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Preliminary groundwater and salinity investigation in the eastern wheatbelt. 1. Brennand's Catchment

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Preliminary Groundwater and Salinity Investigations in the Eastern Wheatbelt
1. Brennand's Catchment

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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.

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1. Summary

Brennand's catchment study was undertaken to determine the impact that clearing 450 ha of native vegetation would have on the development of salinity in the catchment. The study also offered the opportunity to enquire into the processes which led to the formation of ancestral groundwater discharge landforms, observed at the site. These landforms have direct relevance for predicting the spread of future salinity since they mark ancient phases of salinization, and may offer a guide for the current situation related to the spread of the modern phase of salinity.

Groundwaters were found to be 10 in below the floor of the ancestral playa lake in Brennand's catchment. They were extremely saline (~50,00O mg/L TDS). A groundwater flow system was not established on much (80%) of the catchment. Flow was observed to be occurring from recharge areas near the playa lakes (lunettes), towards the midslopes of the catchment. In this area the flow direction did not conform to the catchment's topography. Flow was apparently restricted from leaving Brennand's catchment because of obstruction to groundwaters created by dolerite dykes.

Using estimated historic groundwater gradients, observed from markers in the deeply-weathered zone and presumptions about the likely flow systems within the catchment, a model groundwater flow regime was established for the playa lake. Using the late Pleistocene climatic record and a playa lake genesis model of Bowler and Teller (1986) as a guide, it was estimated that the playa lake would have achieved a maximum discharge of approximately 700 m^3/yr (0.03 mm/yr of recharge). By comparison, recharge under agricultural conditions would be likely to be two orders of magnitude (~1-10 mm/yr) higher.

Given the depth to groundwater observed in the vicinity of the playa lake (10.00 m) and the estimated annual piezometric level rise (0.1 m/yr), it could be expected that when salinity developed in about 100 years, a large area of the catchment upslope from the playa lake would become saline as a result of groundwater discharge. Clearing an additional 25% of the catchment will hasten the process and create the need for a larger discharge area.

Downstream, in the Skeleton Rocks catchment which forms a tributary of the Yilgarn River, re-activation of similar playa lakes has commenced. The risk of salinity is high in these areas owing to shallow groundwaters and the existence of amphibolites and dolerite dykes which appear to act as barriers to groundwater flow. In some areas in the lower parts of this catchment, the spread of dryland salinity may be tempered by the deeply incised nature (up to 10 m) of many of the playa lakes.

Better management of water on Brennand's catchment is needed to reduce the volume of recharge which is currently finding its way to the groundwater systems. The most appropriate management plan for the catchment requires that a 5-10 year moratorium (at the very least) be placed on proposed clearing and that the establishment of perennial (fodder) crops and higher water—use annual crops and pastures be

encouraged. Unfortunately, the lack of a suitable aquifer throughout most of the catchment and the saline nature of the groundwaters (30,000-50,000 mg/L TDS), prevents the use of pumps and trees for groundwater control low in the landscape.

It is strongly recommended that long-term monitoring be carried out at this site to more precisely determine the rates of water—table rise. Finally, a decision must be made on the acceptibility of any future clearing in areas likely to cause future salinity problems. In this region of the eastern wheatbelt, the significant depth to groundwater means that any definition of salinity risk must define an appropriate time—scale, as clearing done in the near future may not impact on the landscape for many decades to come.

2. Introduction

The development of soil salinity in southern Australia is currently said to affect more than 443,441 ha of agricultural land (ASS, 1989). Recharge induced by agricultural practices is estimated to range between 23-60 mm/yr (Peck and Hurle, 1973) in south-western Australia whereas under native vegetation recharge rates are much lower. Williamson et al. (1987) estimated recharge under Darling Range forests in the 750 mm/yr rainfall regime to be 0.05 mm/yr. Similarly, Barnett (pers. comm., 1989) found rates of 0.07 mm/yr under a 300 mm/yr ‘mallee’ type vegetation environment in South Australia.

The recent spread of salinization in the drier environment of the eastern wheatbelt is currently restricted to the development of perched aquifer, midslope seepages (60%) and valley floor salinity (40%). However, the predominant area of salinity (150,000 ha) occurs in the linear, valley palaeodischarge complexes, that comprise innumerable playa lakes and saline drainage lines along the ancient river courses.

The eastern areas of the Eastern wheatbelt are characterized by large catchments which currently have little dryland salinity. The catchments are characterized by numerous playa lakes which grade from being active, saline groundwater discharge areas in the lower reaches of the catchments, to non—saline, ‘ancestral’ playa lakes. These lakes usually have well established, sand dominated lunettes, indicating they were formed under a much wetter environment than which occurs today (Bowler, 1976).

Observations of the recent salinization of lower—slope playa lakes and farmland indicates that groundwater levels are rising in response to the change in the water balance brought about by clearing. However, most of the mid-catchment to upper-catchment farmland and playa lakes remain unaffected to date.

The question which arises is whether or not the current phase of ‘re—salinization’ and lake re—activation is of a similar or greater magnitude to the one, or ones which formed the discharge landforms higher up the catchment? Similarly, it follows on that if the effects of clearing are greater than any previous perturbation brought about by climatic change, then even in landscapes where established groundwater discharge landforms occur, dryland salinity will need to consume large areas of farmland in order to re—create a new condition of equilibrium.

In the process of formulating the project to answer some of these questions the Yilgarn Land Conservation Advisory Committee approached the Department of Agriculture to assist in determining clearing guidelines for the Yilgarn Shire. A case study was proposed for a 2600 ha catchment near Skeleton Rocks (Brennand’s catchment) which comprised a 450 ha application for clearing in a catchment which was already 50% cleared. The Land Conservation Committee asked whether the additional clearing would hasten the development of salinity, and if so, when would salinization occur in the catchment? The catchment chosen had an 18 ha non—saline playa lake, which because of the position and height of a lunette, formed a terminal point for flood waters from the catchment. The site offered the opportunity to determine the effect of clearing on the timing of salinization as well as the chance to briefly examine the palaeohydrology of the playa lake and catchment.

This paper is the first of three catchment studies to be published which reports on preliminary investigations of the hydrogeology of the eastern wheatbelt. This report concentrates on the interpretation of modern and ancient groundwater processes based on hydrologic, geomorphic and geophysical evidence, in the wake of the changing magnitude of recharge and discharge, brought about by clearing.

2.1 Location

Brennand's catchment is located 400 km due east of Perth, approximately 60 km S.S.E. of Southern Cross ($31^{0}45$'s $I99^{0}25$'E). The catchment of 26 km^2 is a part of the larger Skeleton Rocks catchment which drains an area of about 800 km^2 in the headwaters of the Yilgarn-Avon River system.

The region has a semi—arid climate with a mean annual rainfall of about 280 nun and evaporation of over 2800 mm. Mean monthly evaporation exceeds rainfall in all months of the year (Table 1). Rainfall and evaporation data for Merredin, which lies 120 km to the west and Southern Cross (60 km to the north) are presented in Table 1.

TABLE 1. MONTHLY RAINFALL AND EVAPORATION DATA FOR SOUTHERN CROSS (SX) AND MERREDIN (MD) (mm)

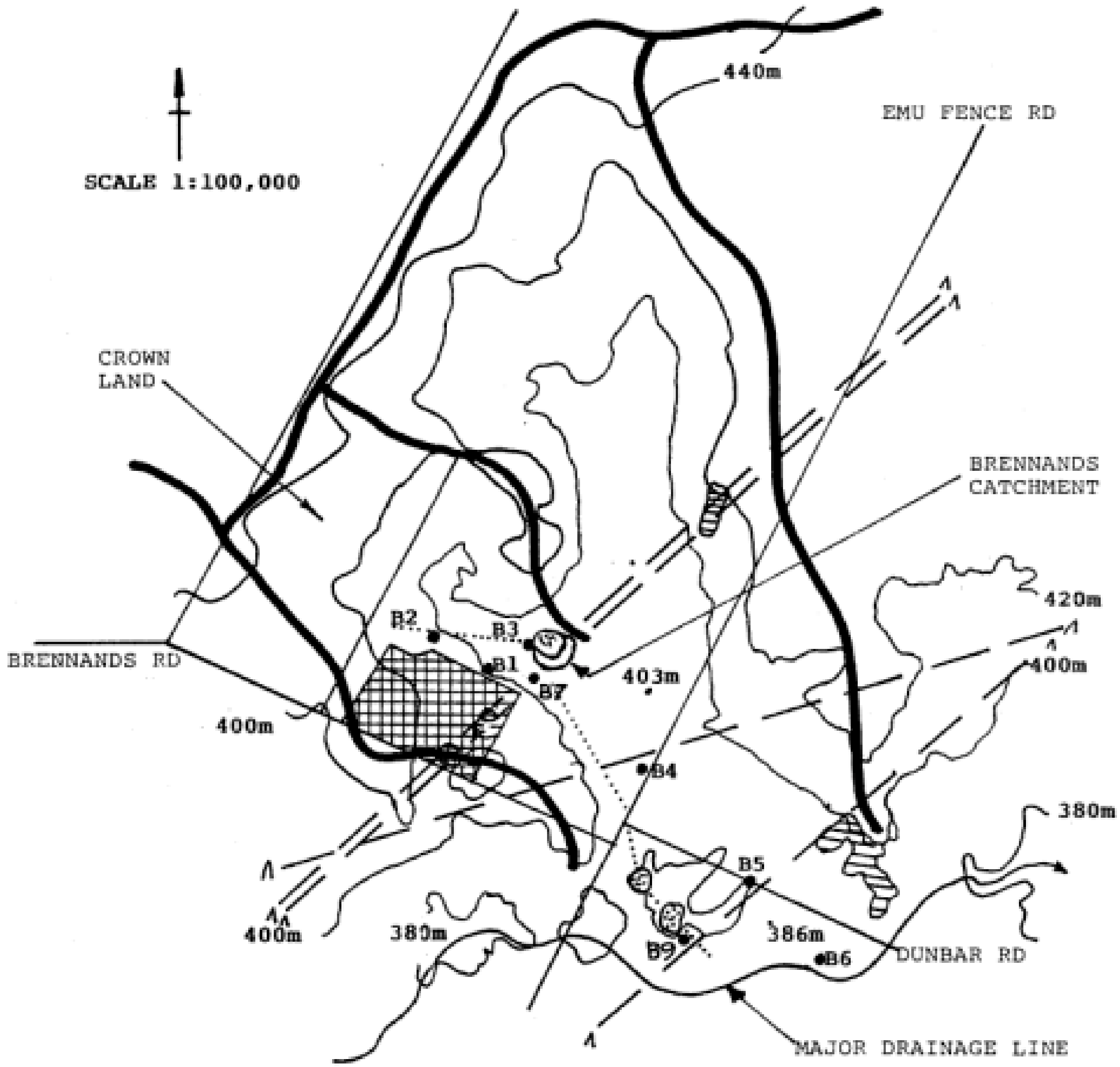
	J	F	K	A	K	J	J	A	S	0	N	D	TOTAL
SX	14	20	21	22	33	41	38	30	19	16	15	12	278
	436	350	314	194	120	80	91	109	151	244	306	409	2804
MD	11	15	21	23	41	53	52	39	26	19	14	13	327
	420	347	309	184	110	70	74	90	129	220	290	390	2629

Source: Bureau of Meteorology.

2.2 Geology

The geology of the Yilgarn region consists of greenstone, gneissic and granitic rocks which have been variably dated at between 2500-2900 million years old (Williams, 1975). Within the Skeleton Rocks catchment, downstream from Brennand's catchment, auriferous meta—sediments occur which are currently the focus of renewed gold mining activity. In the vicinity of Brennand's catchment, variably textured adamellite and granitoid rocks are occasionally intruded by Proterozoic dolerite dykes. Amphibolites occur in the lower slopes and drainage line of the Skeleton Rocks catchment.

BRENNANDS CATCHMENT LOCATION MAP



DOLERITE DYKES
GEOPHYSICS LINES
B2 PIEZOMETER
PALAEO-LAKE
ROCK OUTCROPS
CATCHMENT BOUNDARY
SPOT HEIGHT
AREA TO BE CLEARED
CONTOUR LINE

FIGURE 1.

Deep weathering and subsequent lateritization of the bedrock materials occurred during the Tertiary geologic period (Schmidt and Embleton, 1976) and produced a variable, deeply-weathered regolith to depths of up to 50 m. Subsequent erosion of the lateritized surface and weathered materials occurred in the late Tertiary and Quaternary periods. Valley and hillside soils have developed on various sequences of aeolian, lacustrine and colluvial sediments.

The major drainage lines show relic riverine features from recent geologic history. Holocene and Pleistocene playa lakes currently form the endpoint for most seasonal runoff waters. Only extreme (for example, 1:50 to 1:100 yr) rainfall events cause flow to take place towards Lake Seabrook. The playa lakes are commonly zones of groundwater discharge in the lower reaches of the Skeleton Rocks catchment. However, upstream they are normally either vegetated or form clay pans ranging in size from one to twenty hectares. Lunettes (dune sediments) in the lower catchment area, commonly consist of large gypsum and clay deposits, while those higher in the catchment are predominantly comprised of quartz, with few clay facets.

2.3 Aims and Background

The primary aim of the Brennand’s catchment project was to assess the effect that current and proposed clearing programmes would have on future salinization in the area. In particular, the Yilgarn Land Conservation District Committee sought advice on whether 450 ha of Brennand’s catchment could be cleared. However, in order to do this, an understanding of the groundwater flow regime was considered necessary. At Brennand’s catchment it was apparent that several large playa lakes might provide clues on the nature of groundwater systems under previous climatic conditions. The existence of these lakes also provided the opportunity to assess whether the lakes would re—activate and provided a balance for the new hydrologic regime introduced by clearing.

Similarly, if it was found that the lakes could not cope with the additional water, it would indicate that the modern phase of salinity was more severe than the landscape, developed under previous pluvial conditions, could cope with. Finally it was the aim of the project to produce recommendations for future clearing and advise on appropriate farm management systems to mitigate re—activation of the playa lakes and salinization of other areas.

3. Materials and Methods

3.1 Drilling Investigations

Drill holes were installed using a rotary air-blast drilling rig. Groundwater monitoring was conducted using piezometers located at ten sites throughout the catchment area (Table 2). Drill sites were selected on the basis of preliminary soil and landform surveys and the availability of access for the drilling rig.

TABLE 2. DRILLING DETAILS AND GROUNDWATER FORMATION

PIEZOMETER and SURVEYED LEVEL * No.	ASL (m)	TOTAL DEPTH (m)	CASED DEPTH (m)	SWL ** (m)	SL0TTED LENGTH (m)	AQUIFER TYPE
51	394.802	36.50	34.15	29.10	2	Saprolite Grit
B2	397.442	19.25	19.20	—	2	Saprolite Grit
B3 D	380.232	16.25	16.20	10.20	1	Saprolite Grit
I	380.282	14.20	14.20	10.15	1	Weathering Zone
B4	387.661	16.95	16.91	13.21	2	Weathering Zone
B5	377.627	7.60	7.54	5.54	2	Lake Sediment
B6	379.057	18.16	18.10	8.66	2	Saprolite Grit
B7	385.100	21.05	20.60	18.03	2	Saprolite Grit
B9 D	375.215	15.00	14.50	3.31	2	Pallid Zone
I	375.215	5.10	5.03	3.41	2	Sediments

* Surveyed level corrected for casing height above ground level.

** SWL = Static Water Level, ASL (in) metres above sea-level.

D = Deep piezometer.

I = Intermediate depth piezometer.

Piezometers were constructed from 50 mm PVC tubing, using commercially slotted pipe over the lower one or two metres of the depth of installation. The tubing was lowered down the uncased hole immediately following drilling. A filter pack of washed creek sand was then placed in the annulus alongside the slotted section. Several metres of cement and bentonite were located above this material to prevent contamination from surface or other groundwaters. The remainder of the bore was then backfilled with drill cuttings to the surface.

Drill-hole ‘cuttings obtained during the construction of the bore were sampled and described on site. Description of the samples were carried out to determine the samples’ physical characteristics, and to describe the nature of the lithology. Drill holes were sampled every metre and analysed for minor chemical properties (see Section 3.3).

The depth of the water-level within the piezometers was periodically recorded (usually monthly) after installation in 1987. Initial development of the piezometer, to assure drilling contamination of the aquifer was minimized, was successfully completed soon after drilling. Development consisted of frequent compressed air ‘sludging’ and ‘bailing’ until the casing was free of sediment and the waters were clear.

Hydraulic properties were assessed from slug-tests (Bouwer and Rice, 1976) while the elevation of each of the bores was obtained by surveying from known bench marks.

3.2 Geophysical Investigations

Two geophysical techniques were used to aid the interpretation of geologic features within the catchment. Ground base traverses across the catchment were carried out using the magnetic and electromagnetic systems. The traverse lines are marked on Figure 1 and were carried out along the major drainage line.

3.2.1 Magnetics

A ground magnetic survey was conducted on an eight kilometre transect (Figure 1) using a ‘Geometrics’ G856 proton precession magnetometer with its sensor mounted on a two metre pole. Measurements of the magnetic field displayed by the bedrock materials were taken every 20 m along the transect. In areas of increased or decreased magnetic activity, measurements were taken every 10 in. A base station was set up at the beginning of the survey and was returned to frequently to determine the extent of magnetic drift.

Magnetic surveys are capable of locating bedrock materials with different mineralogic characteristics. Magnetic anomalies have been demonstrated to be primarily caused by basic intrusive (dolerite) dykes. The reader is referred to Engel et al. (1987) for a more detailed account of the operation, limits and interpretation of the magnetic method.

3.2.2 Electromagnetics

An electromagnetic induction (EM) survey was carried out using a ‘Geonics’ EM31 terrain conductivity meter along a 9.5 m traverse, conducted on the same interval spacing as the magnetic survey. However, the EM survey also included an additional 2000 in upslope (Figure 1). The EM31 consists of a transmitter and receiver placed 3.5 m apart. The EM31 has a characteristic depth of penetration of 6 in (McNeill, 1980). The depth is controlled by the conductivity of the profile.

The transmitter in the EM31 produces a primary electric current which is transmitted into the ground by electromagnetic induction. A secondary current is subsequently received from the ground after the current has passed through the soil. The ratio of these fields are measured as a voltage or resistance in the receiver and converted to electrical (terrain) conductivity. Electrical conductivity is expressed in units of milli Siemens per metre (mS/m).

3.3 Soil Chemistry

Approximately 110 soil samples were collected as cuttings from the drilling rig, at one metre intervals to bedrock. These samples were analysed for electrical conductivity (EC), chloride and pH from 1:5 soil-water extracts. Analyses were conducted by the laboratory of the Division of Resource Management, Department of Agriculture, South Perth.

3.4 Groundwater Geochemistry

Groundwater samples were obtained from each of the piezometers located in the catchment. An initial sampling was conducted in June 1987 and waters tested for electrical conductivity and pH. Subsequent sampling was conducted to determine the major ionic composition of the waters. Waters were sent to the Agricultural Chemistry Section of Government Chemical Laboratories for analysis. Five samples were submitted for geochemical identification. Samples were analysed for the major cations; sodium (Na), potassium (K), magnesium (Mg) and calcium (Ca) and anions; bicarbonate (HCO_3), sulphate (504)1 chloride (Cl), nitrate (NO_3), carbonate ($C0_3$) and bromide (Br). Analyses were conducted to determine the levels of iron (Fe) and silica (SiO_2) in the waters. Standard determinations for pH, free acid content, electrical conductivity (EC) and total dissolved salts (TDS) were also carried out.

4. Results – Drilling Information

Drilling was conducted in the catchment in April 1987. A total of 160 m were drilled into weathered bedrock and sedimentary materials. Five boreholes were drilled to bedrock in Brennand's catchment and encountered a weathered gneissic material. Five additional bores were located in the major valley floor at the confluence of Brennand's and the Skeleton Rocks catchments (Figure 1).

4.1 Lithology

The nature and distribution of the weathered gneissic and sedimentary materials overlying bedrock was described from soil cuttings retrieved during the drilling programme. A diagrammatic summary compiled from the drilling records is shown in Figure 2. Details of each bore hole are presented in Appendix 1. The catchment lithology can be divided into two distinct lithologic units. The first consist~ of various sequences of colluvial and aeolian sediments transported into the valley, probably during the Quaternary and Tertiary geologic periods. Sediments were found to depths of 1 to 4 metres in the upper slopes and to 9 metres in the major drainage line.

Below the sedimentary materials the second unit, comprising deeply— weathered chemically altered bedrock, was encountered. This material consisted of three zones; a mottled surface zone; a deeper pallid zone to near bedrock and a poorly weathered, saprolite grit above unaltered bedrock.

4.1.1 Sediments

Three sedimentary groups were recognized from the drilling, geophysical and surveying programmes. These materials ranged from the (1) yellow sandy earths on the hillside, (2) aeolian sands and clays alongside playa lakes, to the (3) layered sands and clays in the major drainage line.

The yellow sandplain soils in Brennand's catchment were investigated with hand augers to determine characteristic depths to the underlying mottled or indurated layers. The sandy earths ranged in depth from over 4 in to less than 0.2 m. The soils were found to increase in thickness upslope from a minor creek channel eroded into the hillside above B2 (Figure 2).

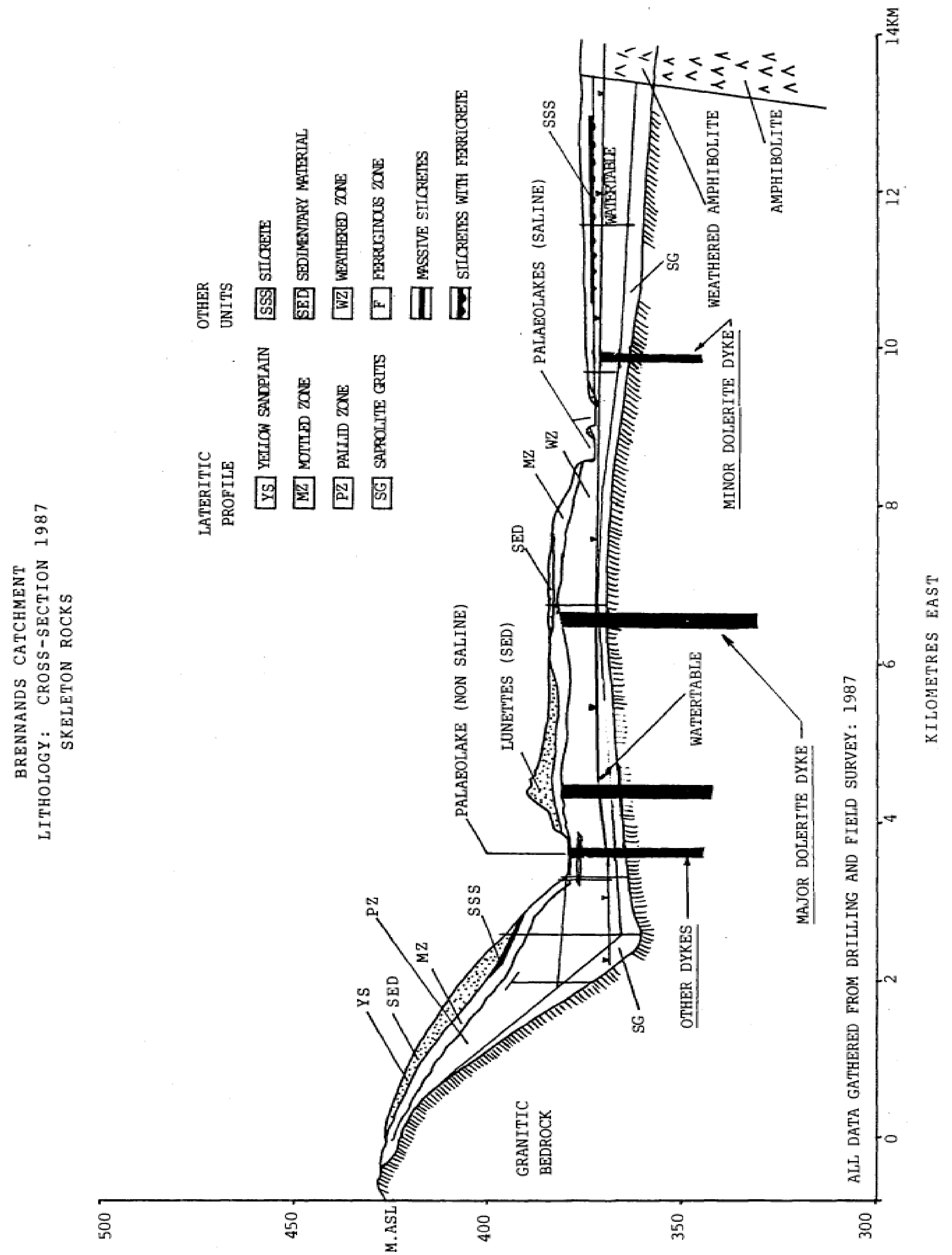

BRENNANDS CATCHMENT
LITHOLOGY: CROSS-SECTION 1987
SKELETON ROCKS
LATERITIC PROFILE
YS YELLOW SANDPLAIN
MZ MOTTLED ZONE
PZ PALLID ZONE
SG SAPROLITE GRITS
OTHER UNITS
SSS SILCRETE
SED SEDIMENTARY MATERIAL
WZ WEATHERED ZONE
F FERRUGINOUS ZONE
MASSIVE SILCRETES
SILCRETES WITH FERRICRETE
YS
SED
PZ
MZ
SSS
SG
GRANITIC BEDROCK
OTHER DYKES
PALAEOLAKE (NON SALINE)
LUNETTES (SED)
WATERTABLE
MAJOR DOLERITE DYKE
SED
MZ
WZ
PALAEOLAKES (SALINE)
MINOR DOLERITE DYKE
SSS
WATERTABLE
SG
WEATHERED AMPHIBOLITE
AMPHIBOLITE
500
450
M.ASL
400
350
300
0
2
4
6
8
10
12
14KM
KILOMETRES EAST
ALL DATA GATHERED FROM DRILLING AND FIELD SURVEY: 1987

FIGURE 2.

At the base of these materials a siliceous hardpan and indurated mottled sandy clay was found along the minor creek lines. Silcretes were observed in several places. Above these exposures, a perched, non-saline, localized groundwater system was occasionally found. Silcrete scree and indurated soil blocks were also common in the upper to middle—slopes of the catchment.

On the south—east corner of the playa lake located adjacent to B3, a deep, extensive lunette deposit has developed. The lunette consists of three crescent shaped sand—dunes standing five to eight metres above the surrounding landscape and lake floor. The dune materials are primarily comprised of fine quartz grains. Minor clay sequences were also observed in the dunes. These dune fields usually prevent surface waters from over flowing the playa lake and continuing downstream.

The lake floor covers an area of 18 ha and comprises a 1.5 in veneer of dispersive, pale grey kaolinitic clay (identified by x-ray diffraction) which is itself underlain by iron-rich, mottled and weathered bedrock materials (Figure 2).

Sediments in the major drainage line consist of heavy textured materials. In the vicinity of the twin playa lakes near B9 (Figure 1), surface materials alternate between aeolian sheets of light textured calcareous soils, and alluvial deposits of heavier, red—brown sandy barns. The area is characterized by deep, circular depressions, many of which appear to be ancient groundwater discharge features, now stranded above the regional groundwater level. The floor level of the twin playa lakes is at an elevation of 374.2 m, while the valley floor upslope (~200 m W), has a typical elevation of 387 m above sea level (ASL). Under present topographic conditions the lakes are between 5 m and 13 m lower than the surrounding landscape. Downstream, where the Skeleton Rocks drainage line crosses the amphibolites, the elevation of the soil surface is 379 m ASL.

In drill holes B5, B6 and B9I-D sedimentary materials were observed to depths of at least 9 m**.** At 85, the red-brown sandy to sandy clays of the surface 0.3 m gave way to medium textured clays. Grey sands and red sandy clays were encountered to a depth of 7 m. At this depth a zone of heavy textured grey clay was intersected. The material was determined from x-ray diffraction as a kaolinitic clay, with its texture, colour and physical characteristics matching lake bed materials at all three playa lakes investigated.

At B6 variably textured sediments were encountered to depths of approximately 9 in. At 4.5 m**,** a massive silcrete (0.9 m thick) was intersected. Below the siliceous layer, a gritty iron rich zone was encountered. At 8.0 m another heavy textured grey clay material was noted to a depth of 9.5 m. Below this zone drill cuttings suggested weathered bedrock of gneissic origin.

4.1.2 Weathered Bedrock

Deeply—weathered granitic and gneissic material was encountered in all deep bore holes drilled below the sediments. At 82 and B7, the grain size characteristics layering and mineralogy suggested a gneissic origin to the profile. The profile descriptions discussed below are presented graphically in Figure 2 and summarized in detail in Appendix 1.

In bore holes at B1 and B2, below the surface mottled sandy clays and whole coloured (white) pallid zone, an iron enriched and silicified layer was noted at 382 m ASL and 380 m ASL respectively. Below this zone (and at B3) the pallid zone sandy clays gave way to variably indurated and poorly bleached grey/green sandy clays. The unit is mapped as WZ on Figure 2. At the base of each profile a saprolite grit was intersected over the final 5 m above bedrock. Air lifting techniques used at sites 51 and B3 produced small groundwater yields (< 10 kill/day), while B2 was dry. Bedrock at B2 is at 375 m ASL, while the water-table level in bore B1 is currently at 369 m ASL. At all drilling locations downstream from B3, only the altered pallid zone materials were encountered.

4.2 Geophysics

4.2.1 Magnetics

It was apparent from the drilling programme and subsequent surveying that a groundwater divide existed between B3 and 84 (see Section 4.3). Air photo interpretation and field surveys revealed a series of three bedrock outcrops, on a consistent NE/SW strike. The information suggested the groundwater divide was either the result of a bedrock ridge, as typically found throughout the eastern wheatbelt, or an intrusive dolerite dyke, more typical of the western wheatbelt (R. Engel, pers. comm., 1987).

A magnetic survey was chosen to precede a seismic or additional drilling surveys to determine the cause of the divides. The results of the 7.5 km traverse are presented in conjunction with the electromagnetic survey in Figure 3. The data shows three minor anomalies (positive) and one major (negative) anomaly, which reflect the existence of dolerite dykes. Subsequent field surveys also located dolerite scree associated with one of the bedrock outcrops.

Basement outcrop patterns observed on air-photos were used to locate the direction of the magnetic anomalies. When combined with trends observed on 1:50,000 Bureau of Mineral Resources and 1:250,000 Geological Survey of WA maps, the information suggests that the minor dykes in the region run NE-SW and major systems ENE—WSW to E—W. The minor positive anomalies were, therefore, interpreted to run NE-SW and the major negative anomaly ENE (Figure 1). These assumptions were not validated by any subsequent surveys. Future surveys could be carried out on parallel transects to those shown on Figure 1 and on detailed grids near the playa lakes.

The first dyke encountered occurs directly under the eastern edge of the non-saline playa lake near B3, while another is located 800 m downstream. Both dykes cut across the catchment perpendicular to the surface drainage direction. The major negative anomaly observed upslope from B4, indicates a dolerite dyke much wider than those upslope, that Street (pers. comm., 1987) considers to be of the order of 50 m wide. This dyke may effectively isolate Brennand’s catchment and an unnamed, larger catchment which drains from the North (Figure 1) from the Skeleton Rocks catchment, downstream. The fourth dyke, located 500 m east of the eastern, twin playa lake, appears to be smaller than the other dykes encountered. It is likely to be responsible for a groundwater divide between 85 and B9 (Figure 1).

4.2.2 Electromagnetics

The electromagnetic survey conducted using the 'Geonics' EM31 was carried out on a 9.5 km transect. This survey included the deep sandplain soils, silcrete exposures and minor creekline above the non—saline lake, and was therefore 2000 m longer than the magnetics survey (Figure 3). The statistical relationship between actual salt storage measured from drilling samples (EC 1:5) and electromagnetic soundings at bore holes (ECa), located at Brennand's and three other catchments in the eastern wheatbelt is shown in Table 3. The good correlation suggests that variations in ECa measured along the transects, accurately maps the changing distribution of salt-storage.

TABLE 3. STATISTICAL RELATIONSHIPS BETWEEN EC1:5 v ECa AT BRENNAND'S AND THREE CATCHMENTS NEARBY USING THE EM31

CATCHMENT LOCATION	R2	PROBABILITY	n
East Belka (80 km W)	0.86	0.01	8
Merredin (100 km WNW)	0.72	0.01	7
North Baandee (120 km NW)	0.64	0.02	7
Brennand's	0.78	0.005	9

R2 = Correlation co-efficient (eg. Brennand's 78% of variability explained).

n = Number of observations (bores).

Note: Effective depth of penetration taken as 6 m for analysis.

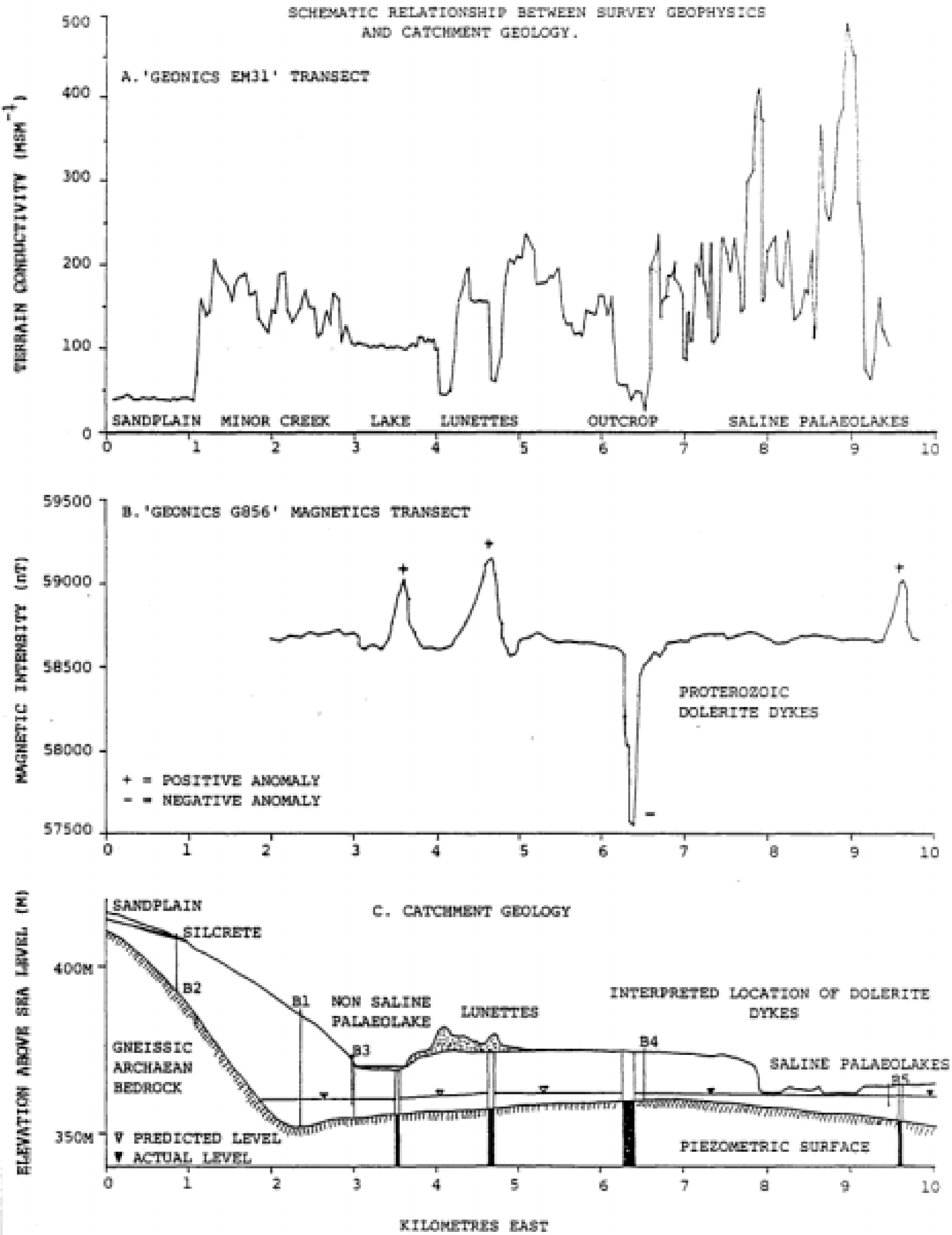

SCHEMATIC RELATIONSHIP BETWEEN SURVEY GEOPHYSICS AND CATCHMENT GEOLOGY.
A. 'GEONICS EM31' TRANSECT
TERRAIN CONDUCTIVITY (mSm^{-1})
SANDPLAIN
MINOR CREEK
LAKE
LUNETTES
OUTCROP
SALINE PALAEOLAKES
B. 'GEONICS G856' MAGNETICS TRANSECT
MAGNETIC INTENSITY (nT)
PROTEROZOIC DOLERITE DYKES
+ = POSITIVE ANOMALY
- = NEGATIVE ANOMALY
C. CATCHMENT GEOLOGY
ELEVATION ABOVE SEA LEVEL (M)
SANDPLAIN
SILCRETE
B2
B1
NON SALINE PALAEOLAKE
LUNETTES
B3
B4
B5
INTERPRETED LOCATION OF DOLERITE DYKES
SALINE PALAEOLAKES
GNEISSIC ARCHAEAN BEDROCK
▽ PREDICTED LEVEL
▼ ACTUAL LEVEL
PIEZOMETRIC SURFACE
KILOMETRES EAST

FIGURE 3.

Survey results show that there is a low terrain conductivity and, therefore, an applied low salt storage (< 50 mS/m) in the deep yellow sandplain soils above B2. However, associated with the silcrete bench and minor creekline, the terrain conductivity increases rapidly to 150—200 mS/m. Traverses conducted perpendicular to the creekline show greatly reduced terrain conductivities on entering sandplain soils.

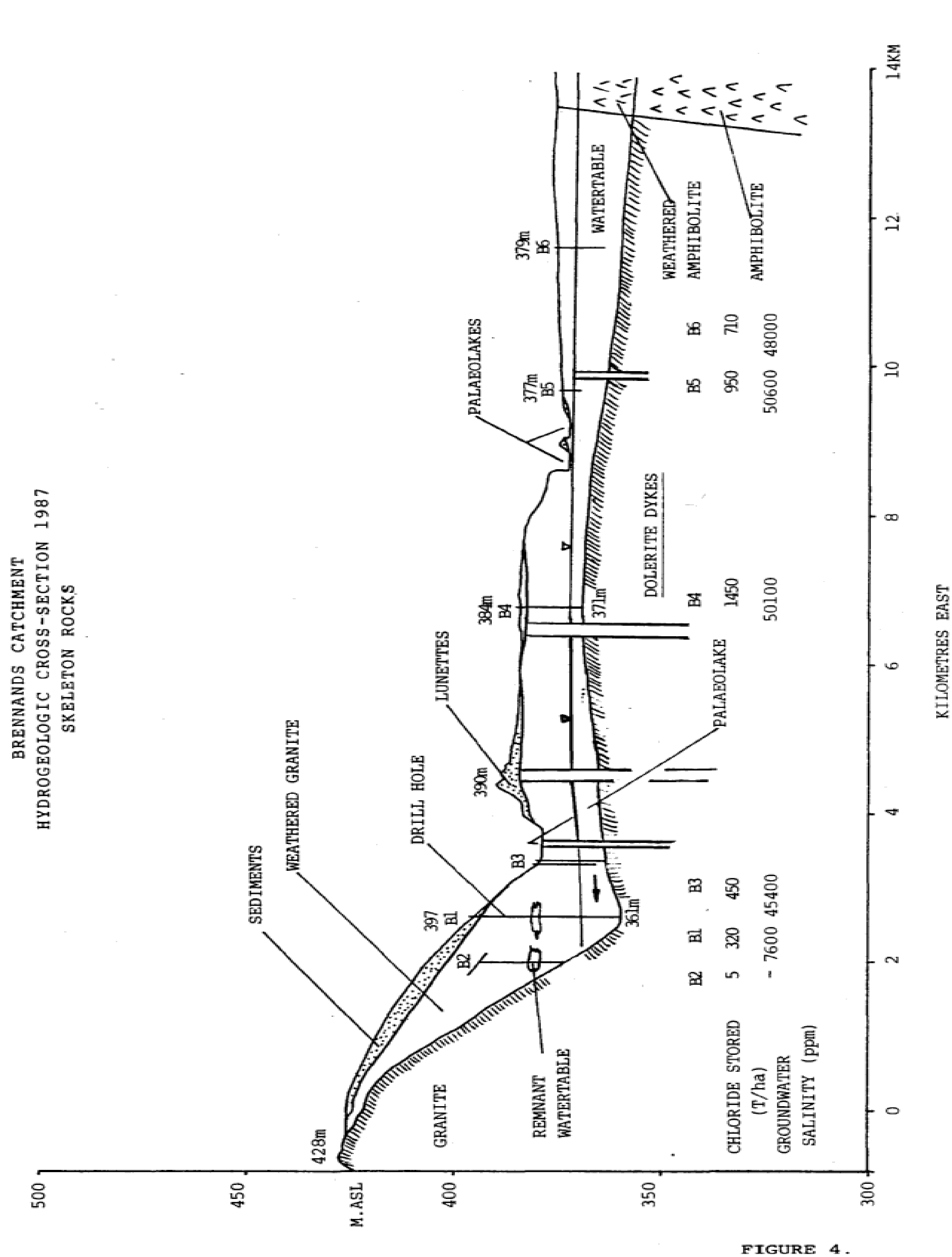
The terrain conductivity below the lake floor is uniform, fluctuating between 100 and 110 mS/m. Conditions change rapidly on entering the lunettes, where dune crests are characterized by low conductivities (< 50 mS/m) and inter-dune valleys by a higher conductivities. An increase in terrain conductivity occurs from the lunettes towards the twin playa lakes, although in association with the major magnetic anomaly near B4, values fall below 50 mS/m. In this region gneissic scree is visible at the surface. Conductivities rapidly increase downslope and peak in the twin playa lakes on the major drainage line (Figure 3).

4.3 Hydrogeology

Groundwater conditions within the catchment were observed by periodic measurements of ten piezometers during 1987, 1988 and 1989. Topographic, geological and geophysical data were also used to interpret regional and local groundwater flow systems. The hydrogeologic conditions within the catchment are presented in Figure 4. Reference should also be made to Figures 2 and 3 when reading this Figure.

4.3.1 Groundwater Flow

The groundwater conditions within the catchment can be broken into three zones on the basis of the direction of groundwater flow. In the upper parts of Brennand's catchment (Zone 1), groundwater below the non—saline playa lake currently exhibits a reverse, horizontal groundwater gradient.



BRENNANDS CATCHMENT
HYDROGEOLOGIC CROSS-SECTION 1987
SKELETON ROCKS
SEDIMENTS
WEATHERED GRANITE
DRILL HOLE
LUNETTES
PALAEOLAKE
PALAEOLAKES
DOLERITE DYKES
WATERTABLE
WEATHERED AMPHIBOLITE
AMPHIBOLITE
GRANITE
REMNANT WATERTABLE
428m
397 B1
B2
B3
361m
390m
384m B4
371m
377m B5
379m B6
CHLORIDE STORED (T/ha)
GROUNDWATER SALINITY (ppm)
B2 5 -
B1 320 7600
B3 450 45400
B4 1450 50100
B5 950 50600
B6 710 48000
M.ASL
500
450
400
350
300
0
2
4
6
8
10
12
14KM
KILOMETRES EAST

FIGURE 4.

This suggests recharge is occurring through the lunettes and/or lake floor (see Table 4) as piezometric gradients between bores 82, B3 and 37 are -0.005 (flow takes place towards SW and in an 'upstream' direction). However, downstream from B4, (Zone 2), groundwater flow occurs towards the major drainage line, in line with the surface topography. Groundwater flow towards the twin lakes also occurs from 35. In the region near B5 and B9 relatively strong, horizontal groundwater gradients were observed (0.001) and suggests the potientiometric contours are closed around the saline lakes. Zone 3 is only represented by Bore 6, located downstream in the major drainage line.

Controls operating on groundwater flow within the catchment would appear to be coming from the dolerite dykes. Indications from B3 and B1 water levels (corrected for density effects), are that flow is taking place towards the south—west, while between 33 and 84 gradients reverse and flow occurs towards the saline lake further downstream. The groundwaters between the two minor dykes downstream of B3 are recharged through the lunettes, causing flow in an upstream and downstream direction. The major dyke (anomaly) at B4 appears to have little control on groundwater flow, however, the smaller dyke (anomaly) near B5 appears to act as the groundwater divide between the flow system in major drainage line flow system and the local, Brennand's system. More drilling information would be required to accurately define these conditions.

Vertical hydraulic gradients were assessed at 83, where two piezometers were drilled into the saprolite grits (Table 4). At this site groundwater salinity did not vary significantly between B5D (45,400 mg/L TDS) and B31, (45,300 mg/L TDS). Water level measurements were, therefore, not corrected for density effects. Observed potientiometric levels displayed a upward head (15/05/87) of 0.02 following drilling and early seasonal rains. By June 1987, during a period when up to 0.1 m of water collected in 80% of the lake, the head remained at 0.02. As the lake dried out during July the head remained unchanged, although by November it had increased to 0.03. The data suggests a discharge potential occurs throughout the winter, peaking in November.

Recharge to the aquifer did not occur beneath the lake during the observation period (1987-1988), but it is speculated that it is being generated within the area presently covered by the lunettes. In 1989, prolonged and heavy autumn and winter rains filled the non—saline, upslope lake. Approximately 3 m of water collected in the lake, flooding B3. After inundation, the bores were bailed and allowed to recover. The levels indicated a strong (-0.04) recharge gradient, suggesting recharge is also taking place through the lake floor after significant volumes of water collect in the lake.

4.3.2 Hydraulic Properties

Hydraulic conductivity estimates made on the piezometers drilled into the saprolite grit zone gave a geometric mean of 0.45m/day (range 0.21-0.85 in/day) (Table 4). At B5 the hydraulic conductivity of sedimentary materials (sandy phase) showed a very high value of 1.15 m/day. This value represents a coarse sandy zone from 4.5 to 5.1 in, rather than the grey, kaolinitic clays at the base of the profile.

TABLE 4. HYDRAULIC PROPERTIES OF BRENNANDS CATCHMENT

BORE LOCATION	HYDRAULIC CONDUCTIVITY	HYDRAULIC GRADIENT		
#	m/day	Vertical	Horizontal	
B1	0.33	-	-	
B2	-	-	-	
B3 D	0.85	+ 0.02	- 0.005	(B1-B3)
I	0.05	to – 0.04	-	
B4	0.40	-	- 0.001	(B3-B4)
B5	1.15	-	+ 0.0002	(B5-B9)
B6	0.40	-	+ 0.0007	(B6-B9)
B7	0.21	-	- 0.005	(B7-B3)
B8	-	-	-	
B9	0.11	+ 0.01	+0.001	(B4-B9)
I	0.05	-	-	

***** Negative values indicate that the horizontal gradient is the reverse of the general land surface gradient (vice versa for positive values). Positive vertical gradients indicate upward flow in the aquifer.

The saprolite grits appear to form the major aquifer responsible for the transmission of groundwater through the catchment. Pump tests conducted in the eastern wheatbelt (George, 1990a) suggest the overlying pallid or weathering zones act as materials that are capable of only minor lateral flow. Fractured rock flow within the upper few metres of bedrock is likely, however, like the overlying grits, the volume of discharge is governed by the groundwater gradient. As a consequence of low gradients, flow velocities are only of the order 0.1-0.01 m/yr. Groundwater ages low in the landscape would therefore be expected to be of the order of $l0^{4}$ to years. However, it is estimated that younger ages for the waters could be expected, since recharge also takes place under the lunettes, lakes and valley soils and occurs into discrete, enclosed basins.

4.4 Salt Storage

Salt storage, calculated from chloride analyses from the sediments and weathered bedrock materials is highly variable. In the upper-slopes, beneath the sandplain soils, salt storage was low in comparison to that found in the mid—slopes and valley floor area. Salt storage from the soil surface to bedrock is in the range from approximately 150-2200 tonnes/ha. Table 5 summarizes the storage characteristics at each bore hole.

TABLE 5. SALT STORAGE SUMMARY

SITE	BORE DEPTH	$kg/Cl^-/m^{-3}$ (A)	CHLORIDE STORED TONNES/HA (B)	AVERAGE Cl^-% (C)	TSS 1 $TONNES/HA^{-1}$ (D)
UPPERSLOPE					
B1	36.50	0.87	320	0.051	680
B2	19.25	0.41	80	0.024	150
MID—SLOPE					
B3	16.25	2.98	480	0.175	870
VALLEY FLOOR					
B4	16.95	7.11	1200	0.42	2200
B5	7.60	9.6	720	0.57	1300
B6	18.16	3.05	550	0.18	950

A. Kilograms of chloride to bedrock per m^3.

B. Tons of chloride to bedrock per hectare.

C. Average Cl^-% for profile.

D. Same as B, however, divided by 0.55 for (TSS) total salt storage.

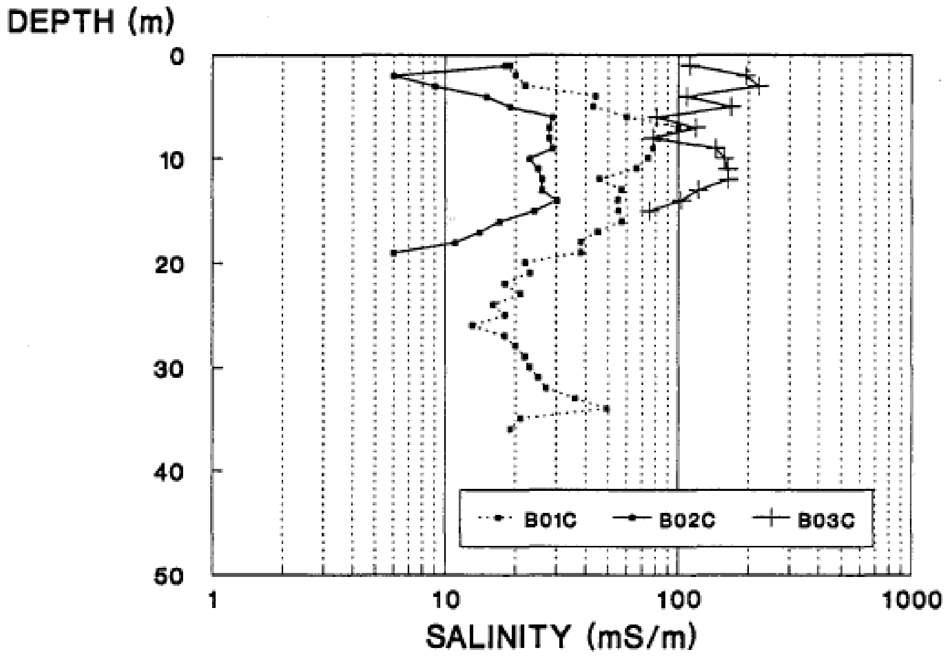
E. Assumed bulk density = 1.70.

The distribution of chloride within the catchment is summarized from the drill-logs (Figure 5). At drill sites B1, 32 and to a lesser degree B3, the chloride profile is characterized by a salt bulge above the water—table. At B3 and B6 a secondary bulge also occurs in association with the water-table. Sites B4 and 35 show rapidly increasing chloride levels from one metre below the soil surface, to below the water-table.

4.5 Groundwater Geochemistry

The results of the geochemical analyses of catchment groundwaters are presented in Table 6. Groundwater salinities range from 7600 mg/L (TDS) at B1 to 45,000 to 50,000 mg/L (TDS) in all the other bore holes. The waters change from neutral at 31 to extremely acidic downstream, steadily acidifying down the catchment.

SALINITY PROFILES - BRENNANDS



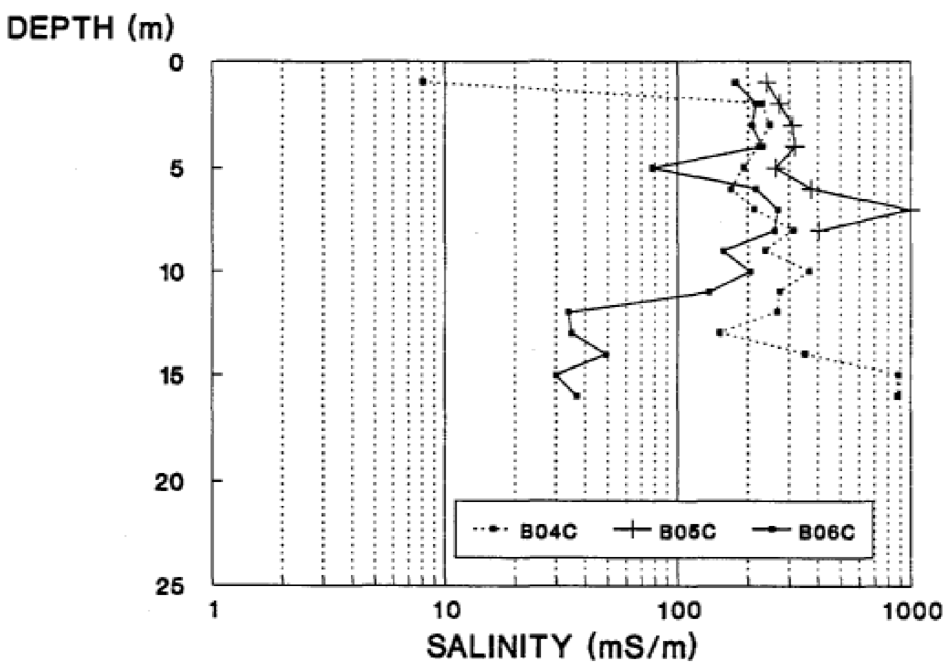


TABLE 6. GROUNDWATER GEOCHEMISTRY

Site	ELEMENT mg/L^{-1} (TDS)												
	pH	**EC****	**TDS**	**Na**	**K**	**Mg**	**Ca**	**HCO^3**	**SO^4**	**Cl**	**Sio_2**	**Fe**	**Br**
B1	6.7	1,250	7,600	2,440	73	240	40	129	6.4	4,030	32	3.7	17
				1.65	*55*	*17*	*100*		*6.5*				*237*
B3	5.5	6,090	45,400	14,800	309	1,510	174	56	3,620	24,900	35	24	77
				1.68	*81*	*16*	*140*		*6.9*				*323*
B4	4.0	6,450	50,100	15,500	358	1,900	166	-	4,340	27,800	63	23	97
				1.79	*77*	*15*	*170*		*6.4*				*286*
B5	3.9	6,830	50,600	16,800	433	1,540	73	-	2,550	29,100	71	10	54
				1.73	*67*	*19*	*399*		*11.4*				*538*
B6	3.5	6,630	48,000	15,700	356	1,660	43	-	2,720	27,400	82	4.9	83
				1.75	*77*	*16*	*640*		*10.0*				*330*
SEAWATER RATIO (after Macumber, 1988)				*1.81*	*50*	*15*	*47*		*7.2*	-	-	-	*288*

***** Ratio of major elements to chloride.

** mS/m^{-1}

Bore B1 had 2 mg/L $N0_{3;}$ $C0_3$ was not detected.

The chloride to major cation and anion ratios are also given in Table 5. Groundwaters have a similar composition to that of seawater. Sodium and magnesium show a strong similarity while lower levels of potassium, calcium, sulphate and bromide occur. Calcium and sulphate depletion downstream may be attributed to aeolian processes of deflation and lunette construction under the highly saline playa lake environments (Bowler and Teller, 1986). The relative abundance of iron also decreases towards the catchment outlet.

Bicarbonate is present in neutral groundwaters at 31 and B3 but is lost downstream due to the increasing acidity. By contrast silicate levels increase with increasing acidity, to approach saturation levels of amorphous silica near 36.

4.6 Hydrographs

Water-level monitoring during the period between 1987 to the end of 1989 indicated that there has been little change in groundwater levels (Figure 6). Of the monitored bores, only those located in the lower reaches of the catchment (84, B5 and B9) show any identifiable upward trend. However, at these sites the trend is only of the order of 0.05 in/yr. At the other sites no trend has been observed to date.

Monitoring over the next 5 to 10 years will be required to assess the effect of the current level of clearing.

5. Discussion

5.1 Landscape Formation

Genesis of the existing landscape probably began in the Early to Mid Tertiary period when lateritization and deep chemical weathering took place. Palaeomagnetic results suggest regional lateritization occurred in the late Oligocene to Early Miocene epochs (Schmidt and Embleton, 1976). The existence of the current morphology of the major valley palaeodrainage systems is thought to have developed in the Late Cretaceous to Eocene epochs (Van de Graaff et al., 1977), with significant and regular river flows considered to have ceased in the mid-Miocene (Lowry and Jennings, 1974). The existence of lignites and lacustrine valley sediments under playa lakes near Kalgoorlie (P. Commander, pers. comm., 1988) corroborates the conclusions that palaeodrainage sediments are of an Eocene or earlier age (Van de Graaff et al., 1977).

It could be postulated that landform genesis in the Yilgarn area and Brennand's catchment in particular, followed the pattern described above.

However, it is believed a more recent sequence of events has moulded the present catchment morphology and may be responsible for some of the sediments observed. This hypothesis is based on several observations.

Valley sediments are characteristically thin in Brennand's catchment in comparison with the deep Eocene sequences observed in the eastern Goldfields by Van de Graaff et al. (1977) and Commander (pers. comm., 1988) reaching a maximum thickness of approximately 9 m at 36 (370 m AHD).

Similarly, the existence of a massive silcrete horizon at B6 (375 m AHD) and an unusual clastic sediment at B5 (371 m AND) suggest a sedimentary morphology, based upon fluctuating groundwaters, of a Pleistocene or Holocene age (Bowler, 1976). Unfortunately, no materials suitable for dating have been found.

The pale cream to grey clay sequence of sediments located at 35 represented an impenetrable obstacle to the drilling rig (as air circulation was lost). Above this zone several coarse sandy horizons were encountered. They were separated by medium to sandy clay soils. The floor levels of the twin playa lakes are presently at a similar elevation to the heavy textured sediments observed in B5. Hand augering in the saline lake floor revealed similar materials to those encountered in B5 and the non—saline palaeolake at 33. X-ray diffraction results on the B3 lake sediments, and B5 borehole sediments, revealed that both have the same mineralogic properties, characterized by kaolinite and halloysite. On the basis of the current stratigraphic (and mineralogic) evidence, it is possible that the clayey sediments in B5 may have been derived from, or were located in, a presently infilled large playa lake, or other type of groundwater discharge landform, of which the existing twin playa lakes are remnants. Bowler and Teller (1986) and Macumber (1983) suggest a Holocene to Pleistocene age for active playa lake systems in south eastern Australia. It is believed that lake activity in south-western Australia also occurred at the same time (Bowler, 1976).

Given the possible similarity between south-east Australian landforms and those found at the sites studied, it could be postulated that the existing lake environment, including both the non—saline and twin lakes, are products of Pleistocene and Holocene climatic changes. This assertion is strengthened by the Carbon 14 dating of lunettes by Bowler (1976) in nearby lakes south of Merredin, which yield ages of 15,000—20,000 years. Similarly, the lake morphology and sediments history probably fit the Bowler and Teller (1986) model for lake genesis and activity. Climatic and morphologic evidence of recent salt lake activity transposed from their work suggests increased groundwater discharge (relative to the present conditions) would have occurred in at least three major periods throughout the past 50,000 years. In Victoria, this activity was associated with increased groundwater levels of between 10—20m**,** which if applicable to Brennand's catchment, is sufficient to have activated groundwater discharge in the currently non-saline lake at B3.

5.2 Salinization

Prior to agricultural development the existence of stable areas of primary salinity (salt lake systems) is evidence that a dynamic equilibrium existed between groundwater recharge, evapotranspiration and discharge. However, in the case of Brennand's catchment, the evidence suggests that at least some of the discharge landforms were, and are still, presently inactive. As Bowler and Teller's (1986) model suggests, the eventual landscape is the result of a complex combination of climatic and hydrodynamic changes through time. At Brennand's catchment it is likely that the relic groundwater discharge features, present in the weathering—zones, represent historic markers of periods of increased, or maximum, groundwater activity.

If it can be assumed that the catchment had reached a state of equilibrium before clearing, it becomes possible to estimate the magnitude of pre—clearing recharge and discharge from known and estimated groundwater data, and hydraulic and chemical properties.

5.2.1 Groundwater Balance

From knowledge of the hydraulic conductivities (K) of the 'saprolite grit' aquifer and pallid zone (0.45 and 0.05 m/day respectively), the width (w) and depth (b) of the saturated zone delivering water to the lake and the (relic) groundwater gradient (i), it is possible to crudely estimate the maximum annual groundwater flux (Q max) necessary to re—activate the lake, (equation 1).

$$Q \max = T.w.i \qquad (1).$$

Where 'T' is the transmissivity of the saturated zone (as T = Kb), 'w' is the maximum width of the groundwater system immediately above the lake, (through which groundwater is focussed towards the lake), and 'i' is the relic hydraulic gradient for flow.

Using characteristics values obtained from the study it can be estimated that the approximate maximum annual flux is of the order of 2 m^3/day or 730 m^3/yr. If the lake previously represented the focus of discharge for all of the catchment's groundwater, and the discharge (730 m^3/yr) was in equilibrium with recharge, then a recharge estimate of 0.03 mm/yr would be required to provide a balance or equilibrium.

The groundwater recharge (0.03 mm/yr) may be an underestimate as it does not include deep aquifer flow under the lake. However, the presence of two dolerite dykes and a flat topography, suggests flow would be minimal and have little effect on the estimate. Moreover, the evidence suggests that small changes in recharge could account for dramatic changes in catchment hydrogeology, in particular, the area required for groundwater discharge. Given climatic changes of the order presented by Bowler and Teller (1986), it is conceivable that the lake has been active at least three times during the past 50,000 years.

5.2.2 Chloride Method

Sharma and Craig (1987) used an alternative approach - the chloride mass balance method, which is based on the concentration of environmental chloride in rainfall and at the water—table, to estimate groundwater recharge using equation 2.

$$R = P\ (Cp/Cf) \qquad (2).$$

They suggest that the long-term recharge rate (R) can be calculated from the ratio of incoming chloride in rainfall (Cp), to the nett accumulation of chloride in the groundwater (Cf) and annual rainfall (P) figures.

Substituting characteristic figures for P (278 mm/yr - Table 1), Cp (6 mg/L/Cl^-; Hingston and Gailitis, 1976) and Cf (24,900 mg/L Cl, B3 and 4030 mg/L Cl—, B2 - Table 6) into equation 1, a recharge rate of 0.07 mm/yr to 0.40 mm/yr is achieved, on a catchment which was primarily covered with native 'mallee' vegetation. Similarly, Barnett (pers. comm., 1987) also estimated recharge rates of the order of 0.07 mm/yr from the chloride ratio method under native, 'mallee' catchments, with similar climatic conditions in South Australia. It is important to note that recharge rates at Brennand's catchment were extremely small under the native vegetation.

5.2.3 Discussion

Studies of groundwater recharge rates in south—western Australia have been conducted in the wetter catchment areas near the coast. Peck and Hurle (1973) and Sharma and Williamson (1983) conclude that recharge, in rainfall regimes of between 700 to 1400 mm/yr is of the order of 20 to 70 mm/yr. Estimates of recharge in the Narrogin region (400 to 700 mm/yr) range from 10 to 50 mm/yr (R. Engel, pers. comm., 1988). Recharge appears to be reduced in an easterly direction as a consequence of decreased annual rainfall and increased evaporation.

Groundwater recharge in the eastern wheatbelt, under deep yellow sandplain soils, (George, 1990b) was found to be approximately 1-10 mm/yr from both the chloride and water balance methods. Conservative estimates of recharge at Brennand's catchment under current agricultural conditions are therefore also likely to be of the order of 1-10 mm/yr.

Under the present land—use conditions recharge is limited to an area of 850 ha, however, future clearing of a further 450 ha is planned. Given a recharge rate of 1 to 10 mm/yr, of the order of 13,000 to 130,000 m^3/yr would pass into the deep aquifer. If the specific yield of the aquifer was of the order of 0.01, water-tables would rise at about 0.01 to 0.1 in/yr.

Evidence of the rate at which groundwater levels have changed during the study period cannot be used as a guide since monitoring only commenced in the winter of 1987. However, evidence from other bore holes drilled in the eastern wheatbelt (unpublished data of the authors) suggest an annual rise in the groundwater levels between the order of 0.05 to 0.20 in/yr. From the estimates of the rate of water—table rise and knowledge of catchment geology, it is therefore likely that the non-saline lake at B3 will become an active, saline groundwater discharge feature in between 50 to 200 years. To determine the effect of agricultural development on the extent of groundwater discharge through non—saline playa lake and surrounding soils it is necessary to attempt to determine whether the increased recharge due to clearing (1 to 10 mm/yr) could be lost through the lake as evaporation. If this was the case, the impact of agriculture on productive soils would be minimal.

Although little is known about the groundwater discharge rates of saline playa lakes, evidence reviewed by Lloyd (1986) suggests that evaporation rates in central Australia are of the order of 100 mm/yr. This represents a nett loss of only 1.0 to 5.0% of the potential evaporation rate.

Lloyd (1986) suggests this relatively low rate can be explained by the high density (salinity) of the waters and reflectance (albedo) of the white, saline surface. Using these figures as a guide, the potential discharge rates of the re—activated, and now saline playa lake, (18 ha) could theoretically discharge about 18,000 m^3/yr far exceeding the estimated inflow (730 m^3/yr) postulated under the last active groundwater discharge phase. However, Macumber (1983) points out that the area of actual groundwater discharge (evaporation), is limited to the spring zone, where upwelling waters move along the equivalent of a Gyben—Hertzberg lens (Macumber, 1983).

The centre of the lake becomes the repository of brines, evaporites and sediment and acts as the focal point for the downward movement of the reflux brines. At Brennand's the width of the spring zone, if similar to other active lakes in the area, would be about 5 to 20 m and, therefore, have an area of between 0.7 to 2.8 ha and a maximum discharge (at 100 mm/yr) of 700 to 2800 m^3/yr.

Since groundwater recharge could be accommodated by lake discharge, soil salinization from the deep groundwater source would not have occurred above B3 in the past. However, using estimated recharge rates of 10 mm/yr for agricultural conditions, the groundwater flow component would increase by at least two orders of magnitude (from 730 m^3/yr to almost 130,000 m^3/yr). The second figure is based on the assumption that only 50% of the catchment is cleared (see Section 6.4).

This groundwater flow rate would far exceed the potential for transmission into the playa lake as the maximum groundwater flux could only accommodate 30,000 m^3/yr, even if the gradient for flow increased to 0.02. (The slope on the landscape varies between 0.02 and 0.025). It is therefore likely that salinization would occur in the valley and lower slope soils about 33.

The occurrence of a zone of high salt storage in the incised drainage line between 81 and B3 (Figure 3) could represent salt deposited from a previous phase of high regional groundwaters, or from perched groundwater discharge associated with sandplain seeps. The water balance discussed above suggests that the second alternative may be more likely to be responsible. Sandplain seeps are common in the Yilgarn and eastern agricultural areas and form when a saturated layer develops at the base of deep yellow sandplain soils (George and Frantom, 1988). Perched groundwater moves laterally downslope until it flows out at the soil surface. Evaporation concentrates salts in the surface soils and dryland salinity develops.

Although no evidence of salinity currently exists at Brennand's, a good relationship has been observed in other catchments nearby between the occurrence of hardpans, especially silcretes, and the location of sandplain seeps. These features occur at the break in slope around the creekline between B1 and B3. Increased clearing (planned) is likely to create or recreate sandplain seeps which have been prevented from forming by the evapotranspiration of native vegetation. Salinity within the creekline would then result in either localized areas, or throughout the depression towards the lake soon after clearing, unless management systems are adopted to control the development of the perched aquifer.

The development of salinity within the major drainage line near 34 also appears likely, given the catchments geology and current hydrologic conditions. Shallow depths to bedrock, the influence of dolerite dykes and low horizontal gradients effectively create cells into which recharging waters are impounded. The eventual development of salinity will occur if groundwaters rise into the surface soils. Given that the depth to groundwater between 34 and B6 ranges between 3—13 m and the rate of water-table rise is at 0.1 m/yr, it may only take 30-130 years to develop.

High salt storage levels in B4 (Figure 4) may indicate a previous phase of groundwater discharge, although this is only speculation and would require long term monitoring to confirm. However, the evidence of phases of increased groundwater discharge postulated by the presence of the playa lake complex near 35, suggests that this has been the case in the past.

Since it is concluded that the previous phases of salinization were induced by a relatively minor change in the hydrologic balance (0.07 to 0.40 mm/yr), it can be reasonably assumed that increasing recharge to the order of 10 mm/yr will inevitably increase groundwater discharge in this zone as well.

The increased volume of recharge appears unable to be accommodated by local and regional aquifers and may, therefore, result in the spread of the groundwater discharge zones into presently non-saline agricultural soils unless management strategies are adopted. Similarly, discharge landforms which probably developed under Pleistocene and Holocene pluvial periods appear unable to cope with the additional water generated by clearing and agriculture. As a consequence, non—saline playa lakes, which are common in the region may re—activate and become saline, together with large areas surrounding them.

6. Recommendations and Conclusions

In Section 5 an attempt was made to place salinization in a regional and historic framework. This was considered necessary to provide a setting into which management techniques could be described. These recommendations and conclusions are a synthesis of some of the current Department of Agriculture recommendations. However, it is apparent that a significant amount of room is available and research needed, for more efficient and economically sensitive management options to be developed.

6.1 Agronomic Manipulation

Research results presented by Nulsen and Baxter (1982) and local field observations, suggest that the lupin-wheat rotation is capable of reducing, but not eliminating, groundwater recharge. The existence of suitable soils, already cleared on Brennand's catchment (Bl-B3), make this option possible. Economic analyses by the Department also concludes that it is a profitable rotation, making its adoption practical.

Lower in the catchment, where heavy textured soils are common (B4—B6), rotation management may include a minimum tillage, wheat or pea—wheat rotation. Soil types capable of maintaining a cereal rotation should be continuously cropped to maximize water—use and reduce recharge. Fallowing should be avoided.

The wheat—lupin and pea—wheat rotations are cited as examples of improved management which will reduce groundwater recharge. However, unsuitable soils, agronomic and management constraints may prevent these rotations from being quickly adopted. In this case, the use of vigorous pastures with equivalent transpiration rates to the other rotations mentioned are required. Recharge is considered to be greater in areas of light textured, freely draining soils, which suggests heavy textured soil rotation management may not be as critical. Under waterlogged or flooded conditions this assumption may not apply and attempts to control these conditions should be encouraged.

6.2 Revegetation

In recharge areas that cannot be continuously cropped, other methods of recharge manipulation will be required. These soils are considered to be the deep acidic sands, soils with shallow gravel and areas around bedrock outcrops. In most cases, water movement beyond the root—zone occurs quickly and seasonal responses of between 0.5—2.0 metres have been observed in other regional and local groundwater systems studied (George, unpublished data).

Deep-rooted perennial vegetation appears to be the best available option to mitigate recharge. The use of productive fodder or 'economic' trees may be preferred to revegetation with native Eucalypts spp. Cytisus *proliferus* (tagasaste) has been shown to grow well on local acidic soils and appears to be suitable for grazing, as long as an active programme of tree management is undertaken.

Revegetation of the deep sands immediately above the soils in the saline creek, using methods outlined by George and Frantom (1988) will prevent the development of sandplain seeps. There is a high probability that the creekline will become saline quickly which suggests the prevention of local groundwater induced salinity problems is a high priority.

6.3 Other Management Options

Sections 6.1 and 6.2 have looked at techniques of recharge manipulation. However, once recharge waters have entered the aquifer the only method of control is by groundwater pumping or drainage. Successful pumping is dependant on locating high yielding aquifers and lowering water-tables across large areas. Within the catchment only one bore was found that would be capable of producing above 10 m^3/day (36 - potential yield > 50 m^3/day). Results obtained from other groundwater pumping experiments conducted locally, indicate it is considered to be inappropriate and too expensive to attempt a pumping programme.

The option of deep drainage can only be considered when groundwaters have risen into the surface soils. Two options are available. The first consists of groundwater manipulation by locating buried or surface drains below the water-table, while the second accepts saltland as inevitable and involves the production of halophytic (saltbush) vegetation for long term grazing. Drainage is expensive and its success is dependant on site characteristics. The existence of heavy textured valley soils to depths of 2—3 m would make drainage very expensive as drains would have to be deep and closely spaced to be effective.

Saltland agronomy would appear to be the more appropriate option as it appears able to approach the financial returns of previous agricultural systems (J. Salarian, pers. comm., 1988). The water-use of Atriplex spp. may also be higher than groundwater discharge rates, thus reducing the area which may become saline (C.V. Malcolm, pers. comm., 1988).

6.4 Effects of Further Clearing

Brennand's catchment covers an area of approximately 2600 ha of which 850 ha are presently cleared. Application has been lodged for permission to clear a further 450 ha. The remaining 1300 ha is Crown land and it is unlikely that future land release would be considered.

Section 5.2 discusses the ramifications of landscape clearing on historic discharge features and local soils. It concluded that the recharge rates indicated by the relic water-table, playa lake and lake inflow controls, were of the order of 0.1 mm/yr. However, clearing has induced recharge conditions which may approach 10 mm/yr.

Recharge rates of 10 mm/yr over the 850 ha already cleared suggest groundwater receives in the order of 85,000 m^3/year after an initial change in water storage in the unsaturated zone. Increasing the cleared area by 450 ha could be considered to be likely to increase aquifer additions by 45,000 m^3 or about 50%. The catchment would then be approximately 50% cleared.

On the basis of the available data it is therefore concluded that the clearing of 450 ha, of high recharge potential soils would significantly increase the area which may become salt-affected and probably increase the rate of water-table rise in the deep groundwater system, thus shortening the time to salinization. Eventual re-activation of the existing lake and the soil salinity, appears to be inevitable unless recharge management agronomy systems and revegetation techniques are adopted. If such systems were adopted on the 850 ha already cleared, the nett effect may only be the re-activation of the playa lake, thus preventing salinization of soils upslope.

It is recommended that the additional 450 ha of land not be cleared so that additional groundwater level monitoring be conducted and an appraisal of the existing use of cleared land be made. If clearing could be delayed for 5-10 years, it may be possible to determine the affect of the existing cleared land, and allow a better interpretation of the effect of clearing another 450 ha. Monitoring groundwater trends would allow this to be achieved. If the land was cleared immediately, resultant water-level trends would represent the effect of recharge from both areas.

A combination of a moratorium on clearing the area for 5-10 years and the adoption of catchment management systems would appear an appropriate solution. Catchment management should include:-

(i) Adoption of profitable high water using rotations designed by the Department and the farmer.

(ii) Revegetation of a 50 m wide strip around the creekline to prevent sandplain seep development.

(iii) Revegetation or improved water-use management systems on recharge areas.

(iv) Regular groundwater observations.

If the results of these procedures appears to have restricted the rate of water-table rise then clearing of part or all of the 450 ha could be considered.

The final decision will rest with the landholder, Land Conservation District Group and the Commissioner of Soil Conservation. On the basis of this preliminary investigation it appears likely that salinization will redevelop. The extent and severity will be determined by the quality and degree of the management systems adopted. The issues raised by the research which need immediate attention concern the time—scale for the development of salinity and the ability of future management systems to be able to control its spread. In terms of the current clearing guidelines, a minimum risk period, say 30 years, could be adopted and known rates of water—level change and landscape factors then used to assess risk.

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WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO:	B 2	RIG TYPE:	R.A.B.
CATCHMENT:	Brennands	CASING DEPTH:	19.00 (m)
DATE DRILLING:	April 1987	DEPTH DRILLING:	19.20 (m)
LOCATION:	Skeleton Rocks	QUALITY:	Nil mS/m
GRID REFERENCE:	31°44’25”N 119°24’42”E	YIELD:	Nil day/day
LAND UNIT:	Norpa	DEPTH TO BEDROCK:	19.20 (m)
		SLOTTED LENGTH:	2 (m)
WATERTABLE DEPTH:	Dry (m)	SAMPLES:	EC,pH,ECe,Cl,Sat %

RESULTS			
DEPTH (M) FROM	TO	DESCRIPTION OF BORE	ZONE
0	0.5	Yellow / brown sandy earth	Sandplain
0.5	0.7	Red/brown gravels (moist)	
0.7	-	Pale, brown indurated zone. Silcrete chips from rig. Drill at 1000 PS1 drill force, 10 mins	Mottled/Pallid (Silcrete)
	(2.5)	Becoming easier. Some iron colour. V. fine qtz. In kaolin etc. powder.	
	(4.5)	Fine/med grained qtz. And kaolin. Pale occasional pink brown zones	
	13.5		
13.5	14.8	Brown-mustard colour change in qtz. Red clay sands (v. dry), Palaeo – watertable?	Weathering
14.8	16.0	Return to pale zone.	
16.0	19.0	Saprolite, fresh feldspar and qtz. Minor micaceous zone. Dry grits.	Saprolite
	19.0	Bedrock	Bedrock
Comments:		Dry borehole	RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO:	B 2	RIG TYPE:	R.A.B.
CATCHMENT:	Brennands	CASING DEPTH:	34.15 (m)
DATE DRILLING:	April 1987	DEPTH DRILLING:	36.50 (m)
LOCATION:	Skeleton Rocks	QUALITY:	1250 mS/m
GRID REFERENCE:	31°44’25”N 119°24’42”E	YIELD:	< 5kL/day
LAND UNIT:	Ulva	DEPTH TO BEDROCK:	36.50 (m)
		SLOTTED LENGTH:	2 (m)
WATERTABLE DEPTH:	29.10 (m)	SAMPLES:	EC,pH,ECe,Cl,Sat %

RESULTS			
DEPTH (M) FROM	TO	DESCRIPTION OF BORE	ZONE
0	0.5	Yellow loamy sand over indurated gravels.	Sandplain
0.5	0.7	Silicified zone, cemented mottled sandy clay.	Mottled
0.7	-	Pallid zone, pale kaolin and fine qtz.	Pallid
		Fine qtz, some roots in airstream, soft.	
-	5.8		
	(13.0)	Grey, pale pallid sands to clay sands.	
16.0		Brown fine clayey sand, occasional coarse qtz sands.	Weathering
		Uniform materials.	
	30.0		
30.0		Fresh feldspar, biotite and large qtz. Zone. Fresh bedrock chunks. Biotite rich zones common. Grits.	Saprolite
	36.5	Bedrock	Bedrock
Comments:		No yield of significance.	RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO:	B3	RIG TYPE:	R.A.B.
CATCHMENT:	Brennands	CASING DEPTH:	16.20 (m)
DATE DRILLING:	April 1987	DEPTH DRILLING:	16.25 (m)
LOCATION:	Skeleton Rocks	QUALITY:	6090 mS/m
GRID REFERENCE:	31°44'17"N 119°25'00"E	YIELD:	< 10kL/day
LAND UNIT:	Lakeside	DEPTH TO BEDROCK:	16.25 (m)
		SLOTTED LENGTH:	1 (m)
WATERTABLE DEPTH:	10.20 (m)	SAMPLES:	EC,pH,ECe,Cl,Sat %

RESULTS			
DEPTH (M) FROM	**TO**	**DESCRIPTION OF BORE**	**ZONE**
0	0.4	Grey brown sand, clay sand.	Sediments
0.4	0.9	Grey fine sandy clay mottled. Fine qtz in yellow pink matrix.	Mottled
0.9	3.3	Mottled sandy clay cont.	
3.3	-	Pale cream brown sandy clay. Qtz. (1-2 mm) and some iron oxide.	Pallid
13.0	16.5	Increased fresh quartz, feldspar. Banded zones of biotite and feldspar. Fresh rock grit. Gneissic banding	Weathering Saprolite
	16.5	Bedrock Intermediate bore drilled to 13m and slotted over 0.5m.	Bedrock
Comments:		Flow rate less than 10 day/day.	RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO:	B4	RIG TYPE:	R.A.B.
CATCHMENT:	Brennands	CASING DEPTH:	16.91 (m)
DATE DRILLING:	April 1987	DEPTH DRILLING:	16.95 (m)
LOCATION:	Skeleton Rocks	QUALITY:	6450 mS/m
GRID REFERENCE:	31°44’27”N 119°24’57”E	YIELD:	< 5kL/day
LAND UNIT:	Merredin	DEPTH TO BEDROCK:	16.95 (m)
		SLOTTED LENGTH:	2 (m)
WATERTABLE DEPTH:	13.21 (m)	SAMPLES:	EC,pH,ECe,Cl,Sat %

RESULTS

DEPTH (M) FROM	TO	DESCRIPTION OF BORE	ZONE
0	0.3	Fine red/brown clay loam – sandy clay loam.	Sediments
0.3	0.5	Carbonate zone.	Mottled
0.5	-	Fine sandy clay zone, limited qtz evident in red, grey matrix.	Weathering
	(6.5)	Grey sandy clay, little qtz.	
	(7.0)	Hard grey, red/grey clay loam - clay.	
	(10.0)	Brown fine clayey sand, occasional coarse qtz sands.	
13.0	-	Grey moist fine sandy clay, layer red/grey colours.	
15.5		Coarse grits zone with highly metamorphosed gneissic rock, with banding present, garnets.	Saprolite
-	16.5	Bedrock	Bedrock
Comments:		Yield limited to less than 5 day/day	RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO:	B5	RIG TYPE:	R.A.B.
CATCHMENT:	Brennands	CASING DEPTH:	7.54 (m)
DATE DRILLING:	April 1987	DEPTH DRILLING:	7.60 (m)
LOCATION:	Skeleton Rocks	QUALITY:	6830 mS/m
GRID REFERENCE:	31°45’37”N 119°25’58”E	YIELD:	< 5kL/day
LAND UNIT:	Merredin?	DEPTH TO BEDROCK:	- (m)
		SLOTTED LENGTH:	2 (m)
WATERTABLE DEPTH:	5.54 (m)	SAMPLES:	EC,pH,ECe,Cl,Sat %

RESULTS

DEPTH (M) FROM	TO	DESCRIPTION OF BORE	ZONE
0	0.3	Red/brown sand.	Sediments
0.3		Red/brown medium clay.	
		Medium red/grey sandy clay (chips 5mm)	
	(3.0)	Not bringing up sample (3.0 – 3.5).	
		Red clay, coarse chips of hardened clay.	
4.5	4.9	Brown/red coarse sand (qtz, rounded).	
4.9	7.1	Grey clay. Fine silty material, like drilling bentonite.	Weathered gneiss or sediments
		No bedrock.	
		Zone (4.9 – 7.1) has saturation % of 150% and is predominately haloysite (XRD).	
		Added water at 7.1m.	
Comments:		Flow 5 day/day	RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO:	B6	RIG TYPE:	R.A.B.
CATCHMENT:	Brennands	CASING DEPTH:	18.10 (m)
DATE DRILLING:	April 1987	DEPTH DRILLING:	18.16 (m)
LOCATION:	Skeleton Rocks	QUALITY:	6630 mS/m
GRID REFERENCE:	31°46 '45"N 119°27'13"E	YIELD:	10-20kL/day
LAND UNIT:	Merredin	DEPTH TO BEDROCK:	18.16 (m)
		SLOTTED LENGTH:	2 (m)
WATERTABLE DEPTH:	8.66 (m)	SAMPLES:	EC,pH,ECe,Cl,Sat %

RESULTS

DEPTH (M) FROM	TO	DESCRIPTION OF BORE	ZONE
0	0.3	Red/brown sandy loam.	Sediments
0.3		Red/brown clay, mottled, carbonate too.	
	(1.5)	Becoming pale coloured.	
	(2.0)	Some grey mottled zones apparent.	
4.5	5.5	Silcrete, wore 1cm off blade bit. Changed to rock roller.	Silcrete
		Silcrete identified as QAZ silcrete (SEM).	
5.5	5.7	Red ochre, ironstone.	
6.7	-	Red/grey – grey sandy clay. Becoming pale with depth. Fresh feldspars becoming hard.	Weathering?
-	8.4	Saprolite grits. Coarse feldspar qtz and biotite/mica. Some gneissic banding.	Saprolite
		Bedrock	Bedrock
Comments:		Flow 10-20 day/day.	RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO:	B6	RIG TYPE:	R.A.B.
CATCHMENT:	Brennands	CASING DEPTH:	18.10 (m)
DATE DRILLING:	April 1987	DEPTH DRILLING:	18.16 (m)
LOCATION:	Skeleton Rocks	QUALITY:	6630 mS/m
GRID REFERENCE:	31°46 '45"N 119°27'13"E	YIELD:	10-20kL/day
LAND UNIT:	Merredin	DEPTH TO BEDROCK:	18.16 (m)
		SLOTTED LENGTH:	2 (m)
WATERTABLE DEPTH:	8.66 (m)	SAMPLES:	EC,pH,ECe,Cl,Sat %

RESULTS

DEPTH (M) FROM	TO	DESCRIPTION OF BORE	ZONE
0	0.3	Red/brown sandy loam.	Sediments
0.3		Red/brown clay, mottled, carbonate too.	
	(1.5)	Becoming pale coloured.	
	(2.0)	Some grey mottled zones apparent.	
4.5	5.5	Silcrete, wore 1cm off blade bit. Changed to rock roller.	Silcrete
		Silcrete identified as QAZ silcrete (SEM).	
5.5	5.7	Red ochre, ironstone.	
6.7	-	Red/grey – grey sandy clay. Becoming pale with depth. Fresh feldspars becoming hard.	Weathering?
-	8.4	Saprolite grits. Coarse feldspar qtz and biotite/mica. Some gneissic banding.	Saprolite
		Bedrock	Bedrock

Comments: Flow 10-20 day/day. RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO:	B76	RIG TYPE:	R.A.B.
CATCHMENT:	Brennands	CASING DEPTH:	20.60 (m)
DATE DRILLING:	March 1988	DEPTH DRILLING:	21.05 (m)
LOCATION:	Skeleton Rocks	QUALITY:	4590 mS/m
GRID REFERENCE:	31°47 '15"N 119°48'00"	YIELD:	5 day/day
LAND UNIT:	Booraan	DEPTH TO BEDROCK:	21.05 (m)
		SLOTTED LENGTH:	2 (m)
WATERTABLE DEPTH:	18.03 (m)	SAMPLES:	

RESULTS

DEPTH (M) FROM	TO	DESCRIPTION OF BORE	ZONE
0	0.3	Red/brown sand.	Surficial
0.3	1.50	Mottled clay sand to sandy clay.	Mottled
1.50		Pallid sandy clay fine qtz.	
	(3.1)	White indurated chips of clay materials.	
	(3.9)	Pallid zone, hard zones.	
	(4.4)		
	(11.0)	Cemented or silicified materials cease quartz fine.	
17.0		Grey, green coarser texture, qtz., feldspar no micas.	Weathering
19.0		Gneissic banding is saprolite zone, biotite common, fresh feldspars, not too gritty.	Saprolite
-		Bedrock	Bedrock

Comments: No supply of note (< 5 day/day) saline RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO:	B8	RIG TYPE:	R.A.B.
CATCHMENT:	Brennands	CASING DEPTH:	- (m)
DATE DRILLING:	March 1988	DEPTH DRILLING:	8.5 (m)
LOCATION:	Skeleton Rocks	QUALITY:	- mS/m
GRID REFERENCE:	31°44 ’21”N 119°24’35”E	YIELD:	- day/day
LAND UNIT:	Collgar	DEPTH TO BEDROCK:	- (m)
		SLOTTED LENGTH:	- (m)
WATERTABLE DEPTH:	Nil (m)	SAMPLES:	

RESULTS

DEPTH (M) FROM	TO	DESCRIPTION OF BORE	ZONE
0	0.5	Yellow sandplain, goethite and some haematite staining is pisolite.	
0.5	1.2	Pallid zone, after very little mottling. (Indurated zone 1.2-2.7m, silicified) (3.1 – 7.2) soft drilling, kaolin and qtz.	
7.2	8.5	Silcrete. Massive silcrete, unable to be penetrated quickly by rock-roller, however after 45 minutes we had reached 8.0m. Continued drilling until we reached 8.5m, after 2 hours. Gave up after rock roller ceased. No water encountered. Hole not cased or monitored.	
Comments:			RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO:	B9, C B	RIG TYPE:	R.A.B.
CATCHMENT:	Brennands	CASING DEPTH:	15.00 (m)
DATE DRILLING:	March 1988	DEPTH DRILLING:	15.00 (m)
LOCATION:	Skeleton Rocks	QUALITY:	7910/5990mS/m
GRID REFERENCE:	31°46 ’30”N 119°26’22”E	YIELD:	5-10kL/day
LAND UNIT:	Merredin	DEPTH TO BEDROCK:	- (m)
		SLOTTED LENGTH:	2 (m)
WATERTABLE DEPTH:	3.31/3.41 (m)	SAMPLES:	

RESULTS

DEPTH (M) FROM	**TO**	**DESCRIPTION OF BORE**	**ZONE**
0	0.5	Well sorted qtz sands in alluvial fans in creekline.	Sediments
0.5	0.5	Grey mottled clay to sandy clay, apparently layered but chemically altered – mottled.	Clays
4.5		Pale (grey-fawn) sand. Well sorted subangular – sub rounded. 0.5 – 1.0mm qtz. Very little clay. Matrix. Layered sediments. Small supply.	Sands
7.5		Medium to heavy clay to s. clay. Grey mottled red/brown zone for 1.5 m Heavy textured, gradational to 12 m where qtz disappeared (Halloysite XRD).	Weathering?
12.0	15.0	Grey thick mud - fine textured slurry poor penetration. Similar to materials encountered in B5 (300 mN). Weathered gneissic or mafic rock. Bedrock? Deep bore screened 13 – 15 m. Shallow bore screened 3 – 5 m.	

Comments: Flow 5-10 day/day. Saline (approx 60,000 mgL). (Flow from 4.5-7.5 m) RJG