Review of current drainage investigations in Western Australia

R.A. Nulsen
IMPORTANT DISCLAIMER

This document has been obtained from DAFWA's research library website (researchlibrary.agric.wa.gov.au) which hosts DAFWA's archival research publications. Although reasonable care was taken to make the information in the document accurate at the time it was first published, DAFWA does not make any representations or warranties about its accuracy, reliability, currency, completeness or suitability for any particular purpose. It may be out of date, inaccurate or misleading or conflict with current laws, polices or practices. DAFWA has not reviewed or revised the information before making the document available from its research library website. Before using the information, you should carefully evaluate its accuracy, currency, completeness and relevance for your purposes. We recommend you also search for more recent information on DAFWA's research library website, DAFWA's main website (https://www.agric.wa.gov.au) and other appropriate websites and sources.

Information in, or referred to in, documents on DAFWA's research library website is not tailored to the circumstances of individual farms, people or businesses, and does not constitute legal, business, scientific, agricultural or farm management advice. We recommend before making any significant decisions, you obtain advice from appropriate professionals who have taken into account your individual circumstances and objectives.

The Chief Executive Officer of the Department of Agriculture and Food and the State of Western Australia and their employees and agents (collectively and individually referred to below as DAFWA) accept no liability whatsoever, by reason of negligence or otherwise, arising from any use or release of information in, or referred to in, this document, or any error, inaccuracy or omission in the information.
Report on Land Degradation Investigations
Kent River Soil Conservation District

Ron Colman
David Miers

Resource Management Technical Report 49
Disclaimer

The contents of this report were based on the best available information at the time of publication. It is based in part on various assumptions and predictions. Conditions may change over time and conclusions should be interpreted in the light of the latest information available.

© Director General, Department of Agriculture Western Australia 2004
## Table of Contents

Summary ........................................................................................................................................... 1  

1. Introduction .......................................................................................................................... 2  

2. Environmental Background ............................................................................................... 2  
   2.1 General ............................................................................................................................ 2  
   2.2 Geomorphology ................................................................................................................ 2  
   2.3 Geology ........................................................................................................................... 3  

3. Study Programme .................................................................................................................. 4  

4. Results .................................................................................................................................... 5  
   4.1 General ............................................................................................................................ 5  
   4.2 Backhoe pits ...................................................................................................................... 5  
   4.3 Drilling and monitoring results ....................................................................................... 6  
   4.4 Geophysical surveys .......................................................................................................... 6  
      4.4.1 Transient Electro-magnetic Induction Survey .......................................................... 6  
      4.4.2 Airborne Electromagnetic Survey ........................................................................... 8  

5. Discussion ................................................................................................................................ 9  

6. Recommendations .................................................................................................................. 11  

7. Bibliography ........................................................................................................................... 12  

8. Glossary ................................................................................................................................... 13
Summary

Based on topographic information, geological data and interpreted palaeohydrology, it is considered that the area covered by the Kent River Soil Conservation District contains three separate palaeodrainage systems which are thought to have been the upper reaches of the Hay, Frankland and Kalgan Rivers.

These ancient drainage lines have been infilled with alluvial deposits of clay, silt, sand and gravel and exhibit complex groundwater regimes which result in shallow, saline watertables in many places throughout the area.

The present Kent River north of the Muir Highway is a mature river system, while south of the Highway the river has been rejuvenated due to continental uplift and its position on the sloping continental margin. The uplift of the Australian continental landmass is thought to have been associated with the separation of Antarctica from Australia in the Eocene (approximately 50 million years ago).

The land surface in the study area is undulating with low relief. Runoff during winter accumulates in lake chains and swampy, low-lying areas in the infilled, palaeodrainage lines. Outflow from these areas is restricted by the ill-defined and discontinuous nature of the present drainage systems.

When runoff does reach the Kent River it is further retarded due to the restrictive effect of several road crossings which do not have the adequate drain capacities and the variable grades of the river bed.
1. Introduction

The National Soil Conservation Programme has provided funding for investigation into land degradation in four areas located throughout the West Australian wheatbelt. The areas are the Kent River and Mobrup catchments plus the Wickepin and Mt Marshall shires. This initial report summarises the investigative work undertaken in the Kent River Soil Conservation District during the first half of 1985.

2. Environmental Background

2.1 General

The study area covered approximately 1,000 km$^2$ of the Kent River Catchment and comprise a triangle between Mt Barker, Rocky Gully and Cranbrook in the southwest of Western Australia (Figure 1). Only 58% of the catchment is cleared partly due to the introduction of clearing bans in 1978 by the State Government. The Kent River is regarded as a potential water supply resource for both the south coastal towns and the Great Southern District. To date, approximately $7m has been spent by the Water Authority of Western Australia (WAWA) to compensate farmers for not being able to use their land due to the clearing ban. Despite this ban, continuing land degradation is causing concern to farmers. The main degradation problem are waterlogging and secondary salinization in the broad flat valleys due to uncontrolled runoff and a restricted drainage system.

The main land uses are merino wool production and cereal cropping (wheat, oats and barley). The area is serviced by a network of sealed or graded unsealed roads (Figure 2).

The area has a Mediterranean climate with warm, dry summers and cool, wet winters. Annual average rainfall ranges from 750 mm in the south to 625 mm in the north with the majority (65%) of the rainfall being recorded in the period from May to October.

Jarrah \( (Eucalyptus marginata) \) forest is the predominant vegetation formation with minor stands of marri \( (E. calophylla) \) on patches of heavier soil. Swamps occur as narrow strips along drainage lines and carry a community of reeds and heath shrubs such as \( Beaufortia sparsa \) and \( Kunzea ericifolia \). The larger expanses of swampy ground occupying broad flat valley bottoms contain reeds and paperbark trees \( (Melaleuca cuticularis) \). A more detailed description of the vegetation is provided by Beard (1979).

2.2 Geomorphology

The land surface slopes gently from an elevation of 310 m in the north-west to between 230 and 250 m in the middle and south-eastern sections of the study area. The northwest plain is characterised by gently undulating surfaces covered with laterite and sand which represents the old duricrust land surface.

A central plain which occupies most of the area is also gently undulating but contains streams which discharge into old drainage systems incised into broad, flat valleys.
Such flat-floored valleys are thought to have resulted from Tertiary infilling of extensive, meandering drainage lines.

This plain is dissected by the headwaters of the southwesterly flowing Kent River as the river flows towards the coast. The Kent River is the current drainage system for some runoff from the area. A large portion of the runoff does not find its way into the Kent River and is ponded in the lakes and swamps of the old Tertiary drainage system (e.g. Lake Poorrarecup, Lake Carabundup, Kwornicup Lake and Nunijup Lake) which have limited connection to the present drainage system.

2.3 Geology

The geology of the study area is presented in the Mt Barker-Albany 1:250,000 geological map and described in the explanatory notes (Muhling and Irakel, 1985). The geology of the area is dealt with briefly in this section.

The Albany-Fraser Geological Province underlies the study area and comprises Proterozoic gneiss, high-grade metamorphic rocks, and granitoids. However, there is very little bedrock outcrop due to lateritization of the land surface and the subsequent deposition of extensive alluvial deposits in the broad, flat valleys and colluvium on the gently undulating slopes. Even the present drainage system has failed to expose the bedrock due to the deposition of clay, silt and gravel in the watercourses (Figure 3).
3. Study Program

The initial step in the study was the identification of the problems within the Soil Conservation District as perceived by the farmers. From discussion at committee meetings and site visits it was evident that the major concern was waterlogging in the broad, flat valleys and other areas of low relief. Where the ground was waterlogged for extended periods there was associated secondary salinization.

Following identification of the problems, all available information relating to geology, hydrology and soils was collected. The data base included soil and geological surveys, topographic maps, aerial photography, Landsat imagery, bore data, salinity records and stream flow hydrographs. Interpretation of these data led to the definition of the hydrogeologic factors dominant in the Kent River Catchment. Models of the processes causing the waterlogging were tested by field investigations which included backhoe pits, piezometer networks and geophysical surveys.
4. Results

4.1 General

Collection of existing data provided a sound basis for the work in the Kent River area. The topography is undulating with gentle upper slopes (3% to 8%) which grade into near flat lower slopes. The valley floors are broad (1 to 2 kilometres) and flat creating large depressions in the landscape. Except for the Kent River, most drainage is ill-defined and/or discontinuous. Flow of water in most areas occurs only after extended rainfall and the ponding of large volumes of water in the depressions and on the flats.

The geological survey indicated that the whole area was covered by an extensive blanket of Cainozoic deposits with little bedrock exposure. These detrital materials consist of mixed alluvial and lake deposits in the broad, flat valleys and colluvium on the hillslopes with laterite developed on the hilltops and ridges. Nearly all the lakes in the study area have sand dune ridges called lunettes on their southeastern shore. Lunettes occur throughout the southern half of Australia and are formed from sand/silt/clay material (Stephens and Crocker, 1946). It was evident that the lunettes had been formed by wind action, and Stephens and Crocker (op. cit) suggested that they were derived from deflation of lake floors when dry. The lunettes in the Kent River area are up to 5 m above the surrounding landsurface.

Many of the lakes in the area once contained fresh water, however, with the clearing of land for agricultural use salinity levels have risen making most lakes unsuitable for use as water supplies. The salinity increase in Big Poorrarecup Lagoon, from which stock water was carted during the 1969/70 drought, has been investigated by Bestow (1979). He concluded that the lake was sustained by rainfall and substantial groundwater inflow. The clearing of native vegetation has resulted in the release of salt stored in the soil profile, with consequent increases in groundwater salinity. This has produced a rise in lake salinity of 230 mg/L per year since about 1964.

There are few successful bores in the study area which provide small quantities of water to supplement farm dams for stock water supplies. As large quantities of low-salinity groundwater are not present in the area, most domestic supplies are obtained from rainwater tanks.

4.2 Backhoe pits

Backhoe pits were excavated during May and June 1985. The pits were located throughout the study area, to encompass the range of geomorphic and hydrologic conditions (Figure 4).

The broad, flat valleys were found to be filled with deposits of silt and clay with sand and gravel lenses. Soil development was variable both in depth and lateral extent due to reworking of the surface materials.

The hillsides have well developed duplex soils (Db and Dy) (Northcote, 1979) with sand to sandy loam over clay. Some lower slopes have sandy clay loam to clay loam soils which inhibit drainage. Where a hard subsurface pan has developed, uniform sandy barns to clay loams have resulted (Uc and Um). A large portion of the clayey
subsoils on the lower slopes were found to be gleyed which is indicative of permanent or periodic chemical reduction processes due to waterlogging.

4.3 **Drilling and monitoring results**

Drilling using a rotary auger was completed during July, 1985. The purpose of the drilling programme was two-fold: (1) to gain further geological information and (2) to install piezometers and observation wells to measure hydraulic gradients and water levels. Each piezometer nest consisted of a deep piezometer (to about 10 m) to measure the pressure of the deep groundwater and a shallow observation well (to about 4 m) to measure the static level of the watertable. Figure 5 indicates the location of the nests throughout the catchment.

The drilling confirmed the interpretation of the subsurface geology and showed alluvial deposits greater than 10 m thick in the main valleys and colluvial material up to 3 m thick overlying weathered bedrock.

Water levels taken from the shallow observation wells are presented in Table 1. The watertable at nearly all drilled sites was at or within 1 m of the surface on 14/10/1985.

The deep piezometers along with the shallow observation wells provided information on the vertical hydraulic gradient of the groundwater system.

Eleven of the sixteen sites showed upward hydraulic gradients ranging from 0.17 to 0.011. Downward gradients were much lower, ranging from 0.04 to 0.0017. Gradients for each site are presented in Table 2.

Salinities varied considerably between sites with the shallow watertable ranging from 3705 mg/l to 35,530 mg/l. The deeper groundwater had a similar salinity range from 7090 mg/l to 29,535 mg/l. Salinities for all sites are included in Table 3.

4.4 **Geophysical surveys**

4.4.1 **Transient Electro-magnetic Induction Survey**

Transient electro-magnetic (EM) surveying is based on evaluation of the resistivity of subsurface material by passing a known current through the ground at one point and measuring the potential difference at another point. Resistivity increases with increasing porosity, decreasing water content, and decreasing salt content of the water in the formation. As resistivity is the inverse of conductivity the more water and higher salt content allows easier conductance of the current, therefore reducing the resistivity.

This survey was conducted using the Geonics E.M. 37 transient electromagnetic system to map both the salinity of the near surface soil and to outline the subsurface geology which may be influencing salt distribution. The information collected included type and depth of materials, depth of weathered zone, depth to groundwater, depth
to bedrock and salt content of groundwater. The depth of the watertable in unconfined aquifers could not be determined with accuracy because the water content in the unsaturated zone often was too high to yield a significant difference between the resistivity above and below the watertable.

Site work was carried out during the period 15-19th April 1985 and consisted of soundings at 13 sites (see Figure 6 for locations). A separate report covers the sounding results and interpretation (P and V Geophysical Services, 1985, E.M. 37 Trial Survey, Kent River Catchment Area). The conclusions to be drawn from the survey were:

(i) the soundings recorded a single, uniform resistivity layer for the sedimentary alluvium-colluvium sequence. Therefore, the soundings were not able to identify variations of salt content with depth within the overburden;

<table>
<thead>
<tr>
<th>Bore</th>
<th>TDS (mg/L)</th>
<th>Resistivity (ohm.m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LS1</td>
<td>3100</td>
<td>4</td>
</tr>
<tr>
<td>LS2</td>
<td>6500</td>
<td>1.9</td>
</tr>
<tr>
<td>LS3</td>
<td>5900</td>
<td>2.2</td>
</tr>
<tr>
<td>LS4</td>
<td>1980</td>
<td>3.6</td>
</tr>
<tr>
<td>LS5</td>
<td>2650</td>
<td>4.2</td>
</tr>
</tbody>
</table>

(ii) a wide range of overburden resistivities were recorded (0.1 to 8 ohm metres). It would be expected that the lower values recorded would correlate with a higher salt content in the sediments;

(iii) the sedimentary overburden/bedrock interface was determined and its depth calculated for the majority of soundings. Where this was not possible was due to highly conductive material being identified at depth, which indicated an underlying, decomposed bedrock containing highly saline groundwater;

(iv) bedrock resistivities ranged upwards from 30 ohm.m depending on degree of weathering.

Five soundings were completed adjacent to previously drilled test holes, LS1 to LS5 (Figure 6), to permit comparison of the E.M. 37 data with a known geological section.

In general, thickness estimated from the soundings agreed with the drill results. Discrepancies occurred at sites where the sediments were predominantly dry and did not exhibit a resistivity contrast with the underlying decomposed bedrock.

A comparison between sounding overburden resistivities and groundwater total dissolved salts (in milligrams per litre) is as follows:
4.4.2 **Airborne Electromagnetic Survey**

In June 1985, Geoterrex Pty Ltd conducted an airborne electromagnetic (INPUT) and magnetic survey of the Kent River area. The survey was flown over the central area of the Kent River Soil Conservation District covering the Kent River and lakes Carabundup and Nunijup as shown in Figure 7.

A separate report (Geoterrex Pty Ltd, 1985) was produced which summarised the logistics, data acquisition parameters, calibration procedures, processing and interpretation details of the survey. The interpretation of the data was based primarily on the apparent resistivity contour map and the multiplots which were generated from the electromagnetic data. The two principal responses within the area were believed to come from:

(a) saline groundwater within alluvial deposits, and  
(b) conductive clay formations within weathered bedrock.

The survey mapped four major zones within the study area (Figure 8). Two of these zones (Zones A and B) were widespread and generally occurred as northwest trends. Zone A delineated the primary areas of alluvial deposition in the valleys which contained saline groundwater. The survey interpreted variable thicknesses from 20 metres to more than 50 metres.

Zone B is considered to be a secondary zone of colluvium and alluvium, and in most parts represented groundwater conditions of lesser salt concentrations than Zone A. Areas designated Zone B are considered to be areas which could become salt affected in the future.

Zones C and D represented more resistive areas which were probably related to weathered bedrock and laterite capping respectively. Neither of these zones appear to be affected by salting.
5. Discussion

It is apparent from this work that the chains of lakes in the Kent River Soil Conservation District are remnants of ancient river courses.

The lakes occupy the floors of valley systems that were once active drainage lines but are now filled with alluvial deposits of clay, silt, sand and gravel. This infilling of the water courses has resulted in a present day drainage system which is ill-defined and discontinuous. Runoff accumulates on flat land and in low-lying areas where it causes waterlogging and exacerbates secondary salinization by contributing to the rising groundwater.

The change in the hydrologic environment was probably due to several factors in the past including tectonic movement and climatic change but probably the most influential change has been that resulting from the effects of uplifting and tilting which dictate the position and state of the present drainage systems.

Geological and topographic data indicate the existence of three palaeodrainage systems as shown in Figure 9. It is considered that these systems were once active tributaries of the Hay, Frankland and Kalgan Rivers. However, at a late stage in their development, tectonic movement of the landsurface reduced the gradients of the drainage lines to the point where streamflow could not remove the sediments which were being washed into the valleys from erosion of the surrounding hills. Coupled with the tectonic movement was a further reduction in flow as a result of an arid climatic period. Changes in climate are evidenced by wind blown (or aeolian) sand ridges and lunettes on the south-eastern side of most lakes which are indicative of extended drier periods.

The tectonic movement is thought to be associated with uplift of the interior of Western Australia. This epeirogenesis probably resulted from the separation of Antarctica from Australia during the Eocene (Cope, 1975). Epeirogeny is the uplifting of a continental landmass as a result of widespread adjustment of level. Movements are generally even in character, producing little more than tilting with slight warping and minor faulting of the rocks around the margin.

The drifting apart of Australia and Antarctica started in the late Palaeocene (e.g. 50 m yr ago) (Falvey, 1974) and continued through the Eocene with minor adjustments occurring in the Miocene (e.g. 20 m yr ago) Following the latest uplift, the continental landmass lies at an average height above sea level of about 350 m. Surface contours indicate an east-west axis of uplift with a gentle westward plunge. The hinge line is considered to be the Jarrahwood axis as defined by Cope (1972).

Cope op. cit also identified a slight reversal of dip to the north of the Axis resulting in a depression. Figure 10 is a generalised topographic profile running perpendicular to the South Coast through the Kent River area and identifying a depression north of the Jarrahwood Axis which runs east-west approximately in line with the Muir Highway at this point.

Magnetic surveys conducted by the Bureau of Mineral Resources (BMR) identified an east-west zone of intense anomalies which were interpreted as the axis of a major
tectonic movement. The BMR map is reproduced in Figure 11 and the position of the study area is indicated.

Under present hydrologic conditions runoff flows into the chains of lakes and swampy depressions developed in the palaeodrainage lines. However, the water has no escape from these areas due to the lack of defined drainage lines. It is only after intense or extended runoff has filled these low lying areas, usually towards the end of winter, that the Kent River experiences peak flows.

Further problems are encountered once the runoff reaches the Kent River. The river bed north of the Muir Highway is flat and wide with an average river gradient of less than 1:900. The culvert pipe capacities of public road crossings at Poorrarecup Road, Kidman Road and Mallawillup Road are inadequate and retard river flow, which periodically causes a flooding problem on the low flats adjacent to the Kent River.

A large portion of these low-lying areas adjacent to the Kent River have been made unproductive due to flooding and subsequent waterlogging. Several areas directly upstream from the road crossings are now only bare ground with dead and dying trees.

Final interpretation will lead to development of a range of treatments and management options which should result in effective husbandry of the lands in the district to reduce waterlogging and salinization problems.
6. Recommendations

The major problem in the Kent River Soil Conservation District is waterlogging of flat, low-lying land. This results in lost production due to the inability of the farmer to crop the land or produce pasture suitable for grazing and exacerbates the secondary salinization in the area.

To alleviate this problem it is essential that:

(i) the runoff from the hillslopes be controlled
(ii) the outflow of water from flooded areas be increased.

These measures need to be achieved over the whole catchment by:

- using appropriate earthworks to control runoff in order to keep it off poorly drained, flat, low lying areas;
- disposing of the runoff onto suitable water disposal areas.
- assisting drainage of flooded areas by removing restrictions to flow and by constructing suitable drains and banks.
- tree planting on recharge areas and salt affected areas to decrease infiltration to groundwater and to increase the water quality of the Kent River.
- reconstructing road crossings to enable culvert capacities to carry river discharges and to reduce upstream flooding.
- undertaking further investigations into groundwater movements within the palaeodrainage system to gain a better understanding of the saline groundwater table and the occurrence of secondary salinization. This will enable determination of aquifer properties and evaluation of specific sites which might be suitable for pumping to relieve groundwater pressures.
- undertaking studies of alternative agronomic agricultural practices to obtain better use of available water.
7. Bibliography

Beard, J.S. (1979). The Vegetation of the Albany and Mt Barker areas, Western Australia: Vegetation of Western Australia, 1:250,000 series, map and explanatory memoir, Vegmap Publications, Sydney.


8. Glossary

**ALLUVIAL**
Weathered material which is transported by a river and deposited at points along the course of the river.

**AXIS (HING LINE)**
The line of folding/faulting along which a change in the amount and/or direction of dip takes place.

**CAINOZOIC**
The division of geological time which has a duration of approximately 63 m.y. from 65 m.y. to 2 m.y. It is commonly used as a synonym for Tertiary.

**COLLUVIAL**
Weathered material transported by gravity which is still at, or near, its point of formation.

**DETRITAL**
A term applied to any particles of minerals, or, more rarely, rocks, which have been derived from pre-existing rocks by processes of weathering.

**DURICRUST**
A layer of strongly cemented material occurring in unconsolidated sediments, often found immediately below the surface - a near synonym of hardpan.

**ELECTROMAGNETICS**
A widely used geophysical prospecting technique. It is based on the induction of electric currents in buried conductors; in this case aquifers with saline groundwater; by the magnetic components of electromagnetic waves generated at the earth’s surface or in aircraft above its surface.

**EOCENE**
A stage of the Tertiary period from 54 m.y. to 38 m.y.

**GNEISS**
A term applied to banded rocks formed during high-grade regional metamorphism (reheating and folding). The term Proterozoic gneiss is used in a stratigraphic sense referring to the time period in which the metamorphism occurred; Proterozoic is the later part of the period of time from the consolidation of the earth’s crust to the base of the Cambrian (600 m.y.). Granitoid is a near synonym.

**HYDRAULIC CONDUCTIVITY**
This term refers to the ability of a material to allow water to flow through it. It is nearly synonymous with permeability.

**HYDRAULIC GRADIENT**
The difference in depth to the watertable at two separate points measured along the streamline on
which the points are located is called the hydraulic gradient of the flow and indicates the direct of flow.

**LATERITE**

A residual deposit formed under special climatic conditions with a well marked division of the year into wet and dry seasons. Laterities consist essentially of hydrated iron oxides which are left after extensive leaching of the original rock.

**PALAEO DRAINAGE**

A term meaning ancient drainage. It represents a reconstruction of the presumed drainage patterns, especially the relative positions of rivers, at a particular period in the past.

**PIEZOMETER**

Piezometer is a small diameter bore designed for monitoring water levels and groundwater pressures and for sampling groundwater.

**RESISTIVITY**

This term refers to the electrical properties of the earth and the use made of variations in these properties to define subsurface geology. The resistivity, the inverse of conductivity, governs the amount of current which passes through the ground when a specific current is applied at one point and measured at another. The salinity of water in aquifers is probably the most critical factor determining the resistivity.

**TECTONIC MOVEMENT**

A term used to relate a particular phenomenon to movements of the earth’s crust.

**WATERLOGGING**

Soil is said to be waterlogged if any part of the plant root zone is saturated with water. In severe cases soil is saturated to the surface and waterlogging is obvious. Waterlogging is distinguished from flooding in which surface runoff brings down water from higher up the catchment. However, flooding may result in waterlogged sites.
Table 1: Water Levels as of 14.10.1985

<table>
<thead>
<tr>
<th>BORE NO. 1</th>
<th>DEPTH TO WATER (M)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>+0.59</td>
</tr>
<tr>
<td>2</td>
<td>0.21</td>
</tr>
<tr>
<td>3</td>
<td>+0.22</td>
</tr>
<tr>
<td>5</td>
<td>0.19</td>
</tr>
<tr>
<td>6</td>
<td>0.70</td>
</tr>
<tr>
<td>7</td>
<td>0.36</td>
</tr>
<tr>
<td>8</td>
<td>0.43</td>
</tr>
<tr>
<td>9</td>
<td>+0.06</td>
</tr>
<tr>
<td>10</td>
<td>+0.14</td>
</tr>
<tr>
<td>11</td>
<td>0.44</td>
</tr>
<tr>
<td>12</td>
<td>0.47</td>
</tr>
<tr>
<td>13</td>
<td>0.41</td>
</tr>
<tr>
<td>14</td>
<td>0.28</td>
</tr>
<tr>
<td>15</td>
<td>+0.29</td>
</tr>
<tr>
<td>16</td>
<td>1.67</td>
</tr>
</tbody>
</table>

* All readings are below ground level except for those marked + which means above ground level.
TABLE 2: Hydraulic Gradients at Bore Sites

<table>
<thead>
<tr>
<th>BORE NO.</th>
<th>HYDRAULIC GRADIENT**</th>
<th>DIRECTION OF GRADIENT***</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0017</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>0.086</td>
<td>+</td>
</tr>
<tr>
<td>3</td>
<td>0.022</td>
<td>+</td>
</tr>
<tr>
<td>5</td>
<td>0.018</td>
<td>+</td>
</tr>
<tr>
<td>6</td>
<td>0.040</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>0.040</td>
<td>+</td>
</tr>
<tr>
<td>8</td>
<td>0.044</td>
<td>+</td>
</tr>
<tr>
<td>9</td>
<td>0.062</td>
<td>+</td>
</tr>
<tr>
<td>10</td>
<td>0.054</td>
<td>+</td>
</tr>
<tr>
<td>11</td>
<td>0.058</td>
<td>+</td>
</tr>
<tr>
<td>12</td>
<td>0.011</td>
<td>+</td>
</tr>
<tr>
<td>13</td>
<td>0.039</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>0.018</td>
<td>-</td>
</tr>
<tr>
<td>15</td>
<td>0.000</td>
<td>+</td>
</tr>
<tr>
<td>16</td>
<td>0.016</td>
<td>-</td>
</tr>
</tbody>
</table>

* difference in water levels 
  difference in depth of bores = Hydraulic Gradient

** using readings as of 14.10.1985

*** + upwards; downwards
TABLE 3: Bore Salinities as of 14.10.1985*

<table>
<thead>
<tr>
<th>BORE NO•</th>
<th>SHALLOW BORE</th>
<th>DEEP BORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9724</td>
<td>9653</td>
</tr>
<tr>
<td>2</td>
<td>10071</td>
<td>8085</td>
</tr>
<tr>
<td>3</td>
<td>12980</td>
<td>12430</td>
</tr>
<tr>
<td>4</td>
<td>-</td>
<td>9631</td>
</tr>
<tr>
<td>5</td>
<td>35530</td>
<td>29535</td>
</tr>
<tr>
<td>6</td>
<td>3878</td>
<td>14245</td>
</tr>
<tr>
<td>7</td>
<td>21450</td>
<td>19580</td>
</tr>
<tr>
<td>8</td>
<td>14520</td>
<td>16720</td>
</tr>
<tr>
<td>9</td>
<td>17875</td>
<td>20350</td>
</tr>
<tr>
<td>10</td>
<td>27610</td>
<td>24090</td>
</tr>
<tr>
<td>11</td>
<td>14355</td>
<td>13805</td>
</tr>
<tr>
<td>12</td>
<td>20625</td>
<td>16610</td>
</tr>
<tr>
<td>13</td>
<td>6331</td>
<td>7865</td>
</tr>
<tr>
<td>14</td>
<td>24145</td>
<td>23870</td>
</tr>
<tr>
<td>15</td>
<td>9658</td>
<td>7706</td>
</tr>
<tr>
<td>16</td>
<td>3705</td>
<td>7090</td>
</tr>
</tbody>
</table>

* Salinities expressed in mg/L Total Soluble Salts.
Figure 2. Detailed Map of Study Area

Boundary of Kent River Soil Conservation District

Scale 1:250,000
Figure 3. Geology of the Kent River Catchment
LEGEND

ZONE A Interpreted areas of porous drainage and high groundwater and surface salinity

ZONE B Salt affected areas which have the potential of becoming highly saline.

ZONE G Weathered bedrock - clay?

ZONE D Laterite? Crystalline bedrock?

Scale 1:100,000

Figure 8. Interpretation Map
Figure 10. Generalised Topographic Profile through the Kent River
Figure 11. BMR Total Magnetic Intensity Contour Map of the Mt. Barker-Albany area