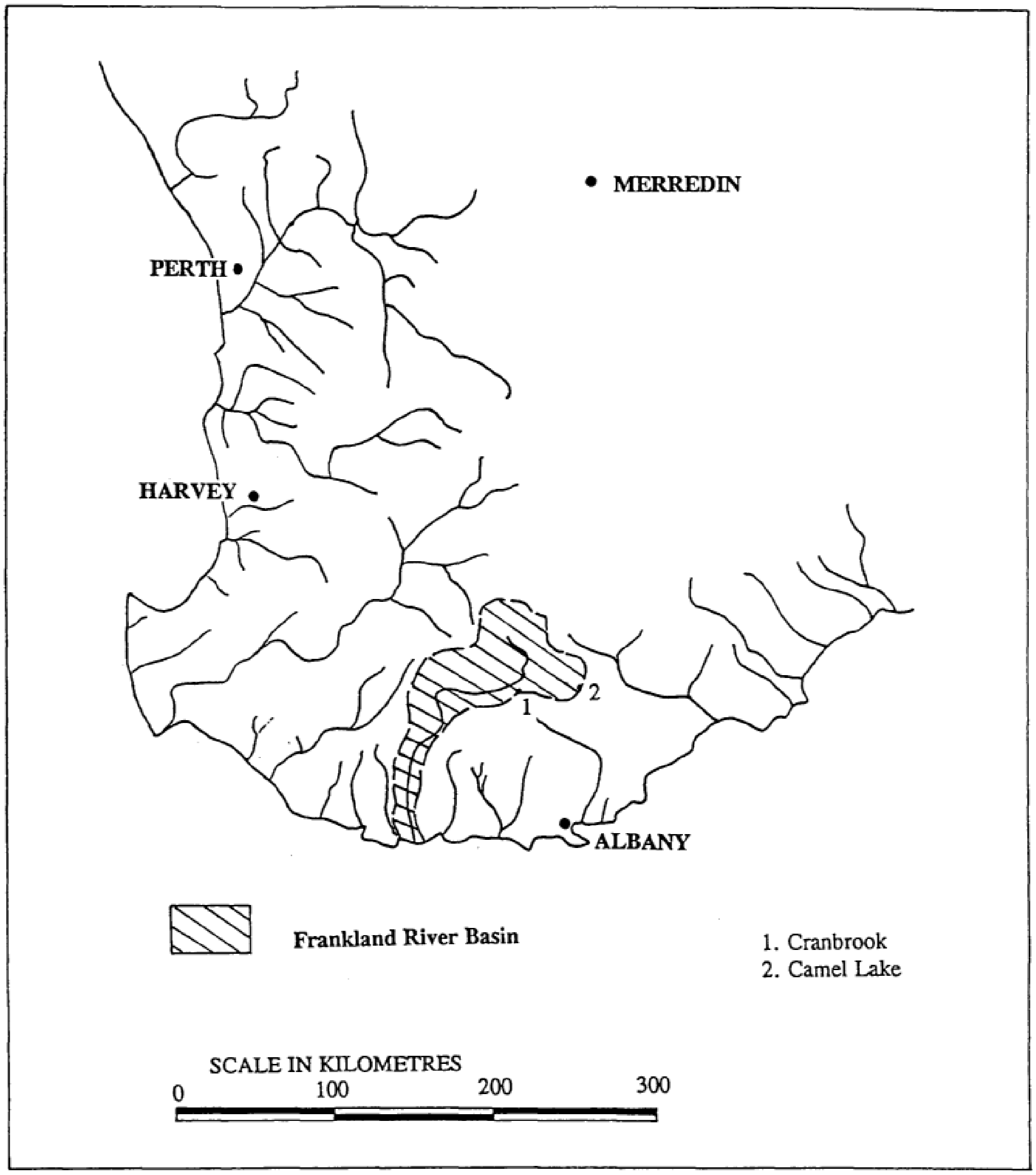

Figure 6. The Frankland River Basin.

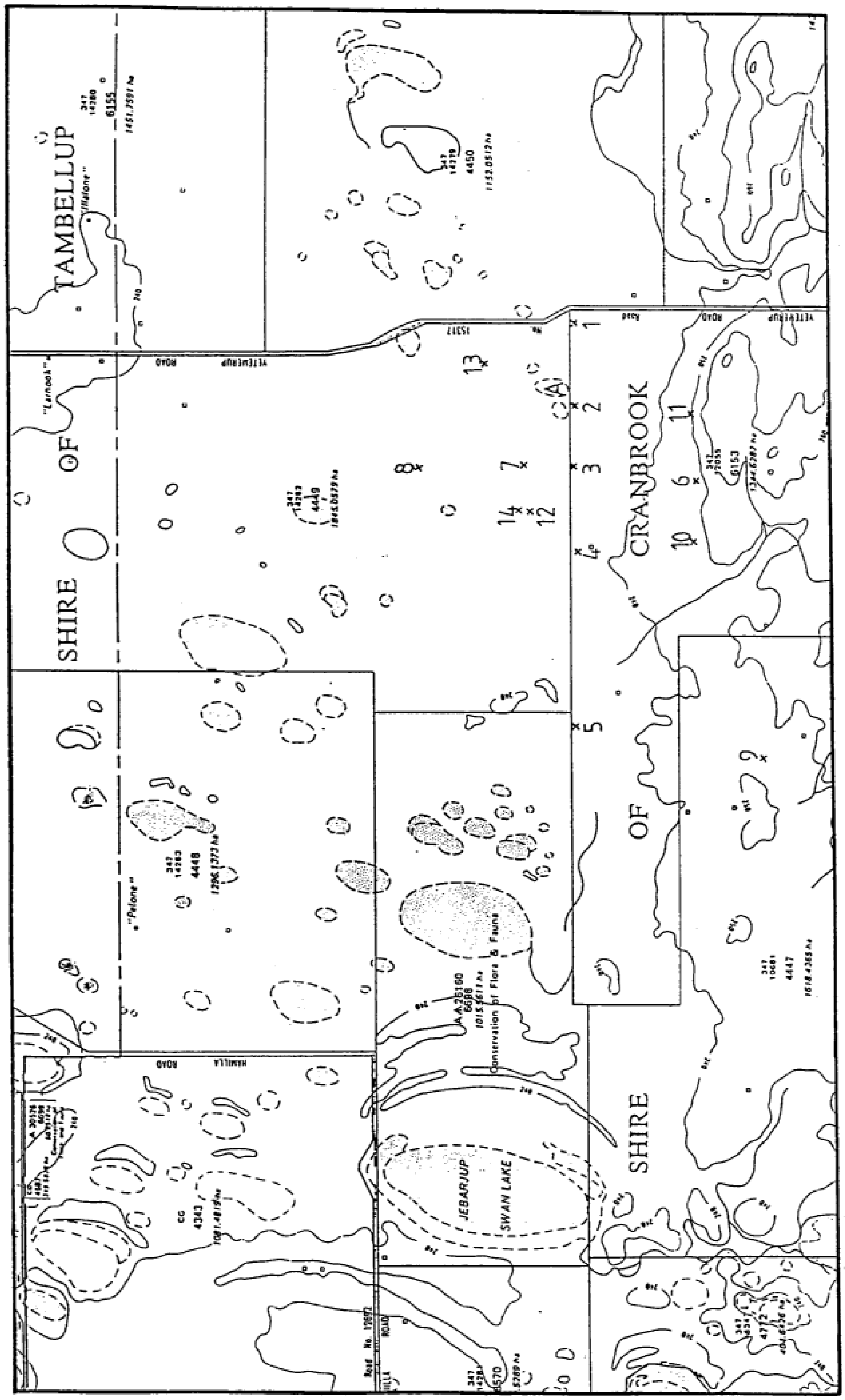

Figure 7. Location of Drilling Sites

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The depths to bedrock show a general increase from south to north, however specific depths in this locality are not entirely consistent with the contour map given in Ellis (1984), but, the general depth trend indicates the basin-like nature of the area.

At most sites two bores were drilled; one a slotted observation well (designated B) and the other a piezoMeter drilled to bedrock if possible and slotted over its bottom 2 m (designated A), (Appendix *5).* The holes were drilled late in 1984. They have been monitored regularly for static water level and water samples taken for electrical conductivity and chloride concentration determination,(Appendix 2). Horizontal and vertical potential gradients and groundwater flow directions have been determined from the bore data. Water levels were standardized to equivalent distilled water levels since salinities between bores varied greatly, (Appendix 6). Figure 8a shows the potentiometric surface at basement and Figure 8b the water table elevation in February 1985. It is clear that groundwater flow is towards the centre of the area around borehole 2 and that there is an upward potential gradient from the bedrock to the surface. The bore hydrographs for 2A and 2B, shown in Figure 9, display this upward gradient. A small salt lake (salt lake A on Figure 7) would seem to be the local discharge point. The vertical hydraulic gradient at site 2 is approximately 0.02 and the saturated hydraulic conductivity as determined by slug withdrawal tests, was about 0.01 m/day (measured in bore 2A), (Appendix 4). These figures indicate a very low flow rate per unit area of cross-section (V) of 2 x 10-4 m/day. Likewise a low V of 4 x 10-5 m/day results form a gradient of about 0.004 and a conductivity of 0.01 m/day between sites 2 and 3. Maximum transmissivity is less than 1 m2/day.

The most saline water is situated in the vicinity of boreholes 7, 8 and 13 (see Figures lOa, lOb and 8b) decreasing upslope towards borehole 6. This is consistent with recharge on the ridges comprising the northern most line of the Stirling Range. More saline water occurs in the centre of the basin due to concentration by evaporation once the water table nears the ground surface and the area around holes 8 and 13 is very badly salt affected.

It is also evident that the most saline water occurs at depth. For example, at site 8 on 6/5/85 the deep groundwater had a TDS of about 60,000 mg/L whereas near the surface its TDS was approximately 36,000 mg/L.

7.2 Salt Storage in Soil Profiles

Salt storages based on Cl- content were calculated for some representative boreholes using estimated bulk densities (Appendix 2). The soils were sampled over wide depth intervals so the data must be viewed with reservations. Results indicated chloride storages in excess of 150 kg/m2 in some places (e.g. Hole 2 has a storage of 157 kg/rn2).

Figure 11 illustrates the soil chloride profiles for the drill sites. The data show that the salt stored in the profiles increases northwards from bore 6 towards bore 8. Bores 6, 10 and 11 have relatively low profile salt contents; bores 2, 3 and *5* a higher amount and bores 8, 12 and 13 the highest values. Most of the salt is stored at around *5* m for 2, 3 and *5* and at the surface for 8,12 and 13. These profiles are consistent with recharge on the Proterozoic ridge and discharge of saline water in the salt-affected area covered by the drilling. Hence good to fair wheat crops could be expected on the higher land, poor crops around borehole 2 and no growth at all in the vicinity of the most northerly bores. If water tables continue to rise, the salt stored at around *5* metres in the hole 2 locale could be expected to concentrate at the soil surface and further reduce land productivity.

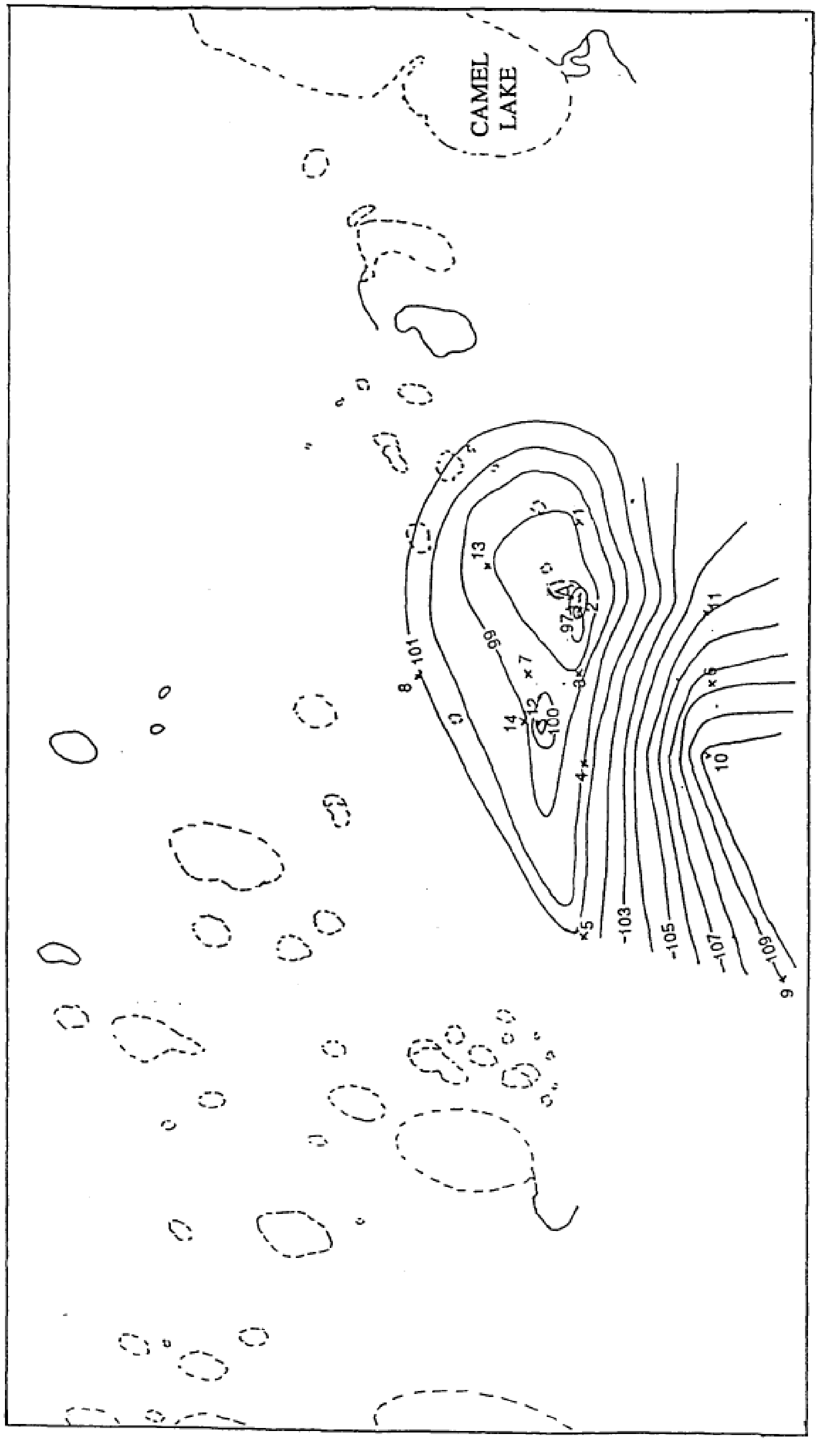

Figure 8a. Potentiometric Map of an Area West of Camel Lake at Basement, Feb. 1985.

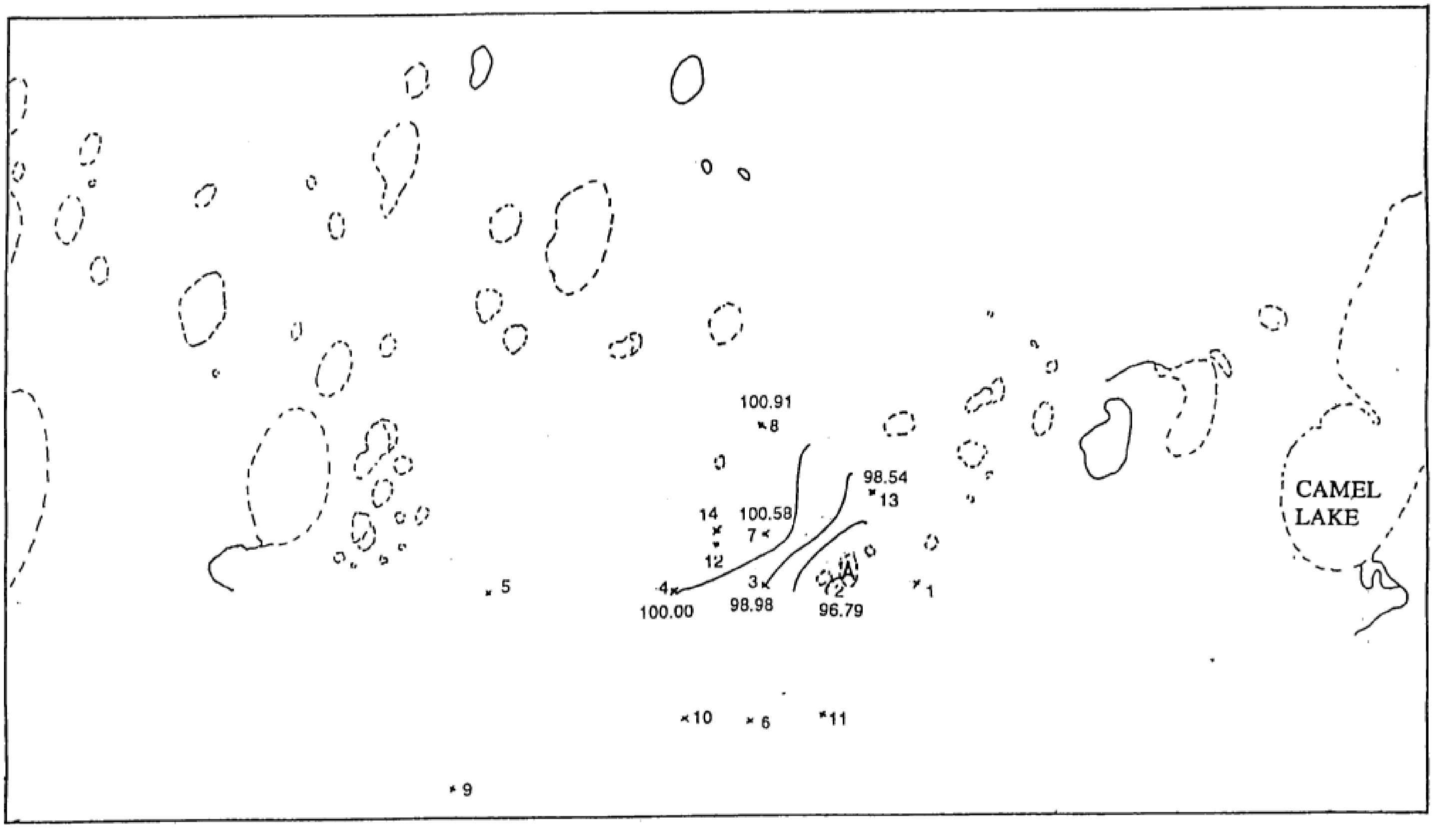

Figure 8b. Potentiometric Map of an Area west of Camel Lake at Water Table, Feb. 1985.

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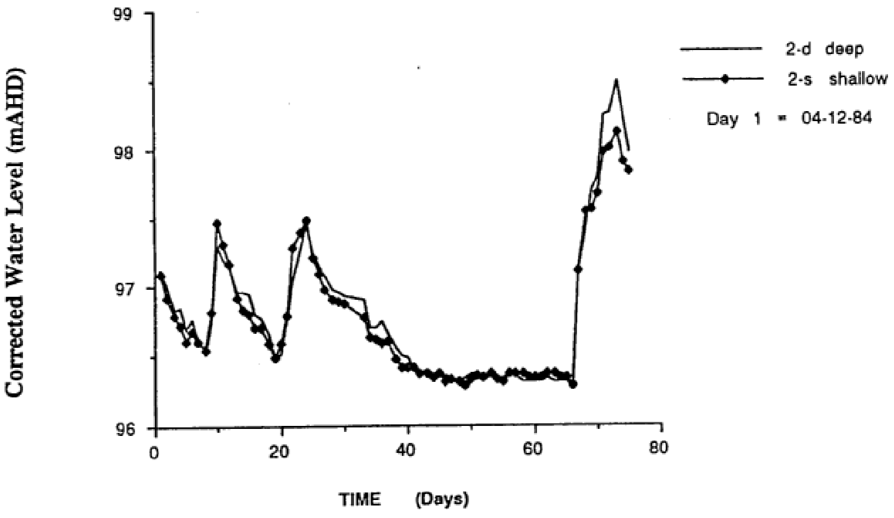

Figure 9. Bore Hydrographs at Site 2.

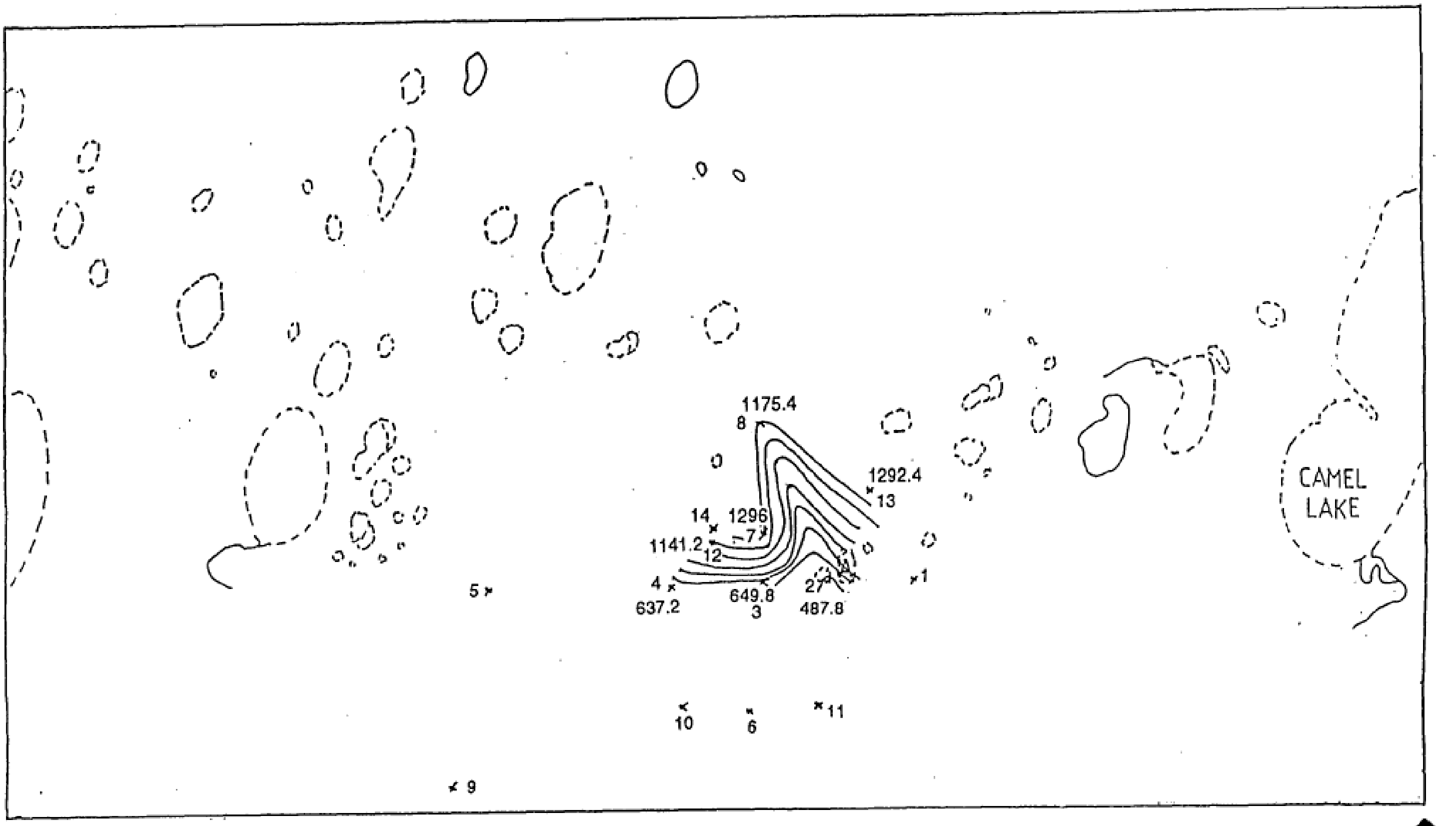

Figure 10a. TDS Water Table Map for 6/5/1985
[Figures oher than bore numbers refer to measured TDS (mg/l)]

SCALE 1:50 000

CONTOURS: TDS (mg/l)

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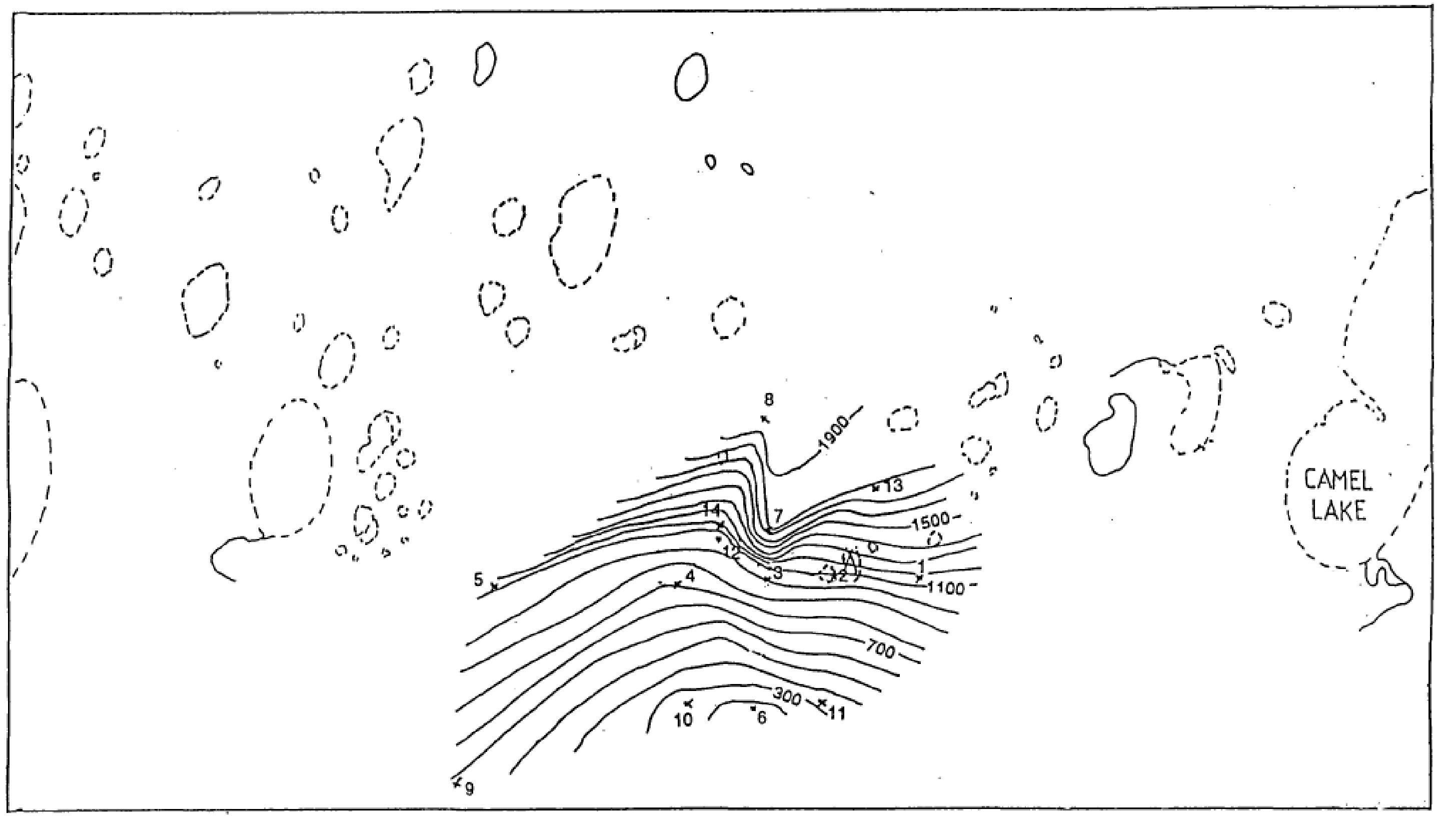

Figure 10b. TDS Bedrock Map for 6/5/1985.

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CONTOURS: TDS (mg/l)

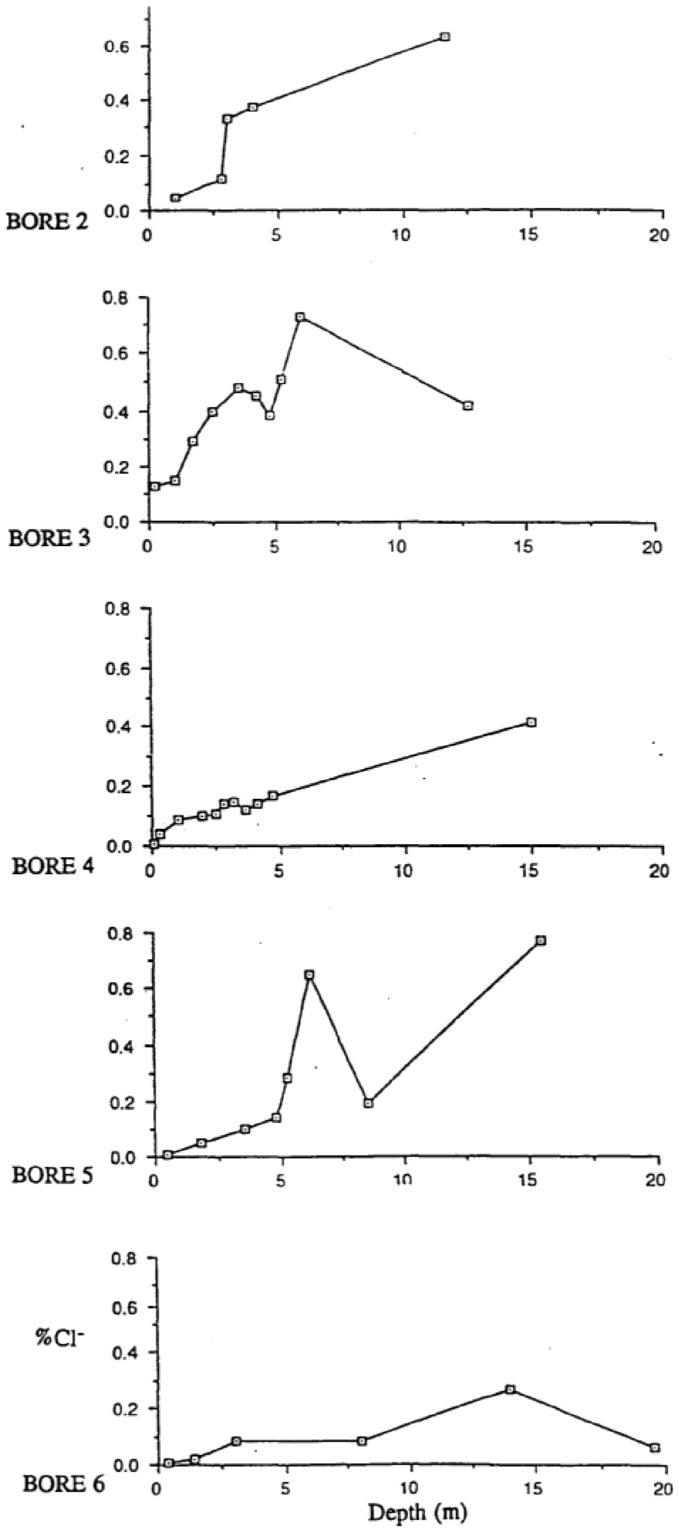

Figure 11. Soil Chloride Profiles for Boreholes.

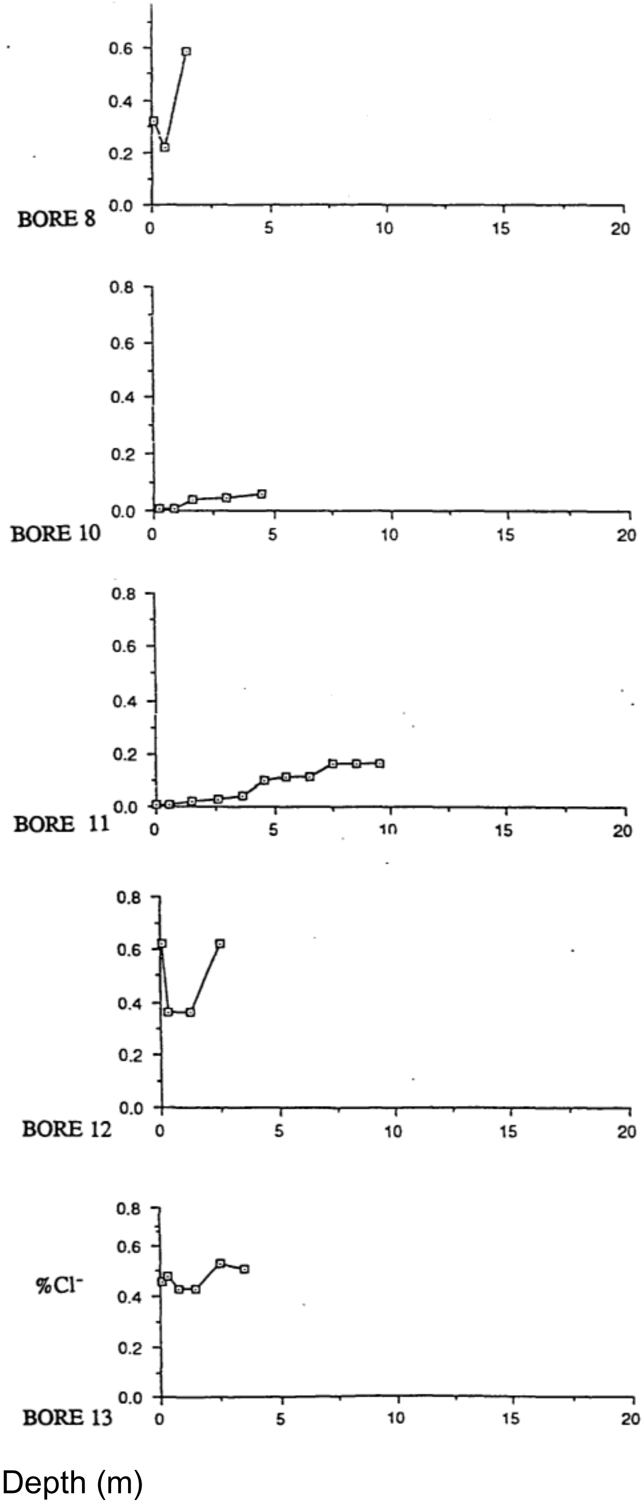

Figure 11. Continued

7.3 Groundwater Prospects

Another major problem north of the Stirling Range is the quantity and quality of stock water supplies. Landowners have to rely on dams because the groundwater is so saline and in many places water tables have risen above the base level of the dams causing the water to become saline. Constructing dams within the central part of the basin is undesirable due to salt encroachment and the lack of runoff from the surrounding sandy soils. During periods of drought these problems are magnified and farmers must resort to carting water from developed low salinity bores in the southern part of the area.

Water supply investigations in the area have been carried out by the Geological Survey of Western Australia (Lord, 1971; Davidson, 1977) to provide an inventory of existing groundwater occurrences and to suggest sites for the development of drought relief bores. For suitable stock water, supplies of less than 4000 mg/L TDS and a yield of at least 9 m3/day were deemed to be necessary (Moncrieff, 1977). Few bores in the North Stirlings Land Conservation District meet these criteria. Those that meet these criteria occur within the Stirling Range Formation joints at some depth, or within piedmont colluvium. Moncrieff (1977) reports:

“Large quantities of stock quality groundwater exist in parts of the valley (between the Stirling Range and Hamillan Hill) and further investigation is warranted, particularly in the area from Hamillan Hill extending to south of Balicup Lake”.

Piedmont colluviurn is recharged by ephemeral streams that flow from the Range. Other areas for locating phreatic water occur downslope from large topographic rises where drainage lines are cut by dolerite dykes; however, this water is often very saline.

Towards the north, groundwater quality deteriorates quickly and any bores which are of acceptable quality often have average to poor yields of 30-10 m3/day.

8. Conclusions

A general summary of our present knowledge of the NSLCD has been presented. Preliminary drilling has demonstrated the severity of the District's salinity problem and shown that groundwater levels in places are within a few metres or less of the surface and have TDS values greater than sea water. Low hydraulic gradients and low hydraulic conductivities have been measured and there is an upward vertical potential gradient by which deep saline water travels towards the surface.

Groundwater tables are rising, as indicated by the steadily expanding salt patches. Farmers also reported that water levels in bores were once much lower than at present. A bore on one property has risen from 17 m BGL (below ground level) 10 years ago to only 5 m BGL in 1985 (J. Smith, pers. comm.).

Salt storage proffles are evidence of the huge reserves of salt in the area.

It is obvious that unless some well researched, long term initiatives are put into effect soil salinity will become a very severe problem limiting production in the area.

9. Recommendations

- A lake water balance study be undertaken to define the hydraulic connection between salt lakes and the underground water system within the Sub-basin. This is essential if the lakes are to be considered as disposal points for effluent from any proposed drainage schemes. If the lakes are hydraulically connected to the groundwater there is the possibility that disposal of saline drainage waters into them will, in the long term, create a groundwater mound which could affect the adjacent land. The study would involve a detailed water and salt mass balance of a suitable lake. Due to its size and centrality to the borehole network already in existence it is proposed that the lake designated “salt lake A” on Figure 7 be chosen. Details of the study procedure are given in Appendix 7.
- If a major deep drainage scheme to the Gordon River is to be developed the relative lake levels for all the major salt lakes in the District must be surveyed. It is proposed that laser levelling be employed, in conjunction with Department of Lands benchmarks, to determine the existing gradients. The feasibility of drainage can then be assessed.
- Installation of more boreholes to the north, west and east of the present network to cover both cleared and uncleared land. East of Yetemerup Road is an area of uncleared mallee heath and scrub heath which would provide a contrast to boreholes 1 to 14. Chloride profiles and depth to water tables could be compared.
- Map areas which are salt affected using aerial photography and multispectral scanning.
- Investigate, on the basis of hydraulic parameters, the potential drawdowns associated with a major aquifer pumping scheme.
- Investigate any relationship between salt affected land and the occurrence of lignite at depth. Low pH groundwater associated with the lignite, due to the pyrite it contains, probably contributes to the salt problem. With vertical hydraulic gradients the water rises to near the ground surface where H+ exchange on the cation exchange surfaces of clay for Na+ which is consequently seen as an increase in salinity.
- Determine the role of alternative agronomic practices, including the role of trees, on control of recharge to groundwater.

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Appendix 1. Drilling Logs for Bores West of Camel Lake

BORE NUMBER	BORE DEPTH (m)	PH (1:5 H_2O)	EC (mS/m) (1:5 H_2O)	%C1^{-} (Titrated)	TEXTURE	MUNSELL COLOUR
8	0.1	6.7	213	0.32		
8	1.0	8.1	157	0.22	6.1 medium clay (SAND)	5Y 5.3 olive
8	2.0	7.7	388	0.59	2.3 fine sandy loam	10YR6.6 brownish yellow
10	0.5	5.8	4.3	<0.01	1.5 loamy sand	I0YR6.3 pale brown
10	1.2	6.3	12.8	0.01	3.6 sandy loam	5YR4.6 yellowish red
10	2.0	6.7	35.2	0.04	4.4 silty clay loam	5YR7.2 light grey
10	4.0	6.7	31.6	0.05	4.2 clay loam sandy	7.5YR5.5 brown
10	5.0	6.5	38.5	0.06	2.6 light sandy clay	10YR4.3 brown - dark brown
11	4.0	5.8	3.5	<0.01	1.5 loamy sand	10YR6.3 pale brown
11	1.0	6.6	14.7	0.01	6.1 medium clay (SAND)	2.5YR4.6 red
11	2.0	6.8	22.2	0.02	6.1 medium clay	2.5YR4.8 red
11	3.2	6.6	23.3	0.03	3.6 sandy clay loam	10YR4.6 red
11	4.0	5.9	30.2	0.04	4.2 clay loam sandy	2.5YR4.8 red
11	5.0	6.0	62.0	0.10	5.2 sandy clay	2.5YR4.6 red
11	6.0	5.9	68.4	0.11	6.1 medium clay	2.5YRS.5 reddish brown
11	7.0	6.0	64.1	0.11	5.2 sandy clay	2.5YR3.6 dark red
11	8.0	6.1	105.9	0.16	5.3 fine sandy clay	2.5YR4.6 red
11	9.0	6.4	108.0	0.16	5.4 silty clay	5YR6.4 light reddish brown
11	10.0	6.5	101.3	0.16	6.1 medium clay	7.SYRS.4 brown
12	Surface	5.4	402	0.62	1.5 loamy sand	5YR4.2 dark reddish grey

Appendix 2. Profile Salt Storages for Selected Boreholes West of Camel Lake

HOLE No.	DEPTH (m)	% C1$^-$	DEPTH (m)	Est. Bulk Density (kg/m^3)	C1 (kg/m^2)
2	0.0- 2.0	0.05	2	1600	1.60
	2.0-3.5	0.12	1.5	1600	2.88
	3.5-4.5	0.33	1.0	1800	5.94
	4.5-5.5	0.37	1.0	1800	6.66
	5.5-17.8	0.63	12.3	1800	139.48
	Total C1$^-$ stored in profile over 17.8m = 156.56 kg/m^2				
3	0.0-0.5	0.13	0.5	1400	0.91
	0.5-1.5	0.15	1.0	1600	2.40
	1.5-2.0	0.29	0.5	1600	2.32
	2.0-3.0	0.40	1.0	1600	6.40
	3.0-4.0	0.48	1.0	1800	8.64
	4.0-4.5	0.45	0.5	1800	4.05
	4.5-5.0	0.38	0.5	1800	3.42
	5.0-5.5	0.51	0.5	1800	4.59
	5.5-6.5	0.73	1.0	1800	13.14
	6.5-19.0	0.42	12.5	1800	94.50
	Total C1$^-$ stored in profile over 19.0m = 156.56 kg/m^2				
4	0.0-0.1	0.01	0.1	1400	0.014
	0.0-0.1	0.04	0.4	1600	0.26
	0.5-1.5	0.09	0.1	1600	1.44
	1.5-2.3	0.10	0.8	1600	1.28
	2.3-2.6	0.11	0.3	1800	0.59
	2.6-3.0	0.14	0.4	1800	1.00
	3.0-3.4	0.15	0.4	1800	1.08
	3.4-3.8	0.12	0.4	1800	0.86
	3.8-4.4	0.14	0.6	1800	1.51
	4.5-5.0	0.17	0.6	1800	1.83
	5.0-24.9	0.42	19.9	1800	150.44
	Total C1$^-$ stored in profile over 24.9m = 160.30 kg/m^2				
5	0.0-1.0	0.01	1.0	1500	0.15
	1.0-2.6	0.05	1.6	1600	1.28
	2.6-4.5	0.1.	1.9	1700	3.23
	4.5-5.0	0.14	0.5	1800	1.26
	5.0-5.4	0.28	0.4	1800	2.02
	5.4-7.0	0.65	1.6	1800	18.70
	7.0-10.0	0.19	3.0	1800	10.26
	10.0-20.9	0.77	10.9	1800	151.07
	Total C1$^-$ stored in profile over 20.9m = 187.97 kg				
6	0.0-0.8	0.01	0.8	1400	0.11
	0.8-2.0	0.02	1.2	1600	0.38

HOLE No.	DEPTH (m)	% C1$^-$	DEPTH (m)	Est. Bulk Density (kg/m^3)	C1 (kg/m^2)
6	2.0-4.0	0.08	2.0	1800	2.88
	4.0-12.0	0.08	8.0	1800	11.52
	12.0-16.	0.27	4.0	1800	19.44
	16.0-23.	0.06	7.0	1800	7.56
	Total C1$^-$ stored in profile over 23.0m = 41.0 kg/				
8	0.0-0.1	0.32	0.1	1400	0.45
	0.1-1.0	0.22	0.9	1400	2.77
	1.0-2.0	0.59	1.0	1600	9.44
	Total C1$^-$ stored in profile over 2.0m = 12.66 kg/m^2				
10	0.0-0.5	<0.01	0.5	1400	<0.07
	0.5-1.2	0.01	0.7	1600	0.11
	1.2-2.0	0.04	0.8	1600	0.51
	2.0-4.0	0.05	2.0	1800	1.80
	4.0-5.0	0.06	1.0	1800	1.08
	Total C1$^-$ stored in profile over 5.0m = 3.57 kg/m^2				
11	0.0-0.04	<0.01	0.01	1400	<0.006
	0.04-1.0	0.01	0.96	1400	0.13
	1.0-2.0	0.02	1.0	1600	0.32
	2.0-3.2	0.03	1.2	1800	0.65
	3.2-4.0	0.04	0.8	1800	0.58
	4.0-5.0	0.10	1.0	1800	1.80
	5.0-6.0	0.11	1.0	1800	1.98
	6.0-7.0	0.11	1.0	1800	1.98
	7.0-8.0	0.16	1.0	1800	2.88
	8.0-9.0	0.16	1.0	1800	2.88
	9.0-10.0	0.16	1.0	1800	2.88
	Total C1$^-$ stored in profile over 10.0m = 16.08 kg/				
12	0.0-0.10	0.62	0.10	1400	0.87
	0.100.45	0.36	0.35	1400	1.76
	0.45-2.0	0.36	1.65	1600	9.50
	2.0-3.0	0.62	1.0	1800	11.16
Total C1$^-$ stored in profile over 3.0m = 23.30 kg/m^2					
13	0.0-0.1	0.46	0.10	1400	0.64
	0.1-0.5	0.48	0.40	1400	2.69
	0.5-1.0	0.43	0.60	1400	3.61
	1.0-2.0	0.43	1.00	1600	6.88
	2.0-3.0	0.53	1.00	1800	9.54
	3.0-4.0	0.51	1.00	1800	9.18
Total C1$^-$ stored in profile over 3.0m = 32.54 kg/m^2					

Appendix 3. North Stirling Bore Water Data

BORE	DATE	DEPTH (BGL +) (m)	C1$^-$ (mg/L)	EC (mS/m)
1	04/12/84	0.82	27257	6970
2A		2.13	24628	6470
2B		2.21	9584	2790
3A		0.84	22707	6080
3B		1.04	13305	3890
4A		0.97	17955	5020
4B		0.91	13770	3970
5		1.55	25740	6660
6		5.90	2949	888
7A		0.94	48174	10860
7B		0.59	30381	7460
8A		1.01	57324	11980
9		0.37	12172	3470
1	02/01/85	0.95	0	0
2A		2.24	25882	6330
2B		2.38	9786	2800
3A		0.81	23354	5880
3B		1.11	14033	3850
4A		1.03	0	0
4B		0.98	14114	3850
5		1.69	26539	6500
6		5.88	2644	851
7A		0.97	51864	10570
7B		0.74	32200	7340
8A		1.10	59447	11530
8B		0.83	28864	6850
9		0.49	12779	3460
10		5.41	4393	1313
11		9.64	6935	1908
12A		0.96	27904	6710
12B		1.17	25224	6270
13A		1.22	50348	10310
13B		0.87	31644	7270
14		0.80	28561	6760
1	05/02/85	0.88	-	6440

BORE	DATE	DEPTH (BGL +) (m)	C1$^-$ (mg/L)	EC (mS/m)
2A		2.39	-	5970
2B		2.51	-	2660
3A		0.73	-	5610
3B		0.94	-	3610
4A		0.94	-	4450
4B		0.94	-	3540
5		1.76	-	6180
6		5.81	-	796
7A		0.92	-	10040
7B		0.57	-	7200
8A		1.17	-	11030
8B		0.79	-	6530
9		0.47	-	3200
10		4.47	-	1362
11		7.88	-	1826
12A		0.98	-	6340
12B		0.99	-	5950
13A		1.11	-	9980
13B		0.77	-	7180
14		0.68	-	6390
1	01/03/85	0.97	-	-
2A		2.38	-	-
2B		2.58	-	-
3A		0.70	-	-
3B		1.09	-	-
4A		0.96	-	-
4B		0.94	-	-
5		1.87	-	-
6		5.70	-	-
7A		1.03	-	-
7B		0.70	-	-
8A		1.20	-	-
8B		0.89	-	-
9		0.47	-	-
10		4.40	-	-
11		7.79	-	-
12A		1.09	-	-
12B		1.12	-	-
13A		1.15	-	-

BORE	DATE	DEPTH (BGL +) (m)	C1$^-$ (mg/L)	EC (mS/m)
13B		0.86	-	-
14		0.79	-	-
1	01/04/85	1.12	-	-
2A		2.53	-	-
2B		2.70	-	-
3A		0.85	-	-
3B		1.33	-	-
4A		1.11	-	-
4B		1.12	-	-
5		2.20	-	-
6		5.71	-	-
7A		1.17	-	-
7B		86.00	-	-
8A		1.29	-	-
8B		1.06	-	-
9		0.57	-	-
10		4.45	-	-
11		7.83	-	-
12A		1.27	-	-
12B		1.29	-	-
13A		1.33	-	-
13B		1.12	-	-
14		0.97	-	-
			-	-
1	01/05/85	0.82		
2A		2.46	-	-
2B		2.63	-	-
3A		0.79	-	-
3B		0.93	-	-
4A		0.93	-	-
4B		0.85	-	-
5		1.91	-	-
6		5.65	-	-
7A		0.88	-	-
7B		0.57	-	-
8A		1.22	-	-
8B		0.71	-	-
9		0.57	-	-
10		4.34	-	-
11		7.73	-	-

BORE	DATE	DEPTH (BGL +) (m)	C1$^-$ (mg/L)	EC (mS/m)
12A		0.91	-	-
12B		0.87	-	-
13A		1.08	-	-
13B		0.77	-	-
14		0.63	-	-
1	11/06/85	0.76	27478	6640
2A		2.61	25093	6230
2B		2.71	14125	3750
3A		1.04	22929	5810
3B		0.84	14275	3990
4A		1.01	13648	3760
4B		0.93	13911	3850
5		2.02	25760	6320
6		5.67	2511	811
7A		0.91	53330	10370
7B		0.37	34091	7720
8A		1.20	59750	11260
8B		0.47	27014	6500
9		0.54	12395	3440
10		4.37	5186	1523
11		7.80	6774	1917
12A		0.81	28065	6750
12B		0.85	25336	6230
13A		1.06	49261	10010
13B		0.68	31078	7230
14		0.47	27560	6620

Appendix 4. Hydraulic Conductivities Determined by the Slug Withdrawal Method

BORE	HYDRAULIC CONDUCTIVITY (m/day) x 10^{-3}
1A	1.73
2A	6.75
3A	8.30
4A	2.52
4B	2.52
5	53.3
6A	3.01
7A	1.44
8A	4.41
8B	25.2
1OA	2.74
11A	13.0
12A	29.3
13A	1.26
13B	159

Appendix 5. Borehole Data

BORE	PIEZOMETER (F) OR OBSERVATION (0)	RGL (m)	DEPTH DRILLED (m)	z_0 (m)	LENGTH OF SLOT AT BASE OF HOLE (m)
1	P	100.00	25.5	74.5	2
2A	P	100.10	17.0	83.1	2
2B	0	100.10	4.1	(96.0)	*
3A	P	100.68	18.8	81.9	2
3B	0	100.68	1.4	(99.3)	*
4A	P	101.68	22.0	79.9	2
4B	P	101.68	9.9	91.8	2
5	P	103.70	20.2	83.5	2
6	P	114.69	33.7	92.0	2
7A	P	101.91	27.0	74.9	2
7B	0	101.91	0.9	(101.0)	*
8A	P	102.08	27.0	75.1	2
8B	0	102.08	5.9	(96.2)	*
9	0	110.46	6.3	(104.2)	*
10	P	115.84	6.2	109.6	2
11	P	113.70	18.2	95.5	2
12A	P	102.61	6.2	96.4	2
12B	0	102.61	6.7	(95.9)	*
13A	P	101.90	22.0	79.9	2
13B	0	101.90	6.1	(95.8)	*
14	0	102.21	4.5	(97.7)	*

RGL = Relative Ground Level (m)

z_0 = Relative level of hole bottom (m)

The point of measurement z for each bore is taken as $z_0 + \frac{\text{slot length}}{2}$

All piezometer radii = 0.0215m

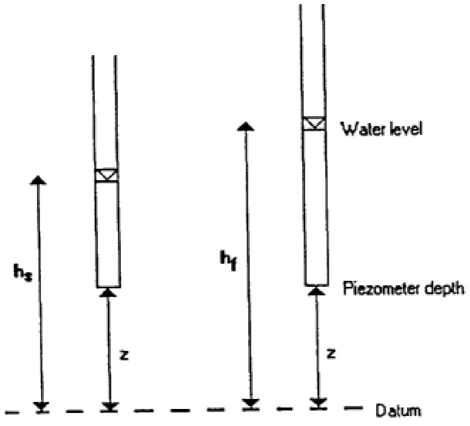
All drill bit radii = 0.0375m

* For observation bores the length of the slot depends on the watertable level;

Slot length = (RGL - BGL) - z_0

(where BGL = watertable depth Below Ground Level).

Appendix 6. Conversion of Salt Water Heads to Distilled Water Heads (F. Lewis, p. comm.)



hf = $(h_s - z)D_s + z$
D_f

hf = distilled water head (in metres)

hs = measured salt water head

s = density of the bore water. [The density of NaC1 saline water of various concentrations is given in the Handbook of Chemistry and Physics, (1983)].

f = density of distilled water (at 20oC)

z = height of point of measurement above datum level.

Appendix 7. Water and Salt Balance of Lake

The water balance for a lake for a given time period is:

$$dV = P - E + SD_i - SD_0 + G_i - G_0 \qquad (1)$$

where

V = the volume of water in the lake (m^3)
P = the precipitation (m^3)
E = the evaporation (m^3)
SD_i = surface drainage in (m^3)
SD_0= surface drainage out (m^3)
G_i = groundwater flow in (m^3)
G_0 = groundwater flow out (m^3) (comprising both lateral outflow and outflow leakage via the lake floor).

(1) can be simplified to:

$$dV = P - E + G_i - G_0 \text{ where } SD_i \text{ and } SD_0 = 0 \qquad (2)$$

The mass balance for salt, for example chloride of the lake described by (2) is:

$d(VC_1)$

= $PC_p + G_i CG_i - G_0 CG_0$ which is equivalent to:

dt

$$\begin{array}{ccccc} dV & & dV & & \\ C_1 & + & V & = & PC_p + G_i CG_i - G_0 CG_0 \ (3) \\ dt & & dt & & \end{array}$$

where

C_1 = the concentration of $C1^-$ in the lake (mg/L)
C_p = the concentration of $C1^-$ in rain
CG_i = the concentration of $C1^-$ in inflow
CG_0 = the concentration of $C1^-$ in outflow

For a well mixed lake $CG_0 = C_1$

To determine if there is a significant groundwater outflow from the lake G_0 can be evaluated using the water balance equation and classical hydrological techniques or by simultaneously solving equations (2) and (3), calculating groundwater inflow and then substituting back into equation (2).

Evaporation measurements would need to be taken with a floating pan filled with lake water and precipitation measured by gauges installed near the lake. While the lake was dry during the summer months tensiometers could be installed to determine potential gradients. Then using Darcy's Law a comparison could be made between outflows determined via equations (2) and (3) and those using hydraulic gradient and hydraulic conductivity data.

Sampling would give values for C_p, CG_i and C_1 and V could be deduced by a bathymetric survey.

A simpler approach would be to choose a period when P was zero, then(2) becomes:

$dV=E+ G_i -G_0$

or $G_i-G_0=V+E$

Assuming no rain for a month in summer a representative value for E would be 200 mm. If the lake level fell 300 mm then:

$G_i-G_0 =-300 +200$
$= -100mm$

If one assumes no significant groundwater inflow over the month due to low hydraulic gradients and low transmissivities (an assumption which could be tested by the installation of a bore network around the lake) then:

$G_0= 100mm$

This implies 100 mm of vertical leakage if the assumption in regards to lateral inflow applies to lateral outflow.

Relative concentrations of stable isotopes of water can also be used to determine leakage from bodies of water.