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Groundwater investigation Buntine-Marchagee Natural Diversity Recovery Catchment

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GROUNDWATER INVESTIGATION

BUNTINE – MARCHAGEE

Natural Diversity Recovery Catchment

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and
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Groundwater Investigation
of the
Buntine-Marchagee
Natural Diversity Recovery Catchment

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ACKNOWLEDGMENTS

Jodie Watts (Recovery Catchment Officer) coordinated and managed the entire drilling program.

John Simons (Dept of Agriculture, Esperance) supervised startup of the field drilling operations.

Anthony Raudino supervised drilling, processed drill samples, developed bores by airlift and collected initial groundwater data.

Clare Forward and Stuart Delphin supervised drilling.

Marguerite D'Alton and Ewan Buckley provided GIS and mapping support. Marguerite also provided the elevation profiles along the transects from which the cross-sections were constructed as well as providing Figure 1-1 and Appendix 2.

Don Bennett and John Simons provided constructive review and comments.

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SUMMARY

A groundwater investigation was initiated in the Buntine-Marchagee Natural Diversity Recovery Catchment in 2002. The investigation aimed to install a regional groundwater monitoring network and characterise the regolith throughout the catchment. Drill site selection was based on establishing a series of transects to enable construction of hydrogeologic cross-sections to enhance conceptual understanding of the catchment and provide input for future groundwater modelling exercises.

A total of 49 piezometers and 40 observation bores were installed at 52 sites in seven transects throughout the catchment. Groundwater monitoring sites are established in every landscape position and measure a range of groundwater occurrences in a range of saturated regolith material.

The main drainage line in the Recovery Catchment is populated with hundreds of lakes. The cross-sections constructed from the drill transects illustrate significant differences in the profiles through the main drainage line and tributaries. The profile beneath the main drainage line was found to have deep (up to 38 m) sequences of alluvial (paleo) channel sediments. Basal groundwater in the main drainage line is hyper-saline (up to 20,800 mS/m).

This project has successfully installed a regional groundwater monitoring network. It has provided a representative snapshot of current groundwater conditions throughout the Recovery Catchment.

The aims of the project have been fulfilled and it is recommended that no further drilling is required. However, it is recommended that ongoing monitoring be undertaken to build an understanding of groundwater dynamics and threats imposed by hydrological processes, in particular rising groundwater.

It is emphasised that the monitoring network is regional and does not capture detailed groundwater processes. Further drilling programs will be required to describe in detail how groundwater systems interact with remnant ecosystems and monitor the performance of intervention to preserve threatened species. However, it is recommended the location of future drilling programs should be determined by ecologists based on nature conservation priorities.

A number of the drill transects appear suitable as input to Flowtube models. It is recommended that Flowtube models be constructed for all suitable transects and the results extended to the community via a workshop.

Finally, if a need is identified for further regional groundwater investigations or regolith mapping (e.g. finding or defining paleo-channels), then it is recommended that any drilling program is preceded by a geophysical survey to delineate target features.

1. INTRODUCTION AND BACKGROUND

The 1996 Salinity Action Plan laid the foundation for Natural Diversity Recovery Catchments with the commitment that "The Government will develop and implement a coordinated Wetlands and Natural Diversity Recovery Program ...to ensure that critical and regionally significant natural areas, particularly wetlands, are protected in perpetuity" (Government of Western Australia 1996, p. 23).

The Salinity Strategy prepared by the State Salinity Council (2000) reiterated this commitment with the Department of Conservation and Land Management to implement a coordinated Natural Diversity Recovery Program. This is in keeping with the Department's responsibility to conserve the State's rich diversity of native plants, animals and natural ecosystems. At that stage the program had targeted five catchments and "...will target at least six more catchments by 2005, based on biological survey findings" (State Salinity Council 2000, p. 33).

The Buntine-Marchagee area was selected as a Recovery Catchment (Department of Conservation and Land Management 2002) because it contains:

- significant diversity of terrestrial and wetland flora and fauna;
- braided saline channels with unique biota poorly represented regionally in natural communities;
- large corridors of remnant vegetation containing good representation of shrublands and woodlands; and
- coverage over two biogeographical zones.

A Steering Committee was formed with diverse membership of which notably, nearly half were landholders within or adjacent to the catchment. At its inaugural meeting in March 2002, the Steering Committee identified a number of objectives for the recovery project. Among them are:

- Understand and identify how groundwater and surface water hydrology within the catchment contributes to secondary salinity.
- Develop a system for monitoring and evaluating the overall effectiveness of the project.

(Bessen and Watts 2002).

To make progress towards these objectives a groundwater investigation was planned and implemented. The investigation consisted of a drilling program to install a groundwater monitoring network and characterise the regolith at points throughout the catchment. Groundwater monitoring points were installed in transects to enable subsequent construction of hydrogeological cross-sections or profiles through selected parts of the catchment and provide the basis for future groundwater modeling exercises (e.g. Flowtube) to test proposed management scenarios.

This report documents some background information for the Buntine-Marchagee Recovery Catchment (Section 1), the groundwater investigations undertaken in this study (Section 2) and recommendations (Section 3).

1.1 The Buntine-Marchagee Recovery Catchment

The Buntine-Marchagee Recovery Catchment is located about 200 kilometres north-northeast of Perth. The Natural Diversity Recovery Catchment project area (Recovery Catchment) encompasses 181,000 hectares of the catchment. The Recovery Catchment spans approximately 40 kilometres north to south by 54 kilometres east to west (Figure 1.1).

The Recovery Catchment overlaps parts of the Shires of Coorow, Dalwallinu, Perenjori and Moora with the towns of Wubin and Buntine located in the eastern portion. The principle commercial activity in the district is agriculture for which approximately 87 per cent of the area is cleared. Most of the clearing (> 60 per cent) occurred between 1920 and 1960. Agricultural production is dominated by cereal (wheat) cropping.

There is nearly 24,000 hectares of native vegetation remaining in the Recovery Catchment, however, only 2225 hectares are contained within Department of Conservation and Land Management managed estate (Jodie Watts, personal communication, 2003).

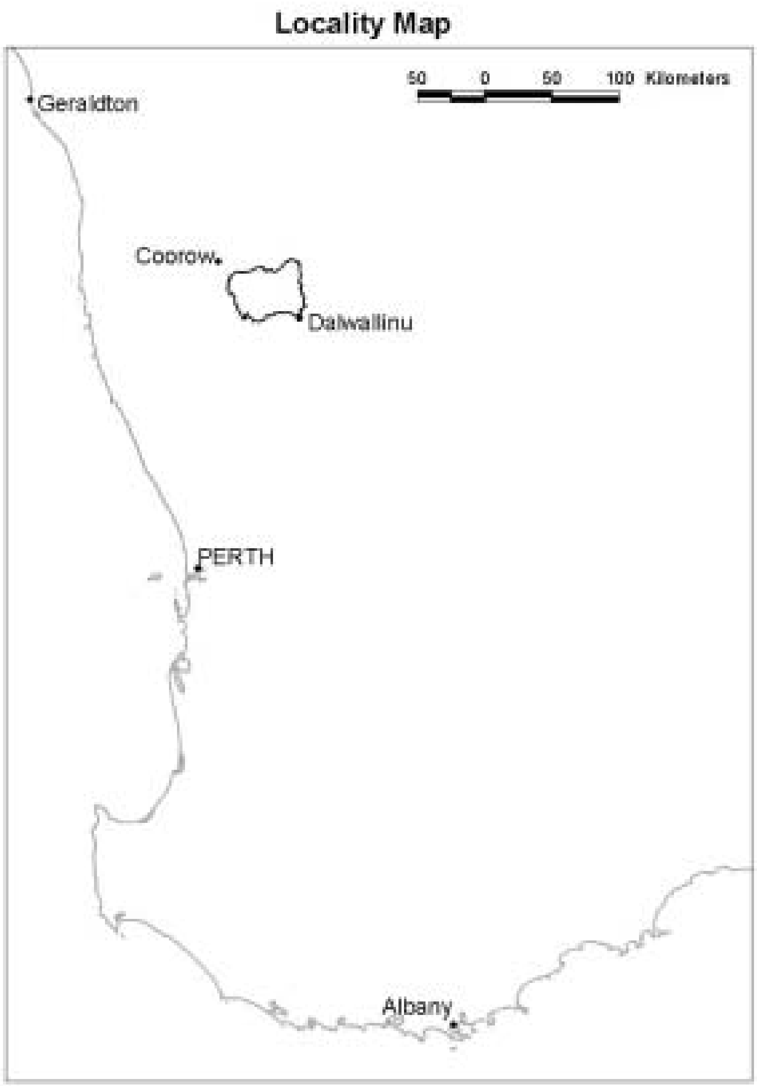

Figure 1.1. Location of the Natural Diversity Recovery Catchment project area.

1.2 Description of the catchment

Topography ranges from 380 metres elevation in the upper catchment, nine kilometres north of Wubin to 248 metres elevation near the discharge point at the northwestern edge of the Recovery Catchment. This is indicative of the subdued relief in the catchment where topographic gradients rarely exceed four percent and are typically less than two percent. Gradients along drainage lines are only fractions of a percent.

While the general direction of drainage is from east to west, the main drainage line loops to the south and approaches within 3.5 kilometres of the western catchment divide before turning north (see Appendix 2).

Much of the drainage appears to be developed along preferred orientations. Indeed the drainage pattern in the Recovery Catchment emphasises structural fabric that exists throughout the Yilgarn Craton in the northern agricultural region. The two main orientations are approximately northeast - southwest and northwest - southeast (~ 040 and 130 degrees True).

The major drainage lines are broad saline braided systems typically up to 1.5 kilometres in width. They are populated with hundreds of lakes ranging in size from less than 50 metres in diameter up to 2.7 kilometres across.

Lake chains are not usually a dominant characteristic of valley floors in the northern agricultural region. In the Recovery Catchment they provide the impression of a mature drainage system. That is, a catchment with an ancient history of surface water flow in contrast to many of the valley depressions, now typically saline, that infrequently carried surface flow prior to clearing.

1.3 Geology

The entire area of the Recovery Catchment is underlain by Archean granitic rock of the Yilgarn Craton (Carter and Lipple 1982, Baxter and Lipple 1985). The Darling Fault, which forms the western edge of the Yilgarn Craton, is about 17 kilometres west of the Recovery Catchment's western divide.

Mafic dykes of doleritic composition intrude the Archean granitic basement. The abundance of dykes increases toward the west. They are generally up to 10 metres thick with a north to northwesterly orientation although cross-cutting relationships occur (Carter and Lipple 1982).

The crystalline basement is poorly exposed throughout the Recovery Catchment. It is obscured by residual laterite profiles, colluvium and quartz sand. A surficial blanket of yellow sandplain covers the western and southwestern area of the Recovery Catchment

1.4 Climate

The climate is typical of a warm temperate to semi-arid region with dominantly winter rainfall and hot, dry summers.

Average rainfall decreases from west to east across the Recovery Catchment. The average annual rainfall is 380 mm at Coorow, about 15 kilometres northwest of the catchment. The average annual rainfall at Wubin is 327 mm near the eastern limit of the Recovery Catchment (Bureau of Meteorology 2003).

On average, about 80 per cent of the rainfall occurs from April to October inclusive. Figure 1.3 shows average monthly rainfall at Buntine located in the northeast of the Recovery Catchment (Clewett *et al.* 1999).

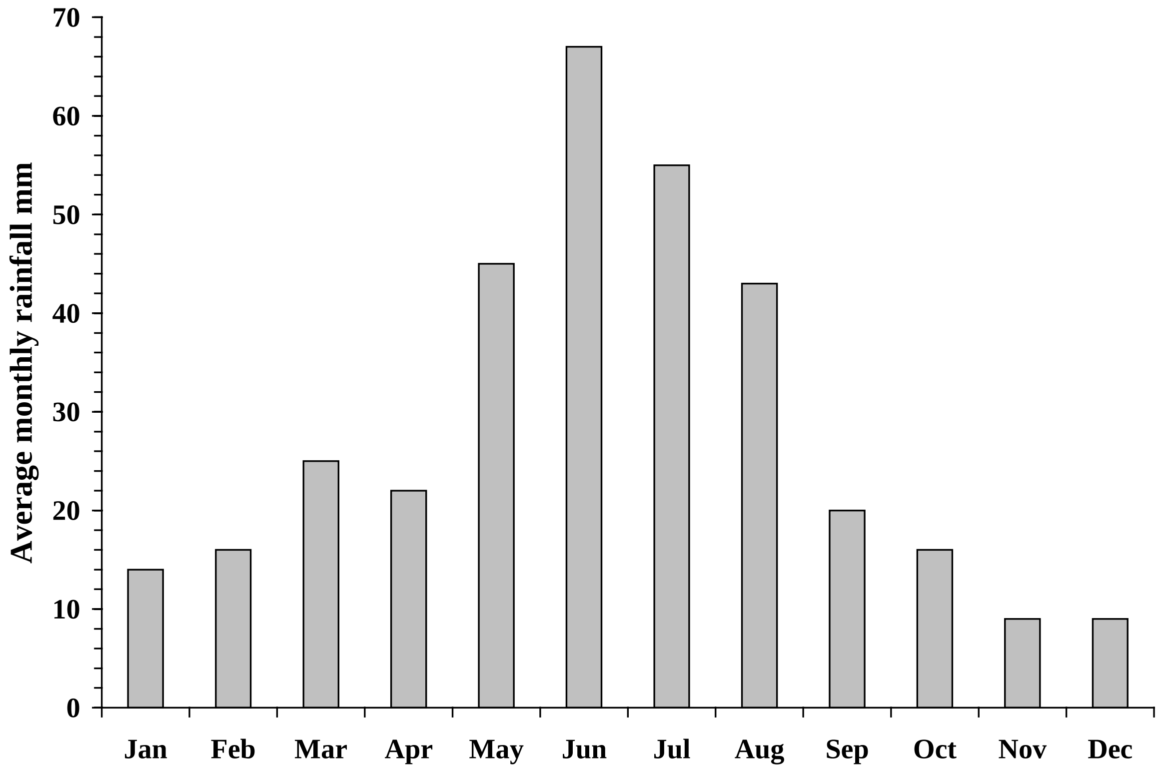

Figure 1.3 Average monthly rainfall at Buntine.

Summer rainfall events can be significant. Often the highest daily rainfall totals in the wheatbelt of Western Australia are recorded in summer or early autumn. Highest daily rainfall observations for stations located within or in close proximity to the Recovery Catchment are presented in Table 1-1.

Table 1.1. Highest daily rainfall totals observed within or in close proximity to the Recovery Catchment (Bureau of Meteorology 2003)

Station	Daily rainfall	Date
Cooroo PO	127 mm	14 April 1961
Buntine	118 mm	29 January 1990
Wubin PO	136 mm	14 April 1961
Maya	175 mm	29 March 1971

2. HYDROGEOLOGY INVESTIGATION

2.1 Previous investigations

More than 120 observation bores and piezometers have been installed in the Buntine-Marchagee area since 1994. An unpublished report by Rachel Bagshaw (Bushcare Officer, 2002), titled 'Marchagee catchment bore information' attempts to collate information about and data from these groundwater monitoring sites. They were installed in four projects undertaken in May 1994, May 1996, March 1998 and March 1999.

During 2002, Rachel Bagshaw coordinated and collated groundwater data for bores installed in 1999. Water level data for a selection of bores within the Recovery Catchment were retrieved from Rachel's archived computer files. Table 2.1 provides some details about these bores.

Table 2.1. Bore information for a selection of Marchagee catchment groundwater monitoring sites

Bore ID	**Easting (m)**	**Northing (m)**	**Depth drilled**	**Depth to basement**	**Groundwater depth Jan '01**	**Landscape position**	**Groundwater trend '99-'02**
19	424771	6677126	16.5 m	16.5 m	7.57 m	Lower slope	- 0.46 m/yr
25	425333	6669174	20 m	unknown	16.07 m	Mid slope	+ 0.39 m/yr
29	429112	6663072	20 m	unknown	6.66 m	Mid slope	- 0.54 m/yr
54	431318	6682953	unknown	unknown	3.92 m	Lower slope	- 0.67 m/yr
57	445750	6683149	unknown	unknown	10.78 m	Upper slope	+ 0.17 m/yr

Hydrographs for three of the bores listed in Table 2.1 are presented in Figures 2.1 to 2.3. Unfortunately because the length of record in all cases is less than four years, it is not possible to separate transient responses from underlying trends.

Figures 2.1 and 2.3 show significant groundwater rise in response to particularly wet conditions in 1999 in bores 19 and 29. However, from 2000 onwards groundwater levels have declined at these two locations during a particularly dry period.

Figure 2.2 indicates a rising groundwater trend in bore 25. However, most of the groundwater rise occurred during 1999 and 2000. The groundwater level remained steady during 2001 and 2002 in response to a particularly dry period that began in 2000.

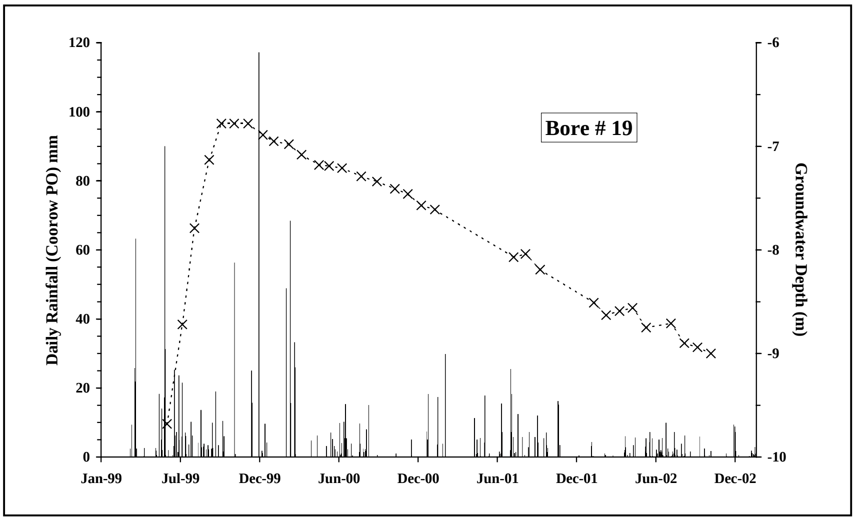

Figure 2.1. Hydrograph for bore 19.

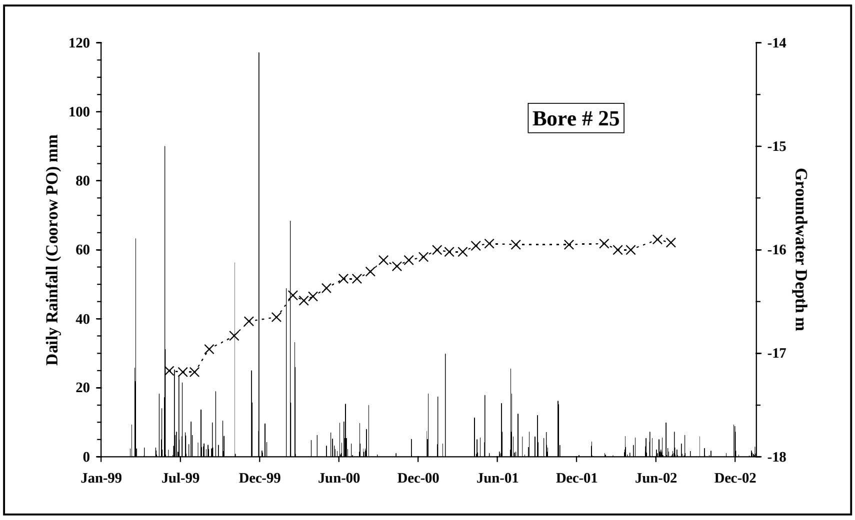

Figure 2.2. Hydrograph for bore 25.

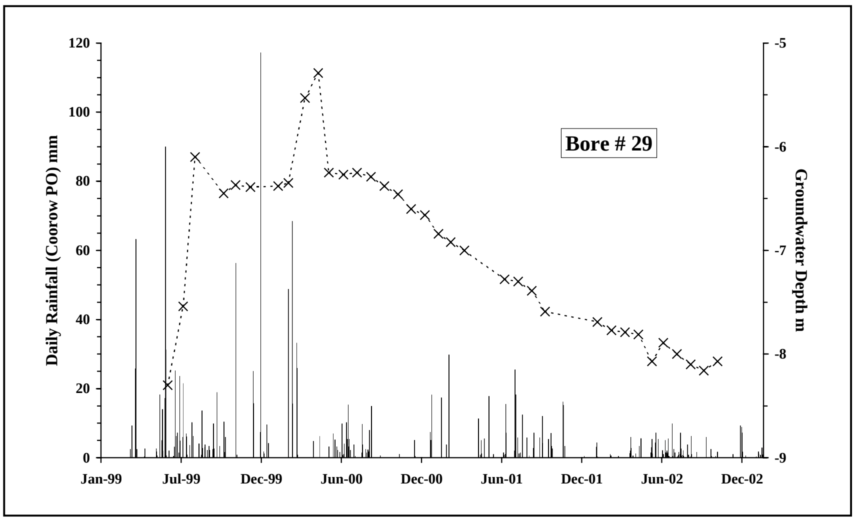

Figure 2.3. Hydrograph for bore 29.

The closest bores to the Recovery Catchment that have been regularly monitored for a decade are located northeast of Carnamah. Groundwater monitoring was established at 30 sites to support evaluation of an airborne geophysical survey (Speed 2002). The survey area is about 50 kilometres north of the Recovery Catchment. Table 2.2 provides details of three groundwater monitoring bores in the survey area that are located on the same slope.

Table 2.2. Site information for three of the Carnamah airborne geophysical survey groundwater monitoring bores

Bore ID	Easting (m)	Northing (m)	Depth drilled	Screened interval	Landscape position	Groundwater depth Jan '04	Groundwater salinity Mar '94
CA2D	401969	6728655	37.4 m	18.17-20.17	Upper mid slope	8.05 m	4610 mS/m
CA26D	402386	6727022	38.3 m	16.37-18.37	Lower mid slope	6.60 m	3100 mS/m
CA3OB	406796	6720191	6.0 m	2.35- 5.95	Lower slope	3.22 m	5300 mS/m

Hydrographs for the three bores listed in Table 2.2 are presented in Figures 2.4 to 2.6. Speed (2002) had considered the Carnamah survey area to have reached post-clearing hydrological equilibrium with the salt affected area unlikely to spread. However, Figure 2.4 shows net groundwater rise in an upper mid slope location and Figure 2.5 appears to show a rising groundwater trend in a lower mid slope location.

The dominant feature of the hydrographs is episodic response to a particularly wet period in 1999. This wet period was followed by particularly dry conditions from April 2000 to April 2003. In response, the groundwater level in piezometer CA26D (Figure 2.5) has declined. However, the groundwater level has remained elevated in piezometer CA2D (Figure 2.4).

The hydrograph for observation bore CA3OB is presented in Figure 2.6. At this lower slope location, there is no apparent rising trend and groundwater response is dominated by seasonal fluctuations.

Thus it appears that while a post-clearing hydrological equilibrium may be established in the valley floor and lower slope regions, there may be continued groundwater rise in mid and upper slope locations that are remote from groundwater discharge areas. This is consistent with and compounded by gentle hydraulic gradients and very low hydraulic conductivities typical of the deeply weathered saprolitic clay profiles encountered throughout much of the wheatbelt of Western Australia.

The catchment implications of these observations are that the area of salinity in the valley floor and lower slope positions may be quite stable but there is long term potential for salinity to develop and spread in minor tributaries in mid and upper landscape positions.

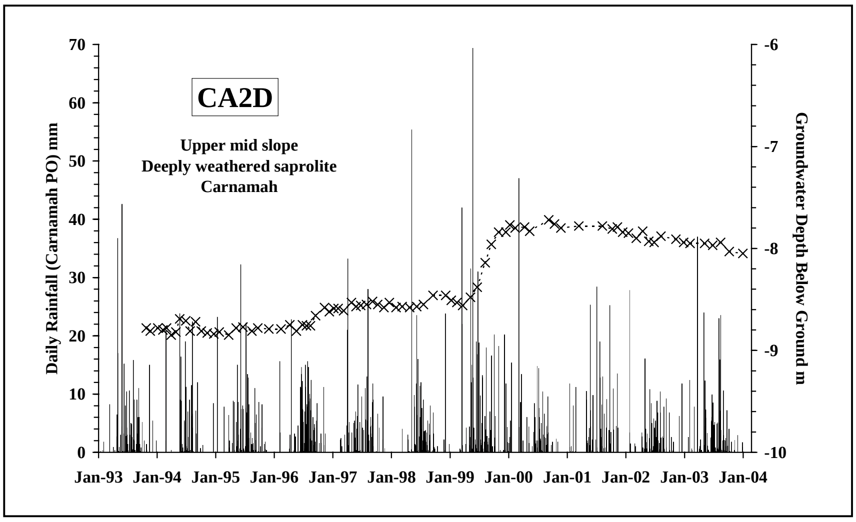

Figure 2.4. Hydrograph for piezometer CA2D.

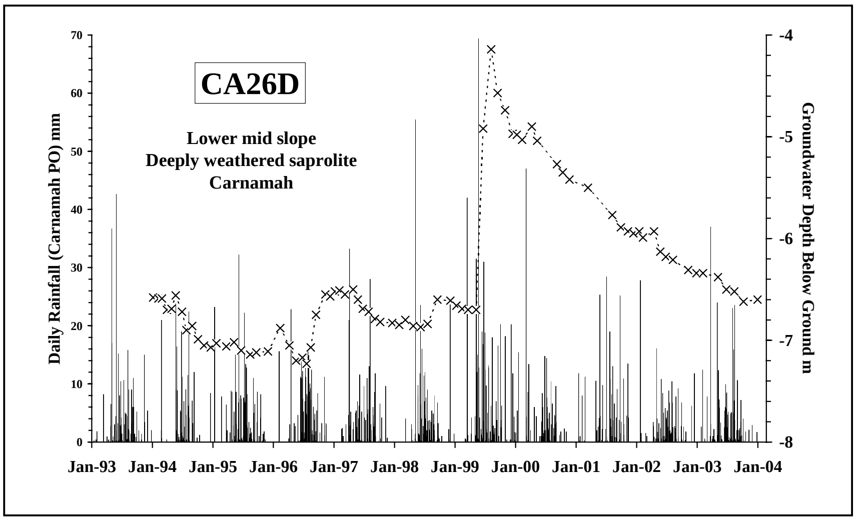

Figure 2.5. Hydrograph for piezometer CA26D.

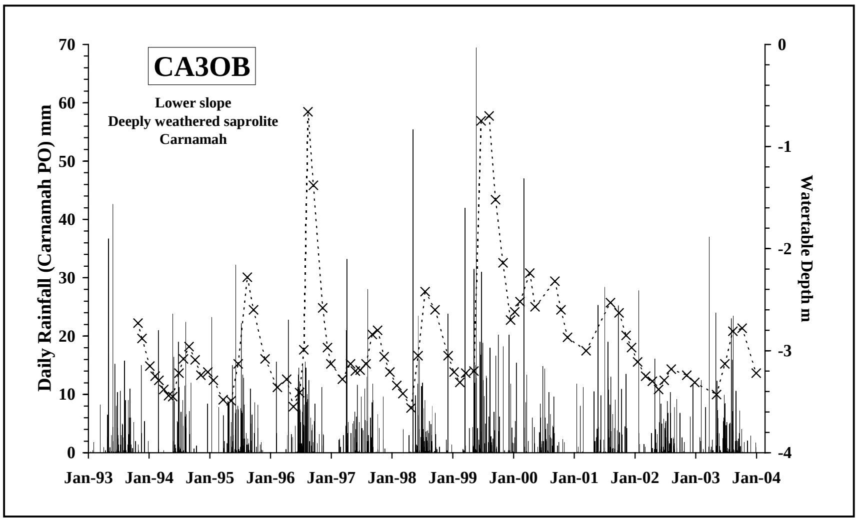

Figure 2.6. Hydrograph for observation bore CA3OB.

2.2 Method for this investigation

Drilling for the Recovery Catchment Project was carried out between the 15 May and 4 June 2002. A total of 49 piezometers and 40 observation bores were installed at 52 sites. The location of these bores is listed in Table 2.3 and shown on the map contained in Appendix 2.

2.2.1 Drill site selection

The overall aim of the drilling program was to establish a regional groundwater monitoring network throughout the catchment. To gain additional value from the drilling program, drill site selection was based on establishing a series of transects through and across the catchment. The aim was to enable construction of conceptual hydrogeological cross-sections to build a series of two dimensional slices through the landscape. Factors considered in locating the drill transects included sampling the range of soil-landscape systems present and spatial representation throughout the catchment.

The drill site selection strategy delivered two secondary goals. Firstly, groundwater monitoring sites were established in all landscape positions. Secondly, some of the transects will provide data for developing Flowtube Models (George *et al.* 2001) which can test the effect of different land management options on managing salinity.

At a local scale, drill site position was determined by access for the rig, long term protection of bore headworks and minimal disturbance to farming activities.

2.2.2 Drilling methods

Austral Drilling Services were contracted to drill the sites and install casing to construct piezometers and observation bores. The drilling method employed was reverse circulation air core with a 123 mm drill bit diameter.

2.2.3 Bore construction

Bores were constructed with 50 mm diameter class 9 PVC casing with class 18 PVC end caps. The bottom end caps are 40 mm and were inserted inside the casing. The bottom end caps of every observation bore had four to five 6.5 mm diameter holes drilled through to ensure the casing and end cap completely drains if the water table recedes below the cased depth.

The casing intake sections were machine slotted. Piezometers were constructed with a 2 metre slotted intake section over the lowest part of the casing.

Observation bores were constructed with casing that had a machine slotted intake section over a 4 metre interval at one end of a 6 metre length.

The PVC casing was inserted down the inner tube of the drill rods at the end of drilling. The drill rods were then pulled and the PVC casing was cut protruding above ground level.

The annulus around the slotted intake section was packed with 8-16 gravel (about 1.6 to 3.2 mm diameter). Bentonite pellets were used to seal the annulus above the slotted intake section in every piezometer. The annulus of piezometers and observation bores was then back-filled to ground surface with drill cuttings if they were suitable, or 8-16 gravel. All bores were then cemented at the ground surface to prevent surface water inflow down the annulus and ensure tube top stability.

After the drill program was completed, all bore tube tops were cut off at 0.20 m above the ground surface. All bores were cleaned and developed by downhole injection of compressed air.

Bore construction details and estimated yields by airlift are listed in Table 2.3.

2.2.4 Drill sample analyses

Drill samples were collected and described over one metre intervals during drilling. Samples were then oven dried at 60^{o} C and duplicate chip trays were prepared.

A set of drill logs was then compiled by reviewing the field drill logs and chip trays. These drill logs are presented in Appendix 1.

One set of chip trays is stored at the Geraldton office of the Department of Agriculture, the other resides with the Department of Conservation and Land Management in Geraldton.

2.2.5 Groundwater monitoring and sample analyses

Initial groundwater levels were measured in July 2002. Since then regular monitoring has been undertaken at approximately six-weekly intervals. This frequency of monitoring is planned for a number of years.

Groundwater samples were collected in July 2002 and May 2003 to measure electrical conductivity.

2.2.6 Surveying

Locations (Eastings and Northings) of groundwater monitoring sites were measured with a global positioning system. The global positioning system receiver was placed on the bore tube top and position information was recorded continuously over a period of a few minutes to reduce the estimated position error. Positions are reported in the Australian Geodetic Datum of 1994 (GDA94).

Elevations of groundwater monitoring sites are reported as datum heights. Height values are calculated from a digital elevation model derived from The Land Monitor Project.

Bore location and elevation details are listed in Table 2.3.

Table 2.3. Drill site location and bore construction details. Groundwater depth and estimated yield were measured in July 2002. Groundwater electrical conductivity was measured in May 2003

Bore ID	Transect number	Location (GDA94)		Site elevation	Depth drilled	Screen interval below ground	Groundwater depth below	Electrical conductivity	Est. yield by airlift
		Easting	Northing	(m)	(m)	(m)	surface (m)	(mS/m)	(m^3/day)
02BMC01D	1	417182	6684703	290	24	23.09 - 21.09	21.54	164	no flow
02BMC02D	1	417196	6685142	272	22.5	21.88 - 19.88	5.79	600	0.4
02BMC02OB	1				6.5	6.42 - 2.42	4.31	150	0.1
02BMC03D	1	416945	6685948	255	11.6	11.59 - 9.59	1.51	13,600	4.8
02BMC03OB	1				6	5.78 - 1.78	1.35	4000	29
02BMC04D		415945	6687950	263	14	13.11 - 11.11	4.94	2700	1.9
02BMC04OB					6	5.93 - 1.93	5.10	2900	no flow
02BMC05D	1	416926	6688328	265	16	15.42 - 13.42	7.76	3330	2.4
02BMC06OB	1	416943	6688991	272	3	2.90 - 0.90	Dry	-	-
02BMC07D	1	416959	6687461	257	35	34.01 - 32.01	3.10	14,800	17
02BMC07I	1				17.5	17.57 - 15.57	2.52	11,740	2.9
02BMC07OB	1				6	5.55 - 1.55	2.21	3020	7.2
02BMC08D	2	425105	6680895	291	6	5.36 - 3.36	3.02	1882	no flow
02BMC09D	2	425065	6679177	271	9	8.32 - 6.32	3.68	1183	no flow
02BMC09OB	2				6.2	5.98 - 1.98	4.00	69	no flow
02BMC10D	2 + 3	425073	6677957	273	9	7.44 - 5.44	3.29	1650	12
02BMC10I	2 + 3				8	7.45 - 5.45	3.29	1670	14
02BMC10OB	2 + 3				6	5.65 - 1.65	3.31	1700	no flow
02BMC11D	2	424769	6677620	274	28	27.16 - 25.16	1.65	2060	0.6
02BMC11I	2				13	13.15 - 11.15	1.90	439	0.7
02BMC12D	2	424774	6676615	300	16	14.97 - 12.97	7.48	1267	0.2
02BMC13D	3	423696	6677860	279	11	10.05 - 8.05	5.85	1165	0.1
02BMC14D	3	422882	6677829	267	15	13.65 - 11.65	1.21	11,230	0.1
02BMC14OB	3				6	5.75 - 1.75	1.35	1071	1.8
02BMC15OB	3	420612	6678060	269	6	5.60 - 1.60	2.54	1368	1.1
02BMC16D	3	419340	6677771	279	18	17.43 - 15.43	4.14	350	4.8
02BMC16OB	3				8	5.64 - 1.64	3.71	592	no flow
02BMC17D	3	417933	6676793	319	20	19.39 - 17.39	7.99	1170	4.4
02BMC17OB	3				6	5.60 - 1.60	Dry	-	-
02BMC18OB	3	421117	6677257	269	4	2.56 - 0.56	1.20	1158	no flow
02BMC19D	3	426094	6677943	276	10	8.92 - 6.92	2.09	286	8.2
02BMC19OB	3				3	2.59 - 0.59	Dry	-	-
02BMC20D	3	427340	6677615	293	32	31.56 - 29.56	4.52	927	3.8
02BMC20OB	3				6	5.64 - 1.64	4.38	444	no flow
02BMC21D	3	428891	6677851	312	18	16.82 - 14.82	8.04	3240	3.2
02BMC22D	3	430130	6678213	307	32	29.97 - 27.97	13.80	797	29
02BMC22OB	3				6	5.51 - 1.51	Dry	-	-
02BMC23D	3	431009	6678434	287	27	26.27 - 24.27	1.38	751	69
02BMC23OB	3				6	5.75 - 1.75	1.33	501	0.5
02BMC24D	3	432807	6678985	283	29	28.36 - 26.36	0.43	8630	4.4
02BMC24OB	3				6	5.60 - 1.60	1.56	8390	3.6
02BMC25D	4	436577	6688281	345	40	39.49 - 37.49	21.70	730	1.4
02BMC25OB	4				6	5.34 - 1.34	Dry	-	-
02BMC26D	4	436733	6687777	337	41	40.48 - 38.48	14.95	1106	3.4
02BMC26OB	4				6	5.39 - 1.39	5.22	-	no flow
02BMC27D	4	436829	6686918	317	19	18.07 - 16.07	2.55	920	58
02BMC27OB	4				6	5.52 - 1.52	2.66	872	no flow
02BMC28D	4	436956	6686027	306	16	15.15 - 13.15	2.13	872	38
02BMC28OB	4				6	5.45 - 1.45	Dry	238	-

Table 2.3 (Continued)

Bore ID	Transect number	Location (GDA94)		Site elevation	Depth drilled	Screen interval below ground	Groundwater depth below	Electrical conductivity	Est. yield by airlift
		Easting	Northing	(m)	(m)	(m)	surface (m)	(mS/m)	(m^3/day)
02BMC29D	5	429028	6671140	301	30	29.75 - 27.75	9.57	3610	12
02BMC30D	5	429047	6669795	285	26	25.24 - 23.24	3.21	11,140	0.2
02BMC30OB	5				6	4.83 - 0.83	Dry	-	-
02BMC31D	5	429103	6660347	327	5	4.56 - 2.56	Dry	-	-
02BMC32D	5	429098	6660945	315	7.35	7.10 - 5.10	Dry	-	-
02BMC32OB	5				5.6	5.35 - 1.35	Dry	-	-
02BMC33D	5	429094	6661520	301	27	26.33 - 24.33	0.47	4400	0.4
02BMC33OB	5				6	5.63 - 1.63	0.90	672	0.2
02BMC34D	5	429094	6662158	307	12	11.70 - 9.70	8.51	858	0.1
02BMC34OB	5				6.5	5.35 - 1.35	Dry	-	-
02BMC35D	5	429087	6663045	297	48.2	47.50 - 45.50	8.89	860	12
02BMC36OB	5	429125	6663886	283	18	5.76 - 1.76	1.77	973	no flow
02BMC37D	5	429074	6665063	285	28	27.05 - 25.05	6.85	16,480	1.4
02BMC37OB	5				6	5.46 - 1.46	Dry	-	-
02BMC38D	5	429071	6665382	280	20	19.19 - 17.19	1.73	16,780	6.1
02BMC38OB	5				6	4.61 - 0.61	1.77	926	0.5
02BMC39D	5	429065	6666105	293	40	34.61 - 32.61	14.42	18,130	3.8
02BMC39OB	5				7	5.95 - 1.95	Dry	-	-
02BMC40D	5	429062	6666498	280	44	40.87 - 38.87	4.07	20,800	2.9
02BMC40OB	5				6	5.96 - 1.96	2.27	2550	5.2
02BMC41D	5	429013	6668617	281	27	25.71 - 23.71	3.05	20,200	58
02BMC41OB	5				6	5.42 - 1.42	Dry	6420	-
02BMC42D	6	447675	6663665	319	19	17.95 - 15.95	13.23	234	1.8
02BMC42OB	6				7	5.88 - 1.88	Dry	-	-
02BMC43I	6	446942	6664841	295	12	10.55 - 8.55	7.67	2270	0.1
02BMC43OB	6				6	5.45 - 1.45	Dry	-	-
02BMC44D	6	446928	6665856	288	40.6	39.09 - 37.09	2.34	19,550	58
02BMC44OB	6				6	5.65 - 1.65	3.17	12,920	no flow
02BMC45D	6	446329	6669423	307	6	2.99 - 0.99	Dry	-	-
02BMC46D	6	446438	6667329	288	27	21.28 - 19.28	3.16	18,130	0.1
02BMC46OB	6				7	5.94 - 1.94	3.08	7930	0.2
02BMC47OB	6	447167	6668634	305	34	6.02 - 2.02	Dry	-	-
02BMC48OB	7	458371	6687820	312	9	5.99 - 1.99	0.66	4630	69
02BMC49D	7	458327	6688310	316	26	24.99 - 22.99	3.03	3840	58
02BMC49OB	7				7	6.03 - 2.03	3.70	1890	no flow
02BMC50D	7	459006	6686749	323	11	9.40 - 7.40	6.41	1781	no flow
02BMC50OB	7				7	6.05 - 2.05	Dry	-	-
02BMC51D	7	459881	6685365	352	29	28.15 - 26.15	Dry	-	-
02BMC51OB	7				7	5.83 - 1.83	Dry	-	-
02BMC52D	7	458774	6686750	319	20	19.34 - 17.34	8.69	1163	3.6

2.3 Results

2.3.1 Profile descriptions

Typically, regolith profiles consisted of a few metres of colluvium overlying around 20 m of gritty clay saprolite, a metre or so of saprolite grits, then competent crystalline basement. The crystalline basement was mostly granitic, however, doleritic basement was intersected in a number of drill holes.

Another typical feature of the profiles is zones of siliceous induration (silcrete). Indurated silcrete typically marked the transition from colluvial material to insitu derived saprolite. At many sites the silcrete was extremely hard which caused drilling to be abandoned at eight sites.

Deep sequences of alluvial sediments were intersected at four sites (BMC33, BMC39 and BMC40 on Transect 5 and BMC44 on Transect 6). The depth of alluvial sediments ranged from 17 m at site BMC33 to 38 m at site BMC44.

Detailed drill logs are presented in Appendix 1 and depth drilled at each site is also listed in Table 2.3.

Figures 2.7 to 2.13 show cross-sections constructed from the seven drill transects. The sections present conceptual models of the profile based on drilling results.

2.3.2 Groundwater data

2.3.2.1 Groundwater levels

The initial measurements of depth to groundwater were taken in July 2002 and are listed in Table 2.3 and recorded on the individual drill logs presented in Appendix 1. The groundwater levels shown on the seven cross-sections (Figures 2.7 to 2.13) were recorded from 22 to 23 May 2003.

In general, the surface of the watertable is a subdued reflection of the topographic surface.

2.3.2.2 Groundwater electrical conductivity

Electrical conductivity of groundwater samples recovered from bores was measured in July 2002 and again in May 2003. The May 2003 data is listed in Table 2.3, recorded on the individual drill logs presented in Appendix 1 and labelled next to the intake sections of observation bores and piezometers in Figures 2.7 to 2.13. The only apparent anomaly this reporting creates is for observation bore 02BMC41OB which was initially dry in July 2002 but subsequently intersected saline (6420 mS/m) groundwater.

There is extreme variability in measured groundwater electrical conductivity values. The freshest groundwater measured 69 millisiemens per metre (mS/m) (~ 380 milligrams per litre). The most saline groundwater measured was 20,800 mS/m (~115,000 milligrams per litre).

2.4 Interpretation and discussion of results

This section firstly presents the seven drill transects individually and then a summary of the transects in relation to the aims of the Recovery Catchment drilling investigation. Some observations and explanations are provided about the cross-sections within each individual section.

2.4.1 Transect 1

Transect 1 begins on the northwest Recovery Catchment boundary and extends northward outside the project area (see Appendix 2). The transect crosses the main drainage line below its junction with another major drainage system that extends from the Bunjil-Latham area to the northeast.

The cross-section (Figure 2.7) shows deep yellow sands in the upland area to the south of the main drainage line. The deep yellow sand overlies gritty clay saprolite. A perched watertable occurs at the base of the sand on the underlying clays. A strongly cemented, thick silcrete layer indicates a long history (i.e. geological) of either an ephemeral or perennial zone of saturation on this transitional boundary.

The cross-section shows two seepage zones on this southern hill-slope. The upper seep occurs where the perched watertable intersects the ground surface. It exhibits the characteristics of a hillside seepage area where low salinity groundwater is discharged (i.e. thickly vegetated with *Juncus* species) and is accessed as a water supply.

The lower seep is more saline and typical of ‘break of slope discharge’ (Coram 1998) from the intermediate groundwater system that extends throughout the catchment regolith.

Drilling did not intersect any deep sequence of alluvial channel sediments. However, no drilling was undertaken within the saline braided drainage system where alluvial channel sediments are most likely to occur. Additionally, there is more than 1500 m distance between sites BMC3 and BMC7 located on either side of the valley floor where there is greatest chance of locating a paleo-channel.

Competent crystalline basement topography broadly reflects surface topography so the thickest section of groundwater in this cross-section coincides with the valley floor. The basal groundwater in the valley floor is very saline with electrical conductivity in excess of twice seawater.

2.4.2 Transect 2

Transect 2 crosses a minor saline tributary in the northwestern part of the Recovery Catchment (see Appendix 2). It extends north along Vanzetti Road to Buntine-Marchagee Road then further north along Mamboobie Road.

The cross-section (Figure 2.8) shows a relatively simple profile. Basement topography broadly reflects surface topography and the watertable is a subdued reflection of the topographic surface.

Groundwater at depth beneath the valley floor is saline. However, it is much less saline than basal groundwater intersected by transects crossing the main drainage line.

2.4.3 Transect 3

Transect 3 extends eastward in proximity to the Buntine-Marchagee Road in the northwestern part of the Recovery Catchment (see Appendix 2). It crosses Transect 2 at site BMC10.

This transect crosses three drainage systems. In the west it crosses the main drainage line and groundwater salinity at depth in this vicinity exceeds 11,000 mS/m. It then crosses a minor tributary in the middle section where groundwater salinity is less than 2000 mS/m. Finally it crosses a major tributary at its eastern extent where groundwater salinity in the valley floor exceeds 8000 mS/m.

The cross-section (Figure 2.9) shows basement topography reflects surface topography. However, where the transect crosses the main drainage line very hard silcrete and difficult regolith profiles caused drilling to be terminated before reaching basement. Hence basement topography in this area is unknown.

The watertable is a subdued reflection of the topographic surface.

The western flank of Transect 3 has sandy textured soils with high recharge potential. If there is watertable rise then the break of slope area from BMC16 to BMC15 has high salinity risk.

2.4.4 Transect 4

Transect 4 extends from a minor drainage line (upper tributary) to the catchment divide in about the middle of the northern catchment boundary of the project area (see Appendix 2). This transect was sited primarily to provide an input profile for Flowtube modeling.

The cross-section (Figure 2.10) shows a relatively simple hill-slope profile where the watertable is a subdued reflection of surface topography. An ephemeral perched watertable has been observed at site BMC26 where 5 m of yellow sands overlie pallid gritty clay saprolite.

Groundwater is moderately saline with only one piezometer (02BMC26D) intersecting groundwater with an electrical conductivity exceeding 1000 mS/m.

Of note is that the regolith and saturated thickness becomes thinner downslope in this cross-section. If the watertable rises this wedging effect will cause groundwater discharge in the valley floor and lower slope area.

2.4.5 Tranect 5

Transect 5 extends northward along Mason Road to the Gunyidi-Wubin Road then further north along Thomas Road in the southwest of the project area (see Appendix 2). The transect crosses a northeastward draining tributary before crossing the main drainage line over the third largest lake in the Recovery Catchment.

The cross-section for Transect 5 (Figure 2.11) indicates two separate alluvial sequences were intersected. At site BMC33, 17 m of alluvial sediments overlie gritty clay saprolite. This sequence prompts speculation of a paleochannel that might have connected the prior main drainage line to a low lying area to the south-west of site BMC33. The paleochannel may have been stranded by tectonic uplift.

The other sequence of alluvial sediments was intersected at sites BMC39 and BMC40 on the southern edge of the main drainage line. It is conceivable that the alluvial sequence is more extensive beneath the main drainage line than indicated on the cross-section. The interpolated saprolite horizon beneath the salt lake is constrained by the regolith profile intersected at site BMC41.

The two hills on the southern edge of the main drainage line (site BMC39 and between sites BMC37 and BMC36) are composed of yellow sand. It is possible they are lunette type features formed from sands blowing off the lakes although they don't exhibit classical crescent shaping.

The basal groundwater beneath the main drainage line is hyper-saline. Electrical conductivity of groundwater samples recovered from piezometers range from 16,480 mS/m to 20,800 mS/m. Density corrections are required to establish true piezometric pressure gradients.

The cross-section for Transect 5 provides a reasonable conceptual profile through the catchment at the scale of this investigation. However, it may over-simplify some more complex groundwater systems and complex groundwater/surface water interactions.

2.4.6 Transect 6

Transect 6 crosses a significant salt lake in the main drainage line below the junction of two major branches in the southeastern part of the project area (see Appendix 2).

The cross-section (Figure 2.12) shows basement topography reflects surface topography. Hole collapse prevented bore installation at site BMC47 however the watertable across the profile is probably a subdued reflection of surface topography in this area.

A deep sequence of alluvial sediments was intersected at site BMC44 with only a thin (2 m) saprolite zone over crystalline basement. The cross-section indicates erosion of the saprolite profile in the main drainage line almost to depth of basement rock. This paleo-channel has been infilled with alluvial sediments. The hole was reported to have made copious amounts of water during drilling. The moderate estimated yield by airlift reported in Table 2.3 and on the drill log in Appendix 1 reflects the position of the screened interval of piezometer 02BMC44D. An intermediate piezometer or production bore screened within more conductive alluvial channel sediments would be expected to have a much higher yield.

The valley floor piezometers on Transect 6 intersect hyper-saline groundwater beneath the main drainage line.

2.4.7 Transect 7

Transect 7 is located in the northeastern area of the Recovery Catchment (see Appendix 2). It extends north from the crest of a discrete hill across the main drainage line in an upper catchment location.

The cross-section (Figure 2.13) shows a relatively simple profile. This transect crosses the drainage line more than 3 kilometres above the formation of lake features in the valley floor. There is no evidence of any significant alluvial channel development within the drainage line and the cross-section shows the regolith profile is dominated by saprolite.

A curious feature in this profile is the dry piezometer (02BMC51D) under the hill. This piezometer is about 350 m north of the largest tract of native remnant vegetation in the catchment, which invites speculation about the impact the vegetation may be having on groundwater.

2.4.8 Transect summary

The cross-sections demonstrate an extensive monitoring network that measures localised perched and intermediate groundwater systems that extend throughout the catchment regolith. Sites are installed in every landscape position. In lower landscape positions the watertable is generally shallow (< 5 m). However, the network demonstrates that both shallow (< 5 m) and deep (> 20 m) groundwater exists in upper landscape positions.

A range of saturated regolith material is monitored. In upper landscape positions this includes sandplain material as well as underlying saprolite. In valley floors, both alluvial channel sediments and saprolite systems have groundwater monitoring sites.

The cross-sections characterise significant differences between transects across the main drainage line and tributaries. There is evidence in the main drainage line profile of deep (up to 38 m) sequences of alluvial (paleo) channel sediments. Basal groundwater within the main drainage line is hyper-saline where-as groundwater in tributaries is generally less than 2000 mS/m.

The drilling program aimed to provide two-dimensional conceptual profiles through the landscape. It was anticipated that some of the transects would provide the basis for developing Flowtube models. A number of cross-sections appear suitable for modelling, in particular Transects 1, 2 and 4. The southern two thirds of Transect 6 may also be suitable and modelling Transect 7 may also be instructive.

Two areas are identified that have high risk of becoming saline. One is the break of slope area on the western part of Transect 3 in the vicinity of sites BMC16 and BMC15. The other is the valley floor below site BMC28 and lower slope area below site BMC27 on Transect 4.

These areas have been identified as high risk because of changes in gradient below areas of deep sands. These two indicators could be used in a preliminary way to define other areas at risk within the Recovery Catchment.

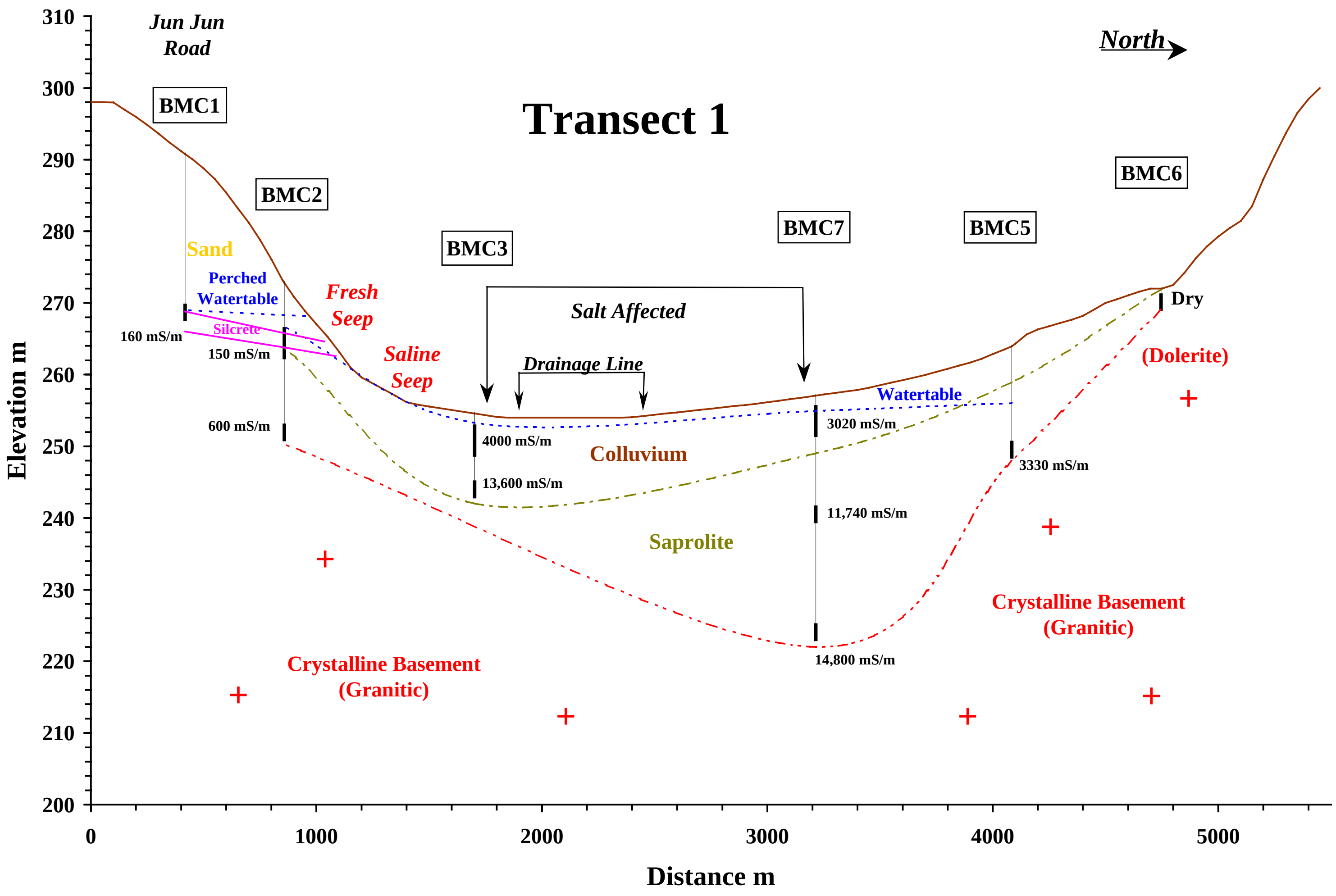

Figure 2.7 Cross-section along drill Transect 1.

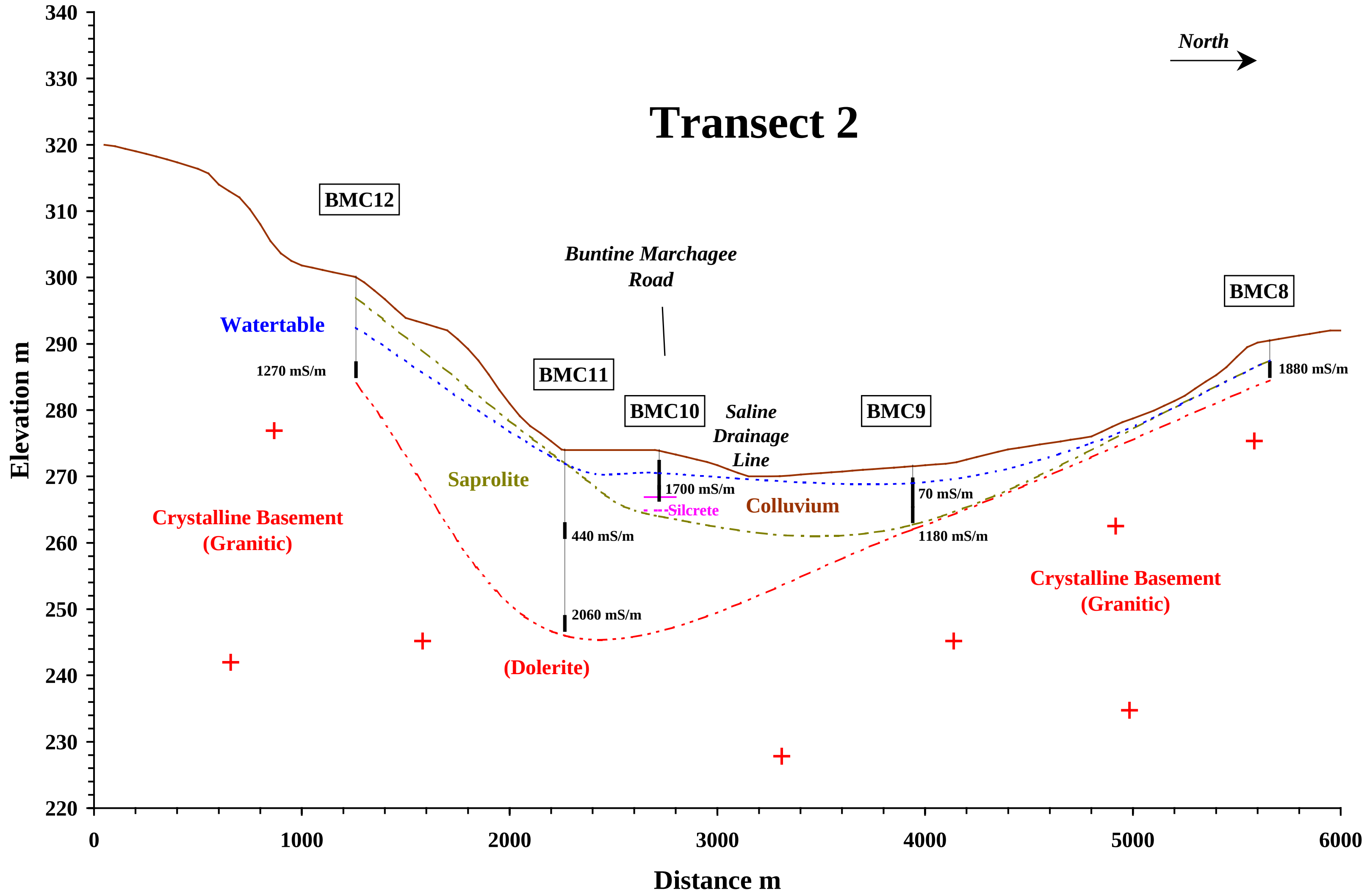

Figure 2.8 Cross-section along drill Transect 2.

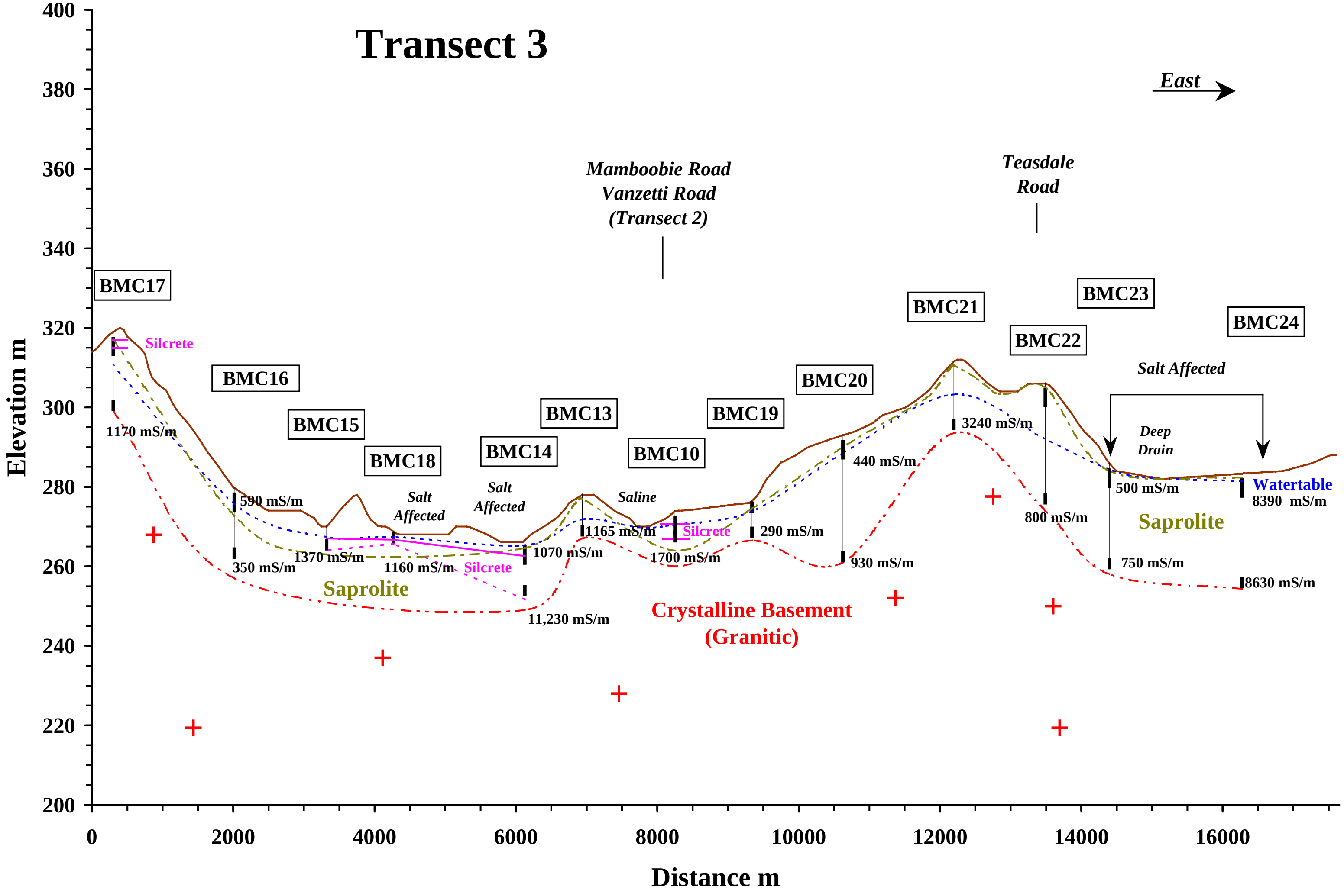

Figure 2.9 Cross-section along drill Transect 3.

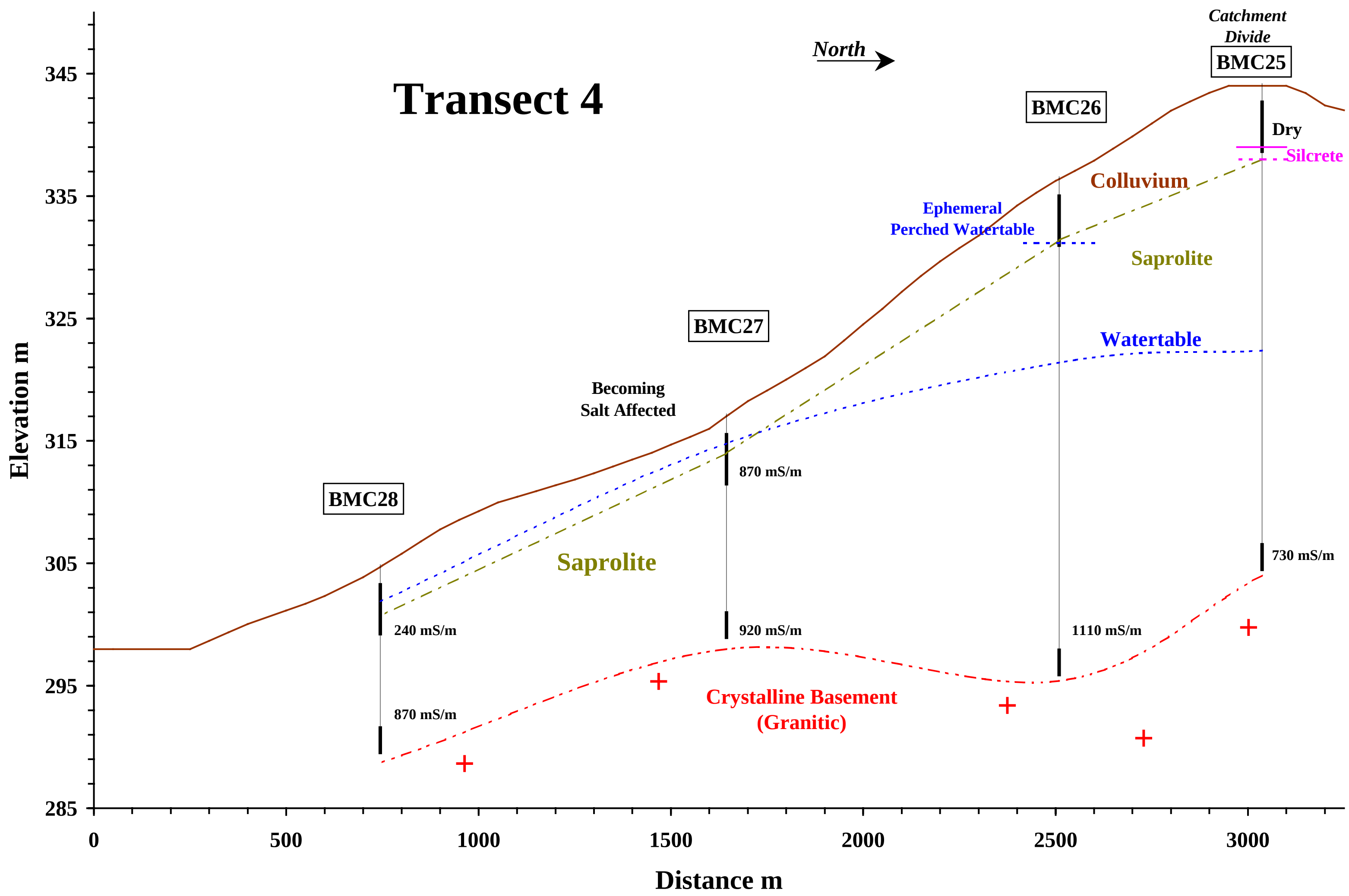

Figure 2.10 Cross-section along drill Transect 4.

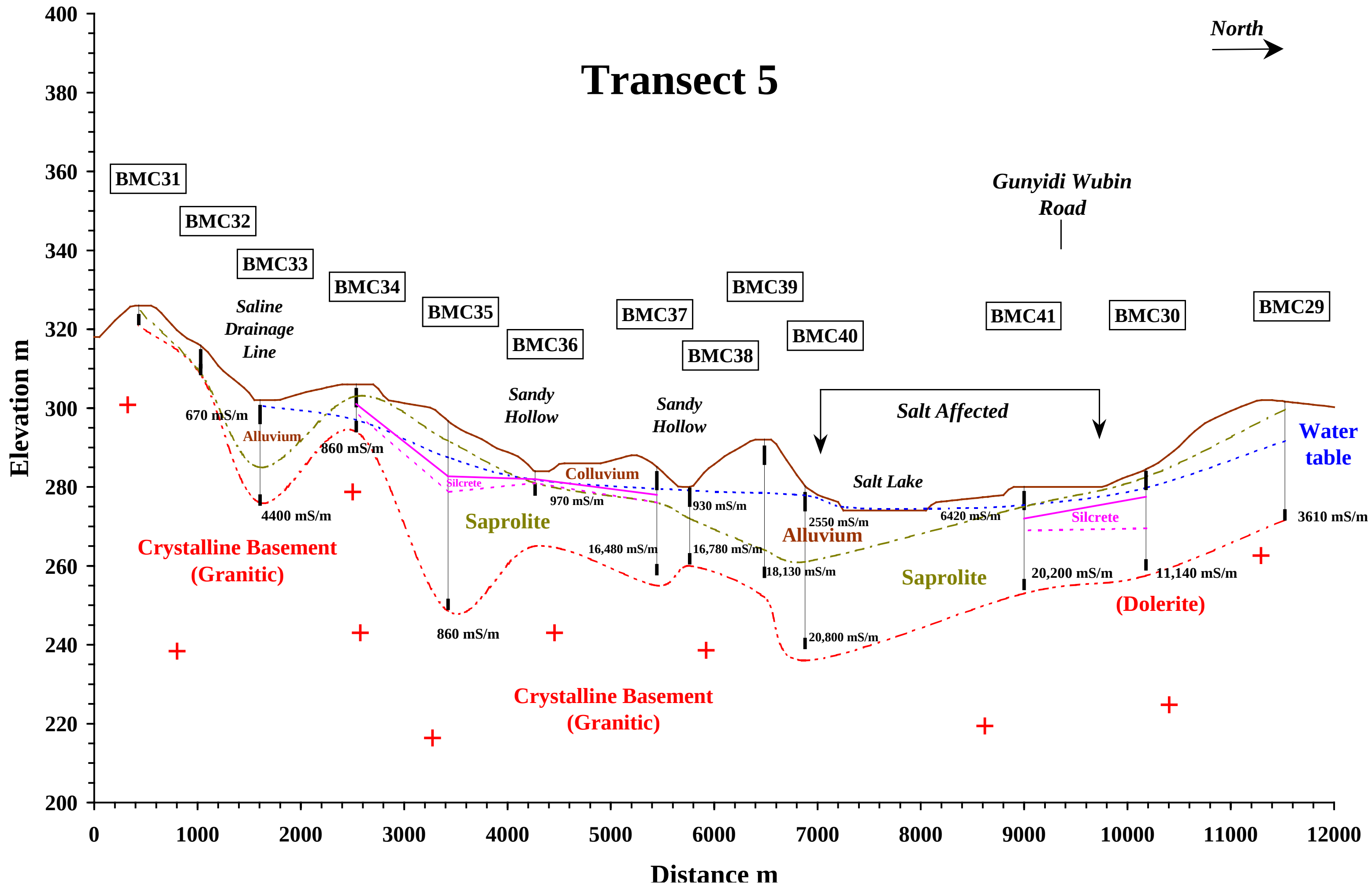

Figure 2.11 Cross-section along drill Transect 5.

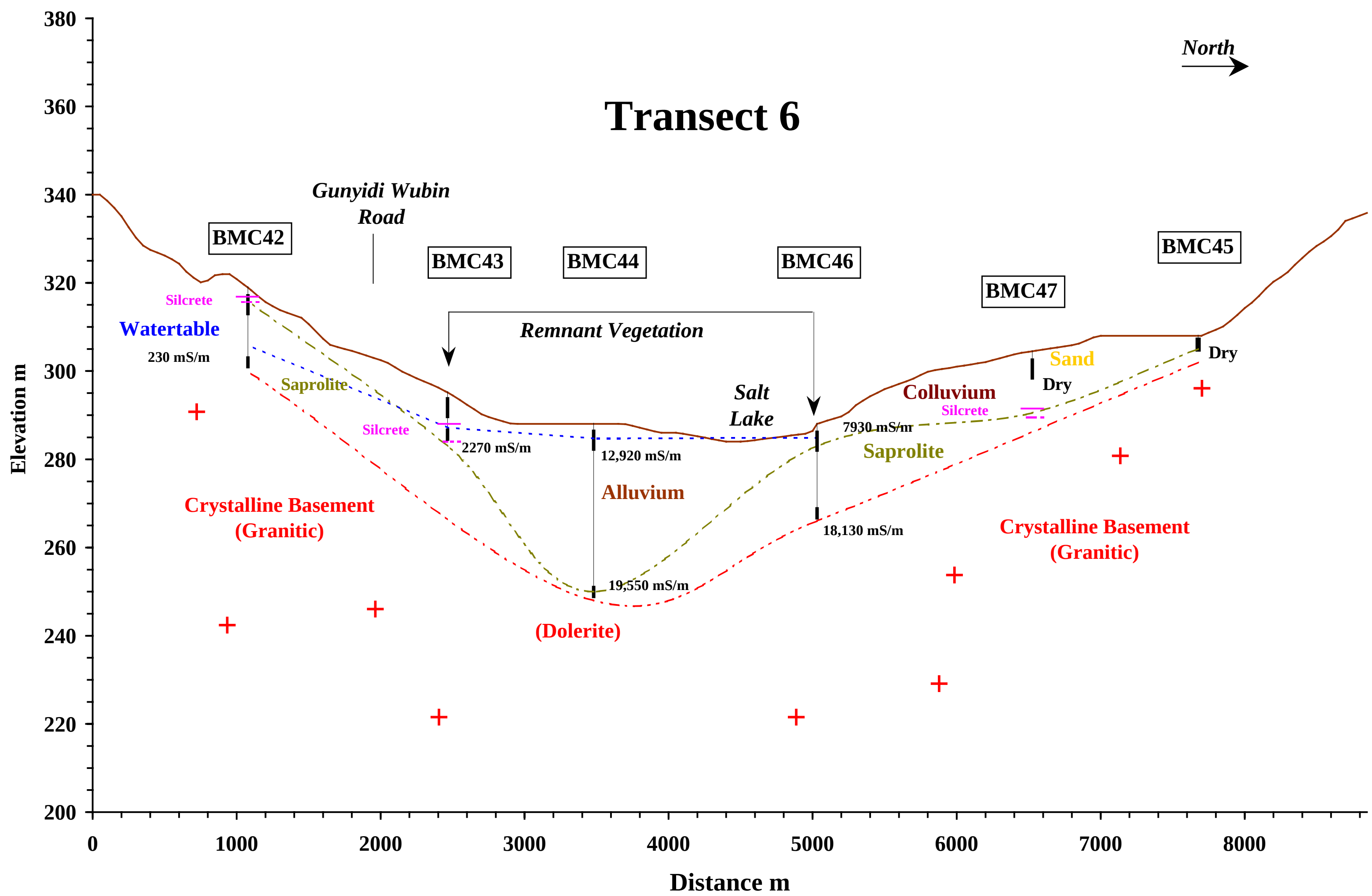

Figure 2.12 Cross-section along drill Transect 6.

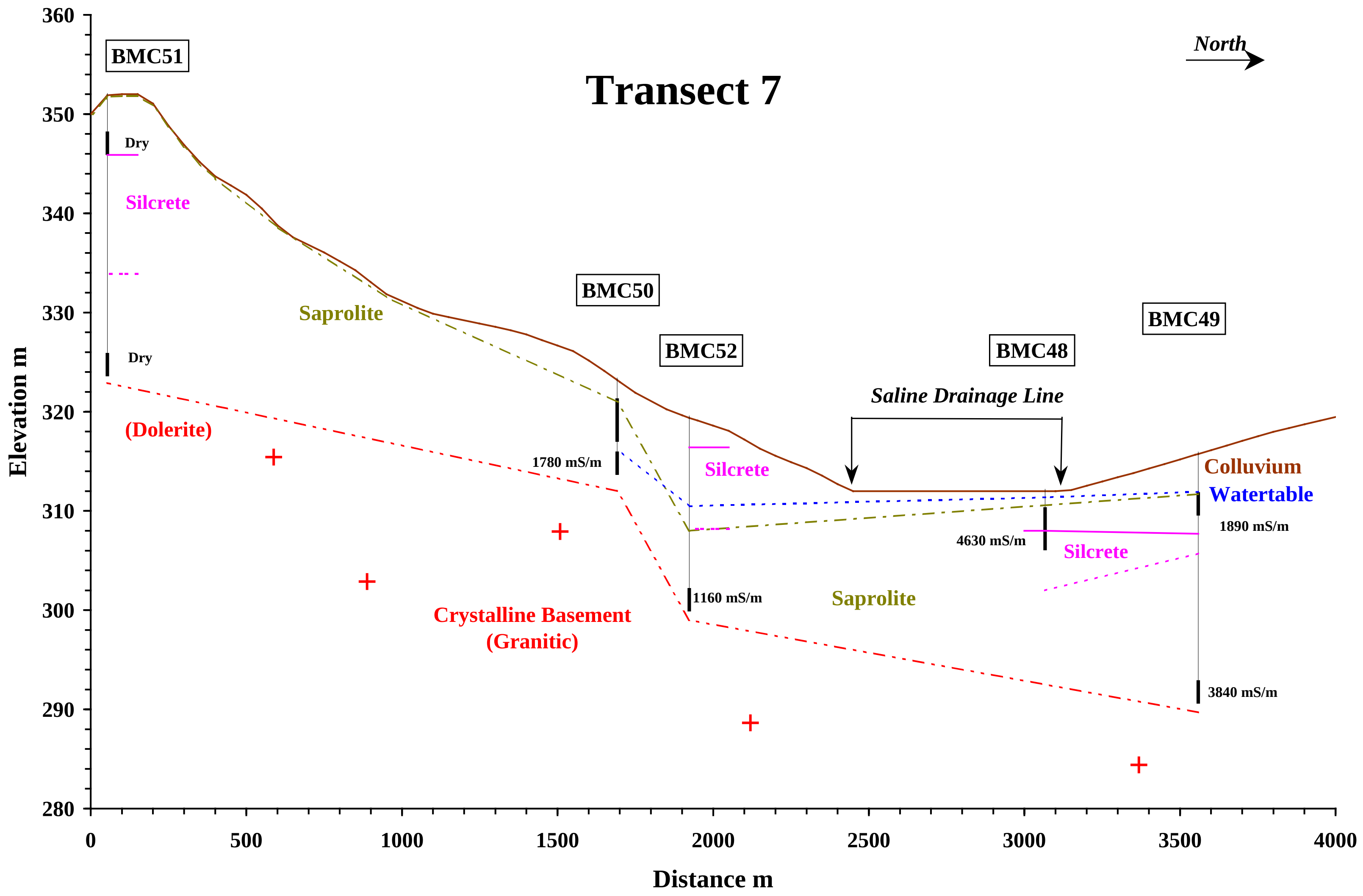

Figure 2.13 Cross-section along drill Transect 7.

2.5 Conclusions

There is evidence of alluvial (paleo) channel sequences in the main drainage line where lake features characterise the surface. The profile at one site (BMC33) indicates paleo-channels may occur elsewhere in the catchment. These features may have implications for future strategic groundwater management. Paleo-channels can be highly transmissive, well connected aquifers allowing the possibility of groundwater pumping as a management tool.

Basal groundwater in the main drainage line is hyper-saline. The Buntine-Marchagee Recovery Catchment has behaved as a sump for salt accumulation akin to the extensive paleo-drainage system that terminates in the Yarra Yarra Lakes some 40 kilometres northwest of the Recovery Catchment.

Hundreds of surface lakes in the main drainage line complete the impression of a long history of catchment development by hydrological processes. The Recovery Catchment exhibits a geological history of alluvial processes. This contrasts with the majority of wheatbelt catchments where the valley floor is simply the relative low in a gently undulating granite terrain.

Highly saline environments would have been a primary feature in the Recovery Catchment. The greatest impact resulting from clearing native vegetation for agriculture may not be exposing remnant ecosystems to hugely different amounts of salt. The change causing greatest impact may be the amount of water stored in the catchment as groundwater and particularly beneath the sloping land. Increased recharge and groundwater storage on the valley flanks has and may continue to increase the amount of groundwater discharge occurring by evaporation through the valley floors.

What may have been an ephemerally arid, or intermittently wet, saline environment may now be a perpetually wet or moist saline environment.

The hydrologic changes caused by clearing in the majority of wheatbelt catchments brings both excess salt and excess water in close proximity to the land surface with typically catastrophic results. The Recovery Catchment wetland ecosystems may be partially tolerant to the changes caused by clearing in that there was pre-existing adaptation to highly saline conditions. The major additional stress is excess water. This resilience may explain why hydrological changes caused by clearing have been as yet less catastrophic in the Recovery Catchment than neighbouring catchments and why there are still remnant ecosystems worthy of preservation.

The data presented in this report shows current groundwater conditions. Further salinity development and risk can be assessed to some extent using groundwater models such as Flowtube. However, validation of these models and robust risk analysis can only be undertaken after a prolonged period of monitoring over many years.

3. RECOMMENDATIONS

3.1 Monitoring

Installation of the groundwater monitoring network has provided an important snapshot of the catchment that is documented and described in this report. However, knowledge of the changes that are occurring and their rates is crucial for future management. Transient responses to seasonal conditions require separation from underlying trends. This requires a long period of time (~ years), persistence and resourcing.

The fundamental parameters to measure are groundwater levels, groundwater quality (salinity and acidity) and rainfall. Each of these are optimally monitored at different frequencies. Ideally, groundwater levels should be recorded on a monthly basis for a decade with extra monitoring in response to significant rainfall events such as those caused by a decaying cyclone. Groundwater quality generally changes very slowly over time and annual monitoring is adequate. Rainfall should be recorded at least daily but preferably continuously logged with a tipping bucket rain gauge to give some indication of rainfall intensity in addition to quantity.

Recommendation 1: Groundwater levels should be monitored on a regular basis (monthly interval) for at least a further five years.

Recommendation 2: Groundwater quality (electrical conductivity and acidity) should be measured annually (late summer/early autumn) for at least a further five years.

Recommendation 3: Tipping bucket rain gauges (2) should be installed in the western and eastern limits of the Recovery Catchment.

3.2 Future drilling

The aim of the drilling investigation was to establish a regional groundwater monitoring network throughout the catchment. This has been achieved.

However, it needs to be emphasised that the network is regional and extrapolations made between drill sites along transects are conceptual. The cross-sections illustrate groundwater processes at a catchment or regional scale. They do not capture detailed groundwater processes. For example, they are not adequate to describe the dynamics of groundwater-surface water interactions in the lake systems, or prescribe salinity management advice at a paddock scale or indeed, monitor the impact of management at a paddock scale.

Future drilling programs will be required to provide detailed understanding of how groundwater systems interact with remnant ecosystems and monitor the performance of intervention to preserve threatened species. However, identifying and prioritising threatened ecosystems is the role of ecologists, not hydrologists.

Recommendation 4: A regional groundwater monitoring network has been successfully installed and no further drilling is required in support of this aim.

Recommendation 5: The regional groundwater monitoring network is not suitable and should not be used to describe detailed groundwater processes at paddock to sub-paddock scales.

Recommendation 6: The location of future drilling programs aimed at providing detailed understanding of groundwater processes should be determined by ecologists based on nature conservation priorities.

3.3 Modeling

A secondary aim of the drilling investigation was to install at least one transect of bores suitable for developing a Flowtube model to test 'What if' scenarios. This has been achieved and three transects in particular (Transects 1, 2 and 4) appear suitable as inputs to Flowtube models.

Flowtube models are ideal for interactive extension of the model, results and input of 'What if' scenarios at workshops with landholder participation.

Recommendation 7: Flowtube models should be built for all suitable transects or parts of transects that are suitable.

Recommendation 8: At least one half day workshop should be conducted with landholders and the community to extend the results of the Flowtube models.

3.4 Further regional groundwater investigations

It may be identified in the future that catchment scale features such as paleo-channels require better definition or mapping, or even prospecting for their existence. A drilling rig can provide much precise information but samples an extremely small area (~ < 0.012 m^2) at considerable cost. As a mapping or prospecting tool, it can be considered extremely inefficient.

Airborne or ground geophysical surveys combined with targeted drilling programs have proven to be a very efficient method of mapping regolith features including paleo-channels.

Recommendation 9: If a need is identified for further regional groundwater investigations or regolith mapping, then any drilling program should be preceded by a geophysical survey to delineate target features.

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5. GLOSSARY

alluvium	Unconsolidated terrestrial sediment that has been deposited by water.
Archean	Geological age used to describe rocks older than 2500 million years.
basal	Pertaining to or forming the base.
biogeographical zone	A region identified by its dominant flora and fauna.
braided stream	A drainage line so choked with sediment that it divides and recombines continuously forming many small and meandering channels.
colluvium	General term applied to loose and incoherent deposits where the mode of transportation is uncertain.
crystalline basement	Solid impervious rock consisting of minerals in a crystalline state.
dolerite	Fine grained mafic igneous rock rich in iron and magnesium that occurs as intruded vertical dykes throughout the Yilgarn Craton.
dyke	A planar body of intrusive rock that cuts through the surrounding rock.
geophysics	The study of the earth by quantitative physical methods.
granite	A coarse grained intrusive igneous rock composed of quartz, feldspar and micas.
groundwater	Water within the saturated zone below the ground.
groundwater discharge	Discharge of water from the saturated zone into surface water bodies or upon the land. The area of salinity coincides with the area of groundwater discharge.
hydraulic conductivity	A measure of the ability of a material to transmit fluid.
hydrograph	A graph showing water level plotted against time.
indurated	Rendered hard through cementation.
insitu	In its original place.
laterite	An ancient heavily weathered and leached soil.
lunette	A crescent shaped dune formed around intermittent lakes by wind (aeolian) deposition.
mafic	Dark coloured.

observation bore	A shallow bore with slotted intake section across the saturated interface that provides a direct measurement of actual depth to the watertable.
paleo	Use to denote ancient or pre-existing.
pallid	White or pale.
perched watertable	A zone of saturation retained in an elevated position by a layer with low permeability that is underlain by an unsaturated zone above the (catchment) watertable.
piezometer	A bore that has a discrete slotted intake section at its base and is sealed above the intake to measure groundwater pressure at the depth of the intake section. It must be emphasised that the point of measurement in a piezometer is at its base, not at the level of water in the casing.
primary salinity	Salinity that existed in the Australian landscape prior to European settlement.
recharge	The infiltration of surface water (from rainfall, lakes, rivers etc) through the profile to become groundwater.
regolith	The mantle of solid material lying on top of basement. It includes soil, alluvium, and material weathered insitu from basement.
saprolite	A soft, earthy, clay-rich, thoroughly decomposed regolith formed insitu by chemical weathering of igneous or metamorphic rocks.
secondary salinity	Salinity in the Australian landscape that has expressed as a result of anthropogenic activity.
siemens	A unit of electrical conductivity that is the reciprocal of resistance. The electrical conductivity of water is directly related to its salinity and is reported in the units of millisiemens per metre (mS/m).
siliceous	Of or pertaining to silica either as crystalline quartz or an amorphous cement.
silcrete	A zone rendered hard (indurated) by secondary cementation with amorphous silica.
watertable	The surface of the zone of saturation below the ground.
Yilgarn Craton	A large area of Archean, stable, granitic, continental crust that underlies most of southwest Western Australia.

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