GROUNDWATER INVESTIGATIONS AT FREGON AND MIMILI COMMUNITIES, ANANGU PITJANTJATJARA LANDS, SOUTH AUSTRALIA

DWLBC Report

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Conservation

Groundwater Investigations at Fregon and Mimili Communities, Anangu Pitjantjatjara Lands, South Australia

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Foreword

South Australia's natural resources are fundamental to the economic and social wellbeing of the State. One of the State's most precious natural resources, water is a basic requirement of all living organisms and is one of the essential elements ensuring biological diversity of life at all levels. In pristine or undeveloped situations, the condition of water resources reflects the equilibrium between rainfall, vegetation and other physical parameters. Development of these resources changes the natural balance and may cause degradation. If degradation is small, and the resource retains its utility, the community may assess these changes as being acceptable. However, significant stress will impact on the ability of a resource to continue to meet the needs of users and the environment. Understanding the cause and effect relationship between the various stresses imposed on the natural resources is paramount to developing effective management strategies. Reports of investigations into the availability and quality of water supplies throughout the State aim to build upon the existing knowledge base enabling the community to make informed decisions concerning the future management of the natural resources thus ensuring conservation of biological diversity.

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Department of Water, Land and Biodiversity Conservation

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INTRODUCTION

The Department of Water, Land and Biodiversity Conservation (DWLBC) received a request from the Department of State Aboriginal Affairs (DOSAA) for a program to improve the water supplies at Fregon and Mimili communities in the Anangu Pitjantjatjara Lands. This was in response to an increased water salinity issue at Fregon and an inadequate water supply at Mimili. A costed program, comprising office studies, field studies, geophysical surveys, drilling and pump testing, was provided and accepted by DOSAA in March 2001. Some field inspection work had already been completed in anticipation of this project. Anthropological clearance was received at the end of March and Geophysical surveys completed in early May 2002. Eleven wells were drilled in late May, and pump testing at Mimili completed in June. Pump testing at Fregon was delayed until December 2002 by misunderstandings on anthropological clearances.

The core results of this program are given in the main body of the report. The appendices contain more detailed descriptions of the geophysical results (Appendix 1), the drilling results (Appendix 2), the pump testing (Appendix 3) and the water quality testing (Appendix 4). Appendix 5 contains a general description of the Transient Electromagnetic (TEM) geophysical method.

RESULTS

Fregon

Groundwater in the Fregon area is generally mildly saline (1 200 to 1 600 mg/L TDS) although there has been little problem finding sufficient quantities of such water. Four wells within 2 km of the community provide a generous and sustainable supply. Increasing salinity with time is a further cause of concern. The request was for better quality water (<1 000 mg/L) that could be used for human consumption without beneficiation.

All known groundwater near and to the west of Officer Creek is more saline than the current water supply. On the east side of the creek, two known sources of water fitting the lower salinity criterion were identified within 15 km of Fregon. One, at Mulga Bore some 10 km southeast of Fregon on the Mimili road, comprised four wells producing water of salinity 800-900 mg/L and with yields of 1.3-3.0 L/s. The source of this supply was considered to be an aquifer recharged from local sand dunes to the east of Mulga Bore. It was regarded as being too far from the community.

The second supply is at Double Tank, 12 km to the north of Fregon on the Umuwa road (Figure 1). There was some disagreement between historical records regarding the quality of the water at Double Tank, so a fresh sample was taken which confirmed the good quality of the water (732 mg/L, Appendix 4). The source was considered to be groundwater draining south from Ernabella creek, and there was thought to be a good possibility of similar water between Irintata and Fregon, 4-6 km north of Fregon.

Since the movement of groundwater is partly controlled by basement topography, a TEM survey was done over 5 east-west lines to help select drilling targets (Figure 1). The results are shown and described in Appendix 1. Drilling targets were selected on the basis of greater depth to basement, modified by resistivity levels that were not so low as to indicate saline groundwater.

Anangu Pitjantjatjara Services cut access tracks to the selected drill sites and six water wells were drilled under the supervision of Dave Clarke. Of these wells two, with the best yields, were developed as production wells and two others kept as observation wells (see Appendix 2). The remaining two wells were abandoned. Pump Test results for the two production wells are shown in Appendix 3 and full chemical analyses of the water in Appendix 4.

CONCLUSION

Two new production wells (5344-64 and 5344-65) have been set up, with long-term yields of 3.5 and 3.0 L/s. While the quality of the water (940-1120 mg/L) is not much better than the existing wells (1050-1820 mg/L) the wells will provide additional supply and the quality may not deteriorate as rapidly or as much as has been the case with the current supply.

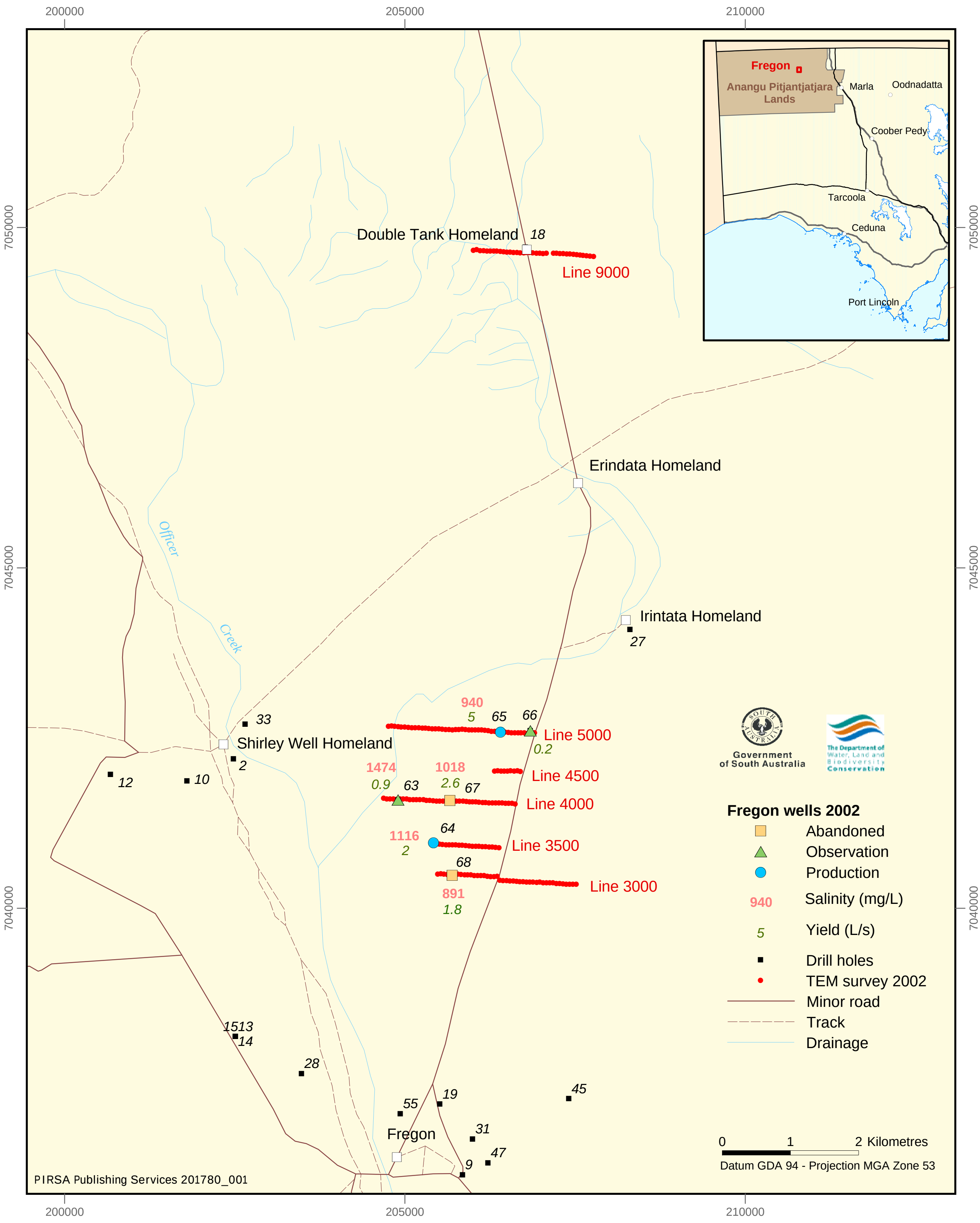


Figure 1 *Well and geophysical survey locations at Fregon, Anangu Pitjantjatjara Land*

Mimili

While the wells at Mimili have yielded sufficient water for normal usage, the quantity is not sufficient for extra demands and difficulty is encountered in replenishing stocks after a period of extra demand. Also, there is no reserve should one of the wells breakdown or an aquifer dry up. Previous attempts to add to the supply have been unsuccessful.

It was decided that the best option was to test areas close to the existing supply wells, but far enough away so as not to interfere with the production of these wells (Figure 2). Drill sites were selected on an earlier visit, but these were revised slightly on the basis of TEM data, which were considered to be worth gathering because the crew and equipment were already in the area.

The TEM data were not very informative, but gave some indication of where near surface resistivity variations occurred (Appendix 1). The data did not fit a layered (inversion) model, so only basic data (apparent resistivities) are given. The usefulness of resistivity data in this environment is limited by the conflicting geological interpretation of salinity and clays.

Five wells were drilled as shown in Appendix 2, three being completed as production wells. Two of these, 5443-59 and 5443-61, were pump tested (0.8 and 1.2 L/s, Appendix 3) and the water fully analysed (1026 and 1149 mg/L TDS, Appendix 4). This effectively doubles the water production capability of Mimili wells, the water being of effectively the same salinity as the existing supply (1050 and 1090 mg/L TDS).

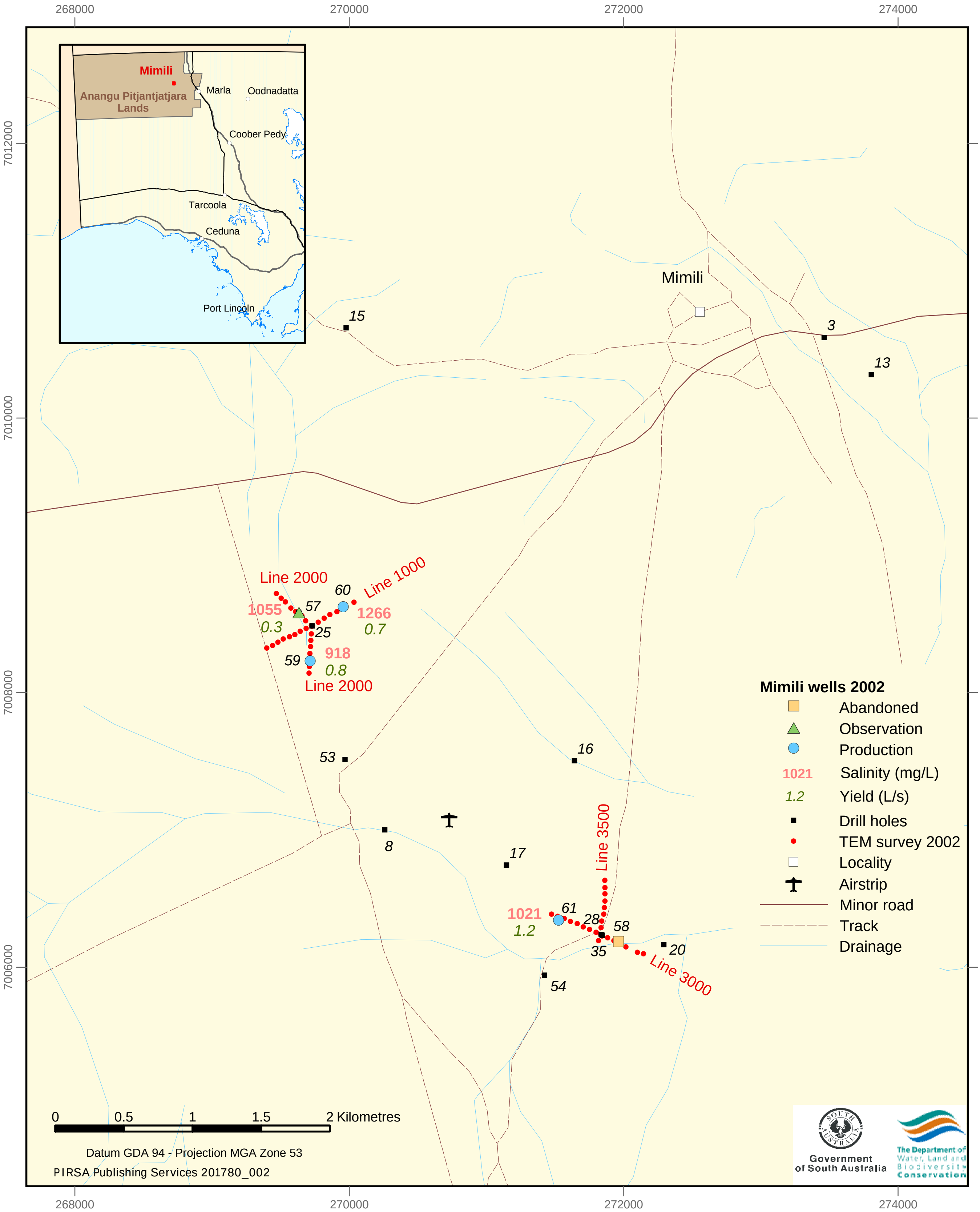


Figure 2 *Well and geophysical survey locations at Mimili, Anangu Pitjantjatjara Lands*

CONCLUSIONS

The Fregon water supply has been increased by two new production wells, but the drilling failed to find the required lower salinity water. Better quality water may be present within 5 km of Fregon, but is difficult to locate.

The Mimili water supply has been doubled by two new production wells, which are within a few hundred metres of existing supplies and should be easy to link in to the distribution network.

SHORTENED FORMS

Name of unit	Symbol	Definition in terms of other metric units	
Millimetre	mm	10^{-3} m	length
Metre	m		length
Kilometre	km	10^{3} m	length
Hectare	ha	10^{4} m^{2}	area
Microlitre	µL	10^{-9} m^{3}	volume
Millilitre	mL	10^{-6} m^{3}	volume
Litre	L	10^{-3} m^{3}	volume
Kilolitre	kL	1 m^{3}	volume
Megalitre	ML	10^{3} m^{3}	volume
Gigalitres	GL	10^{6} m^{3}	volume
Microgram	µg	10^{-6} g	mass
Milligram	mg	10^{-3} g	mass
Gram	g		mass
Kilogram	kg	10^{3} g	Mass

Abbreviations Commonly Used Within Text

Abbreviation		Name	Units of measure
TDS	=	Total Dissolved Solids *(milligrams per litre)*	mg/L
EC	=	Electrical Conductivity *(micro Siemens per centimetre)*	µS/cm
pH	=	Acidity	
TEM	=	Transient Electromagnetic	

APPENDIX 1 TEM Surveys

Introduction

Transient Electromagnetic (TEM) surveys were run at both Fregon and Mimili to assist in the search for groundwater. The background to the use of such methods is given in Appendix 4.

Survey Specifications

A 50 m square loop was used as transmitter and a second identical loop as receiver, the latter being displaced 10 m from the former. This configuration, known as displaced loops, was used to avoid the maghemite effect (see App. 3), which is known to be prevalent in the Musgrave Block area. Readings were taken at 50 m intervals along each survey line. The instrument was a SIROTEM Mark 3, using the HIRES set of windows to get maximum information on ground resistivity variations in the near surface (top 70 m). Two gain settings (x0.1 and x10) were used at each station to optimise the data quality.

Data Processing

All data were downloaded to computer at the end of each days work and then pre-processed to sort the readings into line files, eliminate any defective data and combine the gain settings. The data were then input to EMVision, and inverted to produce a three- or four-layer earth model that is plotted as a section showing the ground resistivity as a function of depth (vertical axis) and location (horizontal axis). The figures plotted on the section are layer resistivities in ohm-metres, the layers being also colour-coded to accentuate the resistivity variations. The figure plotted above each column indicates the reliability of the inversion, with the lower figures meaning a better fit between the model and the data.

Fregon Survey

Survey Dates: May 1-6, 2002.

A 2 km test line (Line 9000) was surveyed past Double Tank Well, to determine the ground resistivity characteristics around this known supply of low salinity groundwater. Five traverse lines were then surveyed between Irintata and Fregon on the west side of the Irintata road, extending to the Ernabella Creek. One line (Line 3000) was also extended on the east side of the road (Fig. A1.1). The results are shown in Figures A1.2 to A1.7.

Discussion of Results

The Double Tank Line (Line 9000, Fig. A1.2) shows high resistivity basement at a depth of 20-70 m. Discrete zones of deeper basement occur at the west end of the Line, between stations 1650 and 2000 and stations 2500 and 2700. These may well be palaeochannel erosion features of the palaeosurface. The top few metres are also resistive, representing the dry surface layer. The interim layer, with resistivity between 5 and 20 ohm-metres, is expected to contain water in weathered basement or alluvial deposits.

Double Tank Well is located on the eastern edge of the central channel with a water cut at 20 m, and a SWL (2001) at 7.8 m, just below the resistive surface layer. Below this a moderately conductive zone, 10-12 ohm-metres, extends down to basement at about 60 m and west 350 m to the other edge of the channel.

The features of the TEM survey that may pertain to the availability of potable water are the depth to basement and the resistivity of the layer above basement and below the water table. The former indicates possible eroded channels that may encourage water movement, favouring better quality water. The lower resistivities within this layer, which generally occur where basement is shallower, may indicate more saline groundwater and/or a more clayey host. In either case these locations are less favourable drilling targets for water wells.

The other five lines show a similar resistivity pattern, with basement at a depth of 20 m (near the road on Lines 4000 and 5000) to 90 m (east end of Line 3000). Six drilling targets were selected on the basis of the middle layer resistivity, with intermediate values (10-12 ohm-metres) regarded as favourable. Areas of deeper basement were preferred, so long as the resistivity of the overlying layer was not too low.

Line 3000

This line was extended for 1 km either side of the Irintata-Fregon Road, which brought it to 1.7 km from Officer Creek. The latter environment is known to be saline, and was therefore avoided. Basement here is at greater depth, 50-90 m, and the cover is rather more conductive at 5-10 ohm-metres (Fig. A1.3). For this reason the area was considered less prospective except at the west end, where the lower resistivities were deeper with about 20 m thickness of moderate resistivity above. This might indicate freshwater overlying saline, so a test well (5344-68) was drilled to 29.6 m.

Water was cut between 14 m and end-of-hole, at a quality of 890 mg/L and a yield (airlifted) of 1.8 L/s. While this yield and quality is acceptable, by this time sufficient supplies at this quality had been proved, so the well was abandoned. It is suggested that the location be recorded in case water is required in this area at some time in the future.

Line 3500

Basement is at a depth of 50-60 m and resistivities are similar to those for Line 3000 (Fig. A 1.4). However, the western end of the line shows slightly higher resistivities and these were taken as a possible indication of lower salinity groundwater. A well (5344-64) was drilled to 37 m and yielded 6 L/s of water from a sand aquifer. The water quality at 1120 mg/L is not as good as was hoped, but is reasonable and the well was completed as a production well.

Line 4000

Basement is quite shallow (20 m) at the east end of this line, near the Irintata-Fregon road, but deepens to 40-50 m further west (Fig. A 1.5). The overlying sediments are quite conductive over the shallow basement and near basement in some of the deeper areas, but are at more prospective resistive levels at the west end of the line and at shallower depths in the centre. Wells were drilled to test both locations.

The west end appeared very hopeful, with resistivities approximating those at Double Tank over 500 m of line. Well 5344-63 was drilled to 37.5 m and cut water in sandy clay below 22 m. However, the water quality, at 1470 mg/L, was not satisfactory and the well was completed as an observation bore.

In the central section the possibility of freshwater overlying salt water was present. Well 5344-67 was drilled to 30 m, intersecting water in clayey sands below 22 m. The water quality (1020 mg/L) and yield (2.6 L/s) were as good as had been achieved, but a sufficient supply at this level had already been proved, so the well was abandoned.

Line 4500

Basement is relatively shallow here, so no wells were drilled (Fig. A 1.6).

Line 5000

A basement high (<20 m) occurs at station 1800, probably sufficient to prevent water movement parallel to the line (Figure A 1.7). On either side basement drops to 40-50 m below surface. To the west the resistivity is too low at 5 ohm-metres to favour potable water, but nearer the road (stations 2500 and 2900) levels of about 10 ohm-metres are more favourable. Wells were drilled to test this possibility.

Well 5344-65 was drilled to 36 m and intersected water below 22 m in silty sand. Both quality (940 mg/L) and quantity (5 L/s) were reasonably satisfactory, although the quality is marginal. The well was completed as a production well. A second well, nearer the road and on the other side of a secondary basement high, encountered gneiss at a relatively shallow depth. The drilling was quick, so the rock was evidently quite highly weathered and conductive, the conductivity being imparted by clays in the weathered rock. The yield was negligible, so the well was completed as an observation well.

Conclusions

The TEM survey has done a reasonable job of defining basement depth, although the well at the east end of Line 5000 showed much shallower basement than expected. This, presumably, resulted from the weathered nature of the basement, although shallow basement was expected nearby to the west.

It is evident that the resistivity of the sediments is not a good guide to water quality in this area. Apart from avoiding areas of shallow basement and clear high conductivity the TEM survey has not succeeded in locating fresher water with any surety. The success rate is probably improved to some extent by the geophysical data, but is only marginally worth the added cost of running the survey.

Mimili Survey

Survey Dates May 7-8, 2002.

Lines were surveyed over each of the existing production wells. These followed roads where possible, for ease of access. The survey lines and exploratory wells are shown in Figure A 1.8.

Discussion of Results

The TEM data were not as useful as had been hoped for locating wells in this area. The data are shown in Figures A 1.9 to A 1.12 as apparent resistivity sections, which reflect the resistivity of the ground to some degree but give only a general idea of variation with depth. Attempts to invert the data to yield a true resistivity section were not very successful, indicating that the resistivity pattern does not fit a layered model. Thus the interpretation has more of a qualitative nature.

In the M1 area there are indications, on Line 2000, of a lower resistivity zone extending northwest of the well. This appears to be some 300 m wide and, from the results on Line 1000, to extend to the full length of this line and beyond. On the assumption that this feature was related to the supply of water in M-1 it was drilled at its thickest point (well 5443-57) and northeast of M-1 (well 5443-60). The former encountered only clay above basement at 37 m and a poor supply of water in the upper layers of basement. The latter was more successful with 0.7 L/s of water from the upper basement but still no water above basement. A third well was drilled south of M-1 (5443-59), with similar results to 5443-60.

At M3 the results (Figs A1.11 and A1.12) showed a thicker or more conductive section southeast of the well which was drilled (5443-58) without success. Clays were again encountered. A well drilled at the western end of Line 3000 was more successful, producing 1.5 L/s of water from basement.

It is clear that the geophysics did not assist in finding water at this site. It was hoped that deeper or more conductive basement might be detected which would indicate more porous material. It is evident that the basement fractures which produce water here have no conductivity contrast with the surrounding rock.

Reference

Dodds, A.R. (Sandy), and Clarke, D.K., 2001; Improvement in groundwater supplies at the communities of Kalka, Amata, Mimili and Kenmore Park, Anangu Pitjantjatjara Lands, South Australia. Dept. for Water Resources Rpt. Bk. 2001/014.

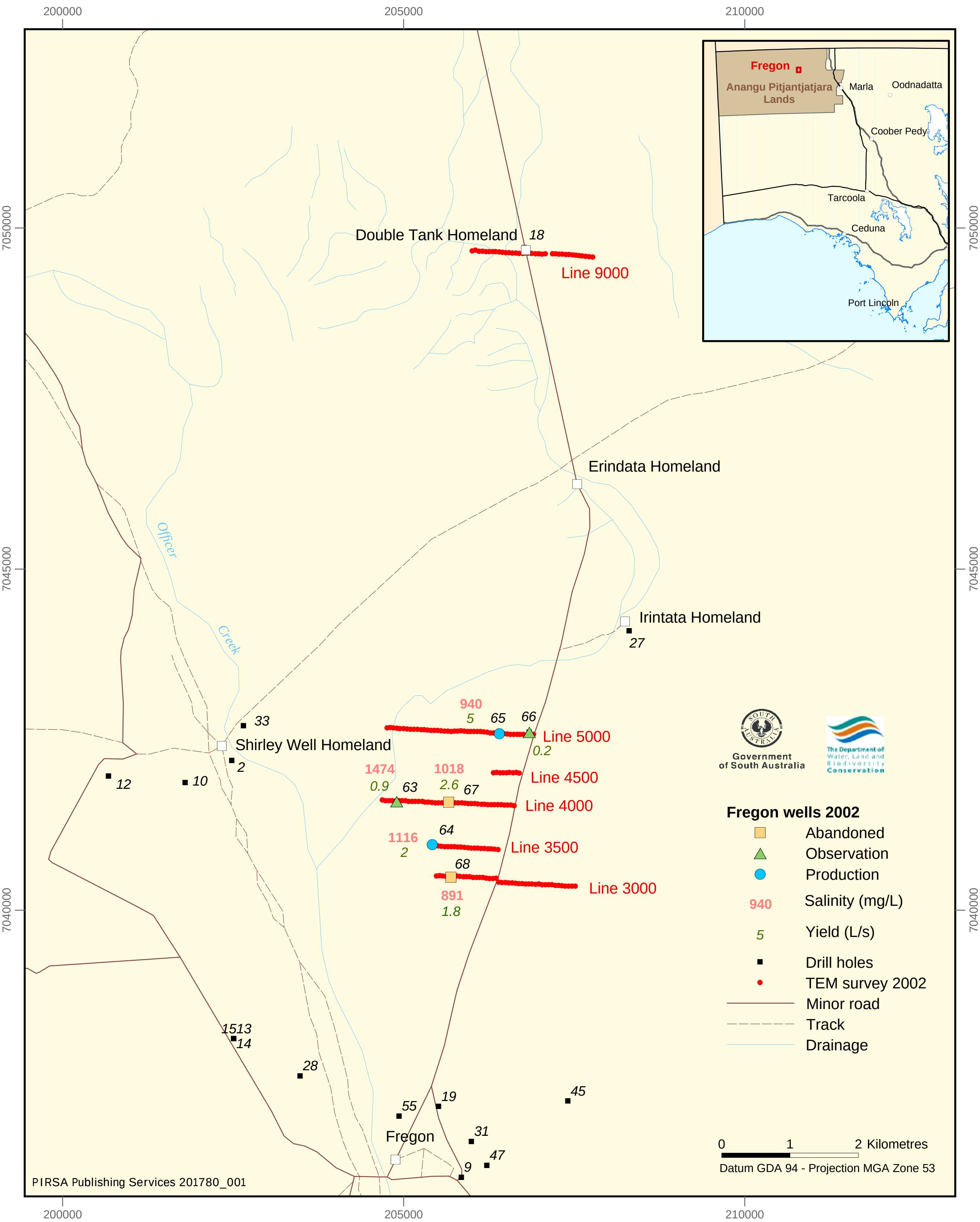


Figure A1.1 *Well and geophysical survey locations at Fregon, Anangu Pitjantjatjara Land*

FREGON WATER SEARCH TEM SURVEY LINE 9000, 3000, 3500

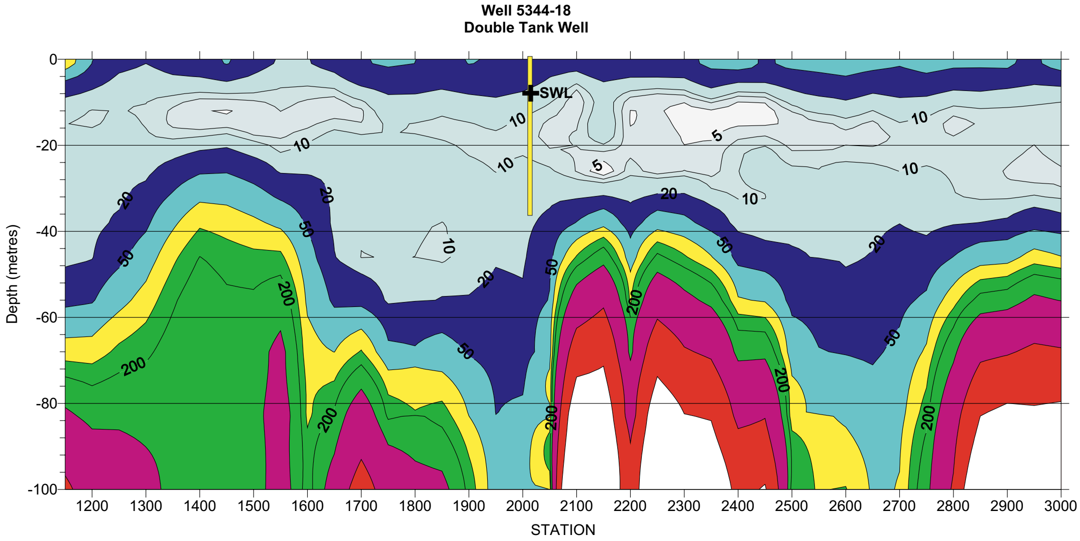


Figure A1.2 Resistivity Section of Line 9000

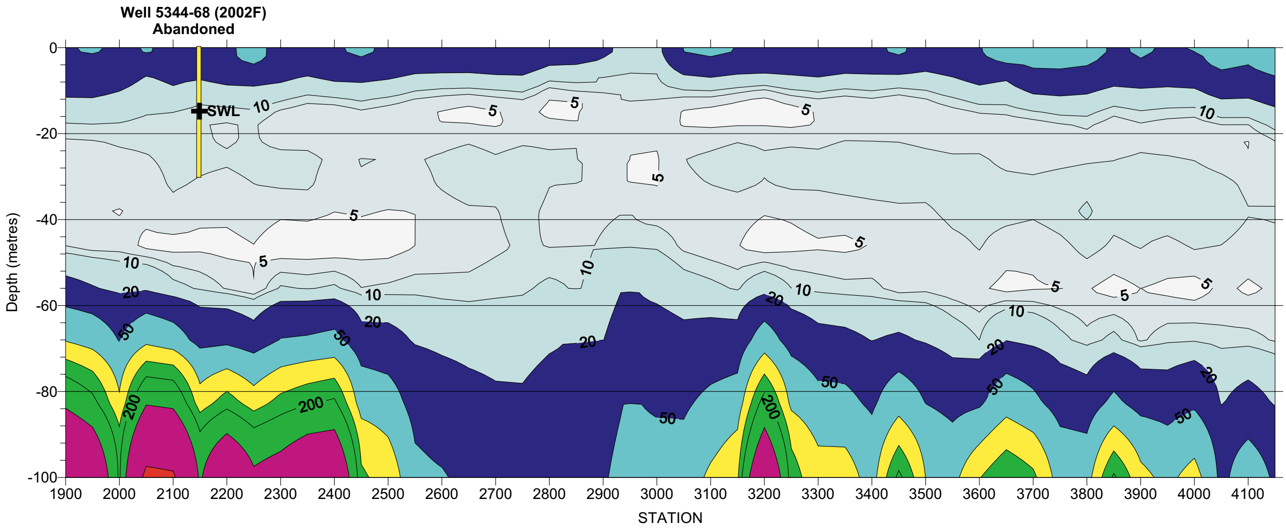


Figure A1.3 Resistivity Section of Line 3000

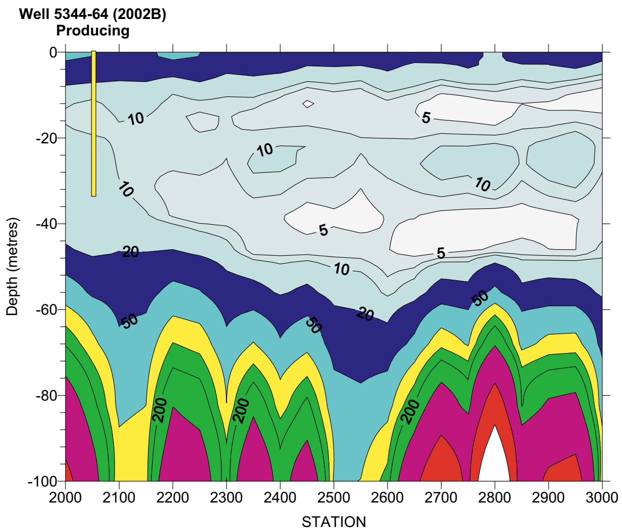


Figure A1.4 Resistivity Section of Line 3500

FREGON WATER SEARCH TEM SURVEY LINES 4000, 4500, 5000

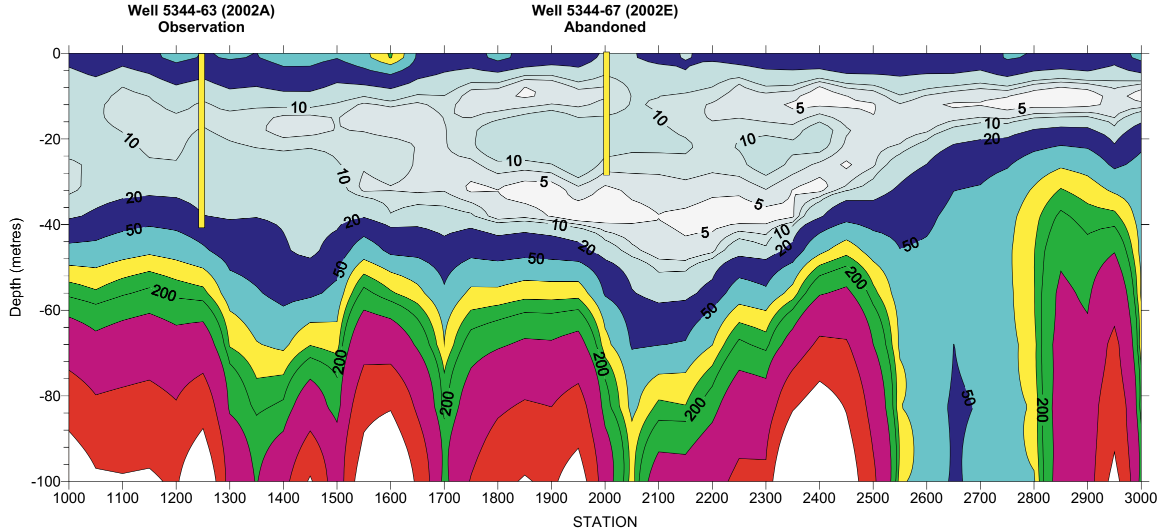


Figure A1.5 Resistivity Section of Line 4000

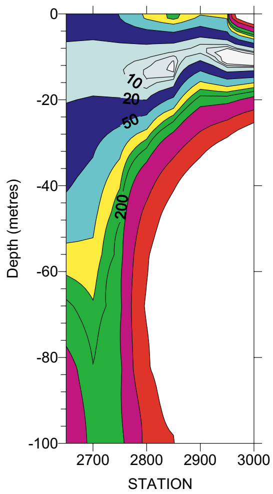


Figure A1.6 Resistivity Section of Line 4500

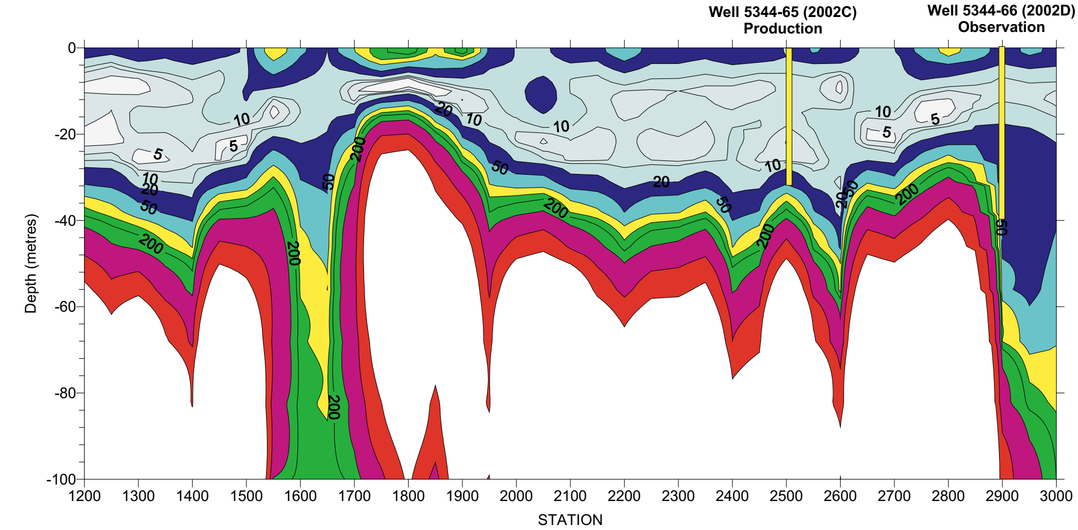


Figure A1.7 Resistivity Section of Line 5000

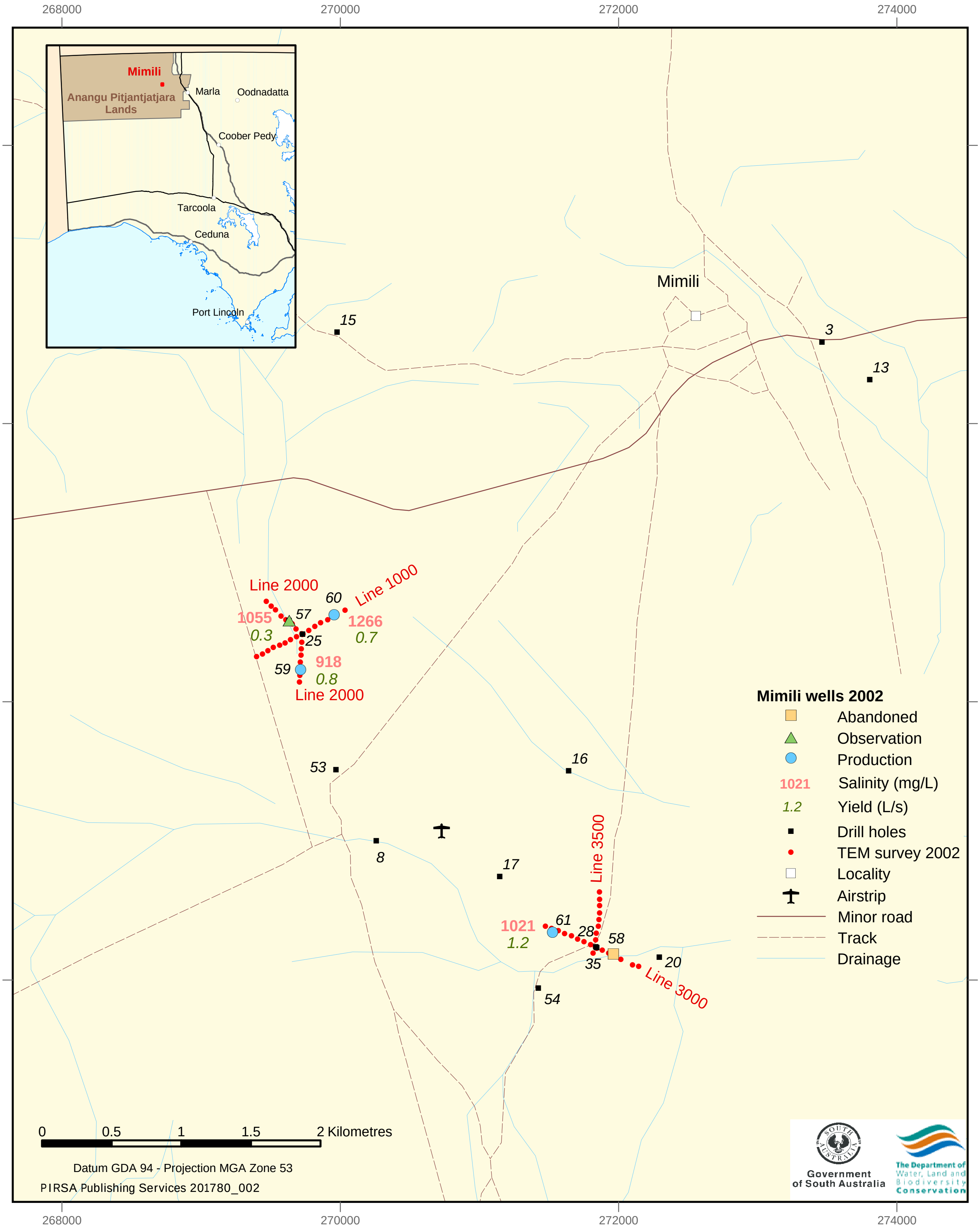


Figure A1.8 *Well and geophysical survey locations at Mimili, Anangu Pitjantjatjara Lands*

MIMILI WATER SEARCH
TEM SURVEY
Apparent Resistivity Contours

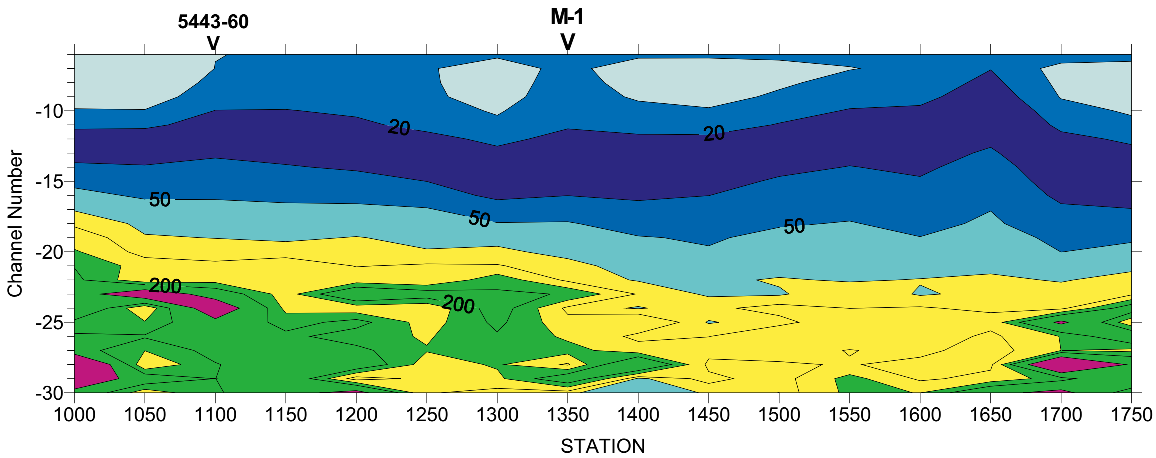


Figure A1.9 Line 1000 - M-1

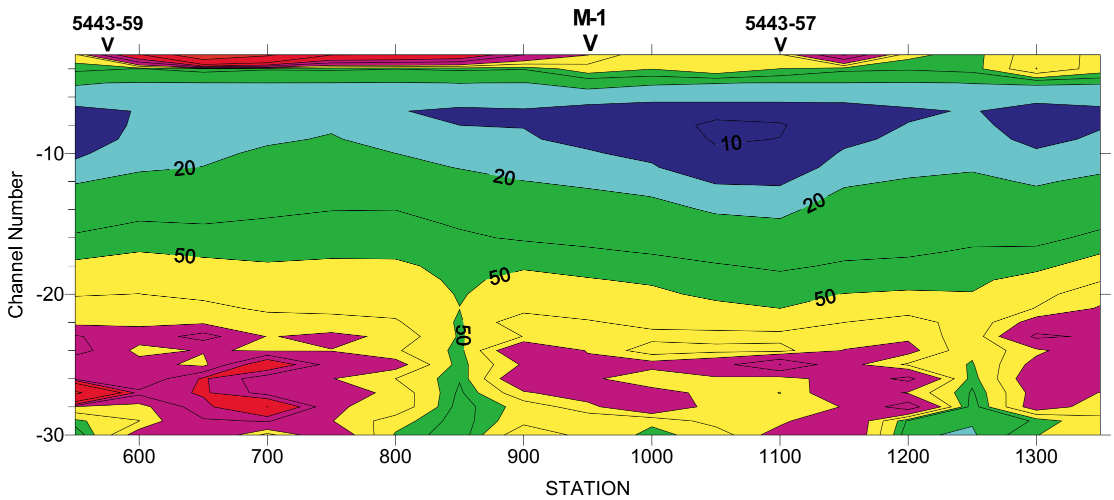


Figure A1.10 Line 2000 - M-1

MIMILI WATER SEARCH
TEM SURVEY
Apparent Resistivity Contours

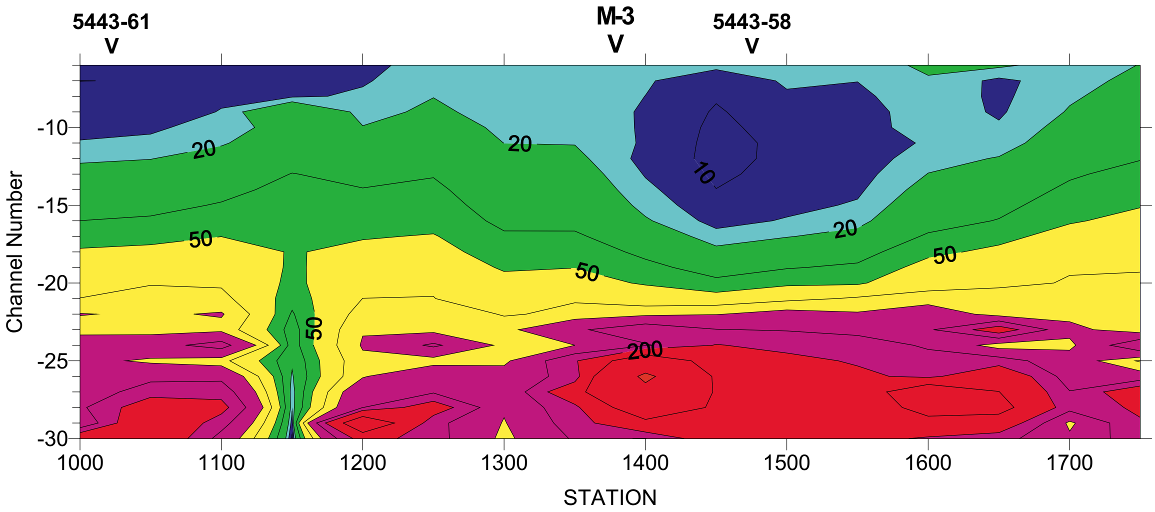


Figure A1.11 Line 3000 - M-3

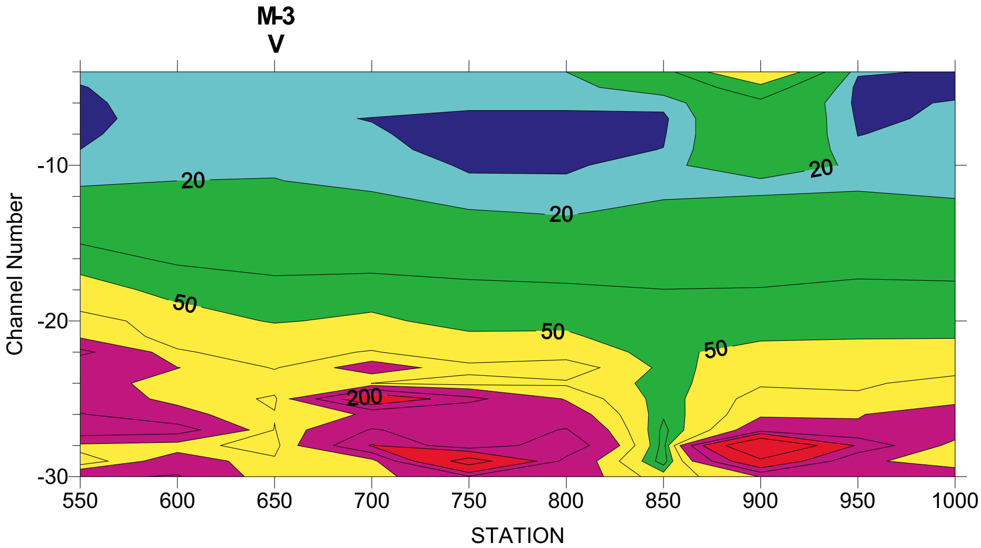


Figure A1.12 Line 3500 - M-3

APPENDIX 2 Drilling at Fregon and Mimili, May 2002

Introduction

Considering the failed attempts of the May 2001 drilling at Mimili, (Dodds and Clarke, 2001) it was decided that the best prospects for successful wells, with minimization of infrastructure costs, would be to drill near the existing community supply wells. A distance of no less than 100 m would allow pumping both existing and new wells with tolerable levels of interference. Keeping the distance below 400 m would improve the probability of finding similar hydrogeological conditions to those at the existing wells while minimizing infrastructure when commissioning the new wells.

Gorey and Cole drilled the wells using a rotary drilling rig, with rotary and down-hole-hammer bits, between 24/05/02 and 29/05/02. Barton Phillips was the driller and David Clarke supervised for DWLBC and logged the lithology.

Five wells were drilled at Mimili to obtain a backup community water supply.

Six wells were drilled at Fregon to try to prove the existence of groundwater of 800-900 mg/L or better within about six kilometres of the community.

Geology and Hydrogeology

Both areas have significant depths of sediments, a little unusual for the Anangu Pitjatjantjara lands.

Fregon

Water was cut in sands and gravels, usually interbedded with clay. The only well in which bedrock (gneiss in well D, apparently a bedrock high) was definitely intersected was the only well to have a negligible yield.

Only one well (2002B) indicated a significant increase in salinity with depth; 1950 to 2190 ECU (field tests). There was an apparent decline in salinity with depth in well A; 3040 to 2870 ECU (field tests).

Mimili

The sediments failed to yield significant quantities of water, while useful water-cuts were intersected in the upper, weathered, part of the bedrock.

Well data tables

Table 1. Well identities and locations

Well name	Permit No.	Unit No.	Site No.	Easting	Northing
Fregon 2002A	55344	5344-63	1	204901	7041598
Fregon 2002B	55345	5344-64	2	205420	7040968
Fregon 2002C	55346	5344-65	3	206402	7042590
Fregon 2002D	55347	5344-66	6	206839	7042612
Fregon 2002E	55348	5344-67	5	205662	7041589
Fregon 2002F	55349	5344-68	4	205694	7040491
Mimili 2002A	55350	5443-57	4	269632	7008584
Mimili 2002B	55351	5443-58	1	271962	7006186
Mimili 2002C	55352	5443-59	6	269714	7008231
Mimili 2002D	55353	5443-60	5	269955	7008625
Mimili 2002E	55354	5443-61	2	271525	7006343

All wells are in zone 53. All coordinates are WGS84

Table 2. Completion details

Well name	Status	**Depth drilled** (m)	**Casing** (mm diameter)	**Casing height above g.l.** (m)	**Slots** (m, from – to)
Fregon 2002A	Observation	37.45	50, with steel screw cap	0.15	31.45 - 37.45
Fregon 2002B	Production	37.18	150	0.05	16 - 34
Fregon 2002C	Production	36.19	150	0.0	24.19 - 36.19
Fregon 2002D	Observation	44.8	50, with steel cap	?	38.8 - 44.8
Fregon 2002E	Abandoned	29.6	-	-	-
Fregon 2002F	Abandoned	29.6	-	-	-
Mimili 2002A	Observation	52.15	50	0.23	40.15 – 46.15
Mimili 2002B	Abandoned	52.4	No casing, steel cap	-	-
Mimili 2002C	Production	44.97	150		32.97 – 44.97
Mimili 2002D	Production	37.25	150		25.25 – 37.25
Mimili 2002E	Production	37.36	150		25.36 – 37.36

All depths are relative to ground level (g.l.) unless otherwise stated.

All wells not abandoned had a 6 m length of steel surface casing, 203 mm ID, 219 mm OD.

All casing other than surface casing was class 9 PVC.

Slotted production well casing has four rows of longitudinal 3 mm slots, about 90° between rows; each slot is about 12 cm long and there is about 18 cm between the end of one and the beginning of the next.

Table 3. Water details

Well name	**Airlift yield** (L/sec.)	**Water cut** (m)	**Field ECU**	**Office ECU**	**SWL** (m below g.l.)
Fregon 2002A	0.9	22 - 37	2900	2660	9.45
Fregon 2002B	6	24 - 37	1950 rising to 2200	2020	8.48
Fregon 2002C	5	22 - 30	1850	1700	?
Fregon 2002D	0.02?	?	No sample	-	Insufficient water
Fregon 2002E	2.6	22 – 29.6	1990	1840	?
Fregon 2002F	1.8	?14 – 29.6	1770	1610	?
Mimili 2002A	0.3	42	2170	1910	15.83
Mimili 2002B	0	-	-	-	-
Mimili 2002C	0.7	33 - 37	1800	1660	14.07
Mimili 2002D	0.7	29	2330	2290	15.78
Mimili 2002E	1.5	20 - 30	2030	1850	11.83

The field determinations of the electrical conductivity of water samples were less reliable than those done in the office. In the field suspended mud and oil (from the drilling process) on top of the water sample can be a problem. In the office it is easier to get the samples to near standard temperature (25°) and to properly calibrate the meter.

Well logs

Log; Fregon 2002A

Interval (m)	**Lithology**	**Description**
0 – 3.8	Silty sand	Red-brown, and red and white calcrete
3.8 – 6.7	Ditto	The sand is fine to medium, red
6.7 – 10.5	Ditto	The sand is course to medium, rounded, reddish brown.
10.5 – 14.3	Ditto	Becoming clayey
14.3 – 21.9	Gritty clay	(Little sample obtained.) Water cut, approx. 0.1 L/sec.
21.9 – 29.6	?Clay	(Very little sample obtained.) Total w.c. 0.35 L/sec.
29.6 – 37.2	Clay with sand	Total w.c. 0.9 L/sec. Field test 2870 ECU.

Drilling was terminated because the water was too saline.

Log; Fregon 2002B

Interval (m)	**Lithology**	**Description**
0 – 3	Calcrete and silty sand	With some weathered gneiss gravel.
3 – 6.7	Gneiss (?rubble)	Highly weathered, including calcrete. Very minor rounded gravel present.
6.7 – 10.5	Silty sand	Very poorly sorted. Many grains are subrounded, some well rounded. Feldspathic, reddish brown.
10.5 – 14.3	Sandy silt	Very little rounding; becoming clayey. Reddish brown. Very damp. Minor water cut.
14.3 – 18.1	Sand	Moderately indurated. Brownish red: very abundant iron staining. Total w.c. 2.3 L/sec. Field test 1950 ECU.
18.1 – 29.5	Sand	Moderately indurated. Similar to above. Field test 2066 ECU
18.1 – 33.4	Ditto	Ditto
33.4 – 37.2	Silicified shale	White, red, and pink. Total w.c. 6 L/sec. Field test 2187 ECU

Drilling was terminated because salinity was rising with depth.

Note that there is doubt about the above depths because the logger miscounted the 7.62 m drill rods.

The casing could not be pushed to more than 34 m. Measured depth after casing was 35.35 m.

Log; Fregon 2002C

Interval (m)	**Lithology**	**Description**
0 – 6	Silty sand	Red. Some of the quartz grains appear to be rounded. There are some fragments of weathered ?gneiss.
6 – 10.5	Silty clay	With grit. Multicoloured: mainly red, some light grey.
10.5 – 14.3	Silty sand	With some clay. Becoming damp. Red, some clay is very light grey.
14.3 – 18.1	?Gneiss	Highly weathered. Brownish red (very abundant iron staining), clayey, silty, gritty, gravelly.
18.5 – 21.9	Gritty clay	Red
21.9 – 25.8	Silty sand	Red. Water cut.
25.8 – 29.6	Ditto	Red. The sand contains magnetite or ilmenite. Total w.c. 4.5 L/sec.
29.6 – 37.2	Ditto	No apparent increase in total w.c. Field test 1850 ECU.

Drilling was terminated because of no further increase in yield with the last 7.6 m rod.

Log; Fregon 2002D

Interval (m)	**Lithology**	**Description**
0 – 3	Silty sand	Red
3 – 6	Gneiss rubble	
6 – 10.5	Silty sand	Red
10.5 – 14.3	Clayey silt	White
14.3 – 18.1	Gneiss gravel	
18.1 – 21.9	Silty sand	White. With some gravel.
21.9 – 37.2	Gneiss	Showing minor weathering (iron staining)
37.2 – 41.0	Gneiss	Very little weathering apparent
41.0 – 44.8	Gneiss	Moderate indication of weathering. Seepage only: ~ 0.02 L/sec.

Drilling was terminated because the prospects of obtaining a useful water supply seemed low.

All the drilling was quite quick until the last two metres. This indicates that the gneiss must have been much more weathered than indicated by the samples.

This well was mainly logged from samples; the logger was not present until near the end.

Log; Fregon 2002E

Interval (m)	**Lithology**	**Description**
0 – 3	Silty sand	Red. Becoming clayey. Calcareous.
3 – 6.7	Silty sand	
6.7 – 10.5	Sand	Moderately indurated. Very highly iron stained.
10.5 – 14.3	Silty sand	Some induration, much iron staining.
14.3 – 18.1	Sandy silt	With clay and gravel. Brownish red. Very damp.
18.1 – 21.9	Silty clay	Variable proportions of clay, silt, sand and gravel. Water cut, approximately 0.5 L/sec.
21.9 – 25.8	Silty sand	
25.8 – 29.6	Gravelly clay	With sand and silt. Total w.c. 2.6 L/sec., field test 1988 ECU.

Drilling was terminated because the objective had been achieved.

Log; Fregon 2002F

Interval (m)	**Lithology**	**Description**
0 – 6.7	Calcrete	With sandy silt. Mainly white, much brownish red.
6.7 – 14.3	Gravelly sand	Highly weathered gneiss. Brownish red. Damp at 14 m
14.3 – 21.9	Clayey sand	Brownish red.
21.9 – 29.6	Sandy clay	Brownish red. Total water cut 1.8 L/sec., field test 1770 ECU.

Drilling was terminated because the objective had been achieved.

Log; Mimili 2002A

Interval (m)	**Lithology**	**Description**
0 – 6.7	Silty sand	Red. Most sand grains are subangular to subrounded. The grains are quartz and feldspar, heavily iron stained.
6.7 – 10.5	Silty clay	Brownish red and grey. Interbedded with silty sand. The sand is angular to subrounded.
10.5 – 12	Ditto	Some of the sand is moderately sorted.
12 – 14.3	Silty sand	White talcy clay is interbedded with sand.
14.3 – 21.9	Talcy clay	And silty sand. White.
21.9 – 25.8	Talcy clay	First white, then light grey.
25.8 – 29.6	Clay	Light brownish grey.
29.6 – 37.2	Clay	Gritty in places (little sample obtained). Pale yellowish grey; light grey at 37 m. The grit is mainly quartz, some feldspar, and some epidote; subrounded to rounded.
37.2 – 48.6	Igneous rock	Medium grained, intermediate (abundant feldspar, mafics abundant in places, little or no quartz, some pyrite). Very little indication of weathering. Water cut about 42 m; by 45 m there was 0.2 L/sec.
48.6 – 52.4	Ditto	Medium grained, intermediate. Composed mainly of feldspar; with biotite and some pyrite. Total w.c. 0.3 L/sec. Field test 2170 ECU.

Drilling was terminated because the prospects of obtaining a useful water supply seemed low.

Log; Mimili 2002B

Interval (m)	**Lithology**	**Description**
0 – 7	Clayey sand	The sand is subangular quartz. Some calcrete. Red.
7 – 8	Sandstone	(Indurated sand). Red.
8 – 10.5	Silty sand	Many of the larger grains are rounded, even well rounded.
10.5 – 14.3	Talcy clay	Yellowish grey.
14.3 – 21.9	Clay	Medium grey to brownish grey. Very damp.
21.9 – 41.0	Clay	Brown
41.0 – 48.6	?Gneiss	Weathered. Much iron staining.
48.6 – 52.4	Igneous rock	Medium grained, intermediate.

Drilling was terminated because the prospects of obtaining a useful supply seemed low.

There were no noticeable water cuts in this well. It was capped with a 50 mm steel screw plug in the hope that it might be useable as an observation well, but the clay had slumped in and blocked it within a day.

Log; Mimili 2002C

Interval (m)	**Lithology**	**Description**
0 – 7	Sandy silt	With clay and calcrete. Red.
7 – 9	Sandy clay	Red
9 – 13	Sandstone	(Indurated sand.) Brownish red.
13 – 14.3	Clay	Pale yellowish grey
14.3 – 18.1	Clay	Damp
18.1 – 21.9	Silty sand	Brown. (No water cut.)
21.9 – 25.8	Silty gravel	The gravel is highly weathered gneiss (composed mainly of quartz and feldspar).
25.8 – 29.6	Gneiss	Highly weathered (composed of quartz and weathered feldspar)
29.6 – 33.4	Igneous rock	Intermediate, medium grained. Some weathering visible. Minor water cut.
33.4 – 37.2	As above	Becoming slow drilling (presumably because of less weathering). Total water cut at 37 m was 0.7 L/sec.
37.2 – 44.8	Igneous rock	Medium grained, intermediate (no quartz, mainly feldspars). Showing some iron staining in joints.

Drilling was terminated because there was no significant additional water cut in the last rod.

Log; Mimili 2002D

Interval (m)	**Lithology**	**Description**
0 – 7	Sandy silt	With clay. Red.
7 – 10.5	?Rubble	Feldspar/quartz/epidote rock. (The degree to which the rock was broken before being crushed by the bit was unknown.)
10.5 – 14.3	Gritty clay	White
14.3 – 18.1	Clayey silt	Pale brown
18.1 – 21.9	Gneiss	Highly weathered. The sample was mainly gravel (composed of feldspar and quartz), with sand and silt. Damp.
21.9 – 25.8	Gneiss	Less quartz, more feldspar?
25.8 – 29.6	Gneiss	Highly weathered. With some clay. Water cut at 29 m. Total w.c. at 29.6 m was 0.5 L/sec. Field test 2330 ECU.
29.6 – 37.2	Dolerite	Medium grained. Approximately 50% feldspar, 50% mafics. There were common indications of weathering in the samples. Total w.c. 0.7 L/sec.

Drilling was terminated because there was little additional water cut in the last rod and the prospects of obtaining more water in the dolerite were thought to be poor.

Log; Mimili 2002E

Interval (m)	**Lithology**	**Description**
0 – 7	Silty sand	With minor calcrete. Red.
7 – 10.5	Sandstone	Indurated sand. Brownish red and light grey.
10.5 – 14.3	Clayey grit	Brownish red, becoming brown
14.3 – 18.1	Gneiss	Highly weathered. (The sample was composed of quartz and weathered feldspar.) Yellowish brown and very pale brown.
18.1 – 21.9	Gneiss	Highly weathered. (The sample was mainly white, gritty, silt.) Water cut, approximately 0.3 L/sec.
21.0 – 25.8	Igneous rock	Medium grained, intermediate. Total w.c. 1.0 L/sec.
25.8 – 29.6	Ditto	Drilling became slow toward the end of this section where the sample was 95% glassy feldspar (no weathering) and 5% biotite. Total w.c. 1.4 L/sec.
29.6 – 37.2	Ditto	Fractures around 32 – 33 m. Total w.c. at end was 1.5 L/sec. Field test 2030 ECU.

Drilling was terminated because no significant additional yield was obtained in the last rod.

APPENDIX 3 Well pump testing

The units used below are metres and days unless otherwise specified.

All data were analyzed using the CG well test analysis and simulation programs (Clarke, 1988).

Fregon

Fregon 2002B

From 8th to 11th December 2002 Pitjantjatjara Council Projects staff conducted a stepped rate discharge test followed by a 24 hour steady rate test with 2½ hours of recovery readings.

Analysis of the test data indicated strip aquifer conditions. (That is; the well is in a strip of formation having greater ability to transmit water than the surrounding rock. Water flows toward the well from two directions only, while in a perfectly isotropic aquifer it flows from all directions equally.) The data further indicate that at least one end of the strip may be obstructed.

The best-fit well equation is:

$$s = 0.0102 * Q + 0.00133 * Q\sqrt{t} + 2.68 * 10^{-6} * Q^2$$

where (as for all well equations in this section) :

s = drawdown;

Q = discharge (pumping) rate;

Units are metres and days.

Transmissivity could not be determined because of the strip nature of the aquifer.

The recommended maximum pumping rate, if the well is to be pumped continually for a year, is 170 m^3/day or 2.0 L/sec, including a 20% safety margin. (Extrapolations of greater than a year are too dependent on aquifer conditions at a distance from the well and on availability of recharge to be advisable; however, it can be said that it is probably that the one-year safe yield is probably not greatly different to the ten-year safe yield.) If the well is to be pumped eight hours per day for one year then the recommended maximum rate is 3.6 L/sec (which equates to an average rate of 105 m^3/day or 1.2 L/sec for the whole year). Again, there was a 20% safety margin.

These recommendations are based on an available drawdown of eight metres (water cut at approx. 17 m and standing water level of 8.5 m).

A graph of the data from the 24 hr steady rate test is given in Figure A3.1

Fregon 2002C

From 5th to 8th December 2002 Pitjantjatjara Council Projects staff conducted a stepped rate discharge test followed by a 24 hour steady rate test with 24 hours of recovery readings.

Analysis of the test data indicated isotropic aquifer conditions.

The best-fit well equation is:

$$s = 0.0146 * Q + 0.00214 * Q \log(t) + 6.76 * 10^{-6} * Q^2$$

Transmissivity is 85 m^2/day.

The recommended maximum pumping rate, if the well is to be pumped continually for a year, is 430 m^3/day or 5.0 L/sec, including a 30% safety margin. If the well is to be pumped eight hours per day for one year then the recommended maximum rate is 6 L/sec (which equates to an average rate of 170 m^3/day or 2 L/sec for the whole year). Again, there was a 30% safety margin.

These recommendations are based on an available drawdown of 15 m (water cut at approx. 28 m and standing water level of 12.6 m).

A graph of the data from the 24 hr steady rate test is given in Figure A3.2

Mimili

None of the tests at Mimili indicated strip aquifer characteristics.

For the recommended maximum discharge rates below, a safety margin of 20% has been used for the 20 days projections, while 30% has been used for the one-year projections.

All data were analyzed using the CG well test analysis and simulation programs (Clarke, 1988).

Mimili 2002C

From 25th to 28th July 2002 Pitjantjatjara Council Projects staff conducted a stepped rate discharge test followed by a 24-hour steady rate test followed by 13 hrs of recovery readings. They also monitored drawdown in Mimili Community Water Supply Bore 1 (Unit No. 5443-25) in which there was 0.18 m drawdown attributable to pumping in the new well.

Recovery in the pumped well was quicker than theory would predict. This is not unusual and is probably due to air becoming temporarily trapped in the aquifer.

The recommendations are based on an available drawdown of 17 m (water cut approx. 31 m and standing water level of 14 m).

Analysis of the test data indicated isotropic aquifer conditions.

The best-fit well equation is:

$$s = 0.078 * Q + 0.0101 * Q \log(t) + 7.4 * 10^{-4} * Q^2$$

and transmissivity is 18 m^2/day.

The recommended maximum pumping rate, if the well is to be pumped continually for a year, is 68 m^3/day or 0.79 L/sec, including a 30% safety margin. If the well is to be pumped eight hours per day for one year then the recommended maximum rate is 0.85 L/sec (which equates to an average rate of 24 m^3/day or 0.28 L/sec for the whole year). Again, there was a 30% safety margin.

These recommendations are based on an available drawdown of 17 m (water cut at approx. 31 m and standing water level of 14 m).

A graph of the data from the 24 hr steady rate test is given in Figure A3.3.

The best-fit aquifer parameters for the data from well 5443-25 were T=133 and S=0.00017. The value for T here was much higher than that calculated for the pumped well. This discrepancy suggests that the aquifer is highly anisotropic and/or heterogeneous. The lower value has been used for the calculation of the recommended maximum discharge rates.

A graph of the data from well 5443-25 (Mimili TWS #1) with the best-it simulation is given in Figure A3.4.

Mimili 2002E

From 30th July to 2nd August 2002 Pitjantjatjara Council Projects staff conducted a stepped rate discharge test followed by a 24-hour steady rate test followed by recovery readings. They also monitored drawdown in Mimili Community Water Supply Bore 3 (Unit No. 5443-28) in which there was 0.05 m drawdown attributable to pumping in the new well.

Recovery in the pumped well was quicker than theory would predict. This is not unusual and is probably due to air becoming temporarily trapped in the aquifer.

Analysis of the test data indicated isotropic aquifer conditions.

The best-fit well equation is:

$$s = 0.025 * Q + 0.0025 * Q \log(t) + 2.6 * 10^{-4} * Q^2$$

and transmissivity is 73 m^2/day.

The recommended maximum pumping rate, if the well is to be pumped continually for a year, is 104 m^3/day or 1.2 L/sec, including a 30% safety margin. If the well is to be pumped eight hours per day for one year then the recommended maximum rate is 1.26 L/sec (which equates to an average rate of 36 m^3/day or 0.42 L/sec for the whole year). Again, there was a 30% safety margin.

The recommendations are based on an available drawdown of 10.5 m (water cut below 22.5 m and standing water level of 12 m).

A graph of the data from the 24 hr steady rate test is given in Figure A3.5.

The best-fit aquifer parameters for the data from well 5443-28 were T=1300 and S=0.00019. These figures are derived from a maximum drawdown of only 50 mm, and the fit between measured data and simulation was poor; therefore the T and S values are questionable. As for well 5443-25, the value for T here was much higher than that calculated for the pumped well. This discrepancy suggests that the aquifer is highly anisotropic and/or heterogeneous. The lower value has been used for the calculation of the recommended maximum discharge rates.

A graph of the data from well 5443-28 (Mimili TWS #3) with the best-fit simulation is given in Figure A3.6.

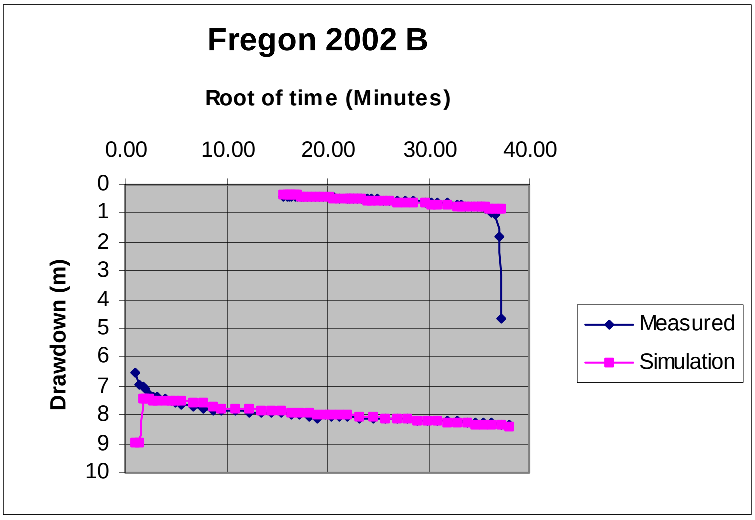
Reference

Clarke, D.K; 1988; Groundwater discharge tests: Simulation and Analysis. Elsevier. ISBN 0-444-43037-7.

Figures

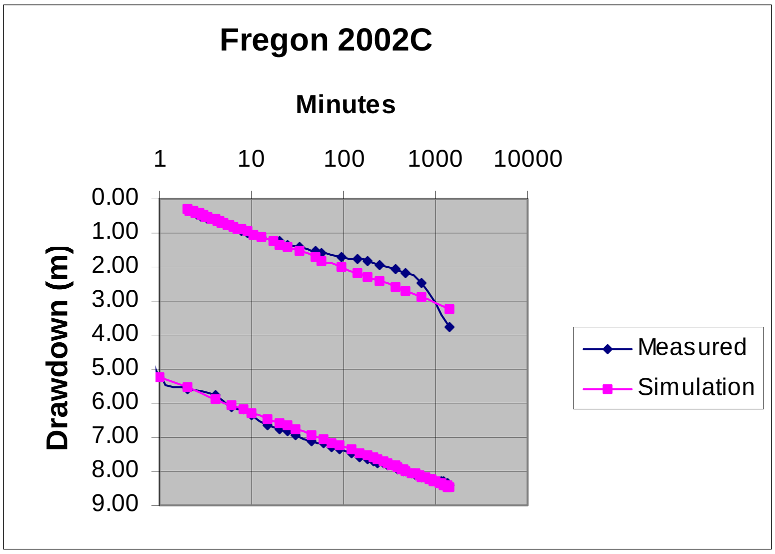
The simulations are based on the well equations given in the text.

Figure A3.1; Fregon 2002 B, 24-hour drawdown and recovery



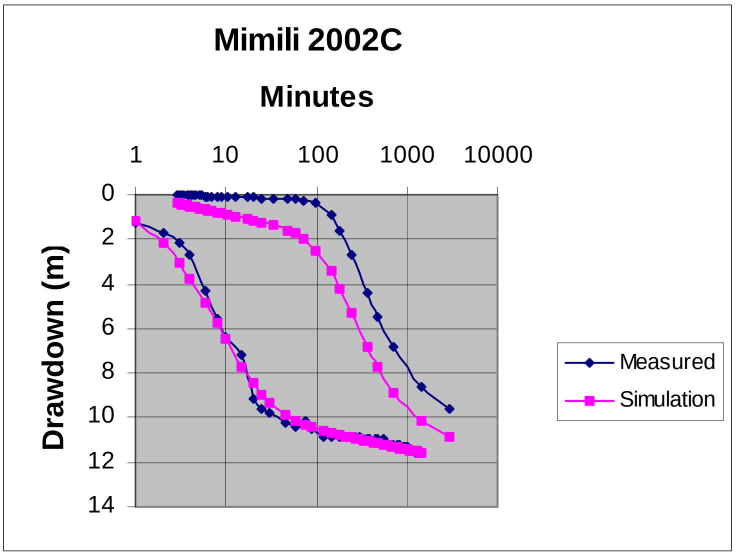
The recovery curves (right and top) are plotted as root t – root t'.

Figure A3.2; Fregon 2002 C, 24-hour drawdown and recovery



The recovery curves (right and top) are plotted as t/t'.

Figure A3.3; Mimili 2002 C, 24-hour drawdown and recovery



The recovery data (top curves) are plotted as t/t'.

Well storage effects are considered in the simulation.

Figure A3.4; Pumping Mimili 2002 C, d ata from well 5443-25 (Mimili TWS #1) used as a piezometer

The simulation is based on T=133 and S=0.00018.

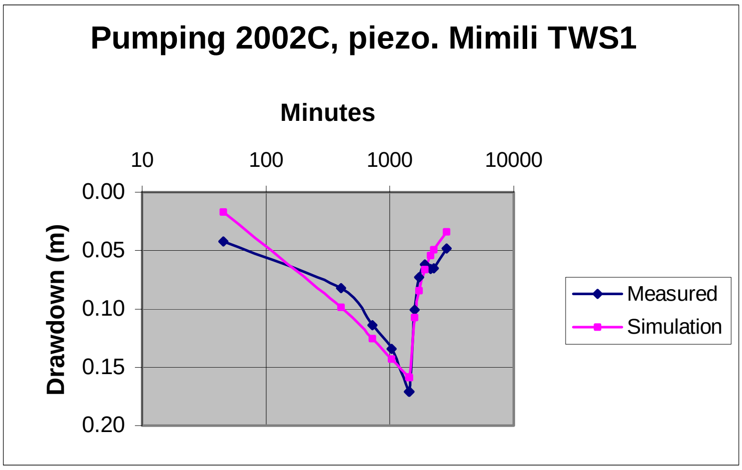
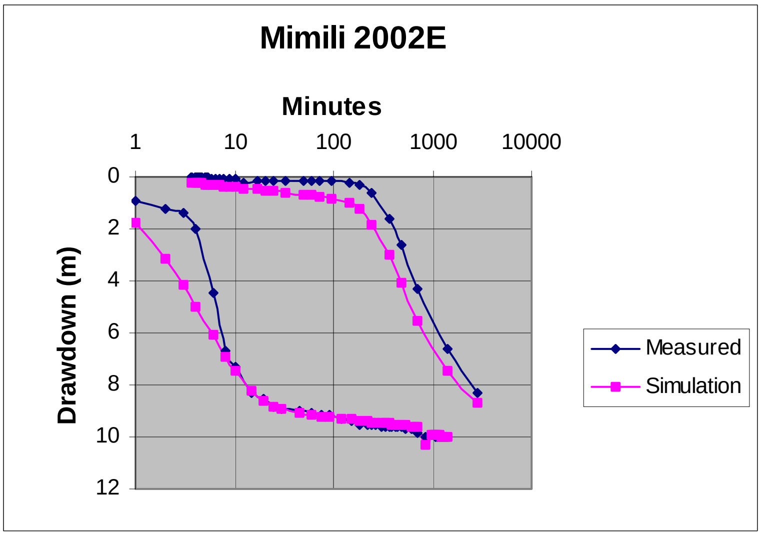


Figure A3.5; Mimili 2002 E 24-hour drawdown and recovery

The recovery data (top curves) are plotted as t/t'.

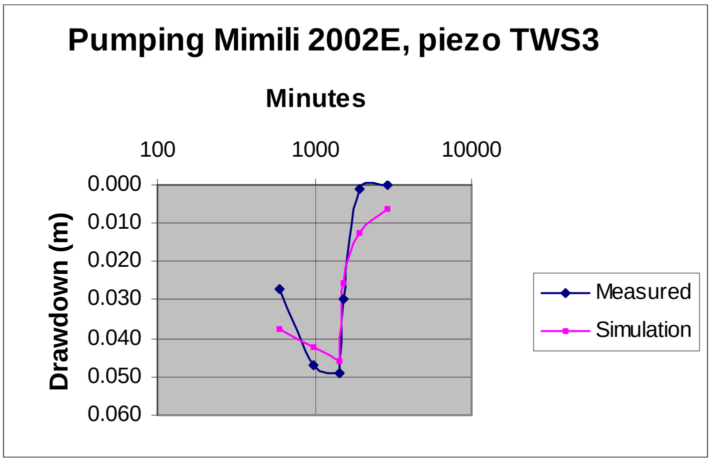
Well storage effects are considered in the simulation.



Well storage effects are considered in the simulation.

Figure A3.6; Pumping Mimili 2002 E, data from well 5443-28 (Mimili TWS #3) used as a piezometer

The simulation is based on T=1300 and S=0.00018.



APPENDIX 4 Water quality

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Northern Territory Government
Department of Business, Industry & Resource Development

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RESOURCE PROTECTION DIVISION
WATER CHEMISTRY LABORATORY

Bottle No:	RE62
Lab Register No:	144
Date Received in Lab:	3/04/02
Time Sampled:	
Date Sampled:	25/03/02
Bore RN:	
Depth (m)	32.9
G.S.No:	
G.H. (m)	
Q:	
Map:	
G.R.:	
Sampler:	McINNES
Location:	FREGON S.A. - DOUBLE TANK
	020423k
Project No :	PIT COUNCIL ORDER #

ANALYSIS - PHYSICAL

	pH	[4500-H⁺B]	7.0		Colour (Hazen units)	[2120B]	
	Electrical Conductivity 25°C (uS cm^{-1})	[2510B]	1,163		Turbidity (NTU)'s	[2130B]	
	Total Dissolved solids (mgL^{-1}dried 180°C)	[2540C]	732		Suspended Solids (mg L^{-1})	[2540B]	

ANALYSIS - CHEMICAL (mg L^{-1})

	Sodium, Na	[3111B]	175		Chloride, Cl	[4500-Cl^- B]	155
	Potassium, K	[3111B]	8		Sulphate, SO_4	[G]	75
	Calcium, Ca	[3111D]	30	X	Nitrate, NO_3	[4500-NO_3^- B]	56
	Magnesium, Mg	[3111B]	22		Bicarbonate, HCO_3	[2320B]	295
	Iron (total), Fe	[3111B]	0.2		Carbonate, CO3	[2320B]	0
	Total Hardness (as $CaCO_3$) calc	[2340B]	165		Hydroxide, OH	[2320B]	0
	Total Hardness (as $CaCO_3$) titr	[2340C]		X	Fluoride, F	[4500-F^- C]	1.7
	Total Alkalinity (as $CaCO_3$)	[2320B]	242		Sodium Chloride, NaCl (calc from Cl)		255
	Silica, SiO_2	[4500-Si D]	82		Dissolved Oxygen	[4500-O B]	

ANALYSIS - ADDITIONAL (mg L^{-1})

\# U/S DENOTES UNSUITABLE FOR ANALYSIS
\# I/S DENOTES INSUFFICIENT SAMPLE
\# F DENOTES FILTRATE ANALYSIS
\# T DENOTES TOTAL ANALYSIS

C1 144 020423k

This report relates specifically to the "samples tested as received".

The test methods used (denoted within brackets) refer to the 1992 18th edition of "Standard Methods for the examination of Water and Wastewater", A.P.H.A. Except [G] which refers to the method of R. Goguel, Anal. Chem. 1969, 41, 1034.

DATE : 9/05/02

CHECKED : KLon

SIGNATORY : K Loon

Boxes marked thus indicate :

☐ Levels are within the limits as quoted in the "Guidelines for Drinking Water Quality in Australia". 1987 N.H.& M.R.C. and the A.W.R.C.

[/] Levels exceed non health related limits.

[X] Levels exceed health related limits.

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0889534580

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Department of Business, Industry & Resource Development

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RESOURCE PROTECTION DIVISION
WATER CHEMISTRY LABORATORY

Bottle No: RD91	Lab Register No: 425	Date Received in Lab: 27/08/02	Time Sampled:
Date Sampled: 27/07/02	Sampler: HABEL	Bore RN:	Depth (m) 45.08
G.S.No:	G.H. (m)	Q:	Map:
G.R.:			

Location: MIMILI S.A.- BORE PERMIT No. 55352

020904k

Project No : PIT COUNCIL

ANALYSIS - PHYSICAL

	pH	[4500-H⁺B]	8.0		Colour (Hazen units)	[2120B]	
	Electrical Conductivity 25°C (uS cm^{-1})	[2510B]	1,659		Turbidity (NTU)'s	[2130B]	
/	Total Dissolved solids (mgL^{-1}dried 180°C)	[2540C]	1,026		Suspended Solids (mg L^{-1})	[2540B]	

ANALYSIS - CHEMICAL (mg L^{-1})

	Sodium, Na	[3111B]	272		Chloride, Cl	[4500-Cl⁻ B]	297
	Potassium, K	[3111B]	20		Sulphate, SO_4	[G]	108
	Calcium, Ca	[3111D]	25	X	Nitrate, NO_3	[4500-NO_3^- B]	87
	Magnesium, Mg	[3111B]	24		Bicarbonate, HCO_3	[2320B]	245
	Iron (total), Fe	[3111B]	0.2		Carbonate, CO3	[2320B]	0
	Total Hardness (as $CaCO_3$) calc	[2340B]	161		Hydroxide, OH	[2320B]	0
	Total Hardness (as $CaCO_3$) titr	[2340C]		X	Fluoride, F	[4500-F⁻ C]	1.7
	Total Alkalinity (as $CaCO_3$)	[2320B]	201		Sodium Chloride, NaCl (calc from Cl)		489
	Silica, SiO_2	[4500-Si D]	72		Dissolved Oxygen	[4500-O B]	

ANALYSIS - ADDITIONAL (mg L^{-1})

\# U/S DENOTES UNSUITABLE FOR ANALYSIS
\# I/S DENOTES INSUFFICIENT SAMPLE
\# F DENOTES FILTRATE ANALYSIS C1 425 020904k
\# T DENOTES TOTAL ANALYSIS

This report relates specifically to the "samples tested as received".

The test methods used (denoted within brackets) refer to the 1992 18th edition of "Standard Methods for the examination of Water and Wastewater", A.P.H.A. Except [G] which refers to the method of R. Goguel, Anal. Chem. 1969, 41, 1034.

DATE : 12/09/02

CHECKED : KRoss

SIGNATORY :

Boxes marked thus indicate :

☐ Levels are within the limits as quoted in the "Guidelines for Drinking Water Quality in Australia", 1987 N.H.& M.R.C. and the A.W.R.C.

/ Levels exceed non health related limits.

X Levels exceed health related limits.

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Northern Territory Government
Department of Business, Industry & Resource Development

RESOURCE PROTECTION DIVISION
WATER CHEMISTRY LABORATORY

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Bottle No: QV28	Lab Register No: 426		
Date Received in Lab: 27/08/02	Time Sampled:	Date Sampled: 31/07/02	
Bore RN:	Depth (m) 37.2	Q:	Map:
G.S.No:	G.H. (m)	Q:	G.R.:
Sampler: HABEL			
Location: MIMILI S.A.- BORE PERMIT No. 55354	020904k	Project No : PIT COUNCIL	

ANALYSIS - PHYSICAL

	pH	[4500-H⁺B]	7.9		Colour (Hazen units)	[2120B]	
	Electrical Conductivity 25°C (uS cm^{-1})	[2510B]	1,868		Turbidity (NTU)'s	[2130B]	
/	Total Dissolved solids (mgL^{-1}dried 180°C)	[2540C]	1,149		Suspended Solids (mg L^{-1})	[2540B]	

ANALYSIS - CHEMICAL (mg L^{-1})

/	Sodium, Na	[3111B]	334		Chloride, Cl	[4500-Cl^- B]	364
	Potassium, K	[3111B]	17		Sulphate, SO_4	[G]	121
	Calcium, Ca	[3111D]	38		Nitrate, NO_3	[4500-NO_3^- B]	8
	Magnesium, Mg	[3111B]	32		Bicarbonate, HCO_3	[2320B]	266
/	Iron (total), Fe	[3111B]	3.0		Carbonate, CO3	[2320B]	0
	Total Hardness (as $CaCO_3$) calc	[2340B]	226		Hydroxide, OH	[2320B]	0
	Total Hardness (as $CaCO_3$) titr	[2340C]		X	Fluoride, F	[4500-F^- C]	1.8
	Total Alkalinity (as $CaCO_3$)	[2320B]	218		Sodium Chloride, NaCl (calc from Cl)		600
	Silica, SiO_2	[4500-Si D]	75		Dissolved Oxygen	[4500-O B]	

ANALYSIS - ADDITIONAL (mg L^{-1})

U/S DENOTES UNSUITABLE FOR ANALYSIS
I/S DENOTES INSUFFICIENT SAMPLE
F DENOTES FILTRATE ANALYSIS
T DENOTES TOTAL ANALYSIS

C1 426 020904k

This report relates specifically to the "samples tested as received".

The test methods used (denoted within brackets) refer to the 1992 18th edition of "Standard Methods for the examination of Water and Wastewater", A.P.H.A. Except [G] which refers to the method of R. Goguel, Anal. Chem. 1969, 41, 1034.

DATE: 12/09/02

CHECKED: KKoin

SIGNATORY:

Boxes marked thus indicate:

- [ ] Levels are within the limits as quoted in the "Guidelines for Drinking Water Quality in Australia", 1987 N.H.& M.R.C. and the A.W.R.C.
- [/] Levels exceed non health related limits.
- [X] Levels exceed health related limits.

APPENDIX 5 Transient Electromagnetic (TEM) Surveys for groundwater

Introduction

The TEM method measures the electrical resistivity of the ground. For groundwater surveys the main interest is a resistivity sounding, which assumes that the ground is laterally homogeneous, ie. that changes in resistivity only occur with depth. From such soundings can be interpreted the depth to crystalline basement and the nature of the sedimentary cover, factors which are basic to the search for groundwater and which are rarely evident at surface. For example, areas of deeper basement often act as collecting points for local recharge, while sandy layers are evidently better water producers than clay. Also, ground resistivity is a direct indicator for the presence of groundwater, since most ground is highly resistive without it, and for the quality of the water, since the resistivity of the water decreases as the salt content goes up.

Thus the electrical resistivity of the ground can be a useful tool for the direct and indirect delineation of groundwater. TEM is a cost-effective method for measuring that resistivity.

The finding of groundwater

Where do we start? The hydrogeologist is presented with the problem of finding water in an area that may be as large at a sheep station or as small as a back yard. He is told what water quality is needed - fresh water for feeding to children or quite saline (stock water) suitable only for sheep in the outback. And he knows how much water - supply - is required - perhaps enough for the operation of a mine or perhaps only enough to hand pump for a small camp water supply. All of these factors will affect how he looks for water, but the basic first step will always be to look at the geology of the area.

Geology controls where water could be stored in the ground. The first requirement is a porous rock in which water can move - an aquifer. In a sedimentary environment such a rock might be a sandstone or limestone, where a whole layer might have these characteristics. In more massive rocks such as crystalline granites or metasedimentary shales, the porosity may depend on rock fractures where faulting has broken up the rock. The search for water starts with a geological study of the area looking for features such as these, determining which type of aquifer might be present. This study is usually done from geological maps and air photographs, but should involve some fieldwork since nothing can substitute for personal observations.

Having decided what sort of aquifer should be sought, the next step is to find the aquifer itself. This may be a simple matter, as in the case of the Great Artesian Basin where the aquifer is continuous over vast areas. Other aquifers are more limited in extent, particularly fracture zones. These must be pinpointed as accurately as possible before the ultimate test, drilling a well, is attempted. Topography may help in picking locations where sedimentary layers may be thicker or may contain more water. Alternatively, geophysical methods may be used to map, indirectly, sedimentary layers or fracture zones. Such methods may also be used to search for groundwater directly. Finally, water dowsing or divining, an art which currently lacks satisfactory scientific explanation but appears to have had success in some hands, can be used to detect groundwater directly.

The combination of air photographs and airborne magnetics can be very useful, particularly when large areas are to be covered. Fracture zones frequently show as lineaments on one or both of these. Also, general geological and topographic information is often evident.

Ground resistivity often yields valuable information on groundwater. Generally the quantity and quality of the contained water determines the resistivity of the ground, so the measurement of this parameter is a good indicator. Resistivity techniques look below the surface of the ground, adding a third dimension to the information available. However, clay, which is generally an aquitard, usually contains water and is highly conductive, while saline groundwater is much more conductive than fresh, so the use of ground resistivity is by no means definitive. It is one more tool to help in understanding the distribution of water and rock beneath the surface.

The final test in all water searches is drilling a well. All the preceding activities lead up to this final test, without which no conclusive proof of the presence or absence of useable water can be claimed. Since drilling is an expensive and intrusive operation, every effort should be made to ensure that each well is located on the best site possible.

Methods for measuring ground resistivity

Ground resistivity can be measured galvanically (VES) or inductively (TEM), the main difference being that the former involves electrical contact with the ground while the latter does not.

Vertical Electrical Soundings (VES) involve injecting electrical current into the ground through two current electrodes and measuring the potential drop between two other (potential) electrodes, the four electrodes usually being in a straight line. The depth penetration is a function of the separation of the electrodes. Usually a series of readings are taken at a range of electrode separations, from which the variation of ground resistivity with depth can be interpreted.

For TEM surveys the energising current is passed through a loop of wire, as described more fully below, and eddy currents are induced in the ground. The distribution of eddy currents is likewise detected inductively, with the depth penetration being a function of time. Thus one reading is sufficient for a full sounding.

VES		**TEM**	
Advantages	*Disadvantages*	*Advantages*	*Disadvantages*
• Simple principle • Simple equipment • Sensitive to resistive layers	• Ground contact required • Long spread of electrodes reqd for deep penetration • Many readings for one sounding	• No ground contact reqd. • One reading for all depths • Sensitive to conductors • Fast • Simple to use • Equidimensional array • Spatial averaging	• Insensitive to resistors • Complex to invert • Expensive equipment

The TEM survey method

A loop of wire, usually 50 or 100 metres square, is laid on the ground and a short pulse of current transmitted through it. On the abrupt termination of this pulse, eddy currents are induced in the ground. Initially these currents are located immediately below the transmitter loop, but they migrate out and down with time until they effectively vanish. The rate of migration depends on the ground resistivity, being faster in resistive ground and slower in more conductive ground.

The ground eddy currents generate a secondary electromagnetic field that is detected by the receiver loop, this being the same as the transmitter loop. This secondary field is measured at a series of delay times and since the response is dependant on the distance between the eddy currents and the receiver loop, the rate of decay indicates the resistivity of the ground through which the eddy currents are passing.

Analysis of this decaying response yields the ground resistivity as a function of depth.

In practice the response is too small to measure directly (low signal-to-noise ratio) and it is therefore stacked, under microprocessor control, by taking up to 1000 individual measurements and accumulating them. The signal is additive, while the noise largely cancels itself out.

Data Processing

The basic measurement is a voltage response, measured in microvolts/amp. This response voltage can be easily converted into an apparent resistivity, which is the resistivity that all the ground under the loop would have to have to yield that particular response voltage at that delay time (the half-space response). This apparent resistivity gives a general idea of resistivity variations in the ground, but lacks details of depth and formation resistivity. To get these the voltages must be inverted, on the assumption that the ground comprises only horizontal layers of different resistivity. The theoretical TEM response of such layers can be approximated mathematically. An initial layered model can then be successively adjusted to fit the measured response as accurately as possible. However, this is an involved process requiring considerable computer resources, and has only really become practicable in recent years with the improvement in computer capabilities. There are several software packages available for doing this; GRENDL, an inversion package devised by CSIRO is one of the better known and is incorporated in the EMVISION data processing package marketed by ENCOM in Sydney. The DWR software package GRENOCC is based partly on GRENDL, but has the advantages of permitting many layers (up to 40) and of starting with a homogeneous half-space as an initial model (Dodds, 1992). While 40 layers may seem excessive, this has the additional advantage of allowing the gradual changes in resistivity which are common in nature. All packages yield the ground resistivity as a function of depth at each station. These figures are much more useful than the apparent resistivities but must be used with caution, as they are the result of an interpretation procedure that includes some assumptions, and may not be totally accurate. Usually, however, the main features of the inversion are correct, and any inaccuracies are restricted to the detail.

Presentation of Results

The results are presented as contoured resistivity sections. The horizontal axis shows distance along the ground surface, while the vertical axis shows depth below ground or elevation, depending on whether surface elevations were available for the particular traverse. The contour fill and levels are selected to show the more important variations in resistivity, and are usually consistent for all sections in a set. Contours are spaced logarithmically as this normally shows variations in resistivity more effectively.

Interpretation of Results

The resistivity sections described above show resistivity variations in the sub-surface, both laterally and with depth, to the extent that the inversions are correct. In most cases it is anticipated that the general pattern will be correct, although some of the detail may be inaccurate because nature is complex, and it is necessary to simplify the model to allow mathematical modelling.

The greatest problem in using the resistivity parameter for groundwater search lies in the ambiguity of indications. The ground resistivity is a function of water content and the salinity of the water. A decrease in resistivity can result from an increase in the water content of the ground or from an increase in the salinity of the contained water, two possibilities which have opposite connotations so far as a desirable water source is concerned. Further, water tends to be held in clay and to be more saline, while it moves through open textured sand with ease and tends to be fresher. Thus the latter, which would be the better water source, will be more resistive. It is evident that there is no simple interpretation of the nature of “drill the conductors”. Each situation must be interpreted in the light of local geology, and even so there is every possibility that a resistivity feature, whether of high or low resistivity, will turn out to be other than expected on drilling.

As a general guide, the causes of resistors and conductors may be:

Resistors:

- dry material above the water table. This may still be porous.
- material of very low porosity, such as granite or other crystalline basement above or below the water table.
- porous material below the water table, but containing water of lower salinity than elsewhere.

Conductors:

- material containing more water than the surrounds, such as fracture zones in basement.
- material containing more saline water than the surrounds.
- clays, in which water does not move readily.
- metallic or graphitic conductors, which are not usually encountered in groundwater situations.

Reference

Dodds, A.R., 1992. Improvements in electrical (TEM) sounding inversion techniques. South Australia. Quarterly Geological Notes, 123:11-17.