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Preliminary groundwater and salinity investigations in the eastern wheatbelt
2. Merredin catchment

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Disclaimer

Contents

1. Abstract

Saline groundwater occurs within twelve metres of the surface throughout the valley of the Merredin catchment. In most bores to the west of the Merredin townsite, saline groundwaters are within two metres of the soil surface.

Saline groundwater occurs within deep sediments deposited in the valley and deeply-weathered bedrock materials. A major aquifer was found at the base of the weathering profile to the west of the Merredin townsite. Rapid groundwater recharge appears to be taking place in sandy-textured soils high in the landscape and directly into the Cainozoic sediments in the valley floor. Recharge rates are apparently two orders of magnitude greater than those which occurred before clearing for agriculture took place. Water-tables are rising at approximately ten centimeters each year in the upper catchment area.

The management of groundwater recharge and discharge is essential to prevent or control steadily rising water-levels. These management techniques should include a combination of high water using crop rotations; perennial vegetation (including fodder, shrubs and other trees); groundwater extraction for stock or other uses and valley floor reforestation of selected areas. The transect of established bore holes will provide an ideal means of monitoring the success of recharge and discharge management systems by observing the rate of water-table rise or fall. The bores will also provide monitoring points to allow the interpretation of a pumping and/or reforestation programme to be established to prevent salinization of the townsite.

2. Introduction

2.1 Environment

The Merredin catchment is located 270 km east of Perth (31°30'S, 118°15'E) on the Great Eastern Highway (Figure 1). It covers an area of over 400 k&. The catchment is characterized by a flat topography with little relative relief (109 m). The catchment is located in the Swan-Avon drainage basin.

The Merredin catchment is predominantly underlain by ancient (age 2,900-2,500 million years) granitic and gneissic rocks. Seriate adamellite and porphyritic granites form the major bedrock materials. Coarse grained biotite adamellite and migmatite is also prevalent. Intrusive Proterozoic rocks such as dolerite dykes were rarely observed in the mid to lower-slopes of the catchment, although dolerite scree and quartz veins were present in the upper, more dissected areas of the catchment. Deep weathering and laterization of the bedrock is suggested to have occurred during the mid Tertiary geologic period (Schmidt and Embleton, 1976). In-situ weathering to depths greater than 30 m is common.

Annual average rainfall varies from east to west. Rainfall at Merredin (1906-1989) had an average of 328 mm, while the average rainfall recorded at Nangeenan, 10 km west, had an average of only 305 mm over the same period of observation. The annual average potential evaporation rate is 2,630 mm, with mean monthly rates exceeding mean monthly rainfall throughout the year.

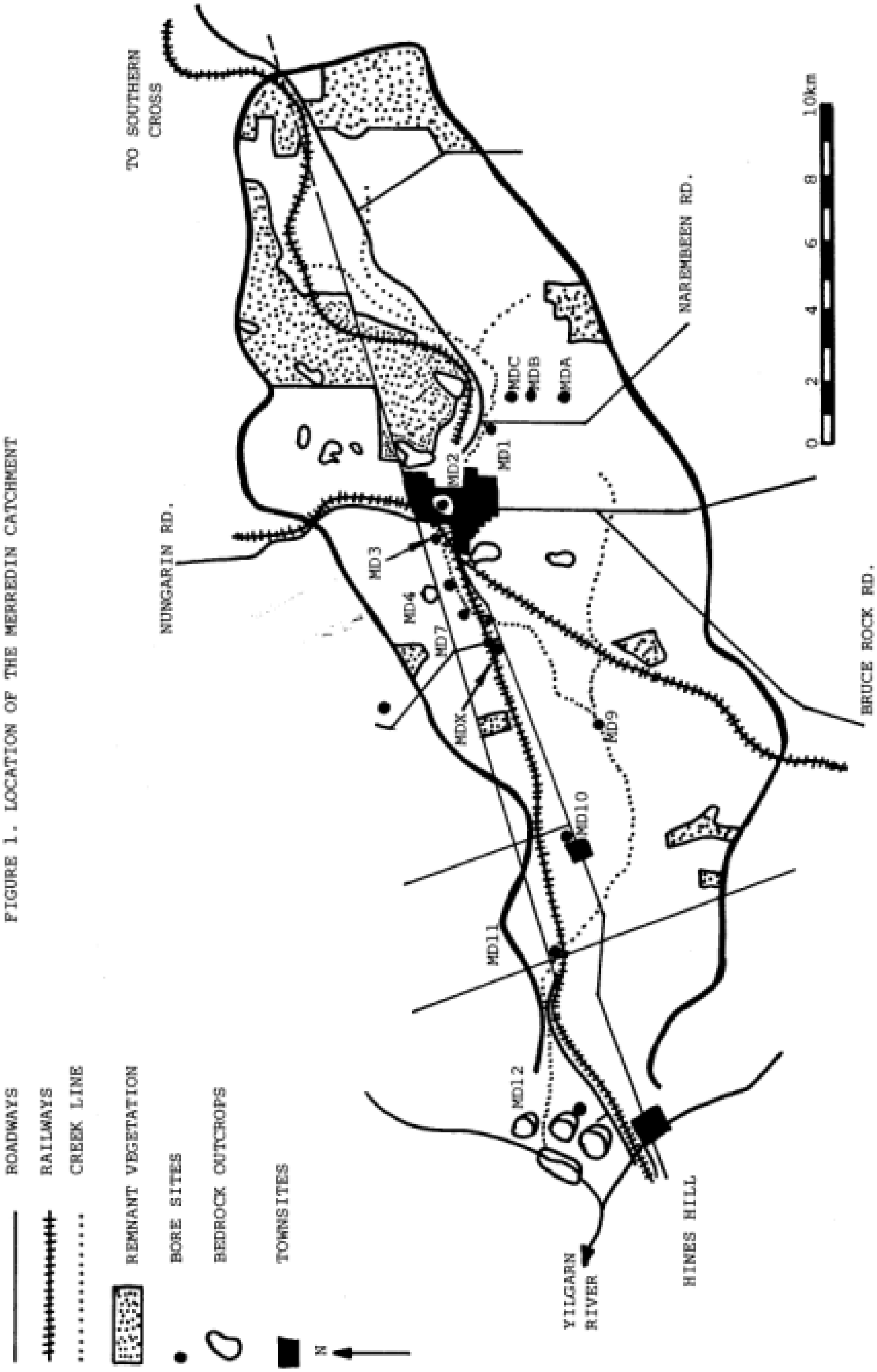
Surface drainage is from the east to west via a series of intermittent creeks (Cons Creek). These creeks flow towards the palaeodrainage, or salt lake chains of the Yilgarn River near Hines Hill (Figure 1).

2.2 Aims

The aim of this report is to describe the nature and distribution of groundwaters and the factors affecting salinization of agricultural and urban land in the Merredin catchment. Within this broad aim there are several secondary objectives. The first was to assess the potential for continued salinization and secondly, comment on remedial steps which might be taken to avert its spread. The report also aims to present hydrogeologic data on which assumptions for groundwater flow are based and comment on the major aquifer systems and their genesis.

This report will precede a second technical report which details the results of additional drilling and pumping tests conducted in co-operation with the Geological Survey of Western Australia. The second report aims to describe in more detail the hydrogeological and geophysical conditions of the West Merredin area. It also aims to present the technical data upon which both the groundwater pumping and reforestation management options are based. This preliminary report presents the results of the research carried out between 1986 and 1989 and introduces the second report.

FIGURE 1. LOCATION OF THE MERREDIN CATCHMENT



3. Materials and Methods

3.1 Drilling Methods

Bore holes were drilled using a rotary air blast drilling rig. Piezometers were installed at 15 locations throughout the catchment, although most were located in the valley floor near the Merredin townsite. Piezometer nests comprising a deep bore (D = to bedrock) and intermediate bore (I = just below the water-table) were usually drilled to determine hydraulic gradients within the aquifer. Piezometers were constructed from 40 or 50 mm PVC tubing and screened over the lower two metres of the casing. The tubing was lowered down uncased holes immediately following drilling. A filter pack comprising one to two millimetre diameter washed sand was then placed in the annulus alongside the screened section. Several metres of cement or bentonite was located above this material to prevent contamination from surface or other aquifer waters. The remainder of the bore was backfilled with drill cuttings and a cement collar placed near the surface to protect the bore.

Drill hole samples obtained from the rig were described on-site (Appendix 1). The geological logs describe changes in lithology which were noted during drilling. The drill cuttings were sampled at 1.0 m intervals at 12 sites and analysed for soil salinity (electrical conductivity - mS/m), pH and chloride (%). At bore sites 14DB and MDC soil moisture contents were measured using the gravimetric method.

One production bore (185 mm diameter) was also drilled and cased. Commercially slotted PVC screens were used on both the pump and observation bores. The pump bore was screened in the Cainozoic sediments located at MD3. Bore hole locations are shown in Figure 1 and graphically presented in Figures 2 and 3.

3.2 Geophysics

Three geophysical techniques were used to help interpret geologic features within the West Merredin area. Magnetic and electromagnetic measurements were undertaken on one transect (Figure 1). Bore hole geophysics, consisting of downhole gamma logging and electromagnetic soundings were conducted at four and twenty locations respectively. Results are presented in Sections 4.3.2 and 4.3.3.

3.2.1 Magnetics

A ground magnetic survey was conducted on a 5,000 m transect between MD3 and MDX, with measurement stations located every 10 m. The survey used a Geometrics (TM) G856 portable proton precession magnetometer with its sensor mounted on a three metre pole.

The magnetic survey was conducted in the upper catchment area (MD3 to MDX) to determine the location of magnetic anomalies often found to be responsible for saline seeps (Engel et al., 1987). Magnetic anomalies can be produced in bedrock materials such as amphibolites and dolerite. Magnetic surveys are usually capable of locating these materials as they display a different magnetic intensity from the surrounding granitic and gneissic materials. The reader is referred to Engel et al. (1987) for a more detailed account on the use, operation and limits of magnetic surveys.

3.2.2 Electromagnetic Induction

An electromagnetic (electrical conductivity) survey was carried out using the Geonics

(TM) EM38 and EM31 terrain conductivity meters. These units consist of a transmitter and receiver placed at 1.0 m and 3.5 m apart respectively.

The EM38 has an approximate maximum depth of penetration of 1 m while the EM31 is capable of measuring to about 6 m (McNeill, 1980).

Both instruments produce a primary electric current which is transmitted into the ground. A secondary current is subsequently received from the ground over the depth influenced by the different instruments. The ratio of these fields is measured as a voltage in the receiver coil and displayed directly as electrical conductivity in milli Siemens per metre (mS/m).

The EM38 and EM31 were used on the same transect (MD3 to MDX) as that used in the magnetic survey (Figure 1). The same survey grid and line spacings were used on both transects.

Measurements were also taken using the EM31 at twenty bore holes (sites MDA to 14D13). Five measurements were taken around and over the bore hole of interest. These measurements were subsequently used to determine whether a statistical relationship exists between terrain conductivity (ECa) and soil sample conductivity (EC 1:5) obtained from drilling.

3.2.3 Natural Gamma Logs

Natural gamma, profile logging was carried out on four bores located in the upper catchment area (MD1, MD2, MD3 and MD4). A truck mounted “Gearhart-Owen” gamma logger was borrowed from the Geophysical Section of the Western Australian Department of Mines. Logging was conducted by lowering a 45 mm diameter active gamma source down the bore hole. Automatic sampling occurred in both the ascending and descending modes. Only the data obtained on the ascending mode was used, as the descending mode data was used as a calibration on each hole.

Bore hole logging detects the natural-gamma radiation emitted by all rocks and weathering products. Anomalies can exist due to high levels of background radiation in response to lange amounts of potassium - 40, uranium - 235, 238 and thorium. It is also caused by the presence of clays which may actively concentrate heavy radio-elements. Sandy materials with little clay have low background gamma radiation (Telford et al., 1986).

3.3 Hydraulic Tests

3.3.1 Pimping Tests

Pump tests were conducted on bore (MD3P) located above the basement ridge shown in Figure 2. Two short duration tests were conducted to determine the hydraulic properties of the Cainozoic sediments. The first test consisted of a 600 minute constant rate test. The pumping rate was held constant at 66 kL/day throughout the test, and was followed by a recovery test over a similar period of time. The second test was conducted at approximately double the initial rate (116 kL/day) until the water-level in the the well approached the pump inlet. The results were analysed using standard procedures outlined in Kruseman and De Ridder (1983). Only time-drawdown analyses could be carried out owing to the lack of suitably positioned observation wells.

3.3.2 Slug Tests

Slug tests were carried using the methods described by Bouwer and Rice (1976). A 2 m head of water was displaced with a sealed aluminium tube and recovery of the bore measured. Graphical analysis of the time-drawdown data was carried out by using early time data (5-15 minutes). A slope value was extracted from this data from semi-logarithmic paper and an estimate of hydraulic conductivity made.

3.4 Runoff Measurements

A 90° V-notch weir was constructed in the main drainage line (Cons Creek) adjacent to drill-hole location MDX. A chart-recorder, located in a stilling well upstream from the weir, recorded fluctuations in water-levels during the winters of 1986, 1987 and 1988. Flow rates were derived from a theoretical rating curve once initial calibration tests were completed.

Rainfall observations were derived from two pluviographs and standard gauges located at the Bureau of Meteorology site in Merredin and at the Dryland Research Institute (MDX).

3.5 Soil Chemistry

Three hundred samples were taken during the drilling programme at one metre intervals to bedrock. These samples were analysed for electrical conductivity (EC 1:5 and ECe) chloride (Cl) and pH. Analysis was conducted by the laboratories of the Division of Resource Management, South Perth

3.6 Groundwater Geochemistry

Groundwater was sampled from all piezometers and wells in the Merredin catchment. Samples were analysed for electrical conductivity and pH at the Merredin office. From the initial salinity survey, ten locations were chosen in the upper catchment area for detailed geochemical analyses.

The analyses were undertaken by the Agricultural Chemistry section of Water Centre of W.A. Samples were analysed for the major anions and cations, as well as total soluble salts (TSS mg/L), electrical conductivity (EC mS/rn), pH, silica and bromide.

4. Results and Comments

Drilling Information

Rotary air blast drilling was conducted in the catchment between March 1986 and June 1987. A total of 20 bores (432 m) were drilled at 15 sites. At eight sites, deep piezometers were installed to bedrock and at the 12 remaining sites intermediate depth bores were located in the water-table zone (Figure 2).

4.1 Lithology

The nature and distribution of the weathered granitic and sedimentary materials overlying bedrock were described from soil cuttings retrieved during the drilling programme. These materials can be classified into two district lithologic units. The first unit consists of various sequences of alluvial and colluvial sediments deposited in the valley to maximum depths of approximately 12 to 15 m. Below these sediments occurs the extensive, chemically weathered saprolite, derived from the isovolumetric or “in-situ” weathering of the bedrock.

4.1.1 Merredin Sediments

A graphical representation of the relationship between the sedimentary and weathered zones in the upper valley area is presented in Figures 2 and 7.

A more detailed account of the characteristics of the sediments and weathered zone is given in the well-log reports (Appendix 1).

The sediments consist of both clay and sand dominated sequences. There is an apparent trend in the grain size distribution downstream, with the sandy materials between MD1-MD7 giving way to greater depths of clay (downstream from MD7). At sites MD1, MD2, MD3 and MD4 the sediments occur as red, to pale brown, clayey sands.

These materials have been variably silicified and occasional cross-bedding with rounded alluvial materials occur. At MD1 and MD3 the upper 2-4 m of the profile consists of heavy-textured, red-brown sandy clay to sandy clay loam soils. This zone is not present at MD2 (Figure 3).

The coarse grained materials are sub-angular to rounded and occasionally sorted. Mineralogically they consist primarily of quartz and feldspar ranging in size (diameter) from approximately 1 to 5 mm. Cementation with both silica and iron is common and produces indurated silicious layers (silcrete) and mottled, iron-rich zones (ferricretes). Some of the more indurated and silicified materials required significant drill force (eg. rock-roller drill bits) to penetrate.

The thin sequence of surface clays in the area between MD1 to MD4 changes gradually to incorporate most of the sedimentary zone from MD7 to MD11. Drill holes through these downstream zones encountered sequences of red-brown sandy clays which comprised kaolonite, hematite and quartz. Occasionally within this clay-rich zone, coarse sand-textured alluvial beds were intersected during drilling. In three deep (6 m) profile pits installed in the zone between MD7 and MDX, these discontinuities could be observed. However, the apparent sharp boundaries interpreted from the drilling information were more appropriately described as gradational, or zonal changes. In all of

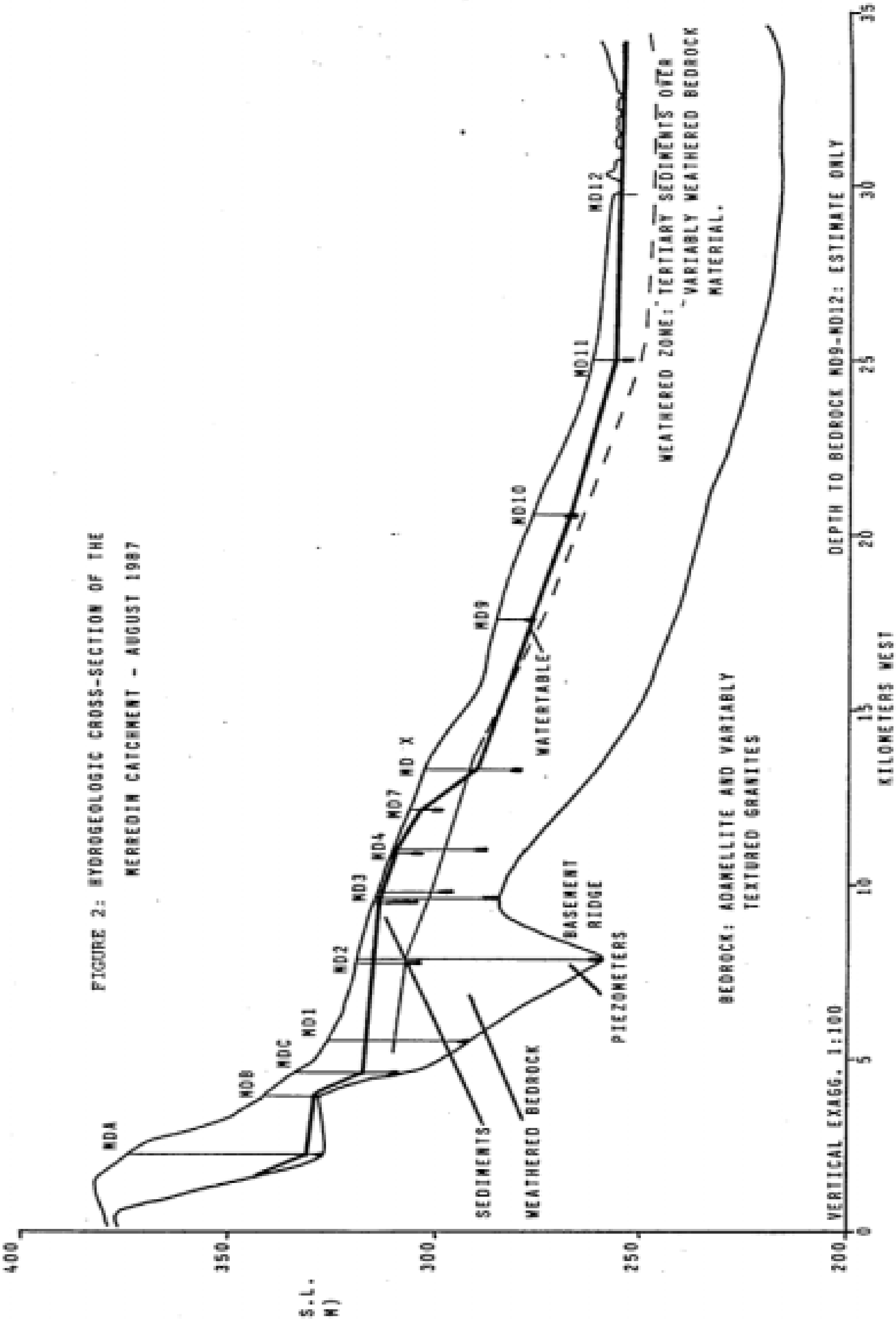
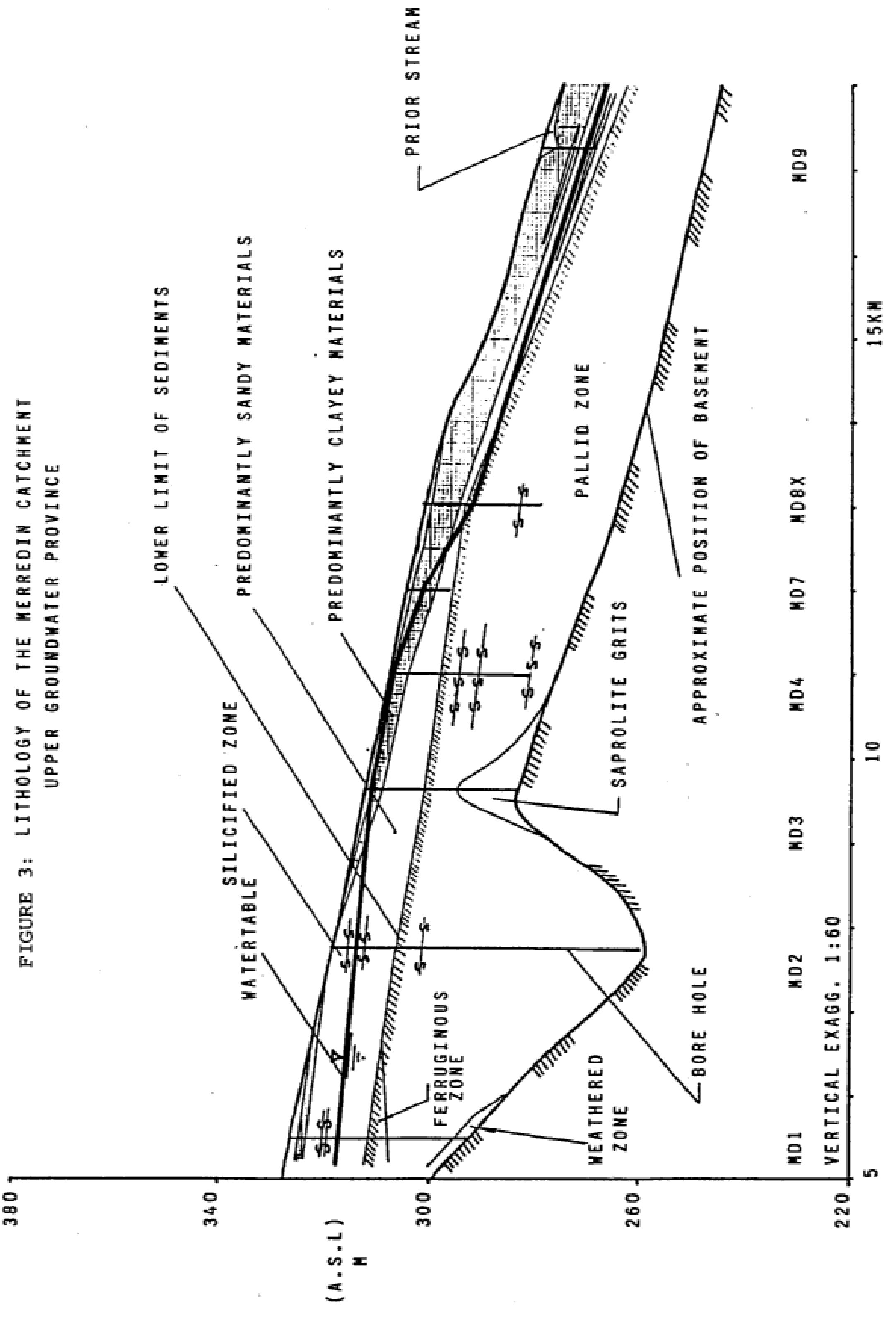


FIGURE 2: HYDROGEOLOGIC CROSS-SECTION OF THE MERREDIN CATCHMENT - AUGUST 1987

FIGURE 3: LITHOLOGY OF THE MERREDIN CATCHMENT
UPPER GROUNDWATER PROVINCE



the pits observed, evidence of “in situ” weathered granitic or gneissic material could not be found.

At MD9 the heavy-textured surface sandy clay loams gave way toa deep (2 m) sequence of sandy materials. At this site the drill hole was placed adjacent to the present creek bed where a delta was forming. Above and below this area the creek floor was gullied into the surrounding sandy clays. Carbonate was common in the upper metre of the soil profile.

4.1.2 Weathered Bedrock

The deeply-weathered, kaolinized profiles under the I4erredin catchment occur below the sedimentary materials in the valley floor and are exposed on the valley sides and divide. The depths of weathering vary from only 14 m at MDB to over 50 m at MD2. The dominant weathering unit in the saprolite that occurs below the sediments is the “pallid zone”. However, other zones which comprise variably-weathered bedrock can be found (Figures 3 and 7).The relationship between these zones are shown. The weathering pattern in the Merredin catchment is similar to that nearby (East Belka - AB13D) and in other deeply-weathered, crystaline basement regions, such as Africa (Ackworth, 1987 - see Figure 7).

The pallid zone is used in this report to describe weathered materials which are almost entirely comprised of quartz and kaolinite. However, within these materials it is often common to find silicified or indurated zones. The pallid zone is also variably textured. Quartz grain sizes may vary from the fine sand (1 mm) to stone (1-20 mm) size. This textural variability is both a function of porphyritic veins or seams encountered during drilling, and is typically caused by the variability of quartz weathering and the nature of the parent material.

Materials encountered near bedrock have a different physical characteristic to that of the pallid zone. From MDA-MD1 the pallid zone gave way to a poorly weathered rock at depth. These materials were characterized by an increase in quartz grain size and the inclusion of weathered, but hard feldspar. The degree of chemical alteration of the weathering zone was also extremely variable. At bores located above MD1 the fine grained materials took on a red-brown or yellow-green appearance, depending on the weathering status of biotite and iron. However, at some sites the weathering history had produced a “saprolite grit”. This material contained minor amounts of clay and was primarily composed of angular quartz and feldspar with an abundance of biotite.

Inspection of railway cuttings located in the upper, or eastern end of the catchment suggests that the saprolite grits are the result of a complex structural disintergration of the parent rock. The resultant weathering pattern is highly variable. Often granitic intrusions within a gneissic groundmass show limited weathering, while the gneissic zone shows complete disaggregation. Foliations within the gneissic rocks are preserved and usually act as the primary weathering fronts. As a consequence, the grits may appear to “dip” towards the valley floor.

Exposures of the saprolite grits are common in the north-eastern catchment area, and have been observed crossing midslope drainage lines and at the base of large bedrock outcrops.

In a catchment nearby (Ardath - R.J. George, unpublished results, 1987), the saprolite grits were observed to depths of 50 m within 10 to 20 m of large outcrops, in response to a major structural control. In the Merredin catchment, drilling only located significant depths of grits in the deep bores near MD3 and MDA. However, subsequent drilling throughout the eastern wheatbelt (George and Frantom, 1990a, b) has shown that 25% of all bore holes drilled encountered this material. Some saprolite grit zones cover extensive areas in the order of 1000's of hectares (East Belka catchment) where as others only occupy small enclaves (1 to 10 ha) within sub-catchments (Harvey's catchment). Similar materials have also been found in the northern and western wheatbelt areas (R. Engel and C.J. Henschke, personal communication, 1988).

Limited drilling information is available below MDX to determine the variability of the depth to bedrock or the nature of weathered materials. However, at a demonstration of the Seismic geophysical method on the Merredin Research Station (1988) it was suggested the depth to bedrock was of the order of 40 m (Geological Survey, personal communication, 1988).

4.2 Hydrogeology

Groundwater within the Merredin catchment was encountered in all of the piezometers installed during the drilling programme (Figure 2). The saturated thickness ranged from approximately 55 m at MD2 to less than 2 m at MDB. Details from the drilling programme are summarized in Table 1. Groundwater flow is dependent on the nature and distribution of aquifer materials and geologic and geomorphic controls. Two groundwater regions dominate catchment flow processes, one located upstream from a bedrock ridge and valley convergence near MD4 and the other downstream from this point.

Table 1. Drilling Details and Groundwater Information

Piezometer No.		Total Depth (m)	Cased Depth (m)	* SWL (m)	Slotted Length (m)	Material Screened (m)
MDA	D**	47.50	46.33	42.15	2	Saprolite Grit
MDB	D	14.15	13.40	12.67	2	Weathering Zone
MDC	D	27.50	27.29	18.21	2	Pallid Zone
MD1	D	33.01	33.00	10.72	2	Weathering Zone
MD2	I	17.55	17.55	7.05	2	Pallid Zone
	D	60.65	45.65	5.64	2	Weathering Zone
MD3	I	9.10	9.08	1.98	2	Sandy Sediments
	D	29.90	25.89	1.58	2	Saprolite Grit
	P	30.01	17.69	1.78	12	Sandy Sediments
MD4	D	22.11	19.41	0.46	2	Pallid Zone
	I	6.00	5.86	0.77	2	Sandy Sediments
MD5	I	12.00	11.81	2.35	1	Pallid Zone
MD6	I	6.00	5.86	2.68	1	Sandy Sediments
MD7	I	6.00	5.85	3.91	2	Sandy Sediments
MD8	D	42.81	41.84	11.86	2	Pallid Zone
MDX	I	37.12	25.01	12.81	2	Pallid Zone
MD9	I	8.90	8.86	7.97	1	Clayey Sediments
MD10	I	8.90	8.86	8.40	1	Clayey Sediments
MD11	I	7.90	7.87	4.25	1	Clayey Sediments
MD12	I	4.90	4.38	0.50	1	Clayey Sediments
		431.76	381.49			

*SWL = Depth below ground of piezometric surface or water-table (August 1987).

**D = Deep bore, I Intermediate or Water-table bore and P = Production bore.

NOTE: Slotted casing was always located at the base of the piezometer, with the exception of 14D3P which has a 6 m sump.

Groundwater flow within the Merredin catchment is controlled by the location of bedrock irregularities and the convergence of groundwater systems caused by lateral and vertical restrictions to flow. Shallow groundwater levels and discharge at MD4 are due to the convergence of groundwaters from the eastern and northern catchments, a decrease in the transmissivity between MD2 and MD3 and recharge across the valley sediments. Groundwater levels are also affected by the restricted lateral cross-section of the valley near MD4 which limits groundwater flow. Low to moderate upward flow (hydraulic head) occurs throughout this area (Figures 4a, b and Table 2). These features effectively divide the catchment in two groundwater regions. The lower catchment region appears to have no significant geologic or geomorphic controls affecting groundwater flow, since the observed groundwater levels are approximately parallel with the soil surface. However, where the Merredin valley meets the Yilgarn River system (14D12) the water-table nears the soil surface. Regional groundwater discharge occurs in the major saline lakes in this region.

The hydraulic properties of the aquifers and aquitards within the catchment are characterized by materials of variable hydraulic conductivity. Variations in hydraulic gradients and conductivity through the catchment are shown in Table 2 and in Figures 2, 3 and 4a, b). Results from pumping and slug tests are summarized in Table 3. The groundwater systems are also characterized by the lack of any significant hydraulic gradient. The gradient ranges from 0.02 (MDB-MDC) to as little as 0.0009 (MD3-MD4). The maximum groundwater flow velocities, where velocity is defined as the hydraulic gradient (Table 2) multiplied by the mean hydraulic conductivity (Table 3) and divided by the effective porosity (maximum 0.4; Gilkes, personal communication, 1988) ranges from 3 m/yr (MDB-MDC) to less than 0.1 m/yr (MD3-MD4). The low groundwater velocities effectively prevents groundwater from being moved downstream of MD4 (Figures 4a, b). Recharge within the valley-floor soils and any increase in hydraulic pressure at depth, causes groundwater levels to rise towards the soil surface. When evaporation occurs, dryland salinity develops.

FIGURE 4A: FLOW NET FOR THE MDX - MD1 AREA (1986)

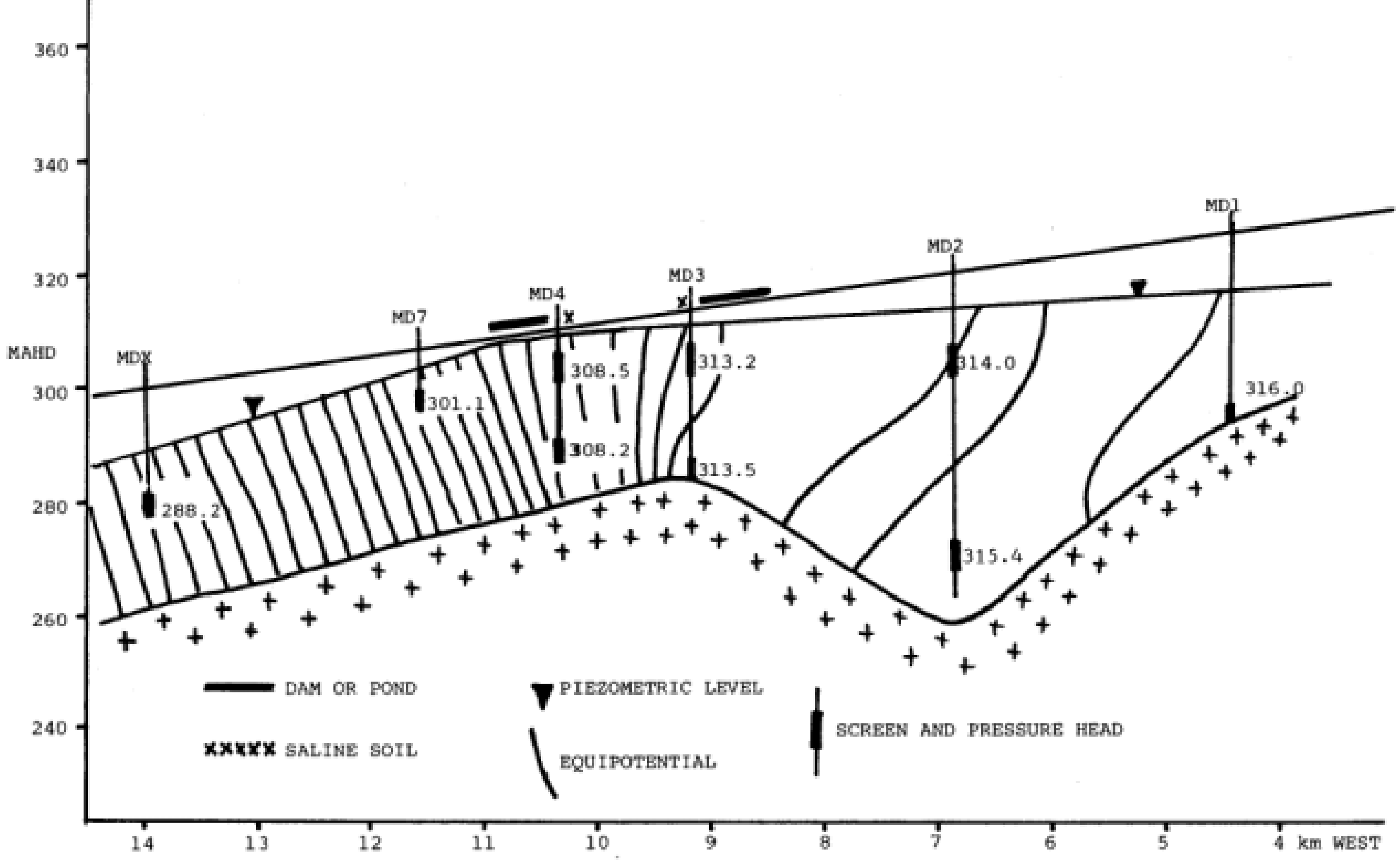


FIGURE 4B: FLOW NET FOR THE MDX - MD1 AREA (1990)

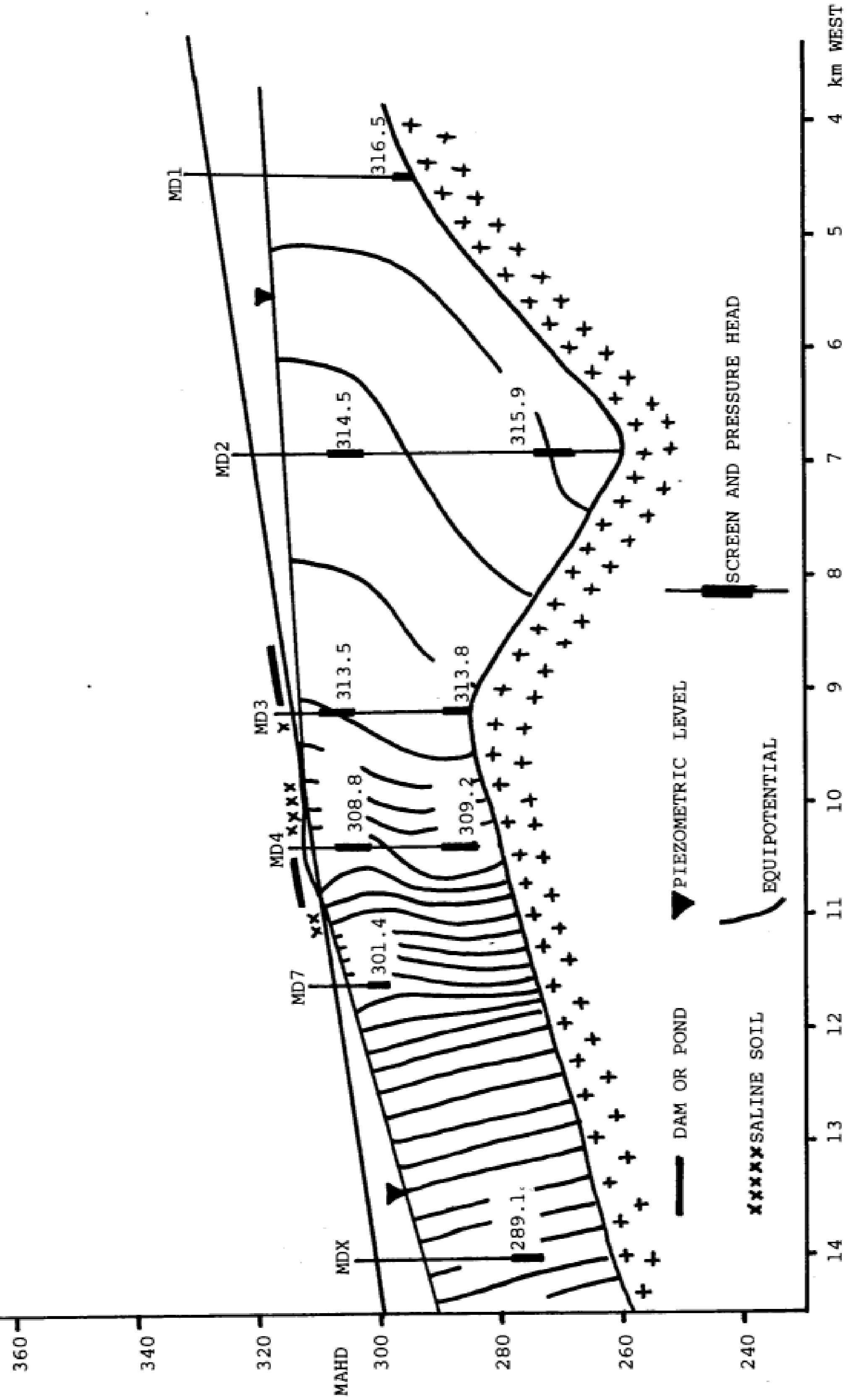


TABLE 2. Hydraulic Properties of Bores in the Merredin Catchment

Bore Site Location *		Hydraulic Gradients		Hydraulic Conductivity		Storage Coefficient D
		VerticalA	HorizontalB	C (m/day)	D (m/day)	
MDA	D	-	-	0.12		
MDB	D	-	0.001	0.01		
MDC	D	-	0.02	0.07		
MD1	D	-	0.001	0.17		
MD2	I	-	-	0.07		
	D	+0.05	0.0007	0.09		
MD3	I	-	-	0.34		
	D	+0.024	0.0009	3.99		
	P	-	-	0.79	0.60-0.80	1 X 10-^{2}
MD4	I	-	-	0.29		
	D	+0.023	0.002	0.22		
MD7	I	-	0.005	-		
MD8	D	-	0.001	0.08		
MDX	I	-	0.01	0.06		
MD9	I	-	1.002	0.05		
MD10	I	-	0.001	0.03		
MD11	I	-	0.001	-		
MD12	I	-	0.0002	0.06		

A. Vertical gradients calculated from intermediate and deep bores at each site (all **+** or upward heads, 1989).

B.Estimated horizontal gradients calculated from each site in sequence down the transect. After MD7 only intermediate bores or water-table gradients were used. Above MD7 only deep or piezometric levels were used.

C.Hydraulic conductivities calculated from slug test method - Bouwer and Rice (1976).

D.Results from pump-test.

*D = Deep Bore, I = Intermediate Bore, P = Pump Bore (see Table 1).

TABLE 3. Groundwater Characteristics from “SLUG” and Pump Test Results

Lithology	Bores Used (MD)	Rank Order	Mean (m/day)	SD[A]	CV[B]
Pallid Zone	B, C, 2D, 4D, XI AND 8D	2	0.10	0.06	60%
Weathering Zone**	A, 1D AND 3D	4	1.42*	2.22	156%
Sandy Sediments	3I, 3P AND 4I	3	0.47	0.27	57%
Clayey Sediments	9I, 10I and 12I	1	0.05	0.02	40%

A = Standard deviation.

B = Coefficient of variation.

* =If MD3D is omitted from the sample population, the mean, SD and CV becomes 0.15, 0.03 and 20% respectively.

**= The weathering zone includes the “saprolite grits” (MDA and MD3D).

4.2.1 Pump Test Results

The most productive aquifer occurs near MD3. The material, a saprolite grit, lies within the weathering zone immediately below a 12 m sequence of sandy sediments and a 6 m zone of pallid zone sandy clays (Figure 7). The grits occur from 18 m to bedrock (30 m).

A production well was drilled to bedrock so that a pump test could be undertaken on the saprolite grits. An initial airlift test, run over two hours using the drill rods and air compressor, suggested a possible yield of up to 200 kilolitres per day (kL/day). A drawdown of 0.1 m was observed at MD3D during this procedure. However, when the casing was run down the hole, only the Bandy sediments and pallid zone materials remained open. It was decided to conduct the pump test on the sandy sediments, since their yield also appeared to be significant, and additional drilling or re-drilling the pump bore was not possible (economics). Subsequent pump tests on the grits at the East Belka and Harvey’s catchments located nearby, gave yields in the order of 32-100 kL/day and displayed a confined to semi-confined aquifer behaviour (George and Frantom, 1990b).

The time-drawdown analysis using the straight line method (Kruseman and de Ridder, 1983) gave a transmissivity estimate of 6 m/day at the pump bore and 8 m/day at the observation well (MD3D). The apparent transmissivity from short-term pumping (600 minutes) appears to be in the order of 6-8 m/day. Using the measured saturated thickness of 10 m for the sandy sediments, a mean hydraulic conductivity of 0.6-0.8 m/day was derived. This corresponds with the slug test results on the pump bore (0.79 m/day) and observation bore (MD3I = 0.34 m/day) and is in the order of the “average” value of 0.47 m/day derived from Table 3. The storage coefficient and lithology suggest semi-unconfined aquifer conditions. The specific yield was estimated to be about 0.01-0.02, however, inadequate controls on the pump test meant an accurate estimate could not be made.

The pump-test data is considered to over estimate the hydraulic conductivity owing to limited pumping duration and poor construction of the pumping bore. Some vertical leakage from the saprolite grits was considered possible and should be noted when using the transmissivity values, although the estimated hydraulic conductivities are similar to those obtained from slug tests and may infer that little leakage occurred.

Groundwater movement within the pallid zone may also be significant. Although the estimated hydraulic conductivity is relatively low, deep sequences of this material give estimated transmissivities (material thickness multiplied by slug test value of hydraulic conductivity) in the order of 1-5 m/day. The clayey sediments have much lower hydraulic conductivities and derived estimates of their transmissivity are only in the order of 0.1-0.5 m/day.

4.2.2 Soil Moisture

Gravimetric soil moisture contents at MDB were lower than at MDC, located downslope (Figure 5). In contrast with decreasing soil moisture levels with depth at 14DB, MDC showed an increasing trend from 7 to 14 m, becoming “uniform” with depth. Low soil moistures at MDC, just above and below the water-table, are probably a result of the drying of clayey soils by the drilling rig (air-blast). Higher moisture contents at depth occur in the more permeable, weathering zone. Neither MDB or MDC have developed a clear trend in groundwater levels (Appendix 2) that could be attributed to differing moisture contents.

4.3 Geophysical Surveys

4.3.1 Magnetic Survey

It was apparent from the drilling information that the potential for groundwater discharge throughout the **MD3-MD4** region was high. Limited drill hole data suggested bedrock topography and catchment geomorphology are sufficient to explain these high water-table levels. However, work conducted by Engel et al. (1987), showed that dolerite dykes were often responsible for controlling the location of saline seeps. It was therefore decided to conduct a magnetic survey across the zone of interest, between MD3 and MDX. The results of the survey are presented in Figure 6a.

Major magnetic anomalies are normally characterized by values in the order of 300-1,000 nanoteslas (nT) above or below the background readings. However, it is apparent from the survey that if dykes exist, they are either deep or poorly magnetic. The decreasing magnetic susceptibility (0.25 nT/m) of the materials along the traverse may represent a change in bedrock materials or an increasing depth to bedrock.

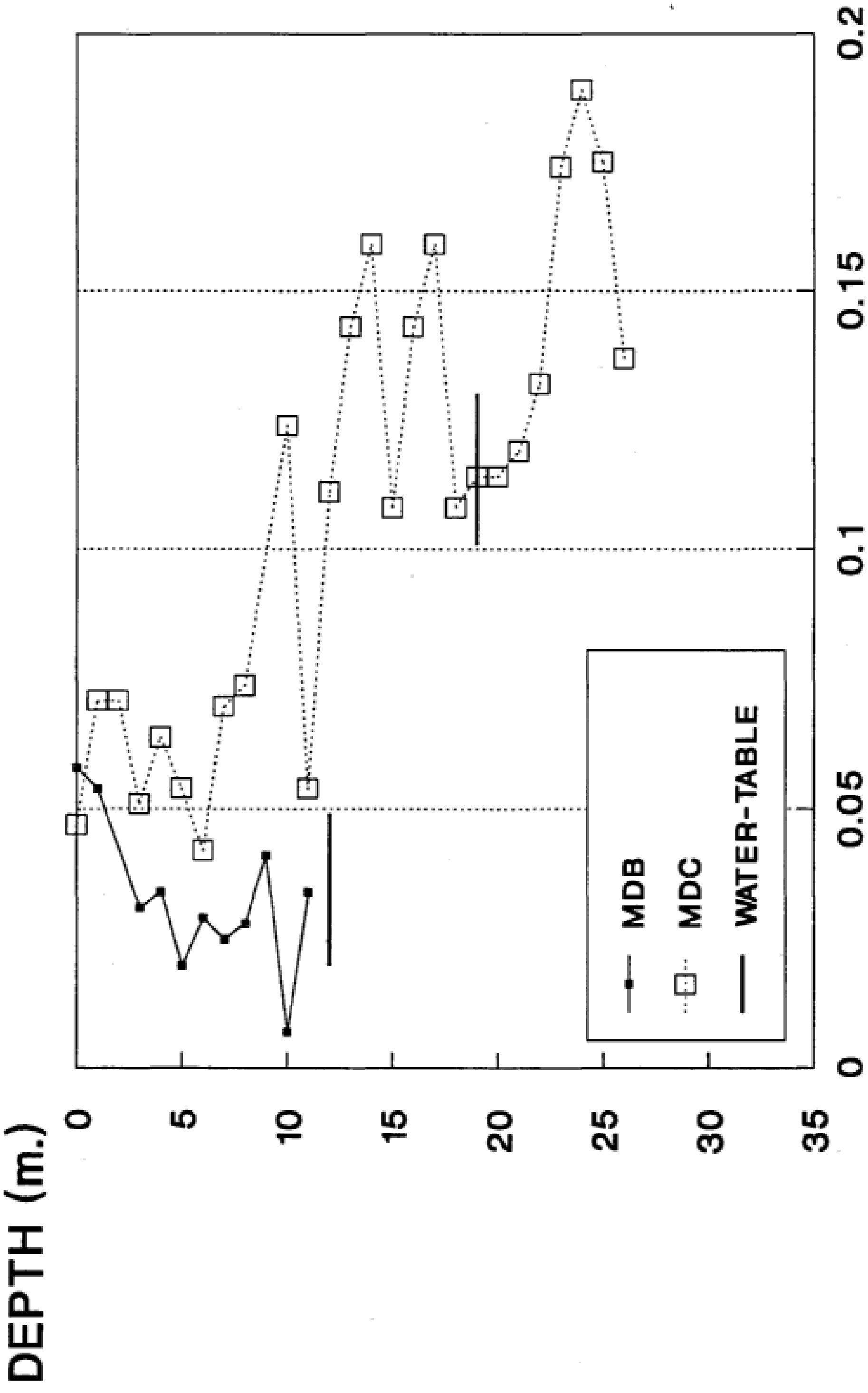


FIGURE 5: GRAVIMETRIC SOIL MOISTURE CONTENTS OF MDB AND MDC PROFILES

4.3.2 Electromagnetic Induction

An electromagnetic induction survey using the EM38 was carried out along the same transect as the magnetics survey. The results from the survey (Figure 6b) suggest that a zone of moderate to high conductivity occurs in the region between MD3 and MD4. Peak values occur immediately adjacent to MD4 in the creek channel and are associated with groundwater discharge and soil salinity. A rapid decrease in conductivity was apparent downstream, where groundwater levels fall well below the soil surface (MD5 and MD6 -Table 1). Peak values below this zone are attributed to the interference from buried and overhead conductors such as power lines, pipe-lines or cables. Terrain conductivities within the MDX area were low.

A second survey using the EM31 was conducted at each bore drilled.

Borehole electromagnetics (ECa) and averaged electrical conductivity measurements taken from the drill samples (EC 1:5) are compared in Table 4.

Electromagnetic soundings were taken to be most effective over the upper 6 m of the profile (McNeill, 1980).

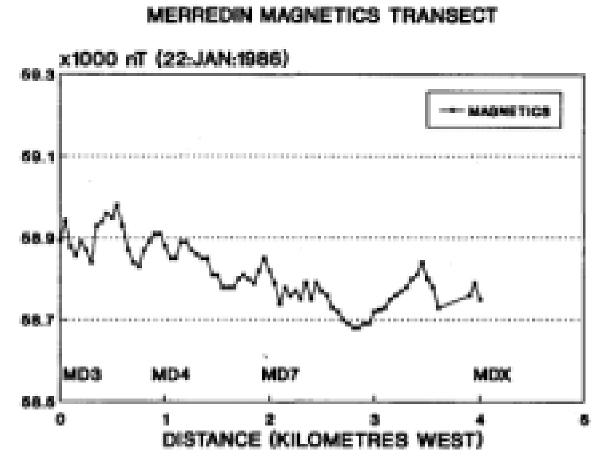


Figure 6: Geophysics Transects (1986) 6a: Magnetics Profile (Geonics 816)
6b: Electromagnetics (Em 38)

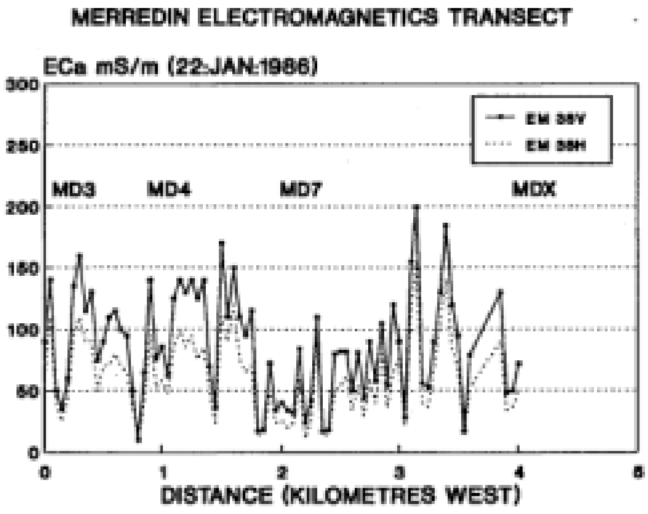


TABLE 4. Comparison of Eca and EC 1:5 Measurements

BORE HOLE		ECa	XC 1:5*	NO. OF SOIL SAMPLES	RATING**
MDA	D	60	16	6	Low
14DB	D	72	19	6	Low
MDC	D	55	4	6	Low
MD1	D	55	37	7	Low
MD2	D	45	41	6	Low
	I	45	41	6	Low
14D3	D	170	87	5	High
	I	170	87	5	High
	P	150	80	5	High
MD4	D	80	-	-	Moderate
	I	80	-	-	Moderate
MD5	I	65	22	6	Low
MD6	I	50	10	6	Low
MD7	I	80	86	6	Moderate
MD8	D	60	53	7	Low
MDX	I	94	-	-	Moderate
MD9	I	25	18	6	Low
MD10	I	85	-	-	Moderate
MD11	I	250	124	6	High
MD12		370	465	6	High

*Data from 1 to 6 m zone.

**Data is arbitrarily ranked according to three divisions. High salt storage occurs above 150 mS/m, moderate salt storage from 75-150 mS/m, and low salt storage below 75 mS/m.

-Data unavailable.

Terrain conductivities within the profile determined with the E1431 (ECa) were correlated with the sampled profiles (EC 1:5). The correlation coefficient was R = 0.84 and the probability of excedence level 0.01. The statistics suggests that a good correlation exists between EC 1:5 and ECa. A regression equation (1) was derived to describe this relationship.

EC 1:5 = 1.182 ECa - 40.7.

When data gathered on two other catchments nearby (North Baandee n = 7, and East Belka = 8) was added to this data set, an R of 0.65 and probability level of 0.01 was achieved. The best relationship was derived within Equation 2.

EC 1:5 = 0.706 ECa - 3.2.

Zones of high salt storage (ECa > 150 mS/m) occur near both non-saline (MD3) and saline soils (MD11). The sites with active groundwater discharge, are at sites MD12 and MD4. The apparent moderate values of conductivity (EM38) in the zone adjacent to MD4 may be explained by relatively fresh groundwater, created by recharge and interference from the sewage treatment works. However, terrain conductivities derived from the E1431 are commonly over 150 mS/m along the creek line, which is incised into or near the water-table between MD3-MD4. High salt storage levels at MD11 occur in naturally saline “morrel” soils. Groundwater is 4.25 m below the soil surface and is not contributing to the high soil salinities.

Areas of moderate salt storage (75-150 mS/m) occur under heavy-textured valley soils within the lower catchment area, while low salt storage (< 75 mS/m) occurs on the upper slopes. Two areas of low salt storage also occur in sandy-textured soils in the valley. At MD2 the sandy sediments are exposed (see Appendix 1, MD2), while at MD9 the low values may be a result of recharge (of fresh streamflow - 500 mg/L TSS) produced after intermittent flows (see Section 4.1). Low salt storage also occurs along the sandy creeklines at MD1 and MD8, while lower values are common under areas of sandplain in the upslope soils.

4.3.3 Natural Gamma Logs

Natural gamma logs from bores MD1 to MD4 show the variable nature of the distribution of gamma radiation in both the sedimentary and weathered bedrock zones. However, the sedimentary materials have characteristically low gamma counts (40 to 90 counts per minute - cpm) with the higher values correlating with regions of high clay content (Figure 7). On the other hand, the deeply-weathered materials have a highly variable signature. In bores MD1, 141)2 and MD3 (141)3 is shown in Figure 7), the peaky responses at depth are considered to relate to differences in the degree of saprolite weathering and the influences of radioactive potassium, thorium and uranium from the weathering process (C. Butt, personal communication, 1988). At both 141)1 and MD3, the extremely high gamma emissions (160 to 200 cpm) relate to the heavy-textured, clay materials, probably derived from weathering potassium rich feldspars. Profiles from MD3, AB13D (East Belka catchment -R.J. George, unpublished data) and from other studies in Africa (Ackworth, 1987) show the differing nature of the profiles encountered (Figure 7).

The gamma log method appears to be appropriate for distinguishing the boundary between the sediments and weathered zones.

4.4 Runoff Measurements

Storm runoff measurements were recorded near MDX (Department of Agriculture) in the main drainage line. Runoff to this area was derived from both the northern and eastern catchments, the Merredin township and a large bituminized area in the Co-operative Bulk Handling (CBH) and railway yards (Figure 1).

Seven storms were recorded at the weir in 1986 (Table 5). Runoff was initially controlled by storage in the Merredin town reservoirs located upstream, but enhanced by the CBH and railway yards. Runoff was only generated from the eastern and northern catchments on two occasions, during storms three and four.

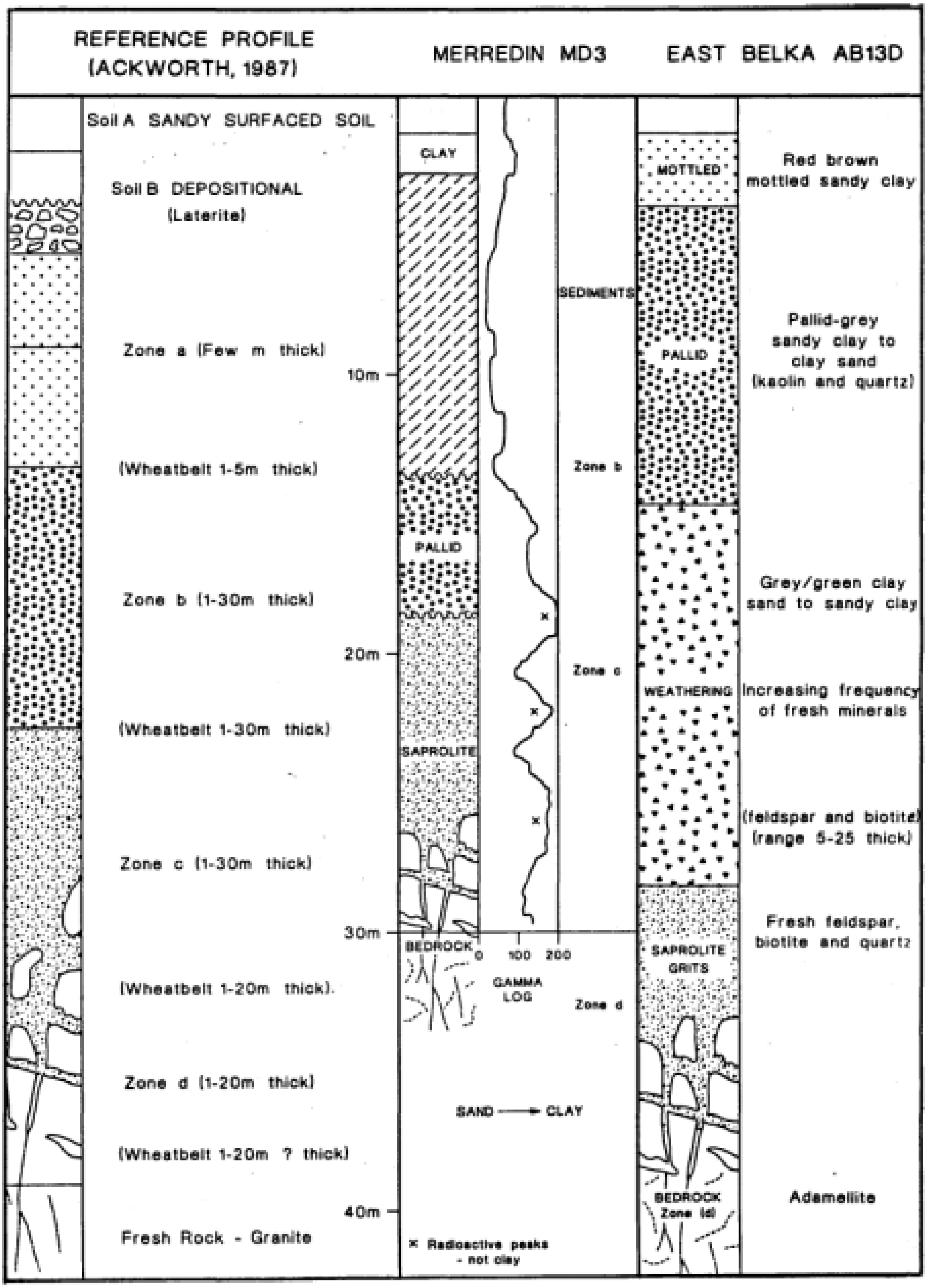


FIGURE 7: COMPARATIVE LITHOLOGIES AT MERREDIN (MD3)

The remainder of streamflows were apparently produced by urban runoff. A total of 75,610 kL of streamflow was recorded during 1986 while in 1987, less than 5,000 kL reached the weir. Lower discharge rates in 1987 were due to the increased storage capacity of the town reservoirs and drier seasonal conditions. In 1988 only limited observations were made due to problems with the security of the weir recorder. However, runoff was considered to be greater than that which occurred in 1986 and estimated to be approximately 100,000 kL.

TABLE 5. Streamflow Recorded at Merredin – 1986 to 1988

Storm	Date	Rainfall (Mm)	Runoff Total * (Kl)	Flow Rate (kL/hour)
1	9/6 - 10/6	18	2,010	145
2	15/6 - 16/6	15	3,720	220
3	25/6 - 1/7	32	42,500	1,300
4	2/7 - 3/7	7	9,100	850
5	8/7 - 9/7	9	7,680	610
6	14/7 - 15/7	13	8,600	620
7	30/7 - 31/7	5	2,000	200
TOTAL	1986		75,610	
1	20/8 - 21/8	12	2,000	120
2	26/8 - 27/8	17	3,000	210
TOTAL	1987		5,000	
TOTAL	1988 (estimated)		100,000	1,800

* Cons Creek runoff through 90°V Notch weir.

Streamflow below the weir is constricted within an eroded channel. The incised channel continues until it reaches MD9. At this location the steep sided, box wall gully, which has eroded into indurated clay materials, gives way to 1,000 m area of sands in a delta. During 1984 and and 1986, with annual rainfalls of 364 mm and 324 mm respectively, much of the streamflow at this point was lost by recharge to the alluvial sediments.

In 1988 only a small flow was noted to have moved further downstream and no water left the catchment. Although no streamflow measurements were taken at this location, farmers' observations (R. Robartson, personal communication, 1988) imply that the total runoff at MD9, although reduced from the runoff recorded at the weir, would have been augmented from runoff from the surrounding farmlands. Recharge from the creekline, derived from urban and agricultural runoff areas, may be a major source of groundwater accessions in the valley soils.

4.5 Salt Storage Characteristics

Estimates of the volume of salt stored within the upper catchment groundwater region were made from an analysis of the drill samples and electromagnetic soundings. Table 6 lists the total salt and chloride storages within this region from seven holes drilled to bedrock.

Table 6. Estimated Chloride and Total Salt Storage in the Merredin Catchment

BORE	DEPTH TO BEDROCK		Cl_3 (kg/rn)	Cl (t/ha)	*TSS** (t/ha)
MDA	45	0.08	1.37	615	1,200
MDB	14	0.04	0.69	98	190
MDC	28	0.032	0.55	150	295
141)1	33	0.126	2.15	710	1,385
MD2	62	0.14	2.38	1,440	2,815
MD3	30	0.36	6.09	1,830	3,560
141)8	43	0.03	0.49	210	410

TSS* = Total Salt Storage calculated if Cl = 0.55 TSS. Average bulk density of 1.7 assumed.

The data suggests that a large store of salts exists in potential groundwater discharge areas such as 141)3. In the other sites a lower salt storage is probably associated with recharge, especially along the sandy sediments of the main drainage line. The average chloride storage appears to increase downslope towards discharge areas.

4.6 Groundwater Geochemistry

The groundwaters within the Merredin catchment were sampled from twenty observation bores in different zones within the aquifer materials. A large range in groundwater salinity occurs, with lower salinities in upslope and valley floor recharge areas and higher salinities in actual and potential groundwater discharge areas. Stratification of waters also occurs, with low salinity groundwaters overlying more saline waters at MD2 and MD3, and the opposite at MD4.

Table 7 lists the detailed geochemical results from 10 piezometers located in the upper catchment groundwater region. Additional chemical-water quality information obtained from other bores is presented in Table 8 and Appendix 3. Table 1 should be used in conjunction with Tables 7 and 8 so that the analyses can be read in context with the hydrogeologic conditions from which they were derived.

TABLE 7. Geochemical Analyses of Merredin Catchment Groundwaters

BORE NO.	PH	EC*	TSS*	Ca	Mg	Na	K	Cl	S0$_4$	NO$_3$	Si0$_2$	Br
MD1 D	6.3	3,210	20,500	318	556	6,630	127	11,400	1,390	1.0	34	36
MD2 I	4.7	3,840	25,000	409	750	7,790	155	14,000	1,830	0.0	92	51
1)	6.3	2,500	15,600	508	442	4,710	89	8,700	999	0.0	30	28
MD3 I D	4.4	4,700	32,000	452	895	10,300	202	17,800	2,310	3.0	56	56
	3.9	5,500	38,400	143	1,080	12,700	331	21,500	2,550	1.0	98	66
MD4 I D	3.9	2,830	17,700	308	524	5,510	147	10,000	1,120	1.0	90	33
	6.1	538	3,070	28	35	1,030	26	1,360	401	1.0	57	5
MD7 I	6.4	1,850	11,200	76	272	3,700	148	5,260	1,110	113.0	35	24
MDX I	4.4	4,160	27,600	373	701	8,290	165	15,400	1,940	1.0	93	53
MD8 D	6.2	1,070	5,830	62	165	1,900	72	3,320	201	1.0	66	13

* EC = Electrical Conductivity of sample at 25°C (mS/m).

*TSS = Total Soluble Salts (mg/L).

TABLE 8. Electrical Conductivities (EC), Chloride and TSS* Other Groundwater in the Catchment

BORE NO.	EC	Cl*	TSS**	BORE NO.	EC	Cl	TSS
MDA	550	2,100	3,470	MD9	100	389	630
MDB	2,450	9,400	15,440	MD10	3,000	11,500	18,910
MDC	315	1,210	1,990	MD11	3,600	13,800	22,690
MD5	1,050	4,020	6,620	MD12	6,970	26,700	43,930
MD6	240	920	1,520				

*Cl values derived from relationship of Cl = 3.83 EC (regression calculated from Table 7).

**TSS was also derived from relationship obtained between TSS and EC from Table 7 data where TSS = 6.303 EC.

Groundwater salinity, as represented by the chloride ion is seen to increase rapidly from MDA and MDC towards the valley floor. Salinities continue to increase in the shallow zones throughout MD1 and MD2 and peak at MD3I and 3D. However, downstream they fall in the sedimentary zones from MD4 to MD9. MDB and MD9 differ from this trend.

Deep groundwater in the pallid zone remains more saline (MDX) as does the shallow groundwater at MD10 and MDll. Extremely saline waters at MD12 may represent historic, regional groundwater discharge conditions from the deep aquifer over long periods of time. Total soluble salt measurements on a small playa west of MD12 revealed waters of 320,000 mg/L.

The use of chloride as a stable ion for the analysis of the relative change with other components within groundwater allows interpretation of regional geochemical changes. Table 9 lists the chloride to major ion ratios. The results suggest that the shallow and deep groundwaters have similar ionic ratios no matter where they are located within the catchment. MD4 appears to be an exception and may be influenced by the sewage ponds. The extremely high nitrate levels at MD7 occur in the vicinity of the (CSBP) fertilizer distributor storage area, and may indicate contamination from this source. If this is the case, then it emphasizes the role and significance of recharge through the drainage lines in the valley soils.

The groundwaters are characterized by high silica contents below 141)3. Silica is almost at levels at which precipitation occurs. At 141)4 this may account for shallow silcretes and extremely high silica levels. Given that the time required for silica solution and mobilization is greater than that caused by recent hydrologic changes brought by agriculture, it may be plausible that the region near MD4 has been a groundwater discharge zone in the Holocene to Pleistocene periods (see Bowler, 1976). This hypothesis is based on the observation that groundwater silcretes are formed in discharge areas. Such observations have been made at other sites in the eastern wheatbelt such as at Skeleton Rocks-Brennands (George and Frantom, 1990), and at Wallatin Creek (George and Frantom, 1990).

Table 9. Ration Between Chloride and the Major Cations and Anions

BORE NO.		Cl:Ca	Cl:Mg	CJ:Na	Cl:K	Cl:$S0_4$	Cl:Br
MD1	D	36	20	1.8	90	8	316
MD2	I	34	19	1.8	90	8	275
	D	17	20	1.8	98	9	311
MD3	I	39	20	1.7	90	8	318
	D	150	20	1.7	65	8	326
MD4	I	32	20	1.8	69	9	303
	D	48	40	1.3	52	3	272
MD7	I	69	20	1.4	35	4	219
MDX	I	41	20	1.8	93	8	291
MD8	D	53	20	1.8	46	16	255
SEAWATER*		48	15	1.8	50	7	288

*Data cited from Floreat Park, Hingston and Gailitis (1976).

Calcium depletion and accumulation with respect to seawater is apparent in all bores (especially MD3D), whilst the magnesium to chloride ratio remains constant except in bore MD4D. Anomalous ratios of chloride with sodium, potassium and sulphate (and nitrate - Table 9) are also apparent from groundwater at MD4D and 141)71. At both sites, bores were located downstream of point source pollutants such as sewage ponds (MD4D) and the fertilizer distributors (MD7). The remainder of the analyses suggest a stable relationship with chloride. Seawater ratios suggest that local groundwaters contain more magnesium, potassium and sulphate.

The chloride to bromide ratio of seawater is considered to be 288 (Gerritse and George, 1988). In bores located upslope from MD4 the ratios suggest a depression in bromide levels, while downslope from this zone groundwaters are more enriched with bromide. Groundwaters which display higher ratios of Cl/Br have low salinities. Groundwaters at MDX are the exception in both cases

4.7 Hydrograph Responses

Water-level fluctuations in bores drilled in the Merredin catchment are presented in Appendix 2. In several of the bores drilled in early 1986 a rising trend has developed, however, it is too early to determine the annual rate of rise. Below MDX, in the lower catchment groundwater region, bores have been monitored for a shorter period (1987). No trends are presently evident, apart from the periodic fluctuations due to localized flooding and seasonal recharge (MD9). Another five years of data are probably required until statistical trend analysis can be used to determine the magnitude of change. However, in bores MD2, MD3, MD4 and MDX, significant annual rises (0.1 to 0.2 m/yr) have been observed in response to winter recharge. The trends are not as obvious in bores drilled above the townsite (MD1 and MD8).

At MD4 groundwaters have risen by approximately 1.0 m over the three year period and are now periodically artesian. In October 1988, dryland salinity was noted for the first time in an area adjacent to the sewage treatment (MD4) works in response to this change. However, in MD4, like MD2, MD3 and MDX the responses cannot be solely attributed to increased groundwater pressure from the agricultural portion of the catchment. Recharge from the townsite (directly and from urban runoff), although difficult to assess, may contribute to the rapid. rise in the pressure potentials. At MD4 the rapid rise in 1987 coincided with an increase in capacity and hydraulic head of the sewage treatment works. While important at a local scale, the effect of this is probably only equivalent to one or two years of “normal” recharge.

The change in the distribution of hydraulic pressure within the aquifer systems which has occurred as a result of increased groundwater accessions is depicted in Figures 4a and b. It is interesting to note that the increased head near MD4 also corresponded with a change in groundwater flow direction.

The heads changed from -0.009 (March 1986) to +0.023 (March 1989), indicating a status change from recharge to discharge across the area and is correlated with the development of soil salinity. It is also interesting to note that groundwater discharge (salinity) also occurs next to both existing town water supply dams, indicating that they are leaky, creating recharge-discharge cells and elevated pressure levels nearby.

5. Discussion

5.1 Sedimentation

Drilling investigations in the Merredin catchment have located deep sequences of sediments in the valley floor, which are underlain by deeply-weathered and kaolinized materials to bedrock. A description of the relationships which exist between these materials was first attempted by Bettenay and Hingston (1964) on the basis of limited drilling information and soil surveys. The authors use a landscape model which comprises five major soil surfaces of the region, which typify its morphology and genesis. It is relevant to discuss their results in the light of current information to enable a clearer picture of landscape evolution and hence groundwater processes to be built.

Bettenay and Hingston (1964) conducted a systematic study of soils in relation to landscape features in the Merredin district, incorporating a 1,400 km^2 study area. The Merredin valley forms a focal point of that survey. The reader is referred to several reports which discuss the environment and its land-use (Bettenay and Hingston, 1961 and Bettenay and Hingston, 1964) and regional hydrology (Bettenay et al., 1964).

The Merredin catchment lies to the east of the zone of active drainage or valley rejuvenation, demarcated as the Meckering line (Mulcahy, 1967), which resulted from uplift of the Darling Scarp in the Tertiary geologic period. In the eastern zone, subdued drainage and extensive deep-weathering gave rise to topographic stability and limited landscape erosion (Bettenay and Hingston, 1964).

The authors conclude that the Merredin valley (surface) soils are derived from the colluvial transport of sediments from the hills towards the valley floor, rather than alluvial deposition from periods of riverine sedimentation.

Evidence presented in the well-log reports in Appendix 1 and gamma-logs (Figure 7) summarized in Figures 3 and 7, suggest weathered bedrock materials are overlain by much deeper colluvial and alluvial deposits. The information also suggests that sedimentation has occurred in the valley along its entire length to depths of up to 15 rn. Bettenay and Hingston (1964) estimated that only the top few metres were of a sedimentary origin.

Mulcahy (1967) suggests that landscape stability east of the Meckering line is due to tectonic activity at the Darling scarp and not due to climatic induced sea-level changes during the Pleistocene. Sedimentation may either pre-date or post-date this period. Bettenay and Hingston (1964) also suggest that periodic changes in landscape stability may be the result of climatic changes during the Pleistocene.

The accumulation of deep sediments in the Merredin catchment (and most other wheatbelt catchments) could suggest valley infilling post dated tectonic uplift at the Meckering nick-point. Geologic activity along this line, also called the South West Seismic Zone (Doyle, 1971) is still apparent, (refer Meckering earthquake, 1968) with major uplifts of the eastern block. Historic activity of a similar or larger magnitude may have been a contributing factor for the sedimentation of wheatbelt valleys, including the Merredin example. Examples of recent faulting (Cainozoic) can be seen in the Belka Valley, where uplift on the downstream side has led to the development of playas.

Significant sedimentation has also been described in the eastern Yilgarn province, east of line between Mt Magnet and Widgemooltha. Here, eastward flowing drainage lines move surface and groundwaters towards the Eucla Basin.

Wilde (personal communication, 1988) believes that these sediments are of a Miocene to Eocene age, and are noted to be over 120 m thick (Van De Graaff et al., 1977).

It appears likely that the sediments which infill Merredin and other wheatbelt valleys have been derived from a combination of climatic induced sea-level changes during the Cainozoic and by movement along the south-west Seismic or Meckering lines. These events appear to post date the major phase of lateritization (Early Tertiary), peneplanation and subsequent massive dissection of the plateau (Jutson, 1950). Major infilling probably post dated the time of the eastern goldfields when Eocene sea-levels were approximately 300 m higher than present.

Continued uplift of the eastern edge of the Meckering line would have restricted subsequent removal of wheatbelt sediments. Late Pleistocene sea-level changes may have had little influence on the wheatbelt valleys upstream from the Meckering line, although consequent climate changes would significantly alter geomorphic processes acting in the region.

In conclusion it appears likely that the Merredin valley sediments began forming contemporaneously with the goldfields sediments in the wake of Eocene to Pleistocene sea-level changes and may have remained stable owing to the effect of the Meckering uplift. Pleistocene climatic changes may have also induced subsequent sedimentation which may explain the thin veneer of red-brown sandy clay loams to sandy clays which overlay the major sedimentary materials (eg. MD3).

The yellow sandy earths of the Ulva association overlay the sediments in many places (eg. l4erredin Research Station) and are, therefore, examples of more mobile or younger deposits. The more recent sediments in the catchment are described by Bettenay and Hingston (1964) as the older, Newdegate parna and young Hines Hill parna. Palaeohydrologic evidence and dating conducted locally (Bowler, 1976) suggests that the Hines Hill lunettes are Holocene to late Pleistocene (~20,000 years BP) while the Newdegate series are Pleistocene remnants. The Newdegate parna is often referred to as “morrell” soils on basis of the dominant eucalypt species found nearby.

5.2 Salinization

Secondary or dryland salinity currently occurs at only two sites in the Merredin catchment, between MD3 and MD4 and downstream of 141)12. However, the potential for the spread of salinity within the valley soils is significant if nothing is done to reverse or halt the trend in groundwater levels.. Although only four years of water-level records exist, other examples of rates of rise from many wheatbelt catchments and anecdotal evidence from the Merredin sites, may be used estimate long-term rates of rise.

The clearing of native vegetation and its replacement with annual crops and pastures has been shown to cause increased groundwater recharge and a subsequent rise in groundwater levels. In the Collie catchments, with a 750 to 1,200 mm/yr rainfall, deep groundwater levels have increased at approximately 0.5 to 2.6 rn/yr since clearing (A.J. Peck, personal communication, 1986). At Cuballing catchment during six years of observations, water-levels had risen at an average rate of 0.1 to 0.3 m/yr under an annual rainfall environment of 450 mm/yr (R. Engel, personal communication, 1987). Other observations throughout the wheatbelt suggest that groundwater levels are continuing to rise at between 0.1-0.3 m/yr (Loh and Stokes, 1981). In the Merredin catchment near MD4, drillers records (M. Rutherford, personal communication, 1988) suggest that the water-table was about 1.6 m below ground level in 1973, while in 1988 the level was at or near the surface. This suggests an annual rise of 0.1 m/yr, through a period of lower than average rainfall and hence recharge. However, it should also be noted that the bores are located below a large township and near sewage ponds and domestic water reservoirs. Possible effects of localized recharge are not discounted.

If it is assumed that groundwater levels are increasing at an average rate of between 0.05 and 0.1 m/yr, and that groundwater lies within 12 m of the surface at the deepest points within the valley (MDX), then soil salinity could affect approximately 8,000 ha or 20% of the catchment (valley soils) by the year 2150. Areas where the water-table is already close, between MD2-MD4 (2.0-0.0 m) and MD11-MD12 (2.0-4.0 m) will become saline sooner (0-80 years). Salinization has already commenced at some locations (141)4).

It is difficult to predict the rate at which groundwater levels will rise over the next few decades or century without either historic or long-term records. However, on the basis of the estimate presented above, salinity of valley soils will be a major problem in the next century unless recharge and discharge are controlled.

5.2.1 Recharge Distribution

Groundwater recharge takes place across the entire catchment, and perhaps even seasonally, in saline groundwater discharge areas. However, certain areas of the catchment are likely to contribute more per unit surface area than other regions. Recharge rates are controlled by rainfall-runoff characteristics, soil properties and the evapotranspiration rates of vegetation. Rainfall, and therefore recharge, is also not uniform across the catchment. Annual rainfall records suggest slightly higher rainfall (-20 mm) in the upper catchment area. The variability in the distribution of summer storms and runoff could also produce a spatial variation in recharge.

The spatial distribution of soils within the eastern wheatbelt, exemplified by the Merredin catchment, were mapped by Bettenay and Hingston (1964). They recognized nine primary surface elements or soil-landform associations and 14 soil series, on the basis of characteristic soil physical and chemical properties. With the exclusion of saline soil zone in the MD12 region (4,000 ha Stirling and Hines Hill Associations) the Merredin catchment is comprised of six major soil-landform associations. They are briefly described below.

The agnonomic (soil-plant-production) characteristics of each landform are detailed elsewhere (Frost and Howell, 1990).

The soil-landform elements also form agricultural or land management units and are the basis of the Merredin Land Management Manual (Frost and Howell, 1990) and MIDAS, an eastern wheatbelt whole-farm economic model (Department of Agriculture authors). On the basis of these models the adoption of land management systems as a framework for recharge control appears practical. It also appears that it may be reasonable to suggest a relationship between hydrologic processes (including recharge and discharge) and these primary soil-landform characteristics. This assumption is seen as a first approximation upon which recharge and discharge control measures can be based. The areal extent of each major “hydrologic province” has been defined from the soil-landform association map of Bettenay and Hingston (1964) and is presented below (Table 8).

TABLE 8. Electrical Conductivities (EC), Chloride and TSS* of Other Groundwater in the Catchment

LAND SURFACE	OR	HYDROLOGIC PROVINCE	AR~ (ha)	%
Danberrin Association		Danberrin Province	3,600	9
Ulva Association		Ulva Province Norpa	8,000	20
		Province	6,000	15
Booraan Association		Booraan Province	8,000	20
Collgar Association		Collgar Province	2,000	5
Merredin Association		Merredin Province	8,000	20
Nangeenan Association				
Hines Hill Assocition				
Stirling Association		Nangeenan Province	4,400	11
TOTAL			)0	

* The Ulva Association has been split into two provinces to take account of the erosional (Ulva-gravels) and depositional (Norpa-deep sand) phases.

**The Nangeenan, Hines Hill and Stirling Associations have been grouped together and are cumulatively known as the Nangeenan Association.

***Salinization currently affects less than 20 ha and is omitted from the “model”.

(i.) Danberrin Province

This province is characterized by large bedrock outcrops and skeletal arkosic soils. Outcrops of the underlying parent material and saprolite grit are common. Management has historically concentrated on a pasture-wheat rotation. The soil is generally considered unfavourable for lupins, owing to the variability of the depth to clay and abrupt changes in surface texture within small areas. Runoff is common both as saturation excess overland flow and exfiltration. Groundwater is often relatively fresh (< 10,000 mg/L TSS) and has potential for developing useful supplies for livestock. The depth to groundwater is highly variable.

(ii) Ulva Province

The Ulva province is characterized by shallow sands to sandy loams overlying massive or indurated gravels of the mottled zone. Soils are commonly acidic and shallow (< 20 cm), restricting root development and potential cr6p yields. Management has been restricted to wheat and pasture rotations, with the recent inclusion of lupine and improved pastures in restricted areas. Runoff is uncommon except after extreme rainfall events and from degraded soils. The groundwaters are usually of a stock quality but have a small saturated thickness and yield owing to their high position within the landscape. The depth of the water-table in these areas may exceed 30 m (eg. MDA).

(iii) Norpa Province

The Norpa province is the depositional phase of the Ulva province and is distinguished by its many different management requirements. Colluvial and/or aeolian transport of loamy sands (earths) from upslope have deposited deep (1 to 8 m) uniform sheets of sandplain soils. The soils are commonly quite acidic (< pH5

CaC1 at 50 cm) and well drained.

Management practices currently include the lupin-wheat rotation on good soils (pH -5.5) and triticale and serradellas on more acidic soils. Surface runoff is unusual. The quality of the deep groundwater and supply rate is variable, although often reasonable low in the landscape. Perched groundwaters adjacent to sandplain seeps may produce small yields (1,000 kL/yr) of stock quality waters.

(iv) Booraan Province

This province combines two soil surfaces (an erosional and depositional phase) with slightly different characteristics, but are classified together for this discussion as they are usually managed as one unit. The erosional phase is typified by exposed weathered granitic (pallid zone) materials, which are usually acidic and often saline (-50-100 mS/m). The depositional phase is more extensive and consists of shallow duplex sandy loams to clay loams. Management consists of a pasture or wheat rotation. The use of peas on this landform is under investigation. Surface runoff occurs most winters from the Booraan erosional surface. Groundwater supplies are often saline, with a small saturated thickness usually encountered at considerable depth (20-40 m). High groundwater salinities are generated by recharge waters passing through unsaturated zones of high salt storage (> 1,000 t/ha).

(v) Collgar

Soils are duplex, often hardsetting sands to sandy barns. They overlie a variably indurated and silicified subsoil horizon. Unlike all of the above mentioned units which are hillside soils, this province is characterized by its midslope or upper valley location. As a result of enhanced soil-water storage characteristics (vertical soil-water flow is impeded in the duplex profile) and runoff generated from upslope, they have higher crop yields and are currently the focus of the wheat-lupin rotation. Surface runoff (saturation overland flow) occurs in winters when the surface horizon becomes saturated.

This was observed during the winters of 1986 and 1988 on the Merredin Research Station and at other sites nearby. Groundwater supplies can be good although they have a higher potential to be saline if the landscape upslope contains large areas of Booraan soils. Catchments with Norpa and Danberrin recharge areas more often contain stock quality groundwates.

(vi) Merredin Province

These soils are characterized by the red-brown sandy clay barns of the valley floor. Within this broad unit sandy-textured soils are also common, especially near drainage lines. Little surface runoff occurs in most winters although local redistribution takes place. Ephemeral streams may form in wet years. Management incorporates continuous cropping (wheat), pasture and the wheat-pea rotation. Groundwater yields may be high while qualities are normally poor (MD3-MD1O).

(vii) Nangeenan Province

These soils may be similar to those of the Merredin province at depth, but commonly have “fluffy” and alkaline conditions near the surface. They are inherently saline near (1-5 km downwind) saltlakes. Groundwaters are extremely saline although high yielding bores may be established.

5.2.2 Recharge Area Location and Definition

Groundwater recharge is suggested to occur in areas of rapid surface infiltration, soil saturation (perched aquifers) and by effluent flow from streams. Drilling and electromagnetic induction information has indicated that in these areas there is likely to be a lower salt storage (see Tables 4 and 6). Hydrologic provinces which exhibit these characteristics are the Danberrin, Ulva and Norpa units.

Sandy-textured surface soils and low terrain conductivity readings were also recorded at MD1 and MD2 located in the Collgar province and near MD9 where an area of Bandy creek-bed soil occurs in the Merredin province.

Hydrologic provinces with lower surface infiltration and slower redistribution properties (the Merredin, Booraan and Nangeenan provinces) have a high to moderate salt storage (Tables 2 and 4). This was recorded at all locations investigated during the drilling and geophysical programme, with the exception of MD9 (Table 4). In the Danberrin and Norpa provinces, infiltration, redistribution and recharge has been observed to occur to significant depths within hours or days of rainfall (Appendix 2 - MDA, January 1990) and in other bores located in other eastern wheatbelt catchments.

However, in the other hydrologic provinces (Collgar and l4erredin) redistribution and recharge is irregular and appears to be related to less frequent, low probability events. In bores located in the valley floor (MD3-MD7, in shallow wells drilled into the sediments) the responses were often observed in the form of gradual, “seasonal” rises over periods of days following rainfall. In deep piezometers drilled in the saprolite or pallid zones below the sediments, water-level fluctuations were erratic and often markedly delayed (days) after rainfall events. Barometric influences were noted. Seasonal trends were not as obvious (Appendix 2).

The data implies that groundwaters beneath the Danberrin and Norpa provinces and within the sediments, especially near the drainage lines, respond rapidly to rainfall events, while the saprolite aquifers in the valleys respond to changes in barometric pressure and from “delayed” recharge. In conclusion, it appears reasonable to suggest that from the hydrograph and soil-landform data that significant groundwater recharge takes place in Danberrin and Norpa provinces and is reflected by significant changes in local groundwater levels. In the Booraan, Collgar and Nangeenan provinces lower rates recharge occur, except where macropore flow takes place.

In the Merredin, and perhaps parts of the Collgar province, recharge may occur from localized flooding (eg. 141)9) and macropore flow following saturation of the surface horizons.

5.2.3 Recharge Estimation

In the past 10,000 years relatively stable climatic conditions have prevailed across Southern Australia (Bowler and Teller, 1986) and groundwaters would have attained equilibrium between recharge and discharge. Without evidence of any areas of groundwater discharge. occurring above 141)11, it is realistic to assume that prior to clearing the annual groundwater outflow (minus any phreatophytic transpiration) would equal recharge. Using realistic estimates of the aquifer width at MD11, hydraulic properties of the aquifer (Table 2), and a pre-clearing saturated thickness of 30 m it is possible to estimate that discharge (groundwater flow out of the catchment) could have been of the order of 15,000 kL/yr. The potential area for recharge above this location is 35,000 ha. If recharge equaled discharge and the catchment was is in equilibrium, then the annual recharge would have been of the order of 0.05 mm. These estimates suggest groundwaters within the catchment were controlled by extremely low recharge rates (~0.1 mm/yr).

It is also possible to attempt to estimate historic groundwater recharge rates using the environmental chloride-mass balance technique (Allison and Hughes, 1978; Sharma and Hughes, 1985 and Farrington and Bartle, 1987). The technique is thought to be appropriate if it is considered that no chloride is absorbed, exchanged or transformed within the soil profile, and that the source of chloride is rainfall. It is also implies that steady state conditions would have existed before clearing.

Given these qualifications, recharge (R) can then be estimated from Equation 1, such that:

$$R=Px\ (Cx\ /\ Cy) \qquad (1)$$

where Px is the long-term annual average precipitation, Cx is the mean chloride concentration of the precipitation and Cy is the mean chloride concentration at the water-table. Characteristic values of Cx and Px are 5 mg/L (Hingston and Gailitis, 1976) and 325 mm respectively. The calculations discussed below are derived from the chloride content data for groundwaters near the water-table (Table 7) and the province areas (Table 8).

Estimates calculated from these records suggest higher recharge rates in the Norpa, Ulva, Danberrin and sandy Merredin provinces (0.15-2.5 mm/yr) and lower rates in the other valley floor bandforms (0.07-0.15 mm/yr). These results tend to corroborate the hypothesis that significant rates of groundwater recharge occurred under sandy-textured soils located both high and low in the landscape. The results are obviously only first approximations of the actual recharge rates, since “contamination” from recent recharge may have changed the original chloride levels within the aquifer. However, the depths of the aquifers screened and general pattern of the results, show an agreement with recharge rates estimated from the catchment water balance approach. Moreover, they suggest that recharge rates under native “mallee” or “woodland” vegetation communities were very small. The role of phreatophytic vegetation in the catchment is unknown. However, it is possible that large volumes of groundwater could be discharged from the water-table in areas of moderate (~10,000 mg/L TSS) groundwater salinity. Given the obvious implications of only a few millimeters discharge by the phreatophytes on the water balance, and ramifications for management of shallow water-tables where both exchange and discharge could be occurring, more emphasis should be placed in this area of research.

Post-clearing recharge rates in the western and southern regions of Western

Australia have been estimated at between 5 and 10% of annual rainfall (Peck and Hurle, 1976). Higher evaporative demand and lower rainfall suggests that recharge in the eastern wheatbelt may be much less (eg. Loh and Stokes, 1981). Recharge rates of only 1 to 3% of annual rainfall imply recharge rates of 3 to 10 mm/yr. Even this estimate which is smaller by comparison, is between one to two orders of magnitude higher than estimates of pre-clearing recharge rates.

To be effective, management options for recharge control must strive for rates of less than one millimetre per year. Similarly if discharge control were to be effective, only small volumes of groundwater, extracted over a wide area, would need to be withdrawn.

6. Recommendations and Conclusions

The manipulation of groundwater recharge could be attained by agronomic manipulation of the water balance, landscape revegetation with perennial trees and shrubs and surface water control structures. Discharge can be manipulated by groundwater pumping, phreatophytes, habophytes and shallow drainage systems. A combination of approaches is favoured.

Recharge manipulation of the Merredin catchment should include high water using rotations in all of the hydrologic provinces (see also Frost and Howell, 1990). Continuous cropping in sandy-textured soils of the Ulva, Norpa and Collgar provinces is preferred to continuous pasture systems as Nulsen and Baxter (1982) have shown lower transpiration rates under pasture than crops at several sites throughout the wheatbelt. The wheat-lupin rotation would appear to be the most profitable and efficient water using rotation available. In areas where crop water-use is poor, quality pastures may be more suitable if their water-use is higher.

Within the Danberrin, Ulva and Norpa provinces, agronomic management using the wheat-lupin rotation may not always be possible due to soil physical (depth to subsoil) and chemical (Al-pH) constraints. Therefore, in skeletal soils surrounding bedrock or saprolite grit outcrops, recharge manipulation should include perennial trees and shrubs. In particular, carefully spaced (100-200 m apart) contour strips (-20 m width) and encircling belts of trees (-50 m width) may be needed to restrict recharge waters entering the deep groundwater system. High water using, deep-rooted eucalpyt species and fodder trees could be appropriate. Perennial shrubs with a short-term economic yield (eg. fodder trees) may be preferred to native eucalypts.

Groundwater extraction should also be encouraged in many mid to upper-slope areas. The development of successful stock and domestic bores has been achieved in many locations throughout the eastern wheatbelt. Drill holes which encounter saturated aquifer thicknesses of the order of 10 to 20 m can yield upwards of 10 to 100 kL/day of stock quality water.

Although locating successful bores is difficult, the interpretation of landforms, geologic structures and use of geophysics may provide a successful methodology. The authors know of several cases where large supplies of fresh water are being obtained from deep drill holes near outcrops in shear zones and faults, and more often, within the saprolite grit aquifer.

Surface runoff manipulation is also possible from large outcrop areas. Successful runoff generation schemes, that have a rainfall-runoff efficiency of approximately 40 to 50% (I. Loh, personal communication, 1988), have been used throughout the wheatbelt. Water harnessing could lessen recharge, and with low cost diversion banks and channels, may be appropriate to supplement town, stock or domestic supplies. The Merredin Peak channel and darn systems is an obvious example.

Recharge management in the Merredin townsite may also need to be considered. Increased recharge due to over-watering, direct accessions to the water-table under ponds and dams and increased runoff from impermeable surfaces needs to be limited. The large rates of rise in bores installed at MD2, MD3 and MD4 and the observation of soil salinity near MD3 is likely to be due to both the influence of the town and agricultural development. The issues of increased recharge caused by the town should be addressed in conjunction with the effect of agricultural development.

Further research would be required to separate the effect of the town from the agricultural areas.

Manipulation of groundwater recharge in the Collgar and Booraan provinces could involve continuous cropping and tree planting. In the Booraan province, recharge rates appear to be less in comparison to the three upper slope provinces. If this is the case, agronomic manipulation may include some less efficient water use practices. Waterlogging should be avoided to prevent macropore recharge processes. Shallow drains and agroforestry systems may be needed.

Recharge manipulation in the clay surfaced Merredin and Nangeertan provinces also involves increased water-use, however, owing to the slower redistribution rates of infiltrating water, rotation management may be more flexible. The current pea-wheat and pasture rotation appears to contribute little to the deep soil-waters (S.J. Trevenen, personal communication, 1988) although only qualitative data exists to support this contention. Groundwater pumping for stock supplies is probably inappropriate owing to the saline nature of the groundwaters, although desalination could be considered. The use of some species of eucalypts as phreatophytes or biologic pumps also appears difficult, owing to the high groundwater salinities. However, it could be a valid method of reducing soil-moisture storage in the unsaturated zone in areas of waterlogging or flooding where water-table levels are below the soil surface (MD7-MD11). The use of salt-tolerant pheatophytes adjacent to the creekline between MD3 and MD7 should be considered (groundwaters are < 10,000 mg/L TSS) as a management option. Research to determine the application of this technique will be considered in the second stage of this project (George and Laws, in prep.).

The application of pumping for water-table control by increasing groundwater discharge could be considered in some situations. For example, the availability of high yielding aquifers in the Cainozoic sediments and weathered bedrock near MD3 may be useful for controlling groundwater discharge and salinity in the West Merredin area.

A groundwater pumping scheme could be established by the installation of a combination of appropriately screened tube-wells to intercept flow in the sediments, saprolite and fracture zones. The discharge of the saline waters (20-30,000 mg/L), estimated to be between 100 and 200 kL/day, is a constraint on the implementation of such a system. However, the use of evaporation basins, which may also have potential recreational value, may provide an alternative to a pipeline to the sabtlake system near Hines Hill. This aspect of management also forms the basis of the second report which discusses drilling and pump-testing carried out in co-operation with the Geological Survey (George and Laws, in prep.).

Groundwater manipulation using a combination of annual and perennial species based farming systems, aquifer pumping and agroforestry may be practical in the Merredin catchment. Revegetation using perennial species might represent a large change in land-use in the catchment. The use of fodder, or economically useful tree species must be emphasized to offset changing management costs.

The effectiveness of recharge and discharge manipulation methods can be measured by the response of the water-table levels in the valley groundwater systems. If manipulation restricts the rate of water-table rise, it could be measured in the bores already established. Manipulation of the water balance must either reduce recharge towards the pre-clearing levels or increase discharge to control salinity.

Recharge area manipulation may be the most “longer-term”, environmentally suitable method of salinity control. However, the shallow depths to the water-table between MD3 and MD4 suggest that whatever system is adopted, it must be efficient and effective within five to ten years, to prevent farmland and some urban areas from becoming salt-affected. Given difficulties in organizing recharge area management schemes, a lack of technical data detailing an appropriate methodology and the need to economically manage approximately 15,000 ha of farmland and the townsite, it may be more appropriate to initially concentrate on short-term discharge area management schemes.

In the discharge area (MD3-MD4), management systems could include both groundwater pumping and afforestation schemes. Pumping has a higher cost and likelihood of success, but greater environmental side-effects. Afforestation with phreatophytes by comparison, has less environmental concerns, but greater risks. Research described in a following technical report outlines both approaches, discusses the technical data and summarizes the positive and negative aspects of both approaches.

7. Acknowledgements

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APPENDIX 1: Well-logs of Bores Drilled in the Merredin Catchment

PROJECT BORE NO: MD A RIG TYPE: R.A.B.
CATCHMENT: Merredin CASING DEPTH: 46.21 (in)
DATE DRILLING: December 1986DEPTH DRILLING: 46.21 (in)
LOCATION: Crooks QUALITY: 550 mS/rn
GRID REFERENCE: 31°30’SI”N 118°19’I2”EYIELD: Small kL/day
LAND UNIT: Norpa DEPTH TO BEDROCK: 46.21 (in)
SLOTTED LENGTH: 2 (in)
WATERTABLE DEPTH: 43.15 (in)SAMPLES: pH, EC, Cl~

RESULTS

DEPTH (in) FROM TO	DESCRIPTION OF BORE	ZONE
2.5	Yellow loamy sand over gravel (2.0).	ain
	Mottled zone (dry).	Mottled
(5.0)	Moisture increased mottles decreased.	
	weathered granitic chips.	ing
1(8.0)	Brown still mottled zone.	
	Light brown mica flakes not pallid!	
(20)	Yellow goethite coloured s. clay with hydrobiotite, qtz, some coarse. vein qtz.	
	Hard patchy weathered granitic chips (Bedrock?)	
21.5 -		
(22)	Biotite rich light blue grey sandy clay loam fresh minerals but not a course grit. Qtz and feldspar weathered.	Saprolite Bedrock
	Biotite bands (gneissic).	
1(28)	Medium to fine grained grits, fine grained biotite, feldspar qtz clay too.	
33.0		
	Hard.	
1(34.	Coarse grained grits, little clay. (Moist)	
36	Bedrock.	
46.2		

COMMENTS : No flow from this depth. No pallid zone.

RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO: MD B RIG TYPE: R.A.B.

CATCHMENT: Merredin CASING DEPTH: 13.45 (in)

DATE DRILLING: Dec 1986. DEPTH DRILLING: 13.45 (in)

LOCATION: Adamsons QUALITY: 2450 InS/In

GRID REFERENCE: 31°30’22”N 118°18’51”YIELD: Minimal kL/day

LAND UNIT: Ulva DEPTH TO BEDROCK: 13.45 (in)

SLOTTED LENGTH: 2 (in)

WATERTABLE DEPTH: 13.42 (in) SAMPLES: pH, EC, C1

RESULTS

DEPTH (in)		DESCRIPTION OF BORE	ZONE
FROM	TO		
0	1.0	Gravelly sandy clay.	Surficial
1.0	3.0	Mottled zone.	Mottled
3.0		Coarse vein qtz and kaolin pseudoinorphs in kaolin matrix pallid. Some cleavage present of feldspars, inc. grain ‘size with depth.	Pallid
7.0		Medium grained saprolite grits, biotite increased by 9.0 in. Dry profile.	Saprolite
13.451		Bedrock.	Bedrock

COMMENTS : No flow, dry looking.

RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO: MD C RIG TYPE: R.A.B.

CATCHMENT: Merredin

CASING DEPTH: 27.25 (in)

DATE DRILLING: Dec 1986
DEPTH DRILLING: 27.25 in)

LOCATION: Adainsons

QUALITY: 315 mS/in

GRID REFERENCE: 3lO3Otl0~N 1l8°l8t4lttE
YIELD: Nil kL/day

LAND UNIT: Ulva DEPTH TO BEDROCK: 27.25 (In)

SLOTTED LENGTH: 2 (in)

WATERTABLE DEPTH: 18.76 (in) SAMPLES:

RESULTS

DE FROM	PTH (in) TO	DESCRIPTION OF BORE	ZONE
0	13.2	Gravelly sandy clay. Haematite/ goethite stained.	Gravels
3.2		Hardpan above pallid sandy clay. Mostly coarse qtz in kaolin matrix.	Pallid
17.0		Increased haematite/goethite stained qtz chips. Pseudornorphs of feldspar kaolin decreasing. Grading into yellow sandy clay. (Moist)	Weathering
	1(24.0)1	WATER ADDED 24 in. Lost circulation no samples/gritty zone.	Saprolite
27.2		Bedrock.	Bedrock

COMMENTS': No flow.

RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO: MD1 RIG TYPE: R.A.B.

CATCHNENT: Merredin CASING DEPTH: 33.00 (in)

DATE DRILLING: Dec. 1985 •
DEPTH DRILLING: 34.00 (in)

LOCATION: Narembeen Rd. QUALITY: 2510 inS/in

GRID REFERENCE: 3l°29’31”N I18°18’17”E YIELD: < 5 RL/day

LAND UNIT: Collgar DEPTH TO BEDROCK: 34.00 (in)

SLOTTED LENGTH: 2 (in)

WATERTABLE DEPTH: 11.44 (m)SAMPLES: pH, EC, C1,
Gamma

RESULTS

FROM	DE (in) TO	DESCRIPTION OF BORE	ZONE
0	11.5	Grey/brown loamy sand. Qtz/feldspar.	ınds/ luvials
1.5		y/brown sand, poorly sorted 'brown sandy clay. Iron rich tles.	
		ay sand sorted, coarse. :rete chips 7.5, 8.5)	ilicified Zone)
		Brown clay sand. Well sorted to grey brown clayey sand, some mica, angular and iron stained feldspar anitic (alluvials).	
)		lack sandy clay & haexnatite ular qtz. grading to pale, light dy clay (in-situ).	allid
)		nustard sandy clay, coarse grain size, however large clay content indicated, although grits zone a possibility from 30 33 in.	eathering
33.0		Bedrock.	Bedrock

COMMENTS : Small flow (< 5 kL/day).

RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO: MD 2 RIG TYPE: R.A.B.

CATCHMENT: Merredin CASING DEPTH: 45.65 (in)

DATE DRILLING: Dec 1985 DEPTH DRILLING: 60.65 (in)

LOCATION: Townsite (east~ QUALITY:
2040 mS/m

GRID REFERENCE: 3l°28’57”N 118 l7’06”EYIELD: <
20 kL/day

LAND UNIT: Merredin/Belka
DEPTH TO BEDROCK: Unknown (in)

SLOTTED LENGTH: 2.00 (in)

WATERTABLE DEPTH: 7.58 (m)
SAMPLES: pH, EC, Cl~, Gainina

RESULTS

DE (in) FROM	TO	DESCRIPTION OF BORE	ZONE
0	112.0	Brown sand to loamy sand.	Sediments
		Brown-yellow clay sand poorly sorted.	
		Red clay - sand well sorted, pink sands silcrete zone at 7.0 m / feldspars.	
		Sands cont.	
12.0		Siliceous hardpan at 12.0. Texture nge from coarse / medium sands to white sandy clay fine qtz and no primary minerals, weathered.	Pallid
		Plastic sandy clay, white grey.	
	1(30)	Granitic fabric apparent.	
	(40)	White/pale sandy clay (Added FOAM).	
	1(55)	Still pale white grey sandy clay.	
	1(60)	Unchanged abandoned hole.	
		(hole collapsed to 45 m).	
		Intermediate 17.55 (‘17.55 15.55).	
		Hole located 500 in from Merredin Rcck.	

COMMENTS : Flow small to moderate < 20 kL/day.

RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO: MD 3 RIG
TYPE: R.A.B.

CATCHMENT: Merredin CASING DEPTH: 25.89 (in)

DATE DRILLING: Dec 1985
DEPTH DRILLING: 29.80 (in)

LOCATION: Merredin (west) QUALITY: 3780 mS/rn

GRID REFERENCE: 3l^{0}28t46flN 118O15~’52ttE
YIELD: < 200 kL/day

LAND UNIT: Merredin DEPTH TO BEDROCK: 29.80
(m)

SLOTTED LENGTH: 2 (m)

WATERTABLE DEPTH: 2.72 (in)
SAMPLES: pH, EC, Cl, gamma

RESULTS

DEPTH (m) FROM	TO	DESCRIPTION OF BORE	ZONE
0	11.0	Red/brown sandy loam.	Surficial
1.0		Some calcareous nodules 2 in in red brown clay loam (sandy).	Sediments
3.0		Yellow brown clay sand. Mottled, haematite/goethite mottles common to 11 m. Silicified sediments. Grey-brown c. sands.	
12.0		White/pink coarse sandy clay, kaolin andqtz.	Pallid
18.0		Saprolite zone, granitic fabric, fresh feldspars and qtz. Increasing grain size with depth. Extremely coarse. Large volume of micaceous flow. High flow (200 kL/day approx).	rolite
29.8		Bedrock.	drock
		Intermediate 8.09 (8.09-6.09)	

Pump bore 18.75 (0.00-12.00) the
lower 6m is a sump. (Q=66 kL/day)
Pump test reliability unknown,
possible effects of leakage from saprolite. Estimated T = 3.8 rn^2/d

S = 0.01 .0.001

Depth of weathering increasing from

south to north into the valley.

COMMENTS : Flow rate < 200 kL/day. 3 pump tests on surficial sands at 20-66 kL/day.

RJG

WELL LOG REPORTS - DRILLING RESULTS
PROJECT BORE NO: MD 4’ RIG TYPE: R.A.B.
CATCHMENT: Merredin CASING DEPTH: 19.40 (in)
DATE DRILLING: Dec 1985 DEPTH DRILLING: 20.50 (in)
LOCATION: Sewage works ‘QUALITY: 1470 inS/m
GRID REFERENCE: 31°28t48t1N ll8Ol5bO6ttE YIELD: 10 kL/day
LAND UNIT: MerredinDEPTH TO BEDROCK: ? (in)
SLOTTED LENGTH: 2 (rn)
WATERTABLE DEPTH: 0.97 (in)SAMPLES: none, gamma

RESULTS

DEPTH (in) DESCRIPTION OF BORE ZONE
FROM TO

11.9

Grey hard loamy sand. Sands

1.9 Red/brown clay sand. Mottled zone. Mottled
sands

Mottled red/brown grey sandy clay iments
over brown sandy clay at 7 in.
(silcrete bands 5.5 7.5)

11.0 Red/orange clay sands over pallid Pallid? or
sands. Sediments

1(12) Complex zone of silicified materials.

1(15.5)1 Hard silcrete (0.2 in thick).

1(19.4)1 Silcrete hardest band, no
penetration drilling ceased. Coarse
silcrete chips (7 mm).

Intermediate 5.86 (5.86 3.86).

Groundwater discharge apparent by
evidence of dead trees. Soil salinity
not apparent until 1988 when 0.5 ha
commenced, after heads approached the
soil surface over the winter months.
Head development (rise of 1 in
artesian deep) probably due to
sewage treatment works enlargement, leakage rechar

s

COMMENTS : Flow 10 kL/day.

RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO: MD 8 RIG TYPE: R.A.B.

CATCHMENT: Merredin CASING DEPTH: 41.84 (in)

DATE DRILLING: Dec 1985 DEPTH DRILLING: 42.00 (in)

LOCATION: North Merredin QUALITY: 1470 inS/in

GRID REFERENCE: 3I°27’42”N 1I8O16I50~E YIELD: < 5 kL/day

LAND UNIT: Belka DEPTH TO BEDROCK: 42.00 (in)

SLOTTED LENGTH: 2 (in)

WATERTABLE DEPTH: 12.33 (in) SAMPLES: pH, EC, Cl

RESULTS

DE FROM	ꟷ (in) TO J	DESCRIPTION OF BORE	ZONE
0	1.0	Brown sand.	Sands
1.0	4.0	Grey/brown sandy clay.	Mottled
4.0		Brown sands to clay sands, mottled.	(Alluvial)
16.0		Sandy clay white/brown pallid. Kaolin and qtz (fine).	Pallid
34.0		Grey/brown medium sandy clay.	athering
ɔ		ɪrock (hard layer slow penetrationl with granitic chips).	ɪrock
		MD 5, 6, 7 similar to MD 4 MD X.	
		Samples taken from all holes (MD 5, 6,1 to depths of 6, 12 and 6 m respectively.	

COMMENTS : Little flow , 5 kL/day.

RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO: MD X RIG TYPE: R.A.R.

CATCHMENT: Merredin CASING DEPTH: 25.00 (in)

DATE DRILLING: Dec 1985
DEPTH DRILLING: 25.00 (in)

LOCATION: Dept of AgricultureQUALITY: 4160 mS/in

GRID REFERENCE: 3l°29’39”N ll8°14’OO”E YIELD: NA kL/day

LAND UNIT: Merredin DEPTH TO BEDROCK: 25.00 (in)

SLOTTED LENGTH: 2 (in)

WATERTABLE DEPTH: 13.05 (in) S
SAMPLES: -

RESULTS

DE FROM	PTH (in) TO	DESCRIPTION OF BORE	ZONE
0	0.2	Brown-red sandy clay loam.	Surficial
0.2		a/a calcareous.	Sediments
		S	
	11.6	gular qtz. mottled sandy clay to clay sands. Iron/haematite stained.	
		Grains occasionally rounded sub-angular (7.2, 8.6, 11.0 hard zones).	
11.0		Moist profile, feldspars pseudomorphs to kaolin.	
14.0		White, pallid sandy clay, fine qtz and kaolin matrix.	Pallid
	1(25)	Hole cased to 25 in as auger rig was ‘bogging’ in pallid zone.	

COMMENTS : No flow.

RJG

WELL LOG REPORTS - DRILLING RESULTS

PROJECT BORE NO: MD9, 10, 11 RIG TYPE: R.A.R.

CATCHMENT: Merredin CASING DEPTH: as below (in)

DATE DRILLING: June 1987 DEPTH DRILLING: as below (in)

LOCATION: Robartsons/Cahills QUALITY: See below inS/rn

GRID REFERENCE: Various YIELD: Nil kL/day

LAND UNIT: Merredin/Nangeenan DEPTH TO BEDROCK: ? (in)

SLOTTED LENGTH: 2 (in)

WATERTABLE DEPTH: As below (in) SAMPLES: Nil

RESULTS

DEPTH (in)
FROM J TO DESCRIPTION OF BORE

MD9 ROBARTSONS (SWL = 6.85) 400 in SW of
(EC = 100 mS/in) house

11.8 Red/rown sandy clay loam.

Heavy clay hardpans. Coarse sandy clay. Mottled

Sandy clay gradation to clay sand.
8.86

Drilled to maximum depth watertable.

MD1O CAHILLS (Kevin house).
(SWL = 8.28) (EC = 3000 mS/m)

0 11.3 Red/brown sandy clay loam. Mottled

1.3 - Hard clay zones, sandy clay.

2.5 Mottled, pale browns fine sandy clay.
Difficult to recover sample.
Added water.

8.87 Watertable reached.

MD 111 CAHILLS Saltbush site (on fence).
(SWL = 3.58) (EC = 3600 mS/in)

0 11.7 Morrell, fine textured clay. Mottled

1.7 - Mottled sandy clay. Coarser with
depth. Nodules of grey clay with
depth - calcium carbonate present.

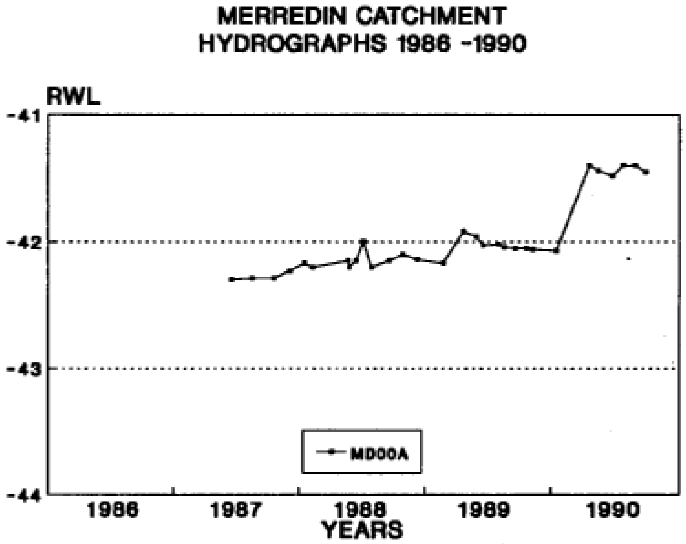
7.4 Watertable struck.

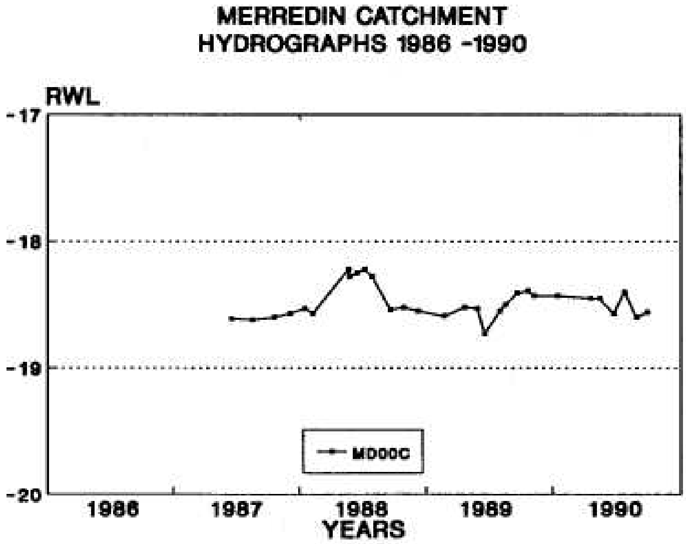
NB: Borehole (7.26 in) drilled on
Bellegutin Ck CSIRO lease block, 150 ml
E of Hubeck Rd floodway. Bore dry.

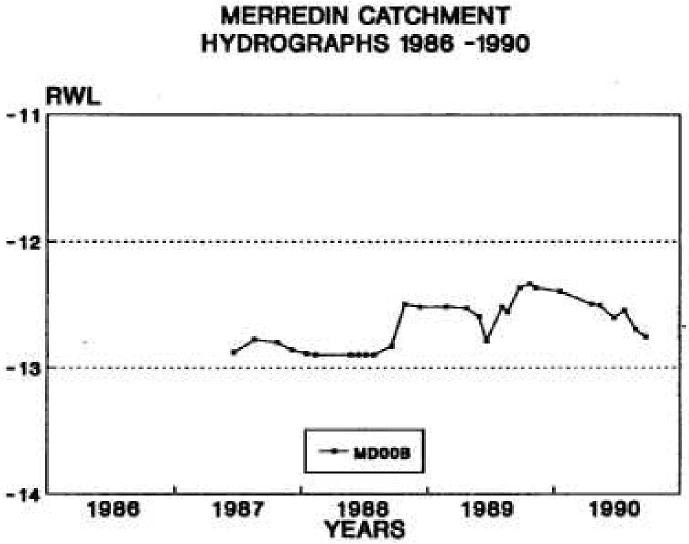
COMMENTS : No flow in any bores.

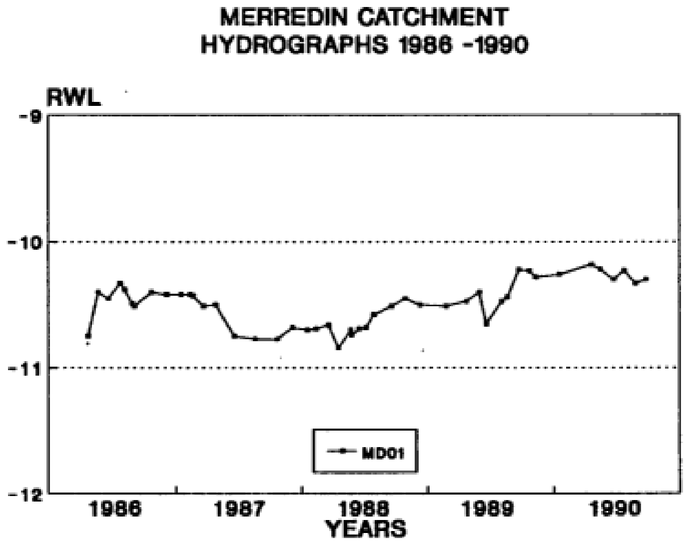
RJG

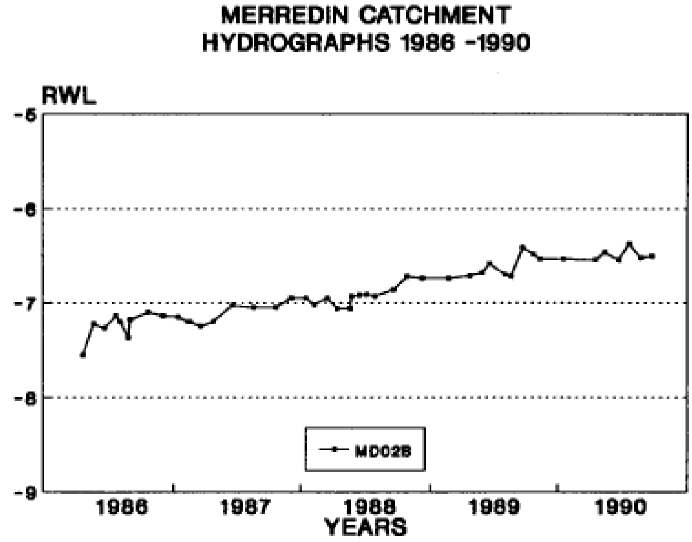
APPENDIX 2: Hydrographs of bores drilled in the Merredin Catchment

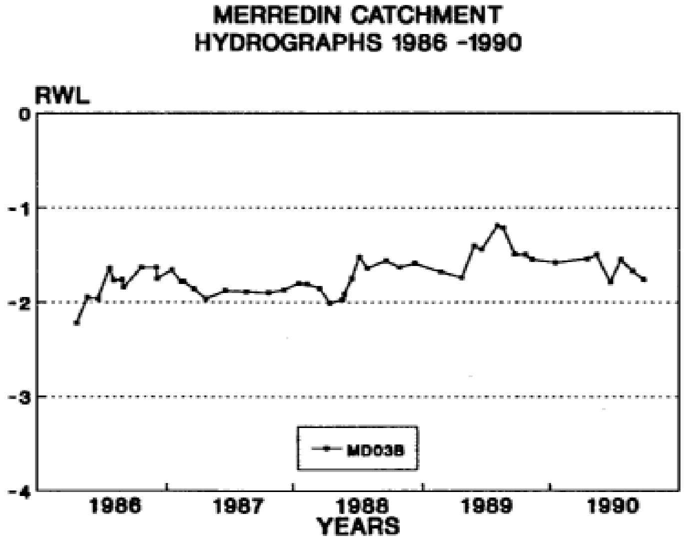


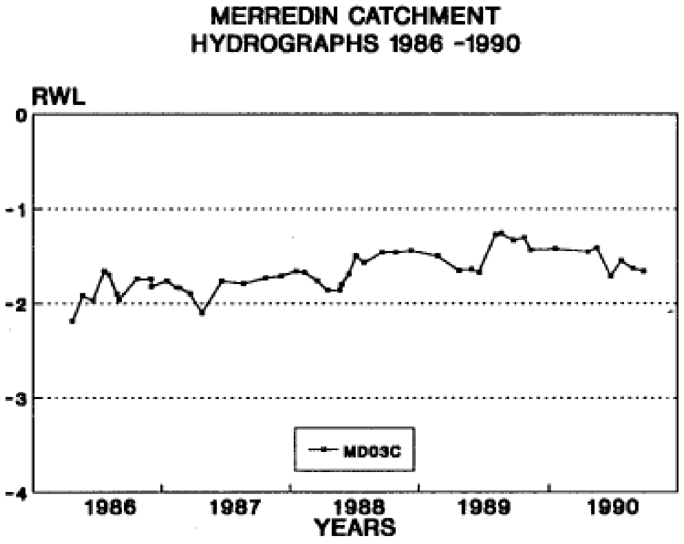





MERREDIN CATCHMENT
HYDROGRAPHS 1986 -1990
RWL
-9
-10
-11
-12
MD01
1986
1987
1988
1989
1990
YEARS


MERREDIN CATCHMENT
HYDROGRAPHS 1986 -1990
RWL
-5
-6
-7
-8
-9
MD02B
1986
1987
1988
1989
1990
YEARS


MERREDIN CATCHMENT
HYDROGRAPHS 1986 -1990
RWL
0
-1
-2
-3
-4
MD03B
1986
1987
1988
1989
1990
YEARS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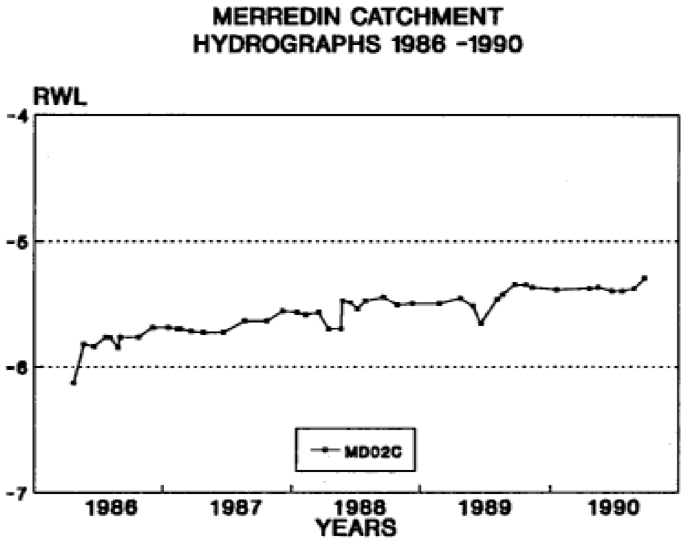
HYDROGRAPHS 1986 -1990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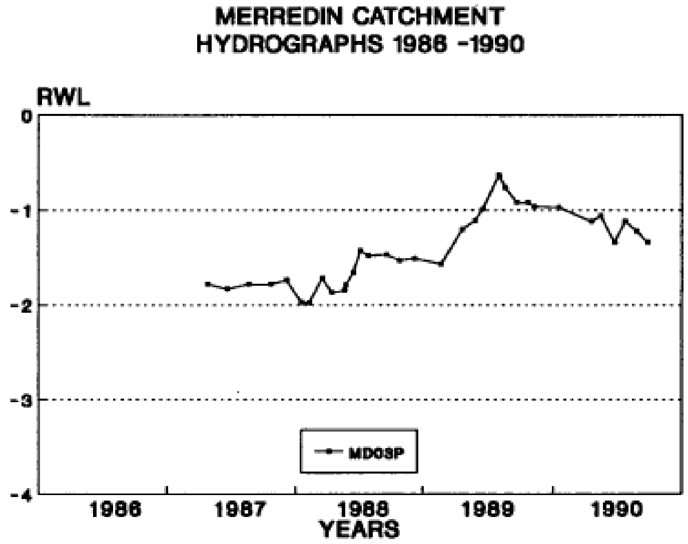
HYDROGRAPHS 1986 -1990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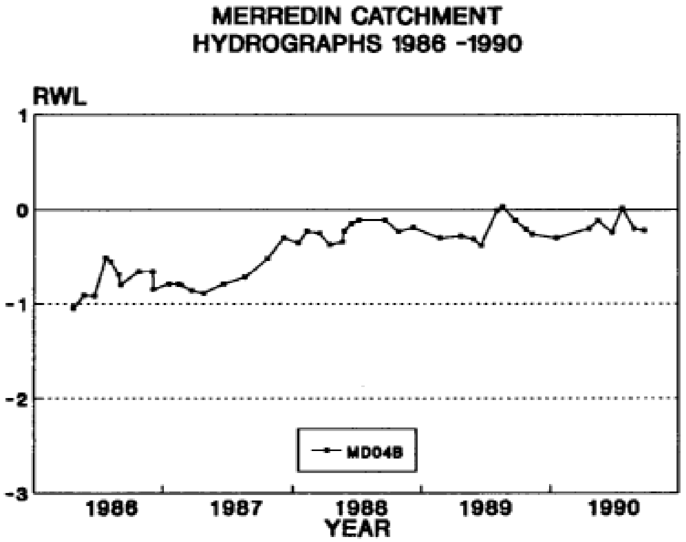
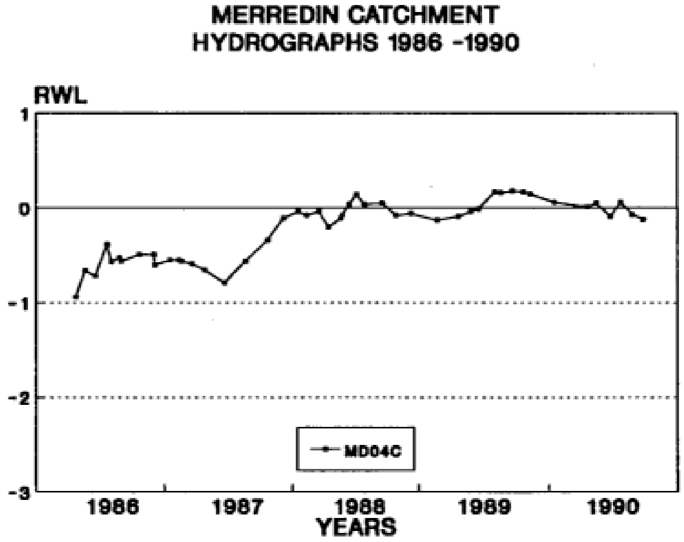
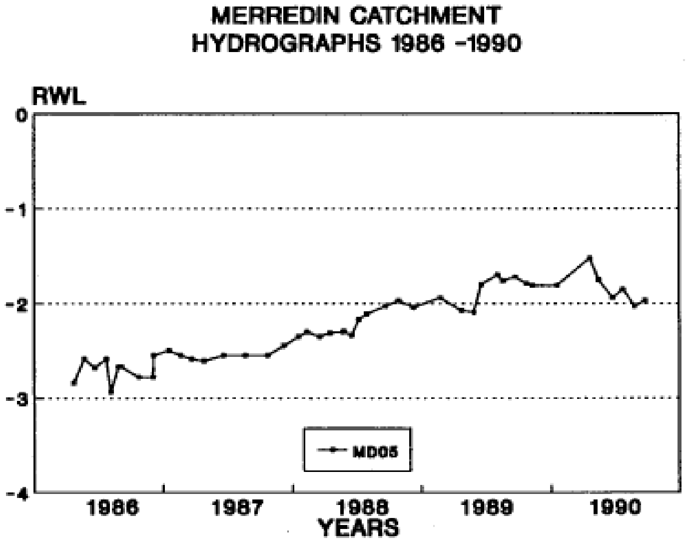

MERREDIN CATCHMENT
HYDROGRAPHS 1986 -1990
RWL
1
0
-1
-2
-3
MD04B
1986
1987
1988
1989
1990
YEAR


MERREDIN CATCHMENT
HYDROGRAPHS 1986 -1990
RWL
1
0
-1
-2
-3
MD04C
1986
1987
1988
1989
1990
YEARS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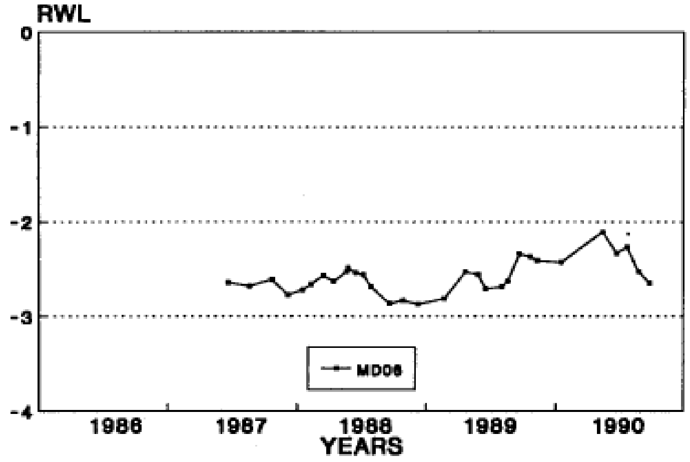
HYDROGRAPHS 1986 -1990
RWL
0
-1
-2
-3
-4
MD05
1986
1987
1988
1989
1990
YEARS

MERREDIN CATCHMENT
HYDROGRAPHS 1986 -1990



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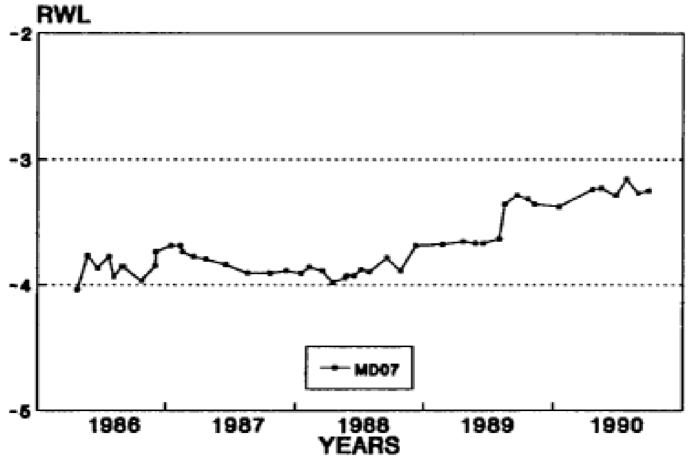
HYDROGRAPHS 1986 -1990



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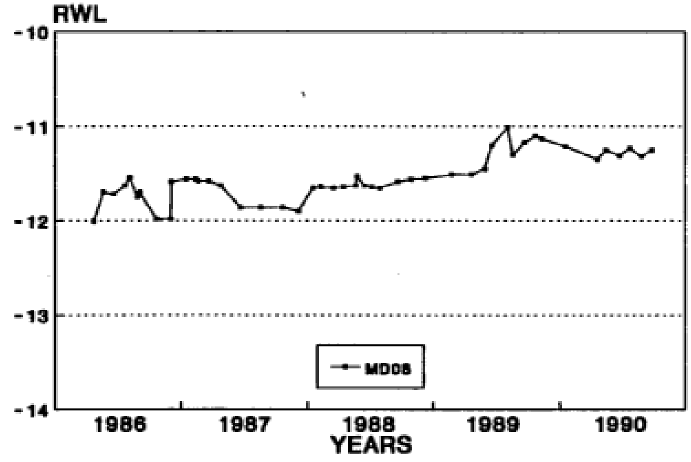
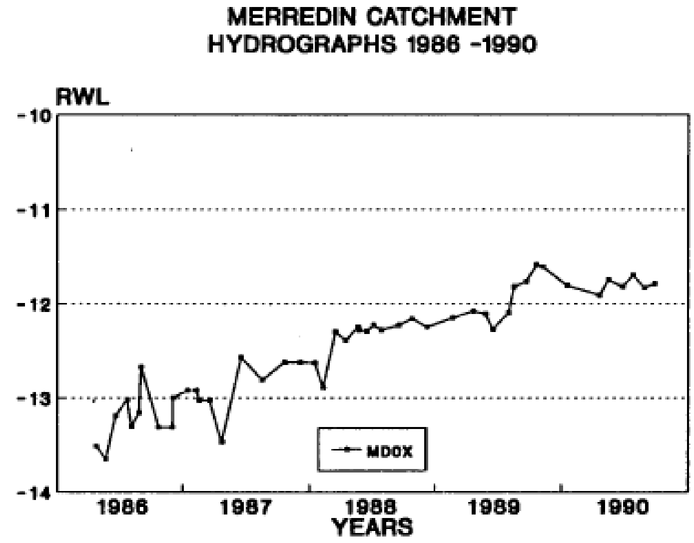
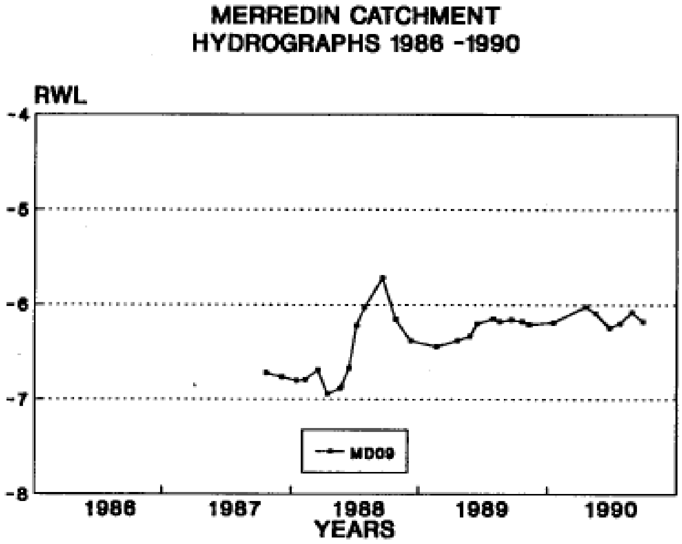
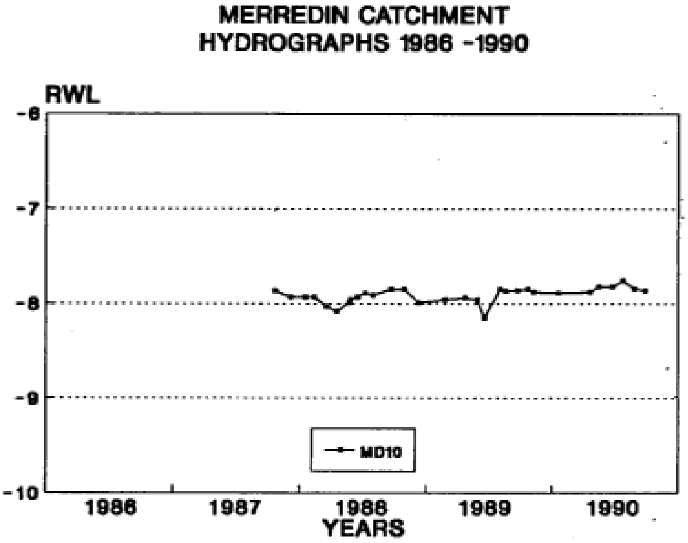
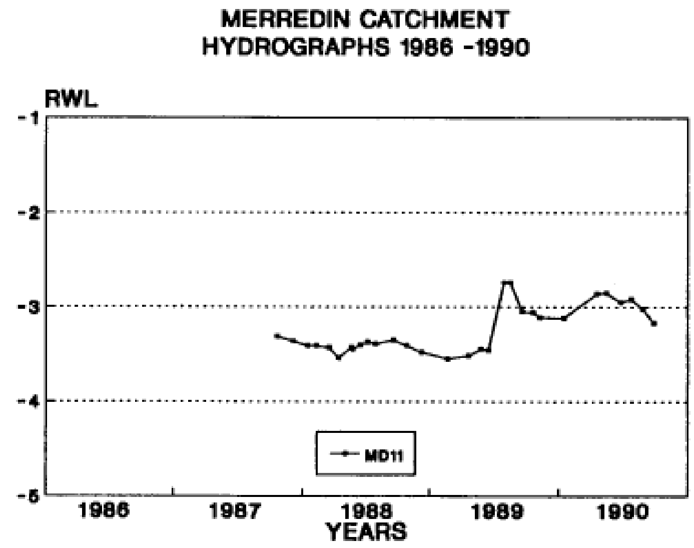
HYDROGRAPHS 1986 -1990




MERREDIN CATCHMENT
HYDROGRAPHS 1986 -1990
RWL
-10
-11
-12
-13
-14
MDOX
1986
1987
1988
1989
1990
YEARS


MERREDIN CATCHMENT
HYDROGRAPHS 1986 -1990
RWL
-4
-5
-6
-7
-8
MD09
1986
1987
1988
1989
1990
YEARS


MERREDIN CATCHMENT
HYDROGRAPHS 1986 -1990
RWL
-6
-7
-8
-9
-10
MD10
1986
1987
1988
1989
1990
YEARS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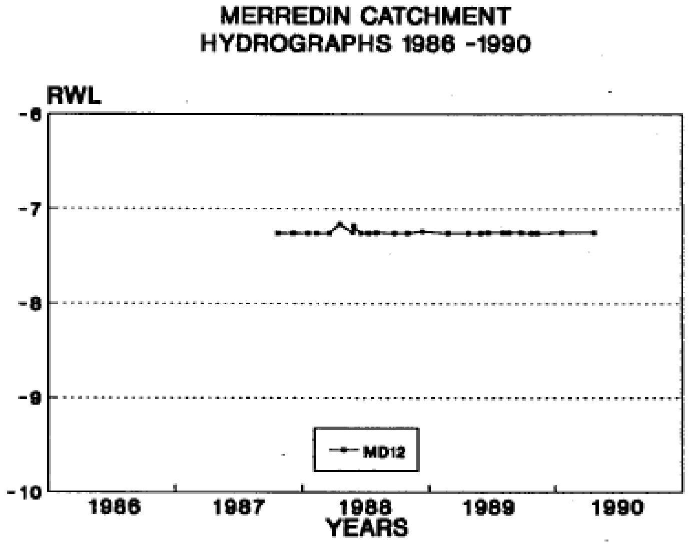
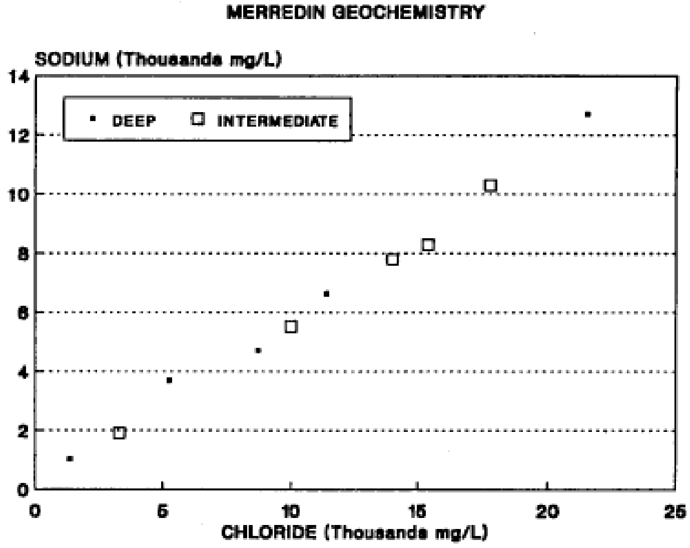
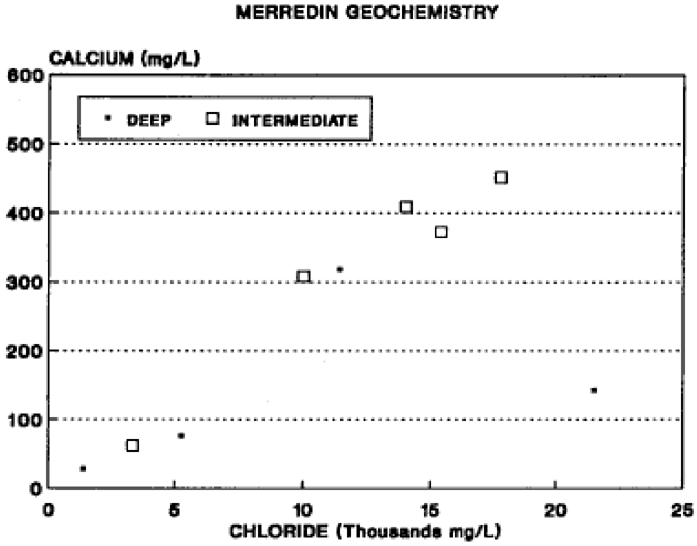
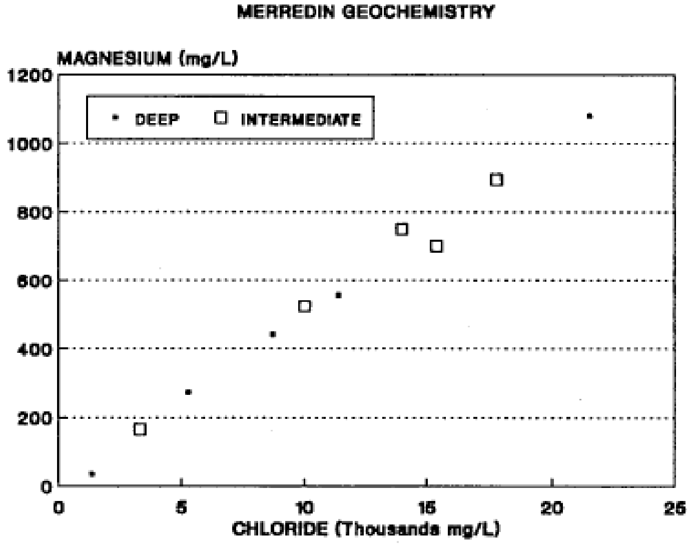
HYDROGRAPHS 1986 -1990

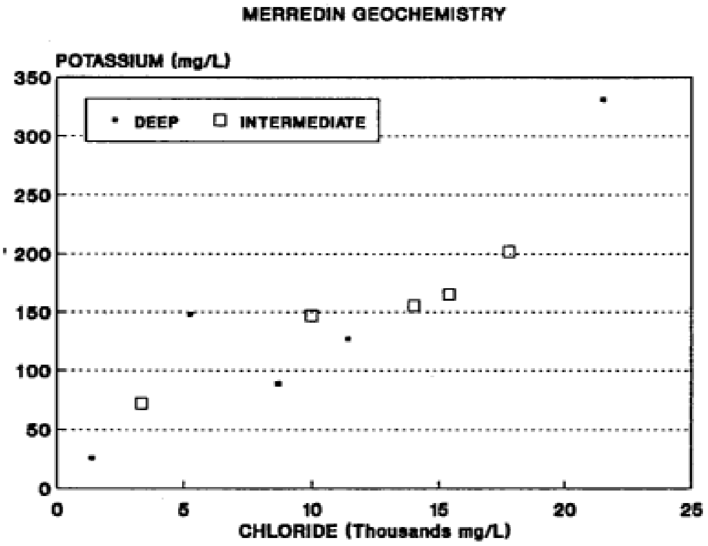

MERREDIN CATCHMENT
HYDROGRAPHS 1986 -1990

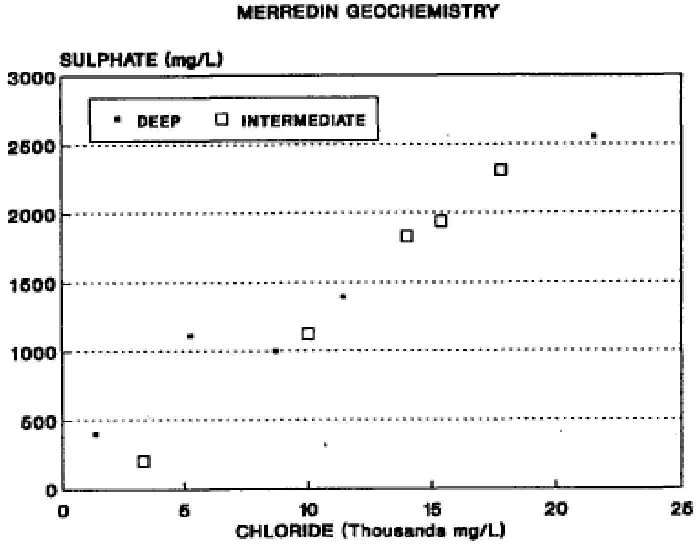
APPENDIX 3: Merredin Geochemistry

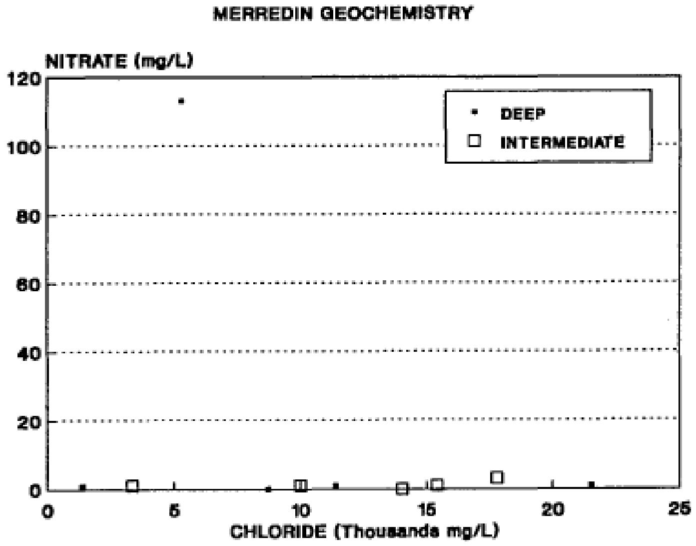


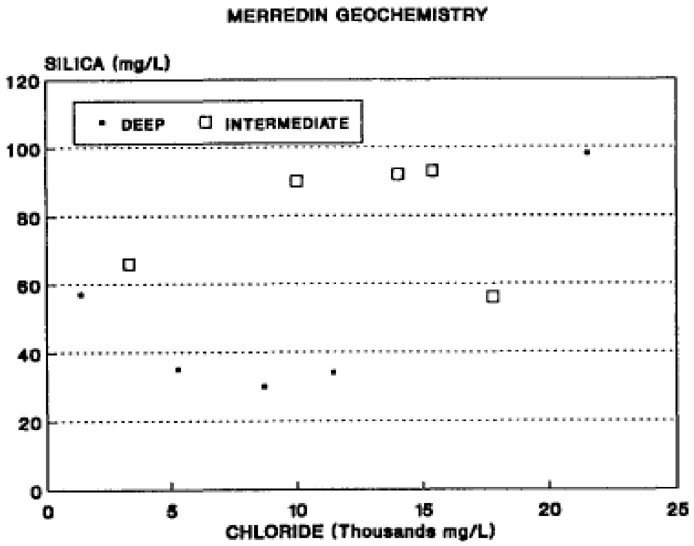


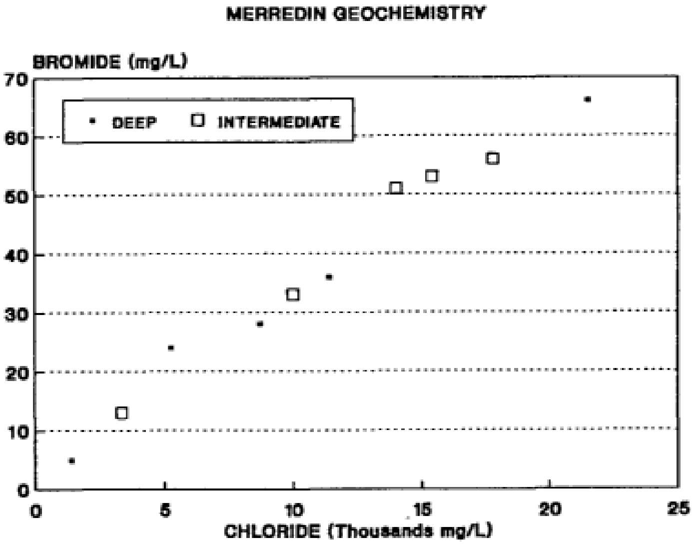


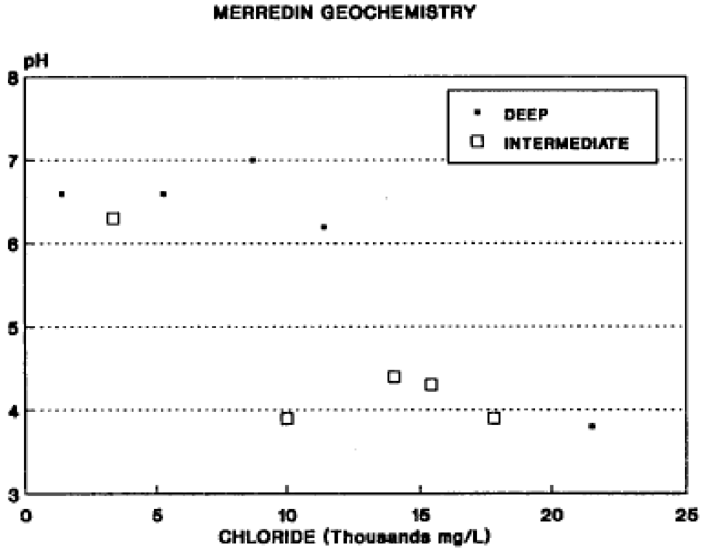

MERREDIN GEOCHEMISTRY
POTASSIUM (mg/L)
• DEEP
□ INTERMEDIATE
350
300
250
200
150
100
50
0
0
5
10
15
20
25
CHLORIDE (Thousands mg/L)

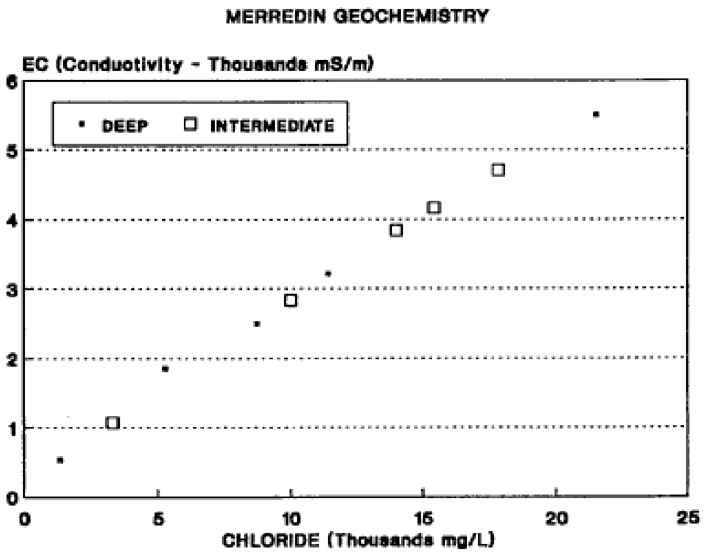

MERREDIN GEOCHEMISTRY
SULPHATE (mg/L)
• DEEP
□ INTERMEDIATE
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
25
CHLORIDE (Thousands mg/L)


MERREDIN GEOCHEMISTRY
NITRATE (mg/L)
• DEEP
□ INTERMEDIATE
120
100
80
60
40
20
0
0
5
10
15
20
25
CHLORIDE (Thousands mg/L)


MERREDIN GEOCHEMISTRY
SILICA (mg/L)
120
100
80
60
40
20
0
DEEP
INTERMEDIATE
0
5
10
15
20
25
CHLORIDE (Thousands mg/L)


MERREDIN GEOCHEMISTRY
BROMIDE (mg/L)
70
60
50
40
30
20
10
0
DEEP
INTERMEDIATE
0
5
10
15
20
25
CHLORIDE (Thousands mg/L)


MERREDIN GEOCHEMISTRY
pH
8
7
6
5
4
3
DEEP
INTERMEDIATE
0
5
10
15
20
25
CHLORIDE (Thousands mg/L)


MERREDIN GEOCHEMISTRY
EC (Conductivity - Thousands mS/m)
• DEEP
□ INTERMEDIATE
0
1
2
3
4
5
6
0
5
10
15
20
25
CHLORIDE (Thousands mg/L)