AGSO

Western Water Study
(Wiluraratja Kapi)

Hydrogeology of the Yuendumu - Papunya - Kintore Region, Northern Territory

Notes to accompany the Western Water Study 1:500 000 Major Aquifer Systems Map

by

John Wischusen

Record 1998/31

AGSO
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

RECORD 1998/31

WESTERN WATER STUDY
(WILURARATJA KAPI)

HYDROGEOLOGY OF THE YUENDUMU - PAPUNYA - KINTORE REGION, NORTHERN TERRITORY

Notes to accompany the Western Water Study 1:500 000 Major Aquifer Systems Map

BY

JOHN WISCHUSEN

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION
1998

DEPARTMENT OF INDUSTRY, SCIENCE & RESOURCES

Minister for Industry, Science & Resources: Senator the Hon. Nick Minchin
Secretary: Russell Higgins

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Executive Director: Dr Neil Williams

ISSN: 1039-0073
ISBN: 0 642 27368 5

CONTENTS

FIGURES

TABLES

PHOTOS

8. A gneiss of the North Arunta System between Nyirripi and Ethel Creek. This outcrop is capped with laterite.

9. The north face of Mt. Udor in the South Arunta System.

10. Vaughan Spring on the southeast flanks of the Truer Range. This spring is part of the Pikilyi Springs originally used by the Walpiri people. In the middle of the clump of trees, Vaughan Spring discharges at a rate of about 2 L/s from laterite-capped Cainozoic gravels and sands.

11. Illpili Spring, Ehrenberg Ranges, South Arunta System. Permanent water is obtained by digging near the *Melaleuca* trees shown.

12. Putardi Spring at the base of Mt Putardi, South Arunta System.

ABSTRACT

The hydrogeology of a 68 000 km^2 region of arid central Australia has been assessed and mapped at 1:500 000 scale using a GIS to interpret various spatial data sets and compile statistics of water bore information. This work forms a part of the Western Water Study, a collaborative venture between Federal, Territory and Aboriginal representative agencies, which has the objective of improving access to groundwater information for Aboriginal people on their land. The study area is underlain by Proterozoic basement (Arunta Block), pre-Mesozoic sedimentary basins (Amadeus and Ngalia Basins) and Cainozoic sediments. Based on the analyses of 850 water bores, the study area is mapped as seven different aquifer systems to cover regional variations in hydrogeology. Palaeodrainages act as a sink along which groundwater drains to associated internal discharge playas. Statistical groundwater data for these systems and the individual geological formations drilled provide a starting point for further groundwater assessment in other areas of central Australia that have similar geology. Only one aquifer system representing about 3% of the study area in Cainozoic sediments along a mountain range consistently provides low salinity (< 1000 mg/L) potable groundwater, though potable water can occasionally be found elsewhere throughout the region. Large individual bore yields of over 20 L/s can be found in the pre- Mesozoic and Cainozoic systems while a lack of storage precludes sustained high yield production from bores in the Proterozoic.

Modern localised and indirect groundwater recharge is known in the vicinity of Proterozoic basement ranges and is thought probable near the edges of Cainozoic sediment cover. Elsewhere in the region, recharge has not been observed, though bore monitoring data are sparse. Stable isotope data on groundwaters from the pre-Mesozoic basins and Cainozoic aquifer systems show an evaporation effect. If only indirect and localised recharge occurs, then the stable isotope data may reflect a residual signal from a time when climatic conditions were wetter and a direct recharge mechanism operated (i.e. an Interglacial, pluvial period). Under such conditions saline and evaporated vadose water stored during arid times may have entered the sedimentary aquifer systems. Thus groundwater in these systems may be considered a mix of waters recharged by various mechanisms at different times. The lack of observed recharge and the demonstrated slow groundwater movement within the pre-Mesozoic aquifer systems may mean that sustainable extraction is not possible, and that the resource is being mined. As hydrogeological and climatic data are limited, detailed studies of groundwater flow and the magnitude and frequency of recharge should accompany any major groundwater development in this arid area.

1. INTRODUCTION

These notes refer to the accompanying 1: 500 000 scale Aquifer Systems Map of the Western Water Study *(Wiluraratja Kapi)*, Northern Territory. Due to the sparsity of drilling data the hydrogeology is poorly known over much of the area. Consequently the map does not follow the international standard for aquifer systems (Struckmeier and Margat, 1995) where recharge areas and processes are delineated, but is more a preliminary overview showing regions perceived to have similar hydrogeology. The Western Water Study covers 58 000 km^2 of Aboriginal land and 10 000 km^2 of pastoral land in the southwest of the Northern Territory comprising four 1: 250 000 map sheets (Fig. 1).

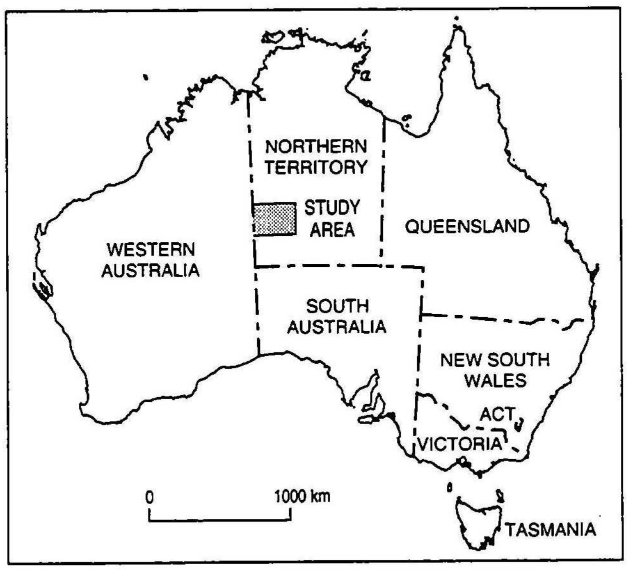
This arid region has several major Aboriginal communities, numerous Aboriginal outstations and two pastoral homesteads. All these settlements rely on groundwater supplies. Previous groundwater studies have usually been at local sites such as community borefield development or individual stock or outstation bore programs. A major aim of this study was to synthesise existing groundwater information into a readily accessible form for the benefit of local stakeholders. This work was undertaken as a collaborative project between the Australian Geological Survey Organisation (AGSO), the Water Resources Division of the Department of Lands, Planning and Environment, NT (DLPE), the Central Land Council (CLC) and Aboriginal communities in the region.

Much effort was expended in collating geological and remotely sensed data sets, checking and interpreting existing and new drill hole data and incorporating these data into a Geographical Information System (GIS). The data sets included in the Western Water Study GIS are described elsewhere by Wischusen et al. (1997). Other aspects of the Western Water Study have previously been reported: Woodcock et al. (1997) discussed remote sensing data interpretation; English (1997) looked at major lineaments over the region and their influence on groundwater prospects; Gallagher (1996, 1998) reported on specialized applications of the GIS and how they may be useful elsewhere; and Macphail (1997) presented Cainozoic palynological data. Several special 1:500 000 geological maps over the Western Water Study region have been compiled: Lau (1997) has compiled a geology map; Lau et al. (1997) a Cainozoic geology map; and Lau and Shaw (1997) a solid geology map. In addition, Toyne et al. (1997) reported on the consultations with Aboriginal communities in the region and outlined a proposal for bicultural water management committees. Hostetler et al. (1998) reported on groundwater quality in the region and Cresswell et al. (1998) discussed aspects of isotope hydrology in the region.

All the information outlined above has been used to some degree in defining and delineating the Aquifer Systems of the Western Water Study region, and the GIS was found to be a very useful tool for classifying large bore data sets and tabulating drilling and chemistry data. There is no drilling data for extensive parts of the study area, and therefore much of the interpretation is based on extrapolation.

2. SETTING

The study area encompasses a variety of geological terrains and landforms. The commonest landform is colloquially known as *sandhill country*, Perry et al. (1962) classified this terrain as the Simpson Desert land system. Much of the southern half , and a fair portion of the northern half, of the study area, is overlain by sand dunes (Photo 1). Areas without much sand dune



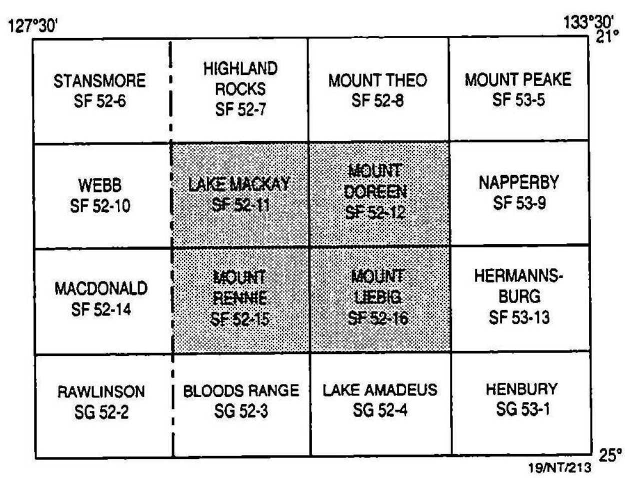


Figure 1. Location of the Western Water Study area, southwest Northern Territory. Area of study is approximately 68 000 km^2.

development correspond approximately to the north and south Arunta aquifer systems marked on the map. Elsewhere regions of high relief such as the Irridiki and Gardiner Ranges at the eastern part of the Amadeus aquifer system and the Naburula Hills and Walbiri Range along the northern edge of the Ngalia aquifer system also mark regions with little sand dune development. Wilson et al. (1990) mapped almost the entire study area as Hummock (spinifex) grasslands with variations in spinifex species and/or overstorey species distinguishing between the six different types recorded.

This region is arid: records at Alice Springs 200 km from the eastern boundary show mean pan evaporation at around 3800 mm/yr to exceed the highly (inter annual) variable precipitation (median 256 mm) by an order of magnitude (Climate, 1986). Summaries of physiography, climate, early geological work and groundwater resources were included in the geological mapping notes for the four 1:250 000 maps that cover the Western Water Study (Nicholas, 1972; Ranford, 1968, 1969; Wells, 1972; Young et al., 1995) and in special regional geological mapping studies that have covered portions of the region (Blake et al., 1979; Wells et al., 1970; Wells and Moss, 1983).

3. OVERVIEW OF AQUIFER SYSTEMS

3.1 Amadeus System

This system encompasses the portion of the Amadeus Basin which occurs in the Western Water Study region. The Amadeus Basin is an intracratonic depression filled with Late Proterozoic and Paleozoic sediments, that occurs over a large area of central Australia (Wells et al., 1970). Lau and Jacobson (1991) overviewed the aquifer characteristics of the different sedimentary units within this basin. Indurated sandstones and limestones are the main aquifers, and fractures and/or joints enhance aquifer properties in some locations. The potential significance of this system is illustrated by the Alice Springs town supply where 10 x 10^6 m^3 per year is drawn from Amadeus Basin aquifers (Jolly and Chin, 1992).

In the study area water bore drilling data is sparse for this system, also much of the drilling was originally conducted as part of petroleum exploration activities where groundwater was not an objective. Therefore most of the knowledge of this system is based on extrapolating from the known drilling data from outside the study area. Outcrops of the main aquifer formations (e.g. Photo 2), identified by Lau and Jacobson (1991), are represented as an ornament cover on the mapped Amadeus system to show areas of potential groundwater development. The formations that make up the ornament cover are the Hermannsburg, Mereenie, Pacoota and Carmichael Sandstones and the Goyder Formation, a calcareous sandy unit. It should be noted that the ornament cover is useful as a guide only, in some instances ornamented areas represent the top of a range, or an area surrounded by sand dunes that is inaccessible to drilling equipment.

The drilling and groundwater quality data for this system are presented in Tables 1 and 2. Moderate quality water of mean salinity, expressed as Total Dissolved Solids (TDS), 1480 mg/L from about 50% of bores are recorded for this system in the study area. The limited drilling and groundwater quality data for individual Amadeus Basin formations is presented in Table 3 and 4; it has been combined with the data of Lau and Jacobson (1991) to give a better statistical indication of aquifer properties. From this data it can be seen that no frequently drilled formation has a mean TDS value of less than 1000 mg/L, although supplies are often significant from these

Table 1. Summary of drilling data for the Western Water Study Aquifer Systems.

	DEPTH DRILLED ALL BORES (m)						DEPTH DRILLED YIELDS > 0.1 L/s						YIELD (L/s)					SWL (m)		
SYSTEM	sample #	mean	median	mode	sigma	range	sample #	mean	median	mode	sigma	range	mean	median	mode	sigma	range	mean	sigma	range
Mountain Front	95	58.5	55.5	52.4	24.4	13 - 171	68	64.4	59.8	37	24.7	30 - 171	1.8	1	0	2.5	0.1 - 16.2	27.1	20.2	0? - 60.1
Cainozoic	165	59.4	37	12.2	61.3	0 - 252	101	51.3	38.1	12.2	48.6	5 - 244	3.2	0.5	1	4.6	0.1 - 25	11	7	0? - 42.7
Ngalia	156	97.6	81.5	91.4	79.1	1.5 - 380	101	128	114.3	128	78.7	12.8 - 380	3.5	2	0.1	4.8	0.1 - 30	36.9	19.3	2.7 - 129.7
Amadeus	63	97.7	95.7	152.4	68.8	7.3 - 277	29	132.9	130	n/a	61.9	16.8 - 277	1.6	1	0.1	2	0.1 - 10	45.3	47.9	0? - 168.5
South Arunta	147	33.7	26.4	61	23	2.4 - 100	77	41.2	36	100	23.2	8.5 - 100	1.4	0.5	0.1	2.5	0.1 - 15	7.1	6.9	0? - 36
North Arunta	204	46.5	37.5	30	33	0? - 200	79	53.3	45.1	90	28.3	13 - 128	1.1	0.6	0.1	1.2	0.1 - 4.9	15	13.1	0? - 50

Table 2. Summary of basic water quality criteria (TDS, nitrate and fluoride) for groundwaters sampled from the Western Water Study Aquifer Systems

SYSTEM		Total dissolved solids (mg/L)					Nitrate (mg/L)			Fluoride (mg/L)		
	sample #	mean	median	mode	sigma	range	mean	sigma	range	mean	sigma	range
Mountain front	217	922	900	860	268	390 - 2159	19.9	14.3	0 - 99	1.1	0.5	0 - 5
Cainozoic	235	3178	1690	1470	3809	240 - 32218	41.7	31.3	0 - 190	1.5	0.9	0 - 6
Ngalia	323	1774	1300	1050	1958	190 - 21268	18.8	34	0 - 224	0.9	0.7	0 - 7
Amadeus	127	1480	1280	1300	1037	80 - 7218	9.8	9.9	0 - 59	1.1	0.8	0 - 4
South Arunta	147	1017	760	760	630	240 - 4830	60.8	50.5	1 - 247	1.5	0.8	0 - 7
North Arunta	126	3656	1945	1090	5078	75 - 40200	56.9	67.3	0 - 423	2.5	1.8	0 - 8
Playa	2	277000				274000 - 280000	505		430 - 580	n/a		

bores that usually exceed 100 m in depth. However, Lau and Jacobson (1991) may have already included some data from the Western Water Study region in their data compilation, therefore these combined statistics may be skewed, i.e. some bores may be counted twice

The hydrochemical data for this system (Fig. 2) shows sulphate-chloride bicarbonate type water in the study area, although as Jacobson et al. (1989a) presented a range of different dominant anion types for groundwaters in the Amadeus Basin, these data may not necessarily characterise all formations within this system. Sulphate-type waters can be the result of long travel times and distances within an aquifer system (Freeze and Cherry, 1979) or can indicate that water has passed through gypsiferous sediments (Mazor, 1991). Given the long travel times and distances postulated for the Amadeus Basin aquifers (e.g. Brown et al., 1990) and recorded gypsiferous sediments within the Basin (e.g. Chandler Formation, Wells et al., 1970) a sulphate-type water is not unexpected for some formations of the Amadeus Basin.

Apart from targeting favourable formations it is not immediately clear what strategies should be adopted to enhance prospects for potable (low salinity) groundwater supplies. The known large resources of low salinity (< 1000 mg/L TDS) water near Alice Springs occur on the northern edge of the basin in the vicinity of major streams such as Todd River and Roe Creek. This may indicate that proximity to significant drainage lines maximises prospects for potable supplies. Apart from the Deering Creek that mainly traverses the Cainozoic system, there are no major drainage lines over the Amadeus system in the study area, thus the prospects for large potable supplies may be diminished in this region.

3.2 Ngalia System

This aquifer system is largely made up of the Kerridy and Mt Eclipse Sandstones of the Ngalia Basin sedimentary sucession, although other Ngalia Basin units can be found along the southern and northern margins of this system. The geology of the Ngalia Basin was described by Wells and Moss (1983) who mapped much of the area marked as Ngalia system on the Aquifer Systems map as being underlain by Late Palaeozoic sedimentary sequences including the Kerridy and Mt Eclipse Sandstones. These sandstones (Photo 3) are arkosic sequences many hundreds of metres thick that overlie older units of the Ngalia Basin.

This aquifer system is tapped for several outstation and stock watering points as well as providing the Yuendumu community water supply. Yields are moderately high from deep bores (median 114 m) and more than half the successful bores encounter water with salinities less than 1500 mg/L TDS (Tables 1, 2). The extensive area and thickness of this system indicate that groundwater storage may be significant in the Ngalia Basin. Detailed studies at the Yuendumu borefield show that yields from some late Palaeozoic rocks are likely to be enhanced by development of fractures (Berry, 1991) although the primary porosity storage within the arkosic sandstones may provide much of the resource.

The Ngalia groundwaters plot as chloride- bicarbonate - sulphate waters on the fingerprint plot (Fig. 2).

Drilling and groundwater quality data for individual geological formations that comprise the Ngalia aquifer system are shown in Table 3 and 4, where it can be seen that most units have similar characteristics. These formations are shown on geological maps and can therefore be

Table 3. Summary of drilling data for individual geological formations in the Western Water Study area. Data for some Amadeus Basin formations has been merged with previously published data of Lau and Jacobson, 1991.

Geological Formation	symbol	DEPTH DRILLED (m) ALL BORES						DEPTH DRILLED (m) YIELDS > 0.1 L/s						YIELD (L/s)				SWL (m)		
Cainozoic Formations		sample #	mean	median	mode	sigma	range	sample #	mean	median	mode	sigma	range	mean	median	mode	range	mean	sigma	range
Tertiary; sands gravels and minor clays	TPY	9	94	56	40	68	38 - 192	8	83	53	40	62	38 - 192	4	3	1.5	1.2 - 10	26	12	9 - 45
Tertiary: clay silt minor sand	TPK	6	94	91	n/a	54	24 - 189	5	108	94	n/a	47	68 - 189	3.2	1.3	n/a	0.3 - 10	18	25	0 ? - 46
Quaternary alluvial	QA	0																		
Quaternary granitic residual	QG	2											13 - 130				0 - 1			0 - 41
Quaternary calcrete	QL	66	15	11	7.6	14	0 - 73	39	16	11	7.6	16	0 - 73	2.2	1.9	2.5	0.1 - 10	6.2	6.7	0? - 29
Quaternary alluvial sheet wash	QR	9	5	2.4	12	5	0 - 12	2	12	12	12	0	12 - 12	1	1	n/a	0.6 - 1.4	5.5	0.8	4.9 - 6.1
Quaternary aeolian	QS	10	12	9	9	11	4 - 38	2	24	24	n/a	21	9 - 38	1.25	1.25	n/a	0.6 - 1.9	13	13	4 - 27
Cainozoic undifferentiated	CZ	105	53.7	52.4	42.7	27.7	.5 - 159.1	77	59.9	58.5	40.3	26.2	.5 - 159.1	2	1.1	0.1	0.1 - 16.2	22	18.9	0? - 51
Cainozoic composite statistics		208	39.9					133	49					2.2				17.1		
Ngalia formations																				
Mount Eclipse Sandstone	1788	85	90	80	0	77	0 - 380	53	110	95	60	79	24 - 380	3.2	1.7	0.1	0.1 - 25	32	17	5 - 69
Kerridy Sandstone	1381	43	133	128	128	73	6 - 256	36	149	141	128	65	40 - 256	4.2	2.5	1.5	0.5 - 30	42	20	11 - 130
Djagamara Formation	876	1						1	70					0.5				29		
Walbiri Dolomite	2590	9	84	91	91	47	15 - 180	6	102	92	n/a	43	57 - 180	3.6	3.2	n/a	0.1 - 9	37	18	0? - 50
Yuendumu Sandstone	2851	6	93	91	91	15	79 - 122	3	97	91	n/a	22	79 - 122	1.1	0.5	n/a	0.5 - 2.3	50	13	42 - 65
Mount Doreen Formation	1786	6	186	185	n/a	59	114 - 249	3	193	220	n/a	69	114 - 244	15	18.7	n/a	1.5 - 25	7.6		
Vaughn Springs Quartzite	4642	19	89	81	50	57	26 - 200	9	62	50	50	33	26 - 128	1.3	1.5	1	0.1 - 2.5	17	11	0? - 33
Amadeus Basin Formations WWS area																				
Hermannsburg Sandstone	1217	10	103	99	152	51	23 - 165	3	113	91	n/a	46	81 - 165	2.6	1.5	n/a	1.3 - 5	68	35	43 - 92
Parke Siltstone	2062	2	187				150 - 225	1	225					0.5				113		
Pertnjara undifferentiated	4307	2	83				45 - 122	2	83				45 - 122	2.3	2.3	n/a	0.1 - 4.3	16		5 - 27
Mereenie Sandstone	4042	17	116	100	n/a	96	12 - 277	7	198	200	n/a	42	152 - 277	2.8	1.8	n/a	0.1 - 10	74	64	0? - 168
Carmichael Sandstone	627	6	75	43	n/a	68	18 - 175	5	86	48	n/a	69	24 - 175	1.3	1	1	0.1 - 3.2	41	55	0? - 136
Stairway Sandstone	2346	4	73	61	n/a	57	24 - 146	1	146					0.5				n/a		
Pacoota Sandstone	2042	4	91	81	n/a	37	61 - 41													
Goyder Formation	3738	1	188																	
Arumbera Sandstone	3158	6						6	96	106	n/a	41	111	2	1.6	n/a	0.7 - 5	43	23	14.2 - 80
Carnegie Formation	NT01	2						2	58	58	n/a	6	54 - 63	0.75	0.75	n/a	0.5 - 1	10	14	n/a
Bitter Springs Formation	3240	4	116	108	n/a	26	94 - 153	2	123	123	n/a	42	94 - 153	1	1	n/a	0.1 - 1.9	n/a		
Heavitree Quartzite	3787	13	20	13	n/a	14	2 - 44	8	25	23	n/a	15	9 - 44	1.1	0.5	0.5	0.1 - 3.3	8	6.5	0? - 21
Kintore Volcanics	NT04	27	31	31	25	14	55	20	32	34	25	9	9 - 50	3.4	1.7	0.1	0.1 - 15	4.3	3.7	0? - 16
Arunta block units																				
Arunta granites undiff.	PG	128	43	34	28	28	0? - 120	54	50	45	90	27	0? - 120	1	0.5	0.1	0.1 - 5	14	12	0? - 41
Arunta quartzites undiff.	PQ	4	64	58	n/a	28	40 - 100	1	100					0.1				?		
Arunta schists undiff.	PS	18	54	52	60	25	20 - 122	7	71	66	n/a	32	20 - 122	0.5	0.5	0.1	0.1 - 1	17	13	0 - 41
Arunta Block undiff	PA	111	45.8	45.3	1.5	29.3	0.7 - 183	53	58	54	30	30	15 - 183	0.6	0.5	0.1	0.1 - 3	12.5	15	0? - 60
Arunta unnamed mafics	PDL	2	64				37 - 91	1	37				1.3				12			
Lander Rock Beds undiff.	900	67	36	31	37	27	3 - 122	24	49	42	33	27	13 - 122	1	0.4	0.1	0.1 - 4.5	23	10	6 - 46
Lander ow grade (A)	900 A	25						14												
Lander high grade (B)	900 B	39						8												
WWS data (X) combined with Amadeus Basin regional data (Y) compiled by Lau & Jacobson, 1991.		Y + X						Y + X												
Hermannsburg Sandstone*	1217							91 + 3	139					3.1				34		
Mereenie Sandstone*	4042							121 + 7	158					5.7				66		
Carmichael Sandstone*	627							20 + 5	157					1.5				29		
Stairway Sandstone	2346							38 + 1	141					1.6				65		
Pacoota Sandstone	2042							49 + 0	144					3.9				50		
Goyder Formation	3738							19 + 0	173					3.9				50		
Arumbera Sandstone*	3158							32 + 6	146					2.3				33		
Bitter Springs Formation*	3240							17 + 2	102					1.7				22		
Cainozoic undiff	CZ	266 + 105	58.9					266 + 77	61					2.23				33		
Calcrete	QL	29 +66	20.8					27 + 39	24					2.7				7.3		

Table 4. Summary of basic water quality criteria (TDS, nitrate and fluoride) for groundwaters sampled from individual geological formations in the Western Water Study area. Data for some Amadeus Basin formations has been merged with previously published data of Lau and Jacobson, 1991.

Geological Formations		Total dissolved solids (mg/L)						Nitrate (mg/L)			Fluoride (mg/L)		
	symbol	sample #	mean	median	mode	stdev	range	mean	stdev	range	mean	stdev	range
Tertiary; sands gravels and minor clays	TPY	7	1956	1900	n/a	1125	580 - 3867	46	29	6 - 93	1.3	0.5	1 - 2
Tertiary: clay silt minor sand	TPK	7	1226	1152	n/a	448	790 - 2149	17	14	37 - 118	1.1	0.4	1 - 2
Quaternary alluvial	QA	1	197			n/a	n/a	33			0		
Quaternary granitic residual	QG	15	1193	1190	1150	39	1120 - 1245	15	4.7	3 - 22	1	0	0
Quaternary calcrete	QL	85	5579	5000	2010	3781	646 - 23990	58	44	0 - 217	1.7	1	0 - 5
Quaternary alluvial sheet wash	QR	10	2643	1404	n/a	3004	935 - 9926	89	51	36 - 165	1.4	1.3	0 - 4
Quaternary aeolian	QS	6	12820	8974	n/a	12258	2468 - 32218	16	22	0 - 45	0.7	0.8	0 - 2
Cainozoic undifferentiated	CZ	329	1311	970	860	1647	240 - 17340	23	22	0 - 66	1.2	0.7	0 - 6
Cainozoic composite statistics		461	2305										
Ngalia formations													
Mount Eclipse Sandstone	1788	72	1541	1107	590	1324	190 - 6400	21	29	0 -170	1.3	0.8	0 - 6
Kerridy Sandstone	1381	193	1514	1240	1330	1004	380 - 8450	7	10	0 - 58	0.8	0.5	0 - 3
Djagamara Formation	876	1	9016										
Walbiri Dolomite	2590	20	2767	2130	2030	1519	1870 - 6510	16	9	1 - 37	1	0.9	0 - 4
Yuendumu Sandstone	2851	21	1585	1622	1670	291	1100 - 2227	60	61	5 - 224	0.7	0.4	0 - 2
Mount Doreen Formation	1786	2	3277				705 - 5850	22			1		
Vaughn Springs Quartzite	4642	8	1829	1060	n/a	1923	240 - 5830	25	27	1 - 81	1.1	0.8	0 - 2
Amadeus Basin Formations WWS area													
Hermannsburg Sandstone	1217	5	824	540	n/a	509	440 - 1660	11	12	1 - 25	0.6	0.5	1 - 3
Parke Siltstone	2062	2	1196					7					
Pertnjara undifferentiated	4307	1	3680					21			6		
Mereenie Sandstone	4042	15	921	623	n/a	978	320 - 4193	6	7.6	0 - 23	1	0.6	0 - 3
Carmichael Sandstone	627	8	1136	1295	n/a	325	610 - 1380	18	24	1 - 57	2	0.8	1 - 3
Stairway Sandstone	2346												
Pacoota Sandstone	2042												
Goyder Formation	3738												
Arumbera Sandstone	3158	20	1119	1075	1020	281	750 - 1720	39	52	1 - 190	1	0.2	1 - 2
Carnegie Formation	NT01	4	1580	104	n/a	2967	80 - 6030	8	14	1 - 28	0.5	1	0 - 2
Bitter Springs Formation	3240	8	1903	1862	n/a	338	1427 - 2520	0.6	0.5	0 - 1	2	1	0 - 3
Heavitree Quartzite	3787	19	1793	760	760	2073	310 - 7218	42	21	1 - 60	1.4	0.8	0 - 3
Kintore Volcanics	NT04	35	675	670	670	60	535 - 810	58	11	23 - 80	1	0	1 - 1
Arunta block units													
Arunta granites undiff.	PG	88	3313	1730	746	4323	340 - 34300	74	81	0 - 423	2.5	1.8	0 - 8
Arunta quartzites undiff.	PQ	1	550					18			1		
Arunta schists undiff.	PS	16	1075	1370	1470	456	390 - 1520	48	33	1 - 83	1.6	1.3	0 - 5
Arunta Block undiff	PA	124	1178	1090	1300	544	390 - 3306	35	39	0 - 248	1.5	0.8	0 - 4
Arunta unnamed mafics	PDL	1	1100					62			2		
Lander Rock Beds unfiff.	900	51	2668	1688	n/a	2267	354 - 9878	60	46	0 - 165	1.9	1.8	0 - 8
Lander low grade	900 A	35	2670				719 - 9878						
Lander high grade	900 B	5	1612				818 - 1952						
WWS data combined with Amadeus Basin regional data compiled by Lau & Jacobson, 1991.													
Hermannsburg Sandstone	1217	76	2035				270 - 4040	43		1 - 127	2.1		1 - 6
Mereenie Sandstone	4042	118	1370				210 - 4000	33		1 - 160	1.9		1 - 6
Carmichael Sandstone	627	26	1219				400 - 3440	29		1 - 127	1.9		1-3
Stairway Sandstone*	2346	27	3743			4841	676 - 5050	46	34	2 - 88	1.9	0.4	1 - 2
Pacoota Sandstone*	2042	40	1554			2454	353 - 5510	29	46	1 - 120	1.7	0.5	1 - 2
Goyder Formation*	3738	16	1347			1223	326 - 4360						
Arumbera Sandstone	3158	48	1675				680 - 5430	45		1 - 190	1.2		1 - 2
Bitter Springs Formation	3240	19	2278				550 - 7108	11	-	0-76	2.3		0-5

Formations marked with asterisk* represent unchanged data from Lau and Jacobson, 1991.

targeted separately. As this system is largely comprised of Mt Eclipse and Kerridy Sandstone, strategies for improving groundwater prospects are limited. Enhancement of permeability, such as faults or folded strata, may improve yields while proximity to hilly outcrop areas may influence water quality in that recharge by concentration of runoff may be more frequent. The older, Adelaidian, rocks mapped to subcrop along the southern boundary of the system (Young et al., 1995) may be less prospective as Wells and Moss (1983) measured lower permeabilities than for the Paleozoic rocks. The Mt Doreen Formation has yielded 25 L/s to some bores (Table 3) and may therefore constitute a prospective formation in some places.

3.3 Mountain Front System

The Mountain Front System is characterised by alluvial sand, gravel and clay beds and is assumed to be unconfined. This system is classified following a description presented in Lerner et al. (1990) and Simmers (1997) where a portion of alluvial fan deposits adjacent to mountain fronts are classified on hydrological criteria as a distinct zone. While this system is hydraulically connected to the rest of the Cainozoic sediments (see map cross-section), proximity to run off from the mountains improves recharge and hence also water quality. Also, proximity to higher energy environments when deposited results in coarser lithologies in this system, which in turn enhances aquifer characteristics.

The drilling and groundwater quality data (Tables 1 and 2) show this system to have moderate bore yields (1.8 mean L/s) and quality (mean 922 mg/L TDS), and a relatively deeper water table when compared to the Cainozoic aquifer system, which is in keeping with a mountain front classification.

The bicarbonate-chloride-sulphate water type plotted for this aquifer system (Fig. 2) is supporting evidence of this system representing a recharge zone. Bicarbonate is the expected dominant anion in arid groundwaters close to recharge areas (Mazor, 1991).

The western extent of this unit is not well defined due to a lack of drilling data. On the map the system is shown to extend to the Talyi Talyi hills, however, other areas such as to the north of the Ehrenberg Ranges may have similar characteristics. The northern boundary of this system is inferred from data at only a few locations, thus this gradational boundary may vary from the line drawn in some places.

Strategies to improve prospects in this system are hard to define. The groundwater quality may improve closer to recharge zones, thus slight improvements in quality may be encountered along the edge of the mountain front close to any stream beds. As lithological variations occur in this alluvial fan sequence (Woolley, 1966; Rooke, 1991) some low yielding holes may be improved by drilling deeper in the expectation of encountering a favourable change in lithology. As this aquifer system appears to be a thick sequence of saturated sediments, significant amounts of water may be stored in this system.

3.4 Cainozoic System

Senior et al. (1994) reviewed Cainozoic sediments of the central Australian region, and some stratigraphic drilling. They observed that the geology, areal extent and boundaries of the Cainozoic sediments are poorly known in this region. Part of the Cainozoic aquifer system drawn

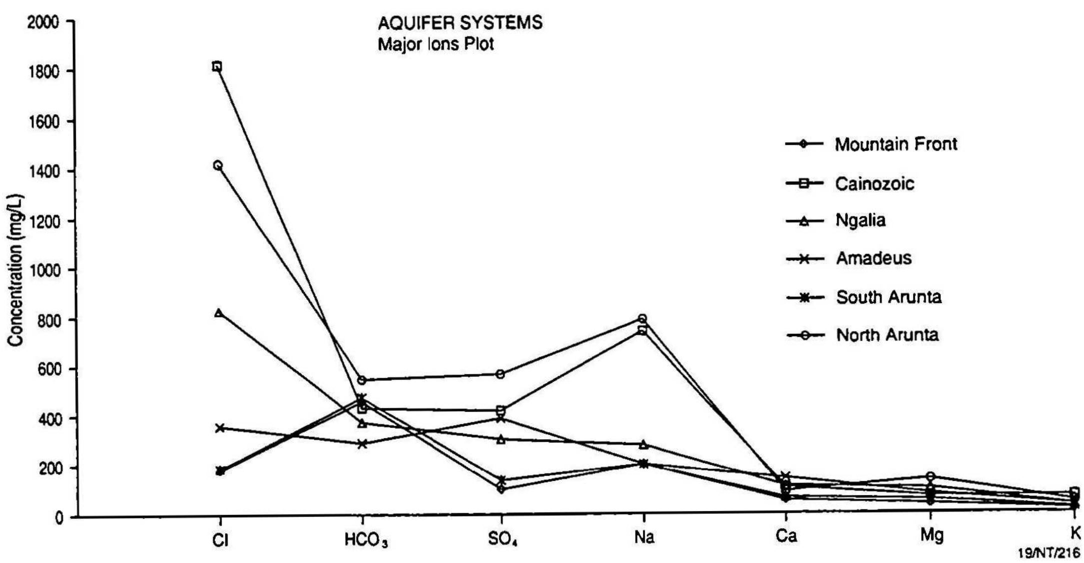


Figure 2. Plot of average chemical analyses of regional Aquifer Systems excluding the Playa System.

on the map coincides with the Mount Wedge Basin drawn by Senior et al. (1994), however, no data or discussion of this Basin was presented. Langford et al. (1995) mapped Late Oligocene to Middle Miocene fluvial/lacustrine sedimentation over much of the study area, and some more restricted Middle to Late Eocene fluvial sedimentation.

With the benefit of some recent drilling and remote sensing data, Lau et al. (1997) have interpreted the extent and thickness of Cainozoic sediments in the Western Water Study area. As large areas remain undrilled in this region, the extent and thickness for much of the Cainozoic remains speculative. Only very limited palynological data were recovered from sediments in the region due to a lack of preservation of fossil spores and pollen, however, preserved lignites sampled from around 80 m depth, 15 km northwest of Kintore, are provisionally dated as Oligo-Miocene (Macphail, 1997).

The Cainozoic system is characterised by alluvial and lacustrine sediments and calcrete. The map cross-section shows the generalised lithologies that may be present in this system. The conceptual model of this system is one of alluvial-filled valleys that may also mark the line of palaeodrainages. Woodcock et al. (1997) mapped a major palaeodrainage line that bisects the study area from east to west. This palaeodrainage coincides with mapping by Langford et al. (1995) who show this palaeodrainage starting 100 km east of the Western Water Study area. The palaeodrainage follows the chain of playa lakes near Central Mt Wedge (*Karrinyarra*) to Lake Mackay (*Wilkinkarra*) in the west (Photo 4, 5).

The drilling and groundwater quality data for the Cainozoic aquifers (Tables 1 and 2) shows that brackish water (mean 3178 mg/L TDS) at good yields (mean 3.2 L/s) is expected from modest depths (mean 51m). The various clay and sand lithologies encountered by drilling, may mean that both unconfined and confined aquifers are present.

The breakup of separate geological formation drilling and groundwater quality data (Tables 3 and 4), shows calcrete aquifers to have a higher mean salinity, 5579 mg/L TDS, than the Cainozoic system as a whole. Groundwater discharges at playa lakes where the water table is at or near the surface, and these playas are commonly bordered by calcrete. Jankowski and Jacobson (1989) and Bowler (1986) noted that saline groundwaters in the vicinity of other playas in central Australia are also associated with calcrete. The large calcrete outcrops ornamented on the Aquifer Systems map occur along the postulated east to west palaeodrainage and in other topographic low areas (Photo 6). Domahidy (1990) noted similar calcrete outcrops delineating palaeodrainages in the Tanami area of the NT, and Van de Graaf et al. (1977) noted “valley calcretes” tens of metres thick that extend tens of kilometres in palaeodrainages in Western Australia. Thus it may be that where deposits of groundwater calcrete occur, groundwater discharge processes increase the groundwater salinity, as evidenced by the data shown in Table 4.

This consideration has been incorporated into the Groundwater Prospects inset diagram shown on the map. The area marked in pink on this diagram depicts the major zones of calcrete outcrops and hence delineates where saline groundwater may be encountered. This area is not marked as a separate aquifer system as there are no drilling data in the western portion of the study area to confirm this interpretation. Also, it is likely that the large calcrete outcrops mapped further west, which are not near large playa lakes (Lau, 1997), do not have the same saline groundwater association. For instance Jacobson et al. (1988) found groundwaters in thick calcrete to be less than 3000 mg/L TDS at distances more than 5 km from playas along a transect at Curtin Springs, NT. Similarly Jacobson et al. (1989b) noted that freshwater lenses are sometimes found within calcrete.

The chemistry of this aquifer system is shown in Figure 2 where it can be seen that chloride-sulphate bicarbonate type water typifies this system. This may indicate that long transit times and/or concentration by evaporation has affected water chemistry in this system (Freeze and Cherry, 1979). The evolution of water chemistry is illustrated by comparing this system to the Mountain Front system chemistry (Fig. 4). On the Aquifer Systems map, the cross-section shows groundwater recharging at the Mountain Front system (bicarbonate type) and then moving through to the Cainozoic system where chemistry evolves to the Cl - SO_4 - HCO_3 type.

Groundwater quality data from this system suggest that potable supplies are not readily obtainable. One strategy that may improve potable water prospects is siting bores close to areas that may be prone to recharge, such as along the system boundaries or along the course of an ephemeral stream. The system boundaries and likely thicknesses are hard to define where drilling data are sparse, therefore the boundaries should not be regarded as accurate, especially in the west of the study area. Use of geophysical techniques, air photo studies and field checks should be considered if targeting the groundwater resources of this aquifer system.

3.5 Playa System

Bowler (1986) classified lake types across the climatic gradient from humid to arid within Australia; in arid areas he recognised two types, broadly classified as types D and E. Type D lakes are ephemeral, and type E lakes are those where surface water has little effect and groundwater processes dominate.

Playas within the Western Water Study region (Photos 4, 7) have not been studied in detail, however their morphology and geographical position allow some comparisons with playas elsewhere in central Australia. The lack of drainage lines running into these playas and their irregular shorelines match the morphology ascribed to type E playas. Bowler (1986) noted type E lakes to have brines over 220 g/L TDS under the playa surface and typically to be Na-Cl type waters. The two available chemical analyses from Western Water Study region playas (Tables 2 and 5) also show these characteristics.

The prospects for bore water supplies are obviously negligible in the vicinity of the playas and their associated brines, however Bowler (1986) and Jacobson and Jankowski (1989) presented several examples where groundwater salinity decreases rapidly to below 10 g/L within 15 km of hypersaline playas. Thus, in the Western Water Study region, highly saline groundwaters are probably only encountered in close proximity (< 15 km) to the playas.

It should be noted that on occasion these Type E lakes can fill. For instance Lake Macdonald (*Karrkurutintji*) southwest of Kintore was shown on aerial photography flown in July 1974, a particularly wet year, to be full of water. It may be that other playas in the region were also full during 1974. Kavanagh (1984) noted that in sandhill country in the vicinity of playa shores, perched fresh water lenses on the regional brine groundwaters were traditionally exploited for drinking water, with careful digging so that brines did not mix with fresh water.

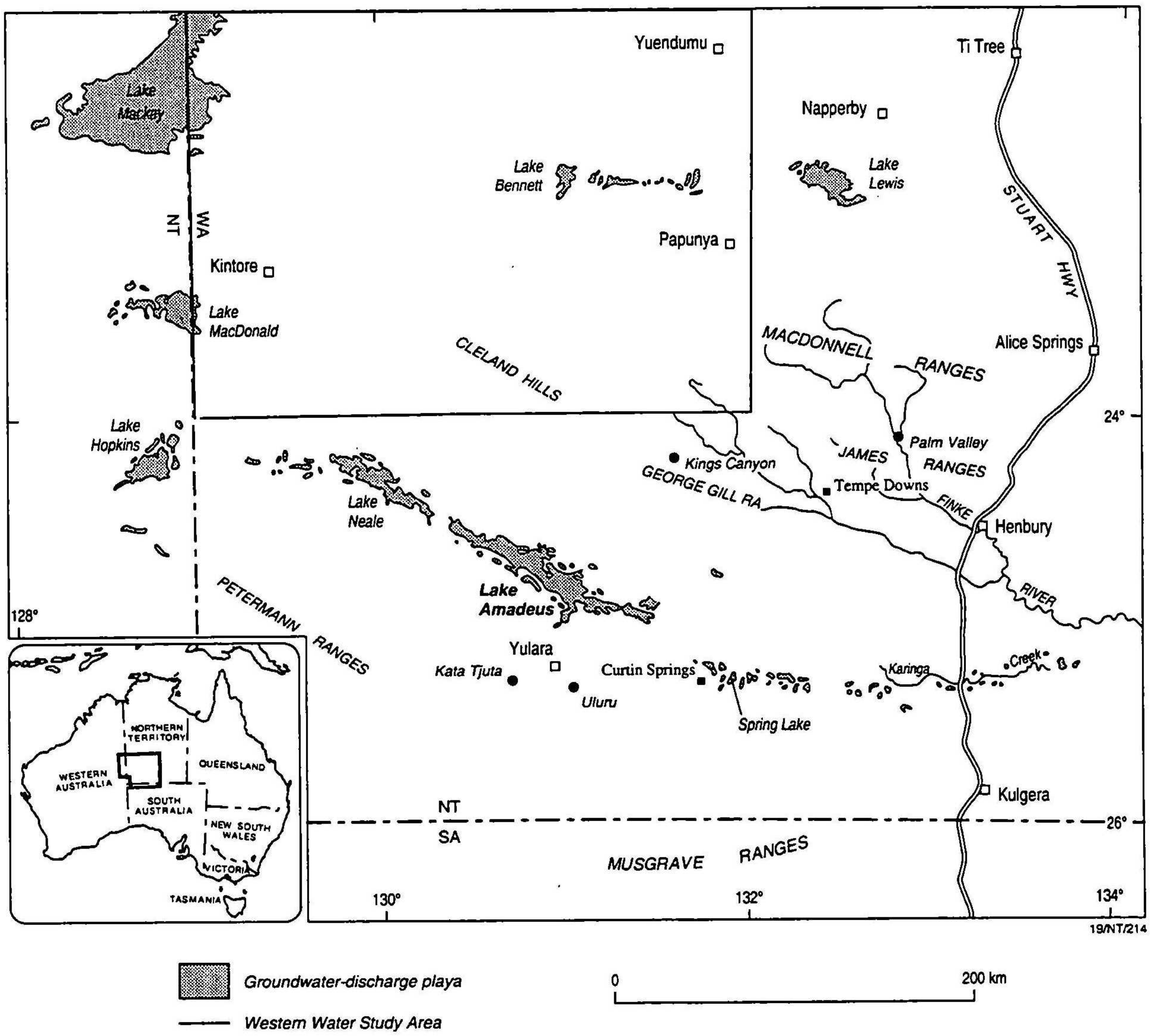


Figure 3. Map showing playa lakes in the region of the Western Water Study.

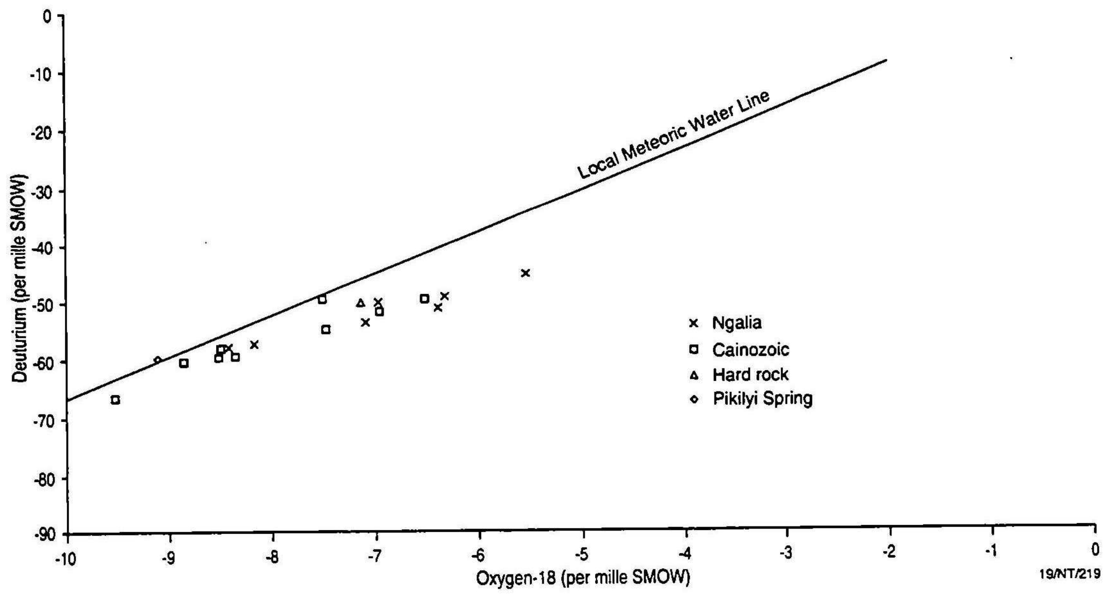


Figure 4. Stable isotope plot of some Western Water Study groundwaters. The Local Meteoric Water Line is the relationship of deuterium to oxygen-18 for Alice Springs rainfall data.

3.6 North Arunta System

The Arunta Block is an extensive metamorphic complex in central Australia. The area shown as the North Arunta aquifer system represents hard rock aquifers of the northern metamorphic province of the Arunta Block (Shaw et al., 1984) and is largely composed of the Lander Rock Beds, Nicker Beds and metamorphosed granite (Lau and Shaw, 1997; Young et al., 1995). Apart from the granite, these units are described in general terms as being fine-grained metasediments and muscovite-rich schists. This northern aquifer system is differentiated from the southern Arunta system outlined below on the basis of lithology and available drilling data.

From the drilling and groundwater quality data (Tables 1 and 2), it is evident that this system is a poor aquifer with a mean TDS of 3730 mg/L, and only one-third of bores striking water at yields greater than 0.1 L/s. This confirms previous assessments of groundwater in the Arunta Block in the Mount Doreen area (Wischusen, 1991; Matthews 1994, 1995). Possible reasons are that the fine-grained rocks of this system may be impermeable (Photo 8), fracture development may be of limited dimensions due to inhomogeneity of rock types, and/or weathering of micas and metasediments may have infilled some fractures with clay.

The chloride - sulphate - bicarbonate type water in this system (Fig. 2), may indicate that long residence time due to factors such as poor fracture connections, clay development and concentration by evapotranspiration, has resulted in chemically mature (Freeze and Cherry, 1979) groundwater. There may be a correlation between groundwater quality (fracture status?) and metamorphic grade as Lau and Shaw (1997) mapped the area northeast of Yuendumu as underlain by high-grade metamorphic Lander Rock Beds. This area has better than average groundwater quality (TDS <2000 mg/L).

Drilling data for different formations from the Arunta Block (i.e. North and South Arunta systems undifferentiated) are presented in Tables 3 and 4. Bores classified as tapping the undifferentiated Arunta are the most productive with 47% yielding > 0.1 L/s and 24% yielding >0.5 L/s. Undifferentiated granite is the next best with 42% yielding > 0.1 L/s and 22% yielding > 0.5 L/s. The undifferentiated Lander Rock Beds in contrast are recorded as having 36% of bores yielding > 0.1 L/s and 18% yielding > 0.5 L/s. From the limited data available where the Lander Rock Beds are differentiated, the low-grade metamorphic beds are more productive with 56% > 0.1 L/s, but have more saline water with a mean TDS of 2670 mg/L. The high-grade metamorphic beds have 20% of bores yielding > 0.1 L/s with a mean TDS of 1670 mg/L. These data suggest a trend of lower salinity groundwater with increase in metamorphic grade, however it should be noted that the lithological classifications within the Arunta Block are mostly based on interpretation of drillers' records of strata.

Apart from the standard practise in hard-rock terrain of locating bores in topographic low areas near fractures / lineaments that are crossed by drainage lines (Larsson, 1984), prospects for potable groundwater supplies in this system may be improved by targeting areas where rocks of higher metamorphic grade subcrop. Major lineaments in the Western Water Study region have been mapped by English (1997), and a simplified coverage of this work has been included in the project GIS package (Gallagher, 1998) so that lineament, geological and remote sensing data can be readily superimposed to aid bore site selection. Recent mapping of estimated depth to magnetic basement (Meixner, 1997a,b) may identify areas of deep weathering or unmapped pockets of Cainozoic deposition, that represent more prospective sites for groundwater supplies within this aquifer system.

3.7 South Arunta System

This system, like the North Arunta system discussed above, represents hard rock aquifers of the Arunta Block (Photo 9). The system overlies the southern and part of the central province of the Arunta Block (Shaw et al., 1984), and extends along the northern margin of the Amadeus Basin. Predominant rock types are quartzo-feldspathic gneiss of the Glen Helen metamorphic suite, felsic to mafic meta igneous rocks of the Narwietooma complex, and various granites (Lau and Shaw, 1997; Warren and Shaw, 1995). Shaw (1991) noted this region to be mainly high-grade granulite facies rocks.

The drilling and groundwater quality data for this system (Tables 1 and 2) show that it is prospective for potable water supplies: the mean TDS is 1017 mg/L and 53% of bores obtain yields >0.1 L/s. A high proportion of the water bore data is from the Kintore Range area (Wischusen, 1994, 1995), thus these statistics may be skewed towards sites that are drilled in fractured rocks which are close to creeks running out of rocky catchments and favourable for recharge.

The chemical plot for this system (Fig. 2) shows the groundwater to be a low salinity bicarbonate-type water. This may result from recharge water picking up carbon dioxide from soil while infiltrating to the aquifer (Mazor, 1991) or it may reflect the general lack of chlorides and sulphates in crystalline rock terrain (Freeze and Cherry, 1979). Whatever the case, there is a marked contrast between the chemistry of this water and that of the North Arunta system (Fig. 4). Standard strategies for bore siting in hard rock areas (e.g. Larsson, 1984) should be employed to maximise the success rate, although site specific strategies may be necessary. Anticipated future mapping of the estimated depth to magnetic basement, similar to that carried out for the northern half of theregion (i.e. Meixner, 1997a, b), may, as outlined above, help delineate prospective bore sites. In the past, some drilling programs have been unsuccessful in this aquifer system, including the 1990 investigation at Inyilingi and Amundurngua outstations (Berry, 1990), and the 1964 drilling program near the Ehrenberg Ranges (Roberts, 1973).

4. GEOLOGICAL FORMATION DATA

Tables 3 and 4 show summary statistics of drilling data for many of the individual formations mapped over the Western Water Study region. The formations shown on the legend of the geological map (Lau, 1997), were assigned to each of the 850 bores after checking paper records of bore lithology such as drillers logs and location, against geological maps. As many bores were interpreted to intersect multiple formations, assignment of which formation best represented the lithology of the aquifer tapped by each bore was necessary. This was achieved by interrogating the Western Water Study bore data with a customised algorithim within the Oracle groundwater database used by AGSO. Where this method failed or gave ambiguous results manual checking of paper records was undertaken.

As discussed above, these data are useful when examining the effects of intra-aquifer system lithological variations. This compilation of hydrogeological data based on geological formation may prove useful in assessing groundwater prospects in other areas of central Australia that have similar geology. For example Tables 3 and 4 demonstrate how data from outside the study area can be used to refine statistical expectations. As the methods and software used to derive this hydrogeological formation data are readily applicable to the entire NT groundwater database, it may be possible to build a database of national significance if the effort is made to classify borehole stratigraphy into standard geological formations in the rest of the NT.

5. SURFACE WATERS

All creeks and rivers in the Western Water Study region are ephemeral. Soaks, creek water-holes, rockholes and springs were relied upon for survival before bore water was readily available. Traditional water sites were numerous as Toyne et al. (1997) reported that over 400 sites are known to Walpiri people in the Yuendumu and Nyirripi areas (about 20% of the study area). Kavanagh (1984) noted that other types of water sources were also used traditionally including succulent plants, some tree roots and hollow trunks, collection of dew fall and even water-holding frogs. Of all these types of water supplies, very few were probably permanent. Consequently, known permanent waters were once very significant.

Table 5B shows water chemistry details for three springs that are generally known as permanent waters. *Pikilyi* is the name for 13 waters in the Truer Range that were important for the survival of the Walpiri people. One of these waters (Vaughan Springs) has since been used to supply the Mt Doreen pastoral lease homestead (Photo 10). This spring has extremely low salinity water and its yield ranges from 0.4 to 2.1 L/s. The groundwater discharges from Cainozoic deposits halfway up the flank of the Truer Range. One possible explanation for this spring's longevity is that the hard Palaeozoic rocks of the Truer Range act as a catchment for any rainwater that falls and the water then runs into the porous Cainozoic sediments where it is stored. If the discharge-storage ratio is sufficiently low, the spring water supply will be maintained between rainfall events, although its yield may vary with fluctuations in head. An analysis of stable isotopes sampled from this spring in 1996 (Deuterium: -59.8; ^{18}O: -9.1) plots on the local meteoric water line (Fig. 4) and, as no evaporation is indicated, rainwater must rapidly enter the draping Cainozoic sediments.

Illpili spring in the Ehrenberg Ranges was a very important water for the Pintupi people of the Western Desert region and at various times supported large populations at ceremonial gatherings (Myers, 1986). The central Australian Gold Expedition led by Harold Lasseter also camped on this spring in 1930 (Marshall-Stoneking, 1989). The spring is found among *Melaleuca* trees in a creek bed that drains north from bare rocky hills (photo 11). Water is found under the surface of the creek, like a soak, but the reputed supply and permanency indicate a spring. Several east-west lineaments cross the creek at this site which sugests that seepage from bedrock features feed this spring. Only one chemical analysis exists for this site, and the measured chloride concentration, 1 mg/L, is extraordinarily low when compared to the TDS.

Putardi spring at the western base of Mt Putardi was an important water source for Luritja people and later also for explorers and camel riders. For example Marshall-Stoneking (1989) records that Harold Lasseter set off on his ill fated camel trek to find the gold reef from Putardi spring in 1930, after having travelled the country to the west. Reports of yield also vary at this site: when visited in 1996 there was only a small pool with little flow evident (Photo 12). This spring seeps from layered gneiss and is presumably recharged from higher up the flanks of Mt Putardi.

Some water points previously assumed to be permanent have since been shown to be ephemeral storages only. Smith (1989) discusses the evidence of human occupation in the Cleland Hills (Photo 2) populated at least 22 000 years ago. Near this site is a large rock hole called *Murantji* which was assumed a permanent water given the evidence of human occupation during the last glacial maximum. On inspection in May 1996, however, this rockhole was observed to be dry. It is therefore an ephemeral storage reliant on runoff from a large rocky catchment in the Cleland Hills rather than a spring discharging from the Mereenie Sandstone as shown on some groundwater maps (e.g. Jacobson and Lau, 1992; Lau and Jacobson, 1992). The ephemeral nature of this rock hole may in part explain the evidence of low use of this area (Smith, 1987) before 12 000 years ago. It should be noted that east of this site in the Macdonnell Ranges many waters thought by Smith (1989) to have supported early occupation are, on limnological evidence, thought to be permanent (Davis, 1995, 1997).

6. GROUNDWATER QUALITY

Hostetler et. al. (1998) present details and discussion of various aspects of groundwater quality in the Western Water Study region. About two-thirds of these groundwaters are saline, beyond acceptable limits for drinking water according to the Australian Drinking Water Guidelines (1996). About one quarter of the groundwaters have unacceptably high fluoride or nitrate concentrations; the high fluoride is associated with granitic rocks of the Arunta Complex. Some of the groundwaters have high uranium or boron concentrations; the high uranium concentrations are associated with several aquifer types, but the high boron concentrations are more specifically associated with granitic rocks of the Arunta Complex. Deleterious elements affecting human health were the focus of much of the Western Water Study, though other water quality issues such as industrial or irrigation use possibilities, will be greatly assisted by use of the GIS database.

Table 2 shows mean values for the main criteria used to determine water quality i.e. TDS (salinity), nitrate and fluoride. These data show that only groundwater in the Mountain Front System has a mean TDS below the recommended 1000 mg/L guideline value for palatability. It should be noted that higher salinity groundwater can still be used for drinking, particularly in emergency situations. Wischusen et al. (1996) showed groundwater sources of < 4000 mg/L TDS near roads in the region that may be useful as an emergency source for stranded road travellers. Elevated salinity and nitrate concentrations seem endemic in central Australian groundwaters and the scarcity of guideline quality water for drinking has long been noted (e.g. Knott and McDonald, 1983; Read, 1986; Nganampa Health Council Inc, 1987; Jacobson et. al., 1990).

The range of values displayed in Table 1 shows that groundwater within the guidelines for drinking water quality may, however, be encountered in each aquifer system at least occasionally. Hostetler et. al. (1998) note that with the implementation of increasingly stringent drinking water quality guidelines, thought should be given to the provision of separate drinking water by way of treatment processes or by harvesting rainwater at communities in this region. This, and the provision of water coolers in communities, would make the drinking waters more palatable and reduce the incidence of dehydration and associated conditions.

7. HYDROCHEMISTRY

The average water chemistry for each aquifer system is shown in Table 5A and is graphically displayed in Figure 2. Plots of chloride concentration versus TDS for all aquifer systems except the Playas are shown in Figures 5a to 5f. These Figures all show a linear correlation between chloride and TDS which suggests that evapotranspiration is largely responsible for elevated groundwater salinities in the region. For these aquifer systems, the rocks have low chloride compositions ruling out dissolution of chloride as a factor in this increase.

Table 5. A, Mean major ion chemistry for the Western Water Study Aquifer Systems; B, major ion chemistry for selected springs in the study area.

5A. WESTERN WATER STUDY AQUIFER SYSTEMS

Mean values only shown (mg/L)

SYSTEM	Chloride	Bicarb.	Sulphate	Sodium	Calcium	Magnesium	Potassium	TDS	count
Mountain Front	177	457	100	197	53	36	17	930	219
Cainozoic	1818	433	419	741	103	70	66	3326	223
Ngalia	823	373	304	279	111	101	34	1774	301
Amadeus	355	290	389	202	141	80	34	1546	124
South Arunta	183	474	137	202	63	54	20	1033	141
North Arunta	1422	546	568	788	91	136	45	3127	113
Playa	144000	n/a	28300	111000	350	4065	4610	277000	2

5B. SELECTED SPRINGS

SPRING	Chloride	Bicarb.	Sulphate	Sodium	Calcium	Magnesium	Potassium	TDS	count
Illpilli	1	372	62	120	78	41	9	810	1
Pikilyi	12	14	13	8	4	2	3	75	1
Putardi	25	n/a	5	32	10	6	10	228	1

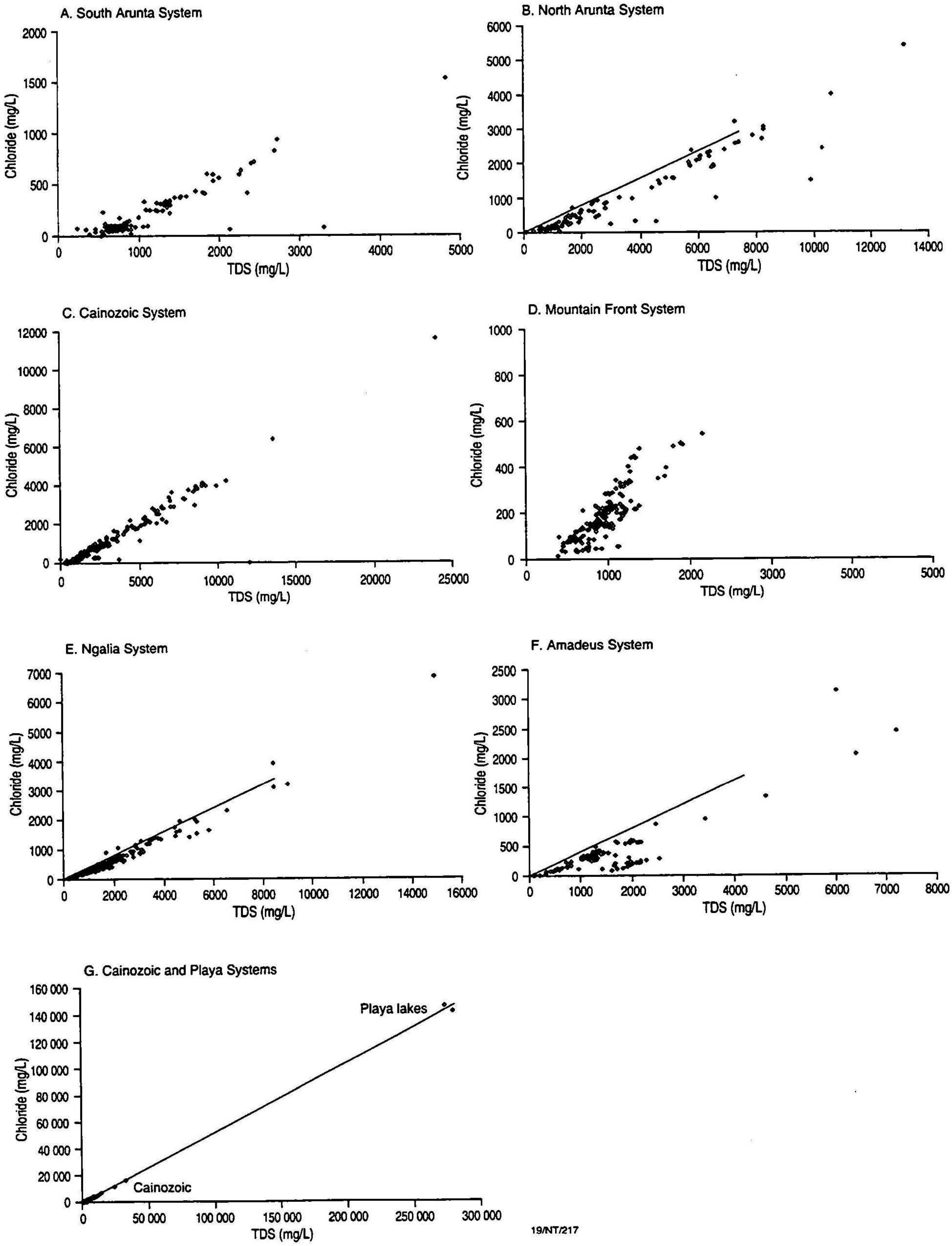


Figure 5. Plots of chloride versus Total Dissolved Solids (TDS) in mg/L for the Western Water Study Aquifer Systems

Figure 5g shows TDS plotted against chloride for the Cainozoic aquifer system and for samples from Lake Bennett and the lake 10 km north of Ghost Gum bore, which in this study has been referred to as 'Lake Ngalia'. This plot provides evidence that the playas and the Cainozoic aquifers are end members of the same hydrochemical system, with the elevated salinities at the playas representing evaporative concentration.

Harrington and Herczeg (1998) plotted TDS concentration versus chloride relative to total anions for the Cainozoic Ti-Tree Basin groundwaters 200 km east of the present study area. At Ti-Tree dilute waters dominated by bicarbonate and sulphate were taken as an indication that anion chemistry is affected by water-rock and water-CO_2 interactions after rainfall enters the ground. Similar plots constructed to examine anion chemistry of the Western Water Study aquifer systems are shown in Figures 6a to 6f. These plots are similar to those for the Ti-Tree Basin data in that dilute groundwaters (<1000 mg/L) in the Western Water Study aquifers are shown to have bicarbonate and sulphate dominant relative to chloride. Similarly the Western Water Study aquifers have more saline (>1000 mg/L) groundwaters mainly dominated by chloride: at Ti-Tree, Harrington and Herczeg (1998) take this to infer that a significant component of the groundwater chemistry is affected by evapotranspiration. The hydrochemical differences between the Western Water Study aquifer systems (Figs. 6a to 6f) may reflect differences in rock composition, and/or frequency and magnitude of recharge, and/or susceptibility to evapotranspiration.

8. GROUNDWATER FLOW

Apart from community borefields where bore elevations may have been surveyed, elevation data for bores in the Western Water Study region is rarely available. The elevations of static water levels for bores used to construct the potentiometric contours and groundwater flow lines marked on the Aquifer Systems map were derived from estimations of bore ground elevation, made from unpublished 1:100 000 topographic maps. As a consequence, the accuracy of potentiometric data near bore holes is thought to be about +/- 10 m . The topography and geology of the region also give some clue to likely groundwater flow directions.

Much of the groundwater is interpreted to drain into the E-W trending palaeodrainage that bisects the study area (Woodcock et al., 1997). The elevation of the playa surfaces represents groundwater elevation (Bowler, 1986). Thus the groundwater level drops from an elevation of 540m AHD at the playas near Central Mt Wedge westwards to about 360 m AHD at Lake Mackay along this palaeodrainage.

A groundwater divide is mapped, approximately along the northern boundary of the Amadeus Basin. South of this divide, groundwater flow in the Cainozoic aquifers is westwards from the Macdonnell Ranges near Haast Bluff, before turning south toward the Lake Hopkins playa , 30 km south of the Western Water Study area (Fig. 3). As drawn, this interpretation indicates that another palaeodrainage acts as sink to groundwater flow in the southern portion of the study area. Southwest of Kintore, groundwater flows towards the Lake Macdonald playa. This interpretation of the hydrodynamics of the southern part of the study area, is in part based on previous maps which show groundwater to flow south in this part of the Amadeus Basin (e.g. Jacobson and Lau, 1992), towards the central Australian discharge zone, a long chain of playas immediately south of the Western Water Study area (Jacobson et al., 1988).

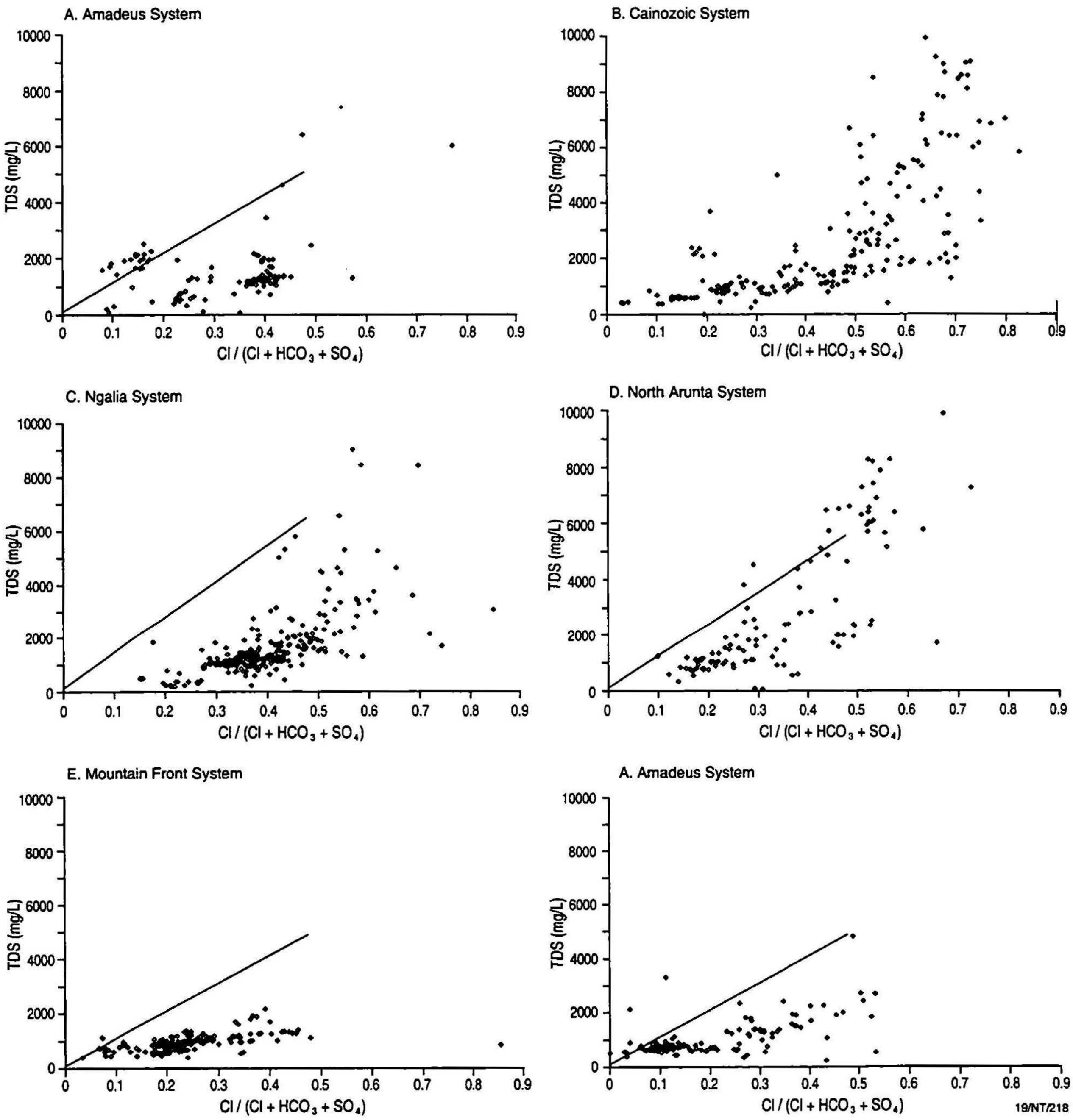


Figure 6. Plots of TDS concentration versus chloride relative to total anion concentration, for the Western Water Study Aquifer Systems

North of the Ngalia aquifer system, potentiometric and topographic data indicate that groundwater flows north towards the Cainozoic Yaloogarrie Basin mapped by Stewart (1976). In areas of high relief, such as the Western Macdonnell Ranges in the Amadeus Basin and the Narburula Hills and Walbiri Ranges in the Ngalia Basin, localised groundwater flow cells of various orientations (e.g. Toth, 1995) may exist. The broad-scale groundwater flow directions that have been mapped assume hydraulic connection throughout the region, however, unmapped groundwater divides, faults, or variations in lithologies may mean that different flow directions and / or hydraulic gradients exist in some places.

The groundwater gradients shown on the map are similar to gradients shown elsewhere in central Australia. For instance the decline in groundwater level in the Cainozoic sediments from Papunya to the Lake Ngalia playa is around 15m in 40 km or a gradient of 0.02°. Near Lake Amadeus and Uluru to the south, Jacobson et al. (1989b) mapped groundwater in Cainozoic sediments to have a gradient of around 0.04°. The 50 m drop in groundwater elevation over 40 km, with gradient 0.07°, from near Injimurri southwest towards Nyirripi in the Ngalia system, compares to the gradient of 0.05° shown for groundwater in Palaeozoic sediments of the Amadeus Basin south of the Waterhouse Range (Jacobson and Lau, 1992).

If aquifer hydraulic conductivity and porosity are known, then Darcys Law can be used to estimate the travel time of groundwater over a specified distance under a given hydraulic gradient by the formula:

$$T = x\phi/ki \qquad (1)$$

Where T= time in days, x = distance in metres, ϕ = porosity, i = gradient and k = hydraulic conductivity in m/day

Measurements of porosity and permeability have been made from drillcores cut in the Mt Eclipse Sandstone within the region (Wells and Moss, 1983). If these data are used in the Darcy equation (mean porosity = 0.086 and mean horizontal k = 0.0042 m/day), travel time within the Ngalia aquifer system is calculated at 2.33 x 10^6 years over 40 km. As the plugs of core taken for analyses of aquifer characteristics are only representative for flow through unfractured sandstone, the calculation is redone using hydraulic conductivity values derived from pump tests. At Yuendumu, the value of hydraulic conductivity derived from a pump test in the fractured Kerridy Sandstone, is significantly higher (i.e. k = 0.1 for bore no. 10556; Berry, 1990) than that derived from analyses of drillcore samples. Using this k value groundwater travel time over the 40 km is calculated at 96 000 years.

These two travel time calculations, even though more than an order of magnitude apart, are taken as an indication that groundwater travels slowly through the Ngalia system. Modelling of groundwater flow through the Amadeus Basin sedimentary rocks by Brown et al. (1990) also showed very slow travel times. From these data it is reasonable to assume that travel of groundwater through the Amadeus and Ngalia systems is likely to be very slow, consequently mean groundwater age may be very old at some locations in these systems.

Test pumping of bores drilled in the Mountain Front system at Mt Liebig (Rooke, 1991), indicated k to be about 3 m/day for this system. This value compares to pump test results obtained in the Cainozoic sediments of the Ti-Tree Basin, 200 km to the east, which indicated k = 1.6 - 15 m/day (Macdonald, 1988). If a porosity of 20 % is taken to be representative of the

Cainozoic sands (cf. Freeze and Cherry, 1979) and the Mt Liebig *k* value of 3 m/day used, then groundwater travel time through the Cainozoic sediments from Papunya to Lake Ngalia is calculated as 20 000 years. This calculation is based on aquifer properties determined at high-yielding production bores and probably reflects transit through sand horizons. A reduction in permeability, and a corresponding increase in travel time is expected in clay horizons. Groundwater within the palaeodrainages is probably a mixture of long-travelled groundwater from 'upstream' along the palaeodrainage with groundwater coming in from the former valley sides, so that the mean groundwater age at any point may vary from that calculated along a supposed flow line.

9. SUSTAINABILITY OF GROUNDWATER RESOURCES

9.1 Concepts

The safe yield of an aquifer has been defined as the amount of water that can be extracted without causing an undesired result (Todd, 1959). This definition allows for utilisation of a non-renewable resource in some instances, e.g. saline water for mineral processing, and for non utilisation when the environment may be adversely affected e.g. the interaction between groundwaters and surface waters maintains some important wetland habitats. Most often a sustainable yield is considered desirable when extracting groundwater, i.e. perpetuation of the resource. Schoeller (1959) defined the safe yield as when no amount in excess of the normal flow (natural yield) is extracted from the aquifer. Bredehoeft (1997) observed that capture from the natural discharge (throughflow) is usually what determines the size of a sustainable development. Both Bredehoeft (1997) and Schoeller (1959) noted that the natural yield of an aquifer does not necessarily equal the amount of recharge to the aquifer, as in some instances it may be greater due to induced recharge or may be less if equilibrium conditions are not attained by the abstraction regime.

In arid areas, groundwater recharge is often irregular, and the natural discharge of an aquifer may then vary with time. This implies that the determination of the likelihood and magnitude of recharge are important factors in assessing sustainable yield. Lerner et al. (1990) and Foster (1988) noted that the determination of recharge is extremely difficult in arid areas, and that overdevelopment of aquifers can occur if recharge is overestimated. Given this potential for uncertainty it was recommended (Lerner et al., 1990) that in arid areas groundwater development be staged, allowing progressive evaluation of resources with collection of aquifer response data. At Kintore (*Walungurru*) a detailed assessment of sustainable yield using response data has been attempted (Wischusen, 1994, 1995).

At many communities in central Australia the extraction to storage ratios are so low that no concerns are held for the viability of water resources in the short term (Wischusen, 1995). At Yuendumu, however, while large volumes of groundwater are believed to be stored in the Ngalia system sediments, and the extraction to storage ratio is low, the water levels have declined continuously since the borefield was commissioned (Berry, 1990). This is due to the lack of recharge. The Yuendumu situation is analogous to the Alice Springs water supply in that declining water levels may mean that production bores have to be moved to other parts of the basin, where water levels are unaffected by pumping (Smith, 1991).

A general overview of recharge and storage potential for the Western Water Study aquifer systems is given below.

9.2 Cainozoic and Mountain Front Systems

At Papunya there has been no recorded change in water levels since observations began in the 1960s, which confirms early estimates of extensive groundwater storage at Papunya (Woolley, 1966). It also highlights the significance of the Mountain Front system as a potential water resource. The lack of water level movement may also, however, indicate a lack of recharge to the Mountain Front system and subsequent transmission to the Cainozoic system (see map cross section).

Jolly and Chin (1991) documented recharge to several Cainozoic aquifers in central Australia during the particularly wet year of 1974. Some of these aquifers such as at Docker River and the Alice Springs Town Basin, are adjacent to large pre-Cainozoic outcrop areas and represent equivalent aquifer systems to the Mountain Front system. This suggests that some recharge can be expected along the edges of the Cainozoic and Mountain front systems where they are adjacent to areas of pre-Cainozoic rock outcrop. The lack of recorded recharge at Papunya may be a consequence of distance from recharge, as the Papunya borefield is 10 km north of the outcrop. Any recharge 10 km away would, on the basis of aquifer parameters discussed above, take thousands of years to travel to Papunya. Apart from concentration of surface runoff (indirect and localised recharge) evidence for direct or diffuse recharge to the Cainozoic aquifer systems of the Western Water Study region has not yet been observed.

Barnes et al. (1994) and Harrington and Herczeg (1998) documented direct recharge in Cainozoic sediments at Yulara and Ti-Tree respectively; both locations are within 150 km of the Western Water Study area (Fig. 3). Stable isotope analyses for groundwaters in both these areas show an evaporation effect consistent with a direct recharge mechanism (Harrington and Herczeg, 1998; Jacobson et al., 1989a). For groundwater in Cainozoic sediments of the Western Water Study region, the stable isotope data indicate a similar evaporation effect with deuterium/oxygen-18 compositions plotting off the meteoric water line (Fig. 4).

Lerner et al. (1990) noted that indirect and/or localised recharge is most likely to be the dominant recharge mechanism in arid areas. This observation is confirmed in other arid regions by Gieske and Selaolo (1988) in eastern Botswana and by Wood et al. (1997) in Texas, who concluded that around 30 % and 5% respectively of total recharge was likely to be direct. In the vast Kalahari sand plains of Botswana, that may represent a similar environment to the flat sandhill country of central Australia, de Vries and von Hoyer (1988) concluded there was no convincing evidence for any direct recharge. Observed recharge in Cainozoic sediments of central Australia is usually associated with episodic incursion of extreme monsoon rainfall events (e.g. Jolly and Chin, 1991). These rainfall events can be large enough to cause superfloods of some central Australian rivers (Patton et al., 1993: Bourke, in press) which highlights the potential for indirect recharge as a consequence of these events. As monsoon conditions quickly pass in central Australia it is debateable that such events would cause much direct recharge. It is not known what percentage of recharge in central Australia is direct, though potentially it may be greater than in eastern Botswana (Mazor et al., 1977) and Texas (Wood et al., 1997) where the stable isotope composition of groundwaters plots on meteoric water lines in contrast to the southwest NT (Fig. 8). Apart from where local conditions are favourable (e.g. Barnes et al., 1994), it is not known why the stable isotope data indicate that direct recharge is significant in central Australia, in contrast to studies elsewhere in arid areas. A possible explanation for these data, assuming that direct recharge is usually limited in central Australian Cainozoic sediments, is examined below.

When vertical flux through the vadose zone is not great, much residual salt from evapotranspiration processes builds up. For instance Kruseman (1997), in the Cainozoic Murray Basin in South Australia, measured the flux of very saline water (chloride 10 000 - 20 000 mg/L), below 2 m depth under eucalypt vegetation and above the 30 m deep watertable, to be 0.04 - 0.06 mm/y (about 1m in 20 000 years). Apart from some preferred pathway flow (localised recharge) it was concluded that most rain falling on this basin must be evapotranspired and that recharge must be minimal. It could be argued that hydrogeological conditions in the Cainozoic aquifer systems of the Western Water Study region are similar to naturally vegetated parts of the Murray Basin, except that evapotranspiration is likely to be even greater.

There is geomorphological evidence for periods of thousands of years within the Quaternary glacial cycles when climate in central Australia may have been significantly wetter than at present (Kershaw and Nanson, 1993; Croke et al., 1996; Magee et al.,1995; Nanson et al., 1992). If these Interglacial pluvial times are assumed to represent long term conditions when vertical flux was sufficient to drive rapid direct recharge (about 10 000 years, Winograd et al., 1997) then the vadose zone salts with their associated depleted stable isotope signal could have infiltrated the Cainozoic aquifers of the Western Water Study region. This suggests that the current mean isotopic composition of groundwater still reflects a directly recharged signal, even though indirect recharge mechanisms mainly apply now. The regional groundwater then represents a mix of directly recharged water from interglacial pluvial times and modern, and probably also ancient, indirectly recharged water. This process may account for some of the evaporated water chemistry in this system (Fig. 6b).

Figure 7 illustrates a possible conceptual model for different recharge mechanisms under different climatic regimes for granular strata in the region. Under pluvial conditions, evapotranspiration was less than direct recharge. The localised, indirect and direct recharge mechanisms were all effective, and the groundwater was a mix of water that travelled to the aquifer by different mechanisms. Evaporated water and residual salts that had been stored in the vadose zone during arid conditions were flushed by direct recharge to the watertable. This component of direct recharge elevated the groundwater salinity and contributed to an evaporated stable isotope signature. Under arid conditions such as those of the present day, evapotranspiration is greater than direct recharge. Localised and indirect recharge are possible, but direct recharge is improbable as the vertical flux is very slow, less than 0.1 mm/year. Most water is taken up at the root zone leaving a residue moving slowly down below the root zone. Vadose zone moisture becomes highly saline (Cl > 10 000 mg/L) and holds an evaporated stable isotope signature. This process may have operated for 90% of the generally arid Quaternary Glacial cycles i.e. for perhaps 90 000 years.

Such a scenario highlights the need to account for long periods of residence within the vadose zone when studying groundwater recharge. Allison et al. (1990) noted that changes to vegetation can alter recharge rates in Cainozoic basins dramatically, therefore the changes to central Australian vegetation brought on by Aboriginal occupation (Latz, 1995) may also need to be considered in hydrogeological studies. The problems noted in determining recharge imply that the determination of groundwater sustainability is also difficult. As the Mountain Front and Cainozoic aquifers are intragranular, aquifer storage is therefore likely to be large, thus determining sustainability for small developments may not be crucial (e.g. no recorded drawdown at Papunya). Any large scale development should be staged so that monitoring data can be assessed to gauge aquifer performance, thereby reducing the likelihood of water-dependent

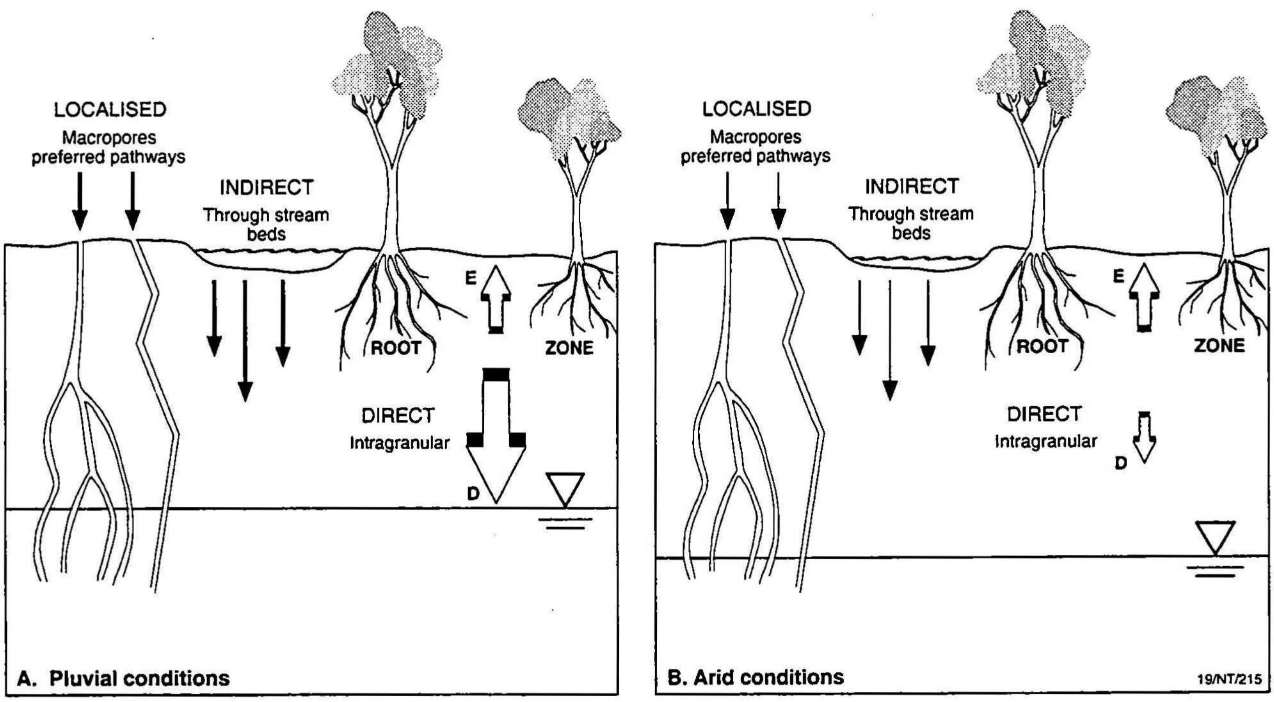


Figure 7. Conceptual model of different recharge mechanisms under pluvial and arid climatic regimes for granular strata in the region; A, Pluvial conditions. Evapotranspiration is less than direct recharge. Localised, indirect and direct recharge mechanisms are all effective, and groundwater is a mix of water that has infiltrated by different mechanisms to the aquifer. Evaporated water and residual salts stored in the vadose zone during arid conditions is flushed by direct recharge to the water table. This component of direct recharge elevates groundwater salinity and contributes to an evaporated stable isotope signature. B, Arid conditions (present day). Evapotranspiration is greater than direct recharge. Localised and indirect recharge possible, direct recharge improbable as vertical flux very slow < 0.1 mm/y. Most water is taken up at the root zone leaving a residue moving slowly down below the root zone. Vadose zone moisture becomes highly saline (Cl > 10 000 mg/L) and holds an evaporated stable isotope signature.

infrastructure commitments being made against an unsustainable water supply.

9.3 North and South Arunta Systems

As these systems represent hard rock aquifers, only indirect and localised recharge mechanisms are possible. Accordingly, modern recharge in response to recorded rainfall events is observed at some locations (e.g. Wischusen, 1994). It should be noted that when drilled, hard rock aquifers often yield water far in excess of the sustainable yield of the aquifer. This implies that any extraction from these systems should proceed with caution as storage may be limited. Any required permanent water extraction should be accompanied by a monitoring program to assess aquifer performance, and commitment to water dependent infrastructure should be staged in accordance with this assessment.

9.4 Amadeus and Ngalia Systems

The recharge mechanisms in the Amadeus and Ngalia Basins are yet to be completely assessed, Jacobson et al (1989a) speculated that indirect recharge through river beds and localized recharge through joints in sandstones are the dominant mechanisms in the Amadeus Basin. The plot of stable isotope data (Fig. 4) shows the Ngalia aquifer samples to plot off the meteoric water line. This evaporation effect matches some of the Amadeus folded rock belt data presented by Jacobson et al. (1989a). These data may indicate that indirect or localised recharge processes happen at a rate that allows evaporation of infiltrating water.

Alternatively, given the double porosity (fractures and matrix) nature of some of these aquifers, it may be that direct recharge through the matrix also occurs. As suggested above, for the Cainozoic systems, it is possible that a mixture of recharge mechanisms contribute to the stable isotope signature of groundwater, and at some locations the influence of direct recharge is shown as an evaporation effect. At other areas such as the Alice Springs borefield, proximity to rivers leads to dominantly indirect recharge, and may mask the evidence of former direct recharge; in these cases the stable isotope data plot on or near the meteoric water line.

It could also be argued that within the Amadeus and Ngalia systems direct recharge processes are only likely to be effective during the episodic onset of interglacial pluvial conditions. Jacobson et al. (1994) discussed the likelihood of Holocene and late Pleistocene recharge in the Amadeus Basin, and Cresswell et al. (1998) speculated that some groundwater in the Ngalia Basin was recharged during the last interglacial (about 100 000 y ago).

Jacobson et al. (1989a) have commented that projected large scale development of the sandstone aquifers of the Amadeus system should be regarded as utilising a non-renewable resource and managed accordingly. This is because there is little evidence of active recharge, apart from areas underlying river beds. These comments may equally apply to the Ngalia aquifer system where dewatering of the aquifer is already happening at Yuendumu (Berry, 1991).

Table 6. Stable isotope data for regional groundwaters.

RN bore	System Type	Oxygen - 18, per mille SMOW	Deuterium, per mille SMOW
10945	Ngalia	-8.42	-57.7
4059	Ngalia	-8.17	-57.2
12910	Ngalia	-6.32	-49
6165	Ngalia	-6.97	-50
14980	Ngalia	-7.08	-53.5
15477	Ngalia	-5.54	-45
14055	Ngalia	-6.39	-51
10935	Ngalia*	-7.75	-53
13485	Hard Rock	-7.13	-49.9
12578	Cainozoic	-6.52	-49.4
15472	Cainozoic	-8.35	-59.3
15463	Cianozoic	-7.47	-54.6
5754	Cainozioc	-8.85	-60.3
11396	Cainozoic	-9.52	-66.6
13795	Cainozoic	-6.95	-51.6
15740	Cainozoic	-8.49	-58
16694	Cainozoic	-8.52	-59.5
10936	Cainozoic	-7.5	-49.3
Pikilyi Spring (RN 4316)	Cainozoic	-9.1	-59.8

Ngalia* This bore is drilled into the Amadeus System,

10. CONCLUSIONS

Seven aquifer systems have been mapped in the Western Water Study region. As drilling data is sparse this mapping is a preliminary regional hydrogeology assessment. Only the Mountain Front system consistently provides potable water as defined by Australian drinking water guidelines. The prospects for potable water are limited over the remaining 97% of the study area, however, potable water has been found in all other systems other than in the vicinity of the playas. A significant volume of groundwater is stored in the sedimentary aquifer systems. Most of this water is marginal or saline, and low maintenance, low cost , water treatment technologies are needed to allow unrestricted settlement. While potable groundwater supplies are occasionally found in crystalline basement rocks, poor storage potential limits the amount of water available from the Arunta Block systems.

The longevity of all groundwater developments in the region are questionable at this stage because groundwater flow and recharge are not yet substantiated. A conceptual model proposes that significant recharge only occurs over much of the sedimentary systems during interglacial pluvial times. This model equates the stable isotope data and the expected recharge mechanisms that operate in arid areas. The lack of observed recharge and/or lack of aquifer storage in this region implies that, as in other arid areas, any large scale developments should be staged with monitoring bore networks in place. This strategy allows for aquifer performance under stress to be assessed, thereby reducing the likelihood of commitment to infrastructure that would be dependent on an unsustainable water supply. The potential for low recharge rates in this arid region highlight the wisdom in having low water use infrastructure developments whenever possible.

The compilation of hydrogeology data that has allowed statistics for aquifer systems and geological formations to be generated, will be of use in assessing the likely groundwater characteristics of other areas with similar geology in central Australia.

11. ACKNOWLEDGEMENTS

I thank my fellow workers on this project: Gerry Jacobson, Libby Lau, Lynne Woodcock, Eleanor Laing, Gayle Young, Robyn Gallagher, Stephen Hostetler and Sonja Lenz at AGSO; Michael Jamieson, Avis Wiegele, Peter Jolly and Adelaide Church at NT DLPE; Bruce Rose, Richard Tuckwell, Geoff Holcombe, Tolly Sawenko and Monty Sollieux at CLC; and Richard Cresswell and Keith Fifield at ANU, for their help and support. Other people whose help was gladly received are: Laurence Roe, Magellan Petroleum; Peter Toyne, Remote Area Consultancies; Colin Plowman, ATSIC; Paul Sweeny, Papunya Tula Artists; Peter Holt, Walpiri Media; Julian Reid, CSIRO; Alex Coppock, Newhaven Station; Dennis Braitling, Mt. Doreen Station; and people from the Mt Liebig, Kintore, Papunya, Haast Bluff, Yuendumu and Nyirripi councils, communities and outstations.

12. REFERENCES

Allison, G.B., Cook, P.G., Barnett, S.R., Walker, G.R., Jolly, I.D. and Hughes, M.W., 1990. Land clearance and river salinisation in the western Murray Basin, Australia. Journal of Hydrology, 119, 1-20.

Australian Drinking Water Guidelines, 1996. National Health and Medical Research Council and Agriculture and Resource Management Council of Australia and New Zealand, 252 p.

Barnes, C.J., Jacobson, G. and Smith, G.D., 1994. The distributed recharge mechanism in the Australian arid zone. Soil Science Society of America Journal 58, 31-40.

Berry, K., 1990. Water supply drilling investigations, Inyillingi and Yumdumbring (Amundurngua) outstations. Northern Territory Water Resources Report 65/90, 20 pp.

Berry, K.A., 1991. Yuendumu borefield and source review 1991. Water Resources Branch, Northern Territory, Report 07/1991 A, 83 pp.

Blake, D.H., Hodgson, I.M. and Muhling, P.C., 1979. Geology of the Granites - Tanami region. Bureau of Mineral Resources, Australia, Bulletin 197, 91pp.

Bourke, M.C., in press. Channel adjustment to extreme floods in arid central Australia. Proceedings of the Institute of Australian Geographers and New Zealand Geographical Society, Second Joint Conference, Hobart, Australia, 1997. Department of Geography, University of Waikato, New Zealand.

Bowler, J.M., 1986. Spatial variability and hydrologic evolution of Australian lake basins: analogue for Pleistocene hydrologic change and evaporite formation. Palaeogeography, Palaeoclimatology, Palaeoecology, 54, 21-41.

Bredehoeft, J. 1997. Safe yield and the water budget myth. Ground Water, 35, p. 929.

Brown, D.M., Lloyd, J.W. and Jacobson, G., 1990. Hydrogeological model for Amadeus Basin aquifers, central Australia. Australian Journal of Earth Sciences, 37, 215-226.

Climate, 1986. Atlas of Australian resources. Third Series, Volume 4, Division of National Mapping, Canberra, 60 pp.

Cresswell, R., Fifield, K., Wischusen, J. & Jacobson, G., 1998. Groundwater sustainability in Central Australia studied using Chlorine-36. Proceedings, Conference on Groundwater - Sustainable Solutions, International Association of Hydrogeologists, Melbourne, February 1998, 25-30.

Croke, J., Magee, J.W. and Price, D.M., 1996. Major episodes of Quaternary activity in the lower Neales River, northwest of Lake Eyre, central Australia. Palaeogeography., Palaeoclimatology,. Palaeoecology, 124,1-15.

Davis, J.A., 1997. Conservation of aquatic invertebrate communities in central Australia. Memoirs of the Museum of Victoria, 56, 491-503.

Davis, J.A., 1995. The aquatic ecosystems of the west Macdonnell Ranges, Northern Territory; with particular reference to the aquatic invertebrate fauna. Report to the Parks and Wildlife Commission of the Northern Territory, 50 pp.

De Vries, J.J. and von Hoyer, M., 1988. Groundwater recharge studies in semi-arid Botswana - a review. In Simmers I. (Ed.), Estimation of Natural Groundwater Recharge. North Atlantic Treaty Organisation, Advanced Science Institutes Series C, Volume 222. D. Reidel Publishing Company, Dordrecht, Holland, 339-347.

Domahidy, G., 1990. Hydrogeology of the Granites Tanami mining region; Explanatory Notes and 1:250,000 Scale Map. Water Resources Branch, Northern Territory, Report 74/1990 A, 23 pp.

English, P., 1997. Lineament interpretation for groundwater assessment, Western Water Study (Wiluraratja Kapi), Papunya - Kintore region, Northern Territory. Australian Geological Survey Organisation, Record 1997/8.

Foster, S.S.D., 1988. Quantification of groundwater recharge in arid regions: a practical view for resource development and management. In Simmers I (Ed.), Estimation of Natural Groundwater Recharge; North Atlantic Treaty Organisation, Advanced Science Institutes Series C, Volume 222. D. Reidel Publishing Company, Dordrecht, Holland, 239-270.

Freeze, R.A. and Cherry, J.A., 1979. Groundwater. Prentice-Hall Inc, New Jersey, USA, 604 pp.

Gallagher, R., 1996. Visualising waterbore data with ArcView2. Australian Geological Survey Organisation, Record 1996/18, 17 pp.

Gallagher, R., 1998. A new GIS extension for visualising water bore data and other tabular geological data. Australian Geological Survey Organisation, Record 1998/12, 22 pp.

Gieske, A.S.M. and Selaolo, E.T., 1988. A proposed study of recharge processes in fracture aquifers of semi-arid Botswana. In Simmers I. (Ed), Estimation of Natural Groundwater Recharge, North Atlantic Treaty Organisation, Advanced Science Institutes Series C, Volume 222. D. Reidel Publishing Company Dordrecht, Holland, 117 - 124.

Harrington, G.A. and Herczeg, A.L., 1998. A geochemical model for groundwaters of the arid Ti-Tree Basin, central Australia. In Arehart, G.B. and Hulston, J.R. (Eds.) Proceedings of the 9th International Symposium on Water-rock Interaction, Taupo, New Zealand, March 1998. A.A. Balkema, Rotterdam, 231-234.

Hostetler, S., Wischusen, J. and Jacobson, G., 1998. Groundwater quality in the Papunya-Kintore region, Northern Territory. Australian Geological Survey Organisation. Record 1998/17, 9 pp.

Jacobson, G., Arakel, A.V. and Chen Y., 1988. The central Australian groundwater discharge zone: evolution of associated calcrete and gypcrete deposits. Australian Journal of Earth Sciences, 35, 549 - 566.

Jacobson, G. and Jankowski, J., 1989. Groundwater - discharge processes at a central Australian playa. Journal of Hydrology, 105, 275 - 295.

Jacobson, G., Calf, G.E., Jankowski, J. and Macdonald, P.S., 1989a. Groundwater chemistry and palaeorecharge in the Amadeus Basin, central Australia. Journal of Hydrology 109, 237-266.

Jacobson, G., Lau, G.J., Macdonald, P.S. and Jankowski, J., 1989b. Hydrogeology of the Lake Amadeus - Ayers Rock region, Northern Territory. Bureau of Mineral Resources, Australia, Bulletin 230, 77 pp.

Jacobson, G., Barnes, C.J., Smith, G.D. and Macdonald, P.S., 1990. High nitrate groundwaters in Australian arid zone basins. In Proceedings of the International Conference on Groundwater in Large Sedimentary Basins, Perth 1990. Australian Water Resources Conference Series No 20, Australian Government Printer, Canberra, 194-204.

Jacobson, G. and Lau, J.E., 1992. The Mereenie Sandstone aquifer map of the Amadeus Basin, 1:500 000. Bureau of Mineral Resources, Australia.

Jacobson, G., Barnes, C.J., Fifield, L.K.and Cresswell, R.G., 1994. The time factor in arid-zone groundwater recharge. Water Down-under 94: 25th Congress of the International Association of Hydrogeologists, Adelaide, November, 1994. The Institution of Engineers, Australia, Preprints of Papers, 2B, 471-478.

Jankowski, J. and Jacobson, G., 1989. Hydrochemical evolution of regional groundwaters to playa brines in central Australia. Journal of Hydrology 108, 123-173.

Jolly, P.B. and Chin, D.N., 1991. Long term rainfall - recharge relationships within the Northern Territory, Australia - The foundations for sustainable development. Proceedings of the International Hydrology and Water Resources Symposium, Perth, October 1991, 824 - 829.

Jolly, P.B. and Chin, D.N., 1992. Hydrogeological modelling for an arid-zone borefield in Amadeus Basin aquifers, Alice Springs, Northern Territory. BMR Journal of Australian Geology & Geophysics, 13, 61-66.

Kavanagh, B.L., 1984. Survival water in Australia's arid lands. The strategic and defence studies centre, research school of Pacific studies, Australian National University, Canberra, ACT, 231 pp.

Kershaw A. P. and Nanson G.C., 1993, The last full glacial cycle in the Australian region. Global and Planetery change, 7, 1-9.

Knott, G.G. and Macdonald, P.S., 1983. Groundwater for central Australian Aboriginal communities. In Papers of the International Conference on Groundwater and Man, Volume 3, Groundwater Development, Australian Water Resources Council Conference Series No 8, Australian Government Publishing Service, Canberra, 141-150.

Kruseman, G.P., 1997. Recharge from intermittent flow. In Simmers, I., (Ed.), Recharge of phreatic aquifers in (semi-) arid areas. International Association of Hydrogeologists, 19, A.A. Balkema, Rotterdam, 145-184.

Langford, R.P., Wilford, G.E., Truswell, E.M. and Isern, A.R., 1995. Palaeogeographic Atlas of Australia. Volume 10 - Cainozoic. Australian Geological Survey Organisation, Canberra.

Larrson, I., 1984 (Editor). Groundwater in hard rocks. Studies and reports in hydrology # 33, United Nations Educational, Scientific and Cultural Organisation, Paris, 228 pp.

Latz, P. K., 1995. Bushfires and bushtucker: Aboriginal plant use in central Australia: Institute of Aborigional development press, Alice Springs, Australia, 400 pp.

Lau, J.E., 1997. (Compiler) Geology of the Papunya - Yuendumu - Kintore region, Northern Territory, Western Water Study (Wiluraratja Kapi), 1:500 000 map. Australian Geological Survey Organisation.

Lau, J. E. and Jacobson, G., 1991. Aquifer characteristics and groundwater resources of the Amadeus Basin. In Korsch, R.J. and Kennard, J.M. (Eds.) Geological and geophysical studies in the Amadeus Basin, central Australia. Bureau of Mineral Resources, Australia, Bulletin 236, 563-580.

Lau, J.E. and Jacobson, G., 1992. Groundwater systems map of the Amadeus Basin, 1:1 000 000, Bureau of Mineral Resources, Australia.

Lau, J.E. and Shaw, R.D., 1997 (compilers) Solid geology of the Papunya - Yuendumu - Kintore region, Northern Territory, Western Water Study (Wiluraratja Kapi), 1:500 000 map. Australian Geological Survey Organisation.

Lau, J.E., Bierworth, P.N., Jacobson, G., Wischusen, J.D.H., Woodcock, L.G. and Jamieson, M.C., 1997. Cainozoic geology of the Papunya - Yuendumu - Kintore region, Northern Territory, Western Water Study (Wiluraratja Kapi), 1:500 000 map. Australian Geological Survey Organisation.

Lerner, D.N., Issar, A.S. and Simmers, I., 1990. Groundwater recharge, a guide to understanding and estimating natural recharge. International Association of Hydrogeologists - International Contributions to Hydrogeology, Volume 8, Heise Hannover, Germany, 345 pp.

Macdonald, P.S., 1988. Groundwater studies Ti Tree Basin 1984-1988. Water Resources Branch, Northern Territory, Report 01/1990 A, 180 pp.

Macphail, M.K., 1997. Palynostratigraphy of Late Cretaceous to Tertiary basins in the Alice Springs district, Northern Territory. Australian Geological Survey Organisation, Record 1997/31, 27 pp.

Magee, J.W., Bowler, J.M., Miller, G.H. and Williams, D.L.G., 1995. Stratigraphy, sedimentology, chronology and palaeohydrology of Quaternary lacustrine deposits at Madigan Gulf, Lake Eyre, South Australia. Palaeogeography, Palaeoclimatology, Palaeoecology, 113, 3-42.

Marshall-Stoneking, B., 1989. Lasseter in quest of gold. Hodder and Stoughton, Sydney, 239 pp.

Matthews, I., 1994. Mount Doreen 1:250 000 map sheet groundwater notes. Water Resources Branch, Northern Territory, Report 68/98, 43 pp.

Matthews, I., 1995. Groundwater. In Young, D.N., Edgoose, C.J., Blake, D.H. and Shaw, R.D., 1995. Mount Doreen, SF 52-12, 1:250 000 geological map series explanatory notes, Northern Territory Department of Mines and Energy and Australian Geological Survey Organisation, 45-48.

Mazor, E., 1991. Applied chemical and isotopic groundwater hydrology. Open University Press, Milton Keynes, U.K., 274 pp.

Mazor, E., Verhagen, B.Th., Sellschop, J.P.F., Jones, M.T., Robins, N.E., Hutton, L. and Jennings, C.M.H., 1977. Northern Kalahari groundwaters: hydrologic, isotopic and chemical studies at Orapa, Botswana. Journal of Hydrology, 34, 203-234.

Meixner, A.J., 1997a. Estimated depths to magnetic basement of Mount Doreen, NT, scale 1:250 000, Australian Geological Survey Organisation.

Meixner, A.J., 1997b. Estimated depths to magnetic basement of Lake MAckay, NT, scale 1:250 000, Australian Geological Survey Organisation.

Myers, F.R., 1986. Pintubi country, Pintubi self. Smithsonian Institute Press, Washington, 334 pp.

Nanson, G. C., Price, D.M. and Short, S.A., 1992. Wetting and drying of Australia over the past 300 ka: Geology, v. 20, p. 791-794

Nganampa Health Council Inc, 1987. Report of Uwankara Palyanyku Kanyinjtaku: An environmental and public health review within the Anangu Pitjantjatjara Lands. South Australian Health Commission and Aboriginal Health Organisation of South Australia, 94 pp.

Nicholas, T., 1972. Lake Mackay, SF 52-11, Northern Territory, 1:250 000 geological map series. Bureau of Mineral Resources, Australia, Explanatory Notes, 14 pp.

Patton, C.P., Pickup G. and Price, D.M., 1993. Holocene palaeofloods of the Ross River, central Australia. Quaternary Research, 40, 201-212.

Perry, R.A., Mabbutt, J.A., Litchfield, W.H., Quinlan, T., Lazarides, M., Jones, N.O., Slayter, R.O., Stewart, G.A., Bateman, W., and Ryan, G.R., 1962. General report on lands of the Alice Springs area, Northern Territory, 1956-57. Commonwealth Scientific and Industrial Research Organization, Australia, Land Research Series 6, 300 pp.

Ranford, R.C., 1968. Mount Rennie, SF 52-15, Northern Territory, 1:250 000 geological map series. Bureau of Mineral Resources, Australia, Explanatory Notes, 15 pp.

Ranford, R.C., 1969. Mount Liebig, SF 52-16, Northern Territory, 1:250 000 geological map series. Bureau of Mineral Resources, Australia, Explanatory Notes, 15 pp.

Read, R.E., 1986. Pitjantjatjara homelands, nitrate and fluoride in outstation groundwater supplies. Department of Mines and Energy, South Australia, Report Book 1986/53, 18 pp.

Roberts, K.P., 1973. Report on Talyi Talyi investigation. Water Resources Branch, Northern Territory, Report 02/1973 A, 13 pp.

Rooke, E.R., 1991. Mount Liebig community, groundwater investigation and construction of production bores, 1990. Northern Territory Water Resources Report 47/1990, 70 pp.

Schoeller, H., 1959. Arid zone hydrology: Recent Developments. United Nations Educational, Scientific and Cultural Organisation, Paris, 125 pp.

Senior, B.R., Truswell, E.M., Idnurm, M., Shaw, R.D. and Warren, R.G., 1994. Cainozoic sedimentary basins in the Alice Springs region: records of drilling and reconnaissance geology. Australian Geological Survey Organisation, Record 1994/66, 85 pp.

Shaw, R.D., Stewart, A.J. and Black, L.P., 1984. The Arunta Inlier: A complex ensialic mobile belt in central Australia: Part 2: Tectonic history. Australian Journal of Earth Sciences, 31, 457-484.

Shaw, R.D., 1991. The tectonic development of the Amadeus Basin, central Australia. In Korsch, R.J. and Kennard, J.M. (Editors), Geological and geophysical studies in the Amadeus Basin, central Australia. Bureau of Mineral Resources, Australia, Bulletin 236, 429-462.

Simmers, I. (Ed.), 1997. Recharge of phreatic aquifers in (semi-) arid areas. International Association of Hydrogeologists, International Contributions to Hydrogeology, 19, A.A. Balkema, Rotterdam, 277 pp.

Smith, I., 1991. Alice Springs water management strategy. In Abstracts, Arid Zone Water Conference, April 1991, Alice Springs. BMR Journal of Australian Geology & Geophysics, 12, 275-277.

Smith, M.A., 1987. Pleistocene occupation in arid central Australia. Nature, 328, 710-711.

Smith, M.A. 1989. The case for a resident population in the central Australian ranges during full glacial aridity. Archaeology in Oceania, 24, 93-105.

Stewart, A.J., 1976. Mount Theo, SF 52-8, 1:250 000 geological map series. Bureau of Mineral Resources, Australia, Explanatory Notes, 17 pp.

Struckmeier, W.F. and Margat, J., 1995. Hydrogeological maps, a guide and standard legend. International Association of Hydrogeologists, International Contributions to Hydrogeology 17, Heise, Hannover, 177 pp.

Todd, D.K., 1959. Groundwater Hydrology. John Wiley and Sons, New York.

Toth, J., 1995. Hydraulic continuity in large sedimentary basins. Hydrogeology Journal, 3, 4-16.

Toyne, P., Granites, R.J. and Zimran, S., 1997. Towards a bicultural regional water program in

Central Australia - consultations with Aboriginal community groups. Australian Geological Survey Organisation, Canberra, 32 pp.

Van de Graaff, W.J.E., Crowe, R.W.A., Bunting, J.A. and Jackson, M.J., 1977. Relict Early Cainozoic drainages in arid Western Australia. Zeitschrift fur Geomorphologie, 21, 379-400.

Warren, R.G. and Shaw, R.D., 1995. Hermannsburg, SF 53-13, 1:250 000 geological map series explanatory notes, Northern Territory Department of Mines and Energy and Australian Geological Survey Organisation, 81pp.

Wells, A.T., 1972. Mount Doreen, SF 52-12, Northern Territory, 1:250 000 geological map series. Bureau of Mineral Resources, Australia, Explanatory Notes, 23 pp.

Wells, A. T., Forman, D.J., Ranford, L.C. and Cook, P.J., 1970. Geology of the Amadeus Basin, central Australia: Bureau of Mineral Resources Australia, Bulletin 100, 222 pp.

Wells, A.T.and Moss, F.J., 1983. The Ngalia Basin, Northern Territory: stratigraphy and structure. Bureau of Mineral Resources, Australia, Bulletin 212, 88 pp.

Wilson, B.A., Brocklehurst, P.S., Clark, M.J. and Dickinson, K.J.M., 1990. Vegetation survey of the Northern Territory, Australia, 1990. Northern Territory Conservation Commission, Technical Report 49, 222 pp and 1:1,000,000 maps.

Winograd, I.J., Landwehr, J.M., Ludwig, K.R., Coplen, T.B. and Riggs, A.C., 1997. Duration and structure of the past four interglaciations. Quaternary Research, 48, 141-154.

Wischusen, J.D.H., 1991. Review of drilling statistics, Mount Doreen Station, NT Pastoral Lease 901. Northern Territory Water Resources, Report 06/91, 3p.

Wischusen, J.D.H., 1994. Sustainability of a hard rock aquifer at Kintore, Gibson Desert, central Australia. 25th Congress of the International Association of Hydrogeologists / International Hydrology and Water Resources Symposium of The Institution of Engineers, Australia. Adelaide, November 1994. The Institution of Engineers, Australia, Preprints of Papers, 343-349.

Wischusen, J.D.H., 1995. Hydrogeology and sustainable yield of a hard rock aquifer at Kintore, Gibson Desert, central Australia. Master of Science thesis, Monash University, 256 pp.

Wischusen, J.D.H., Jamieson, M. and Dudley-Bestow, I. 1996. Western water study GIS: Emergency water for road travellers. Poster paper at "Aboriginal perspectives on water: improving community health" March 1996, Alice Springs NT. A workshop sponsored by Aboriginal and Torres Strait Islander Commission, Australian Health and Water Research Consortium and Cooperative Research Centre for Water Quality and Treatment.

Wischusen, J., Jamieson, M., Rose, B., Bierworth, P., Woodcock, L, Lau, J, Sollieux, M. And Jacobson, G., 1997. The Western Water Study GIS, an aid to groundwater assessment and prospecting on Aboriginal land in central Australia. In, Third National Forum on GIS in the Geosciences, March 1997, Australian Geological Survey Organisation, Record 1997/36, 84-89.

Wood, W.W., Rainwater, K.A. and Thompson, D.B., 1997. Quantifying macropore recharge: examples from a semi-arid area. Ground Water, 35, 1097-1106.

Woodcock, L.G., Bierworth, P.N. and Lau, J.E., 1997. An integrated remote sensing study for the Papunya-Kintore region, Northern Territory. Australian Geological Survey Organisation, Record 1997/45, 36 pp.

Woolley, D., 1966. Groundwater investigation at Papunya settlement, NT. Bureau of Mineral Resources, Australia, Record 1996/150.

Young, D.N., Edgoose, C.J., Blake, D.H. and Shaw, R.D., 1995. Mount Doreen, SF 52-12, 1:250 000 geological map series explanatory notes, Northern Territory Department of Mines and Energy and Australian Geological Survey Organisation, 55 pp.

Photo 1. View of sandhill country north east of Mt Morris.

Photo 2. View of the eastern side of the Cleland Hills looking south. These hills are outcropping Mereenie Sandstone, a formation of the Amadeus Basin renowned for high yielding and often good quality water elsewhere in central Australia.

Photo 3. Steeply dipping outcrop of Mt Eclipse Sandstone, an arkose of the Ngalia Basin, northeast of Bluebush Bore. Many bores tap this unit in the northeast part of the region.

Photo 4. View to the southwest of Central Mt Wedge (*Karrinyarra*). The flat plains that typify the topography of the Cainozoic Aquifer System are evident. The southern edge of Lake Ngalia is seen on the right hand border of the photo.

Photo 5. Central Mount Wedge (*Karrinyarra*) along the southern margin of the Ngalia Basin. A thick capping of Dean Quartzite overlies Arunta Block metamorphic rocks. The contact is at the break in slope at the bottom of the cliff. Gypsiferous dunes can be seen in the foreground.

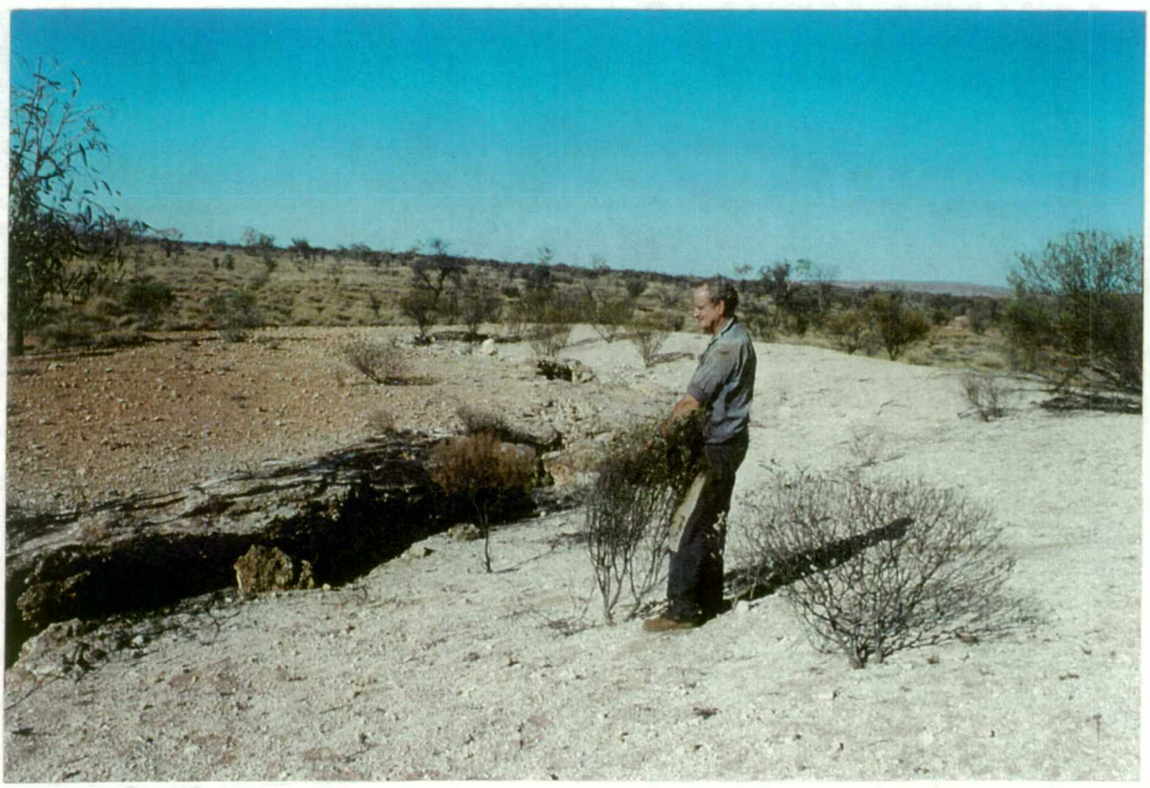


Photo 6. A large outcrop of calcrete on Newhaven Station, part of the palaeodrainage calcrete also associated with playas in this region. This outcrop shows signs of former warrens of the burrowing bettong, now extinct in the region.

Photo 7. Lake Bennett, a large playa near the centre of the region. The white halite crust of this groundwater discharge feature is evident.

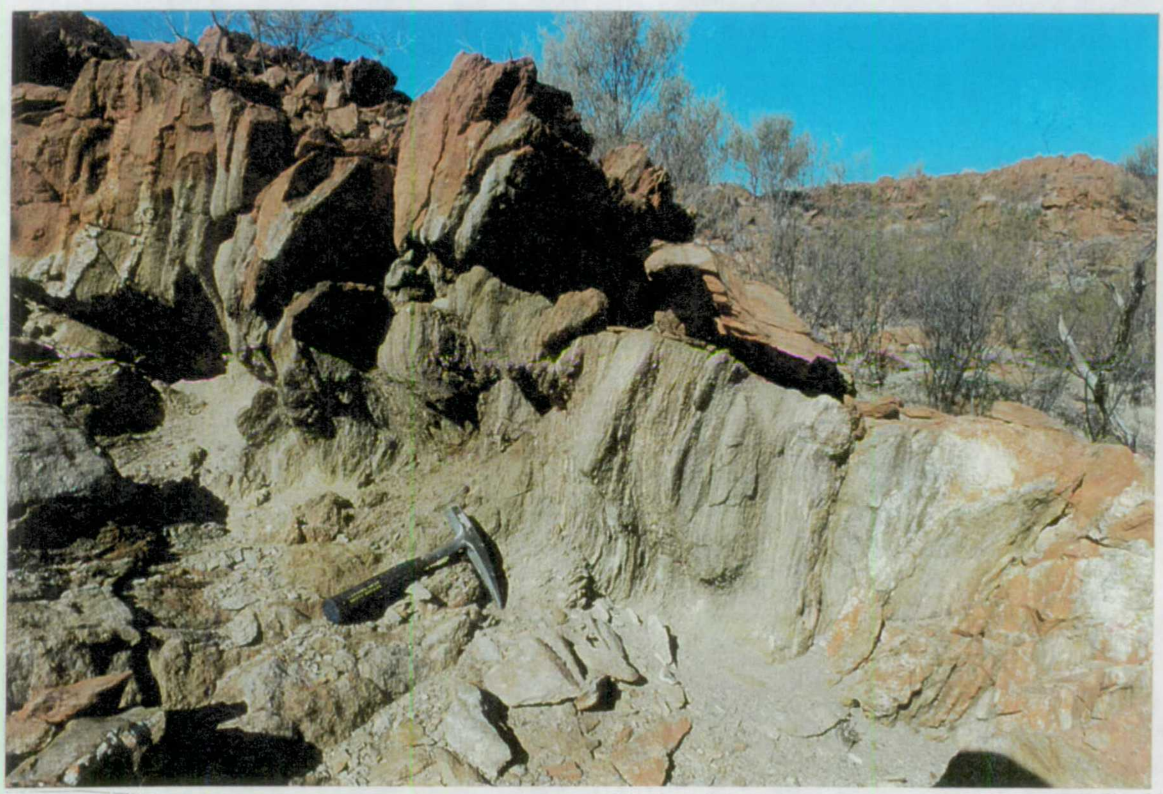


Photo 8. A gneiss of the North Arunta System between Nyirripi and Ethel Creek. This outcrop is capped with laterite.

Photo 9. The north face of Mt. Udor in the South Arunta System.

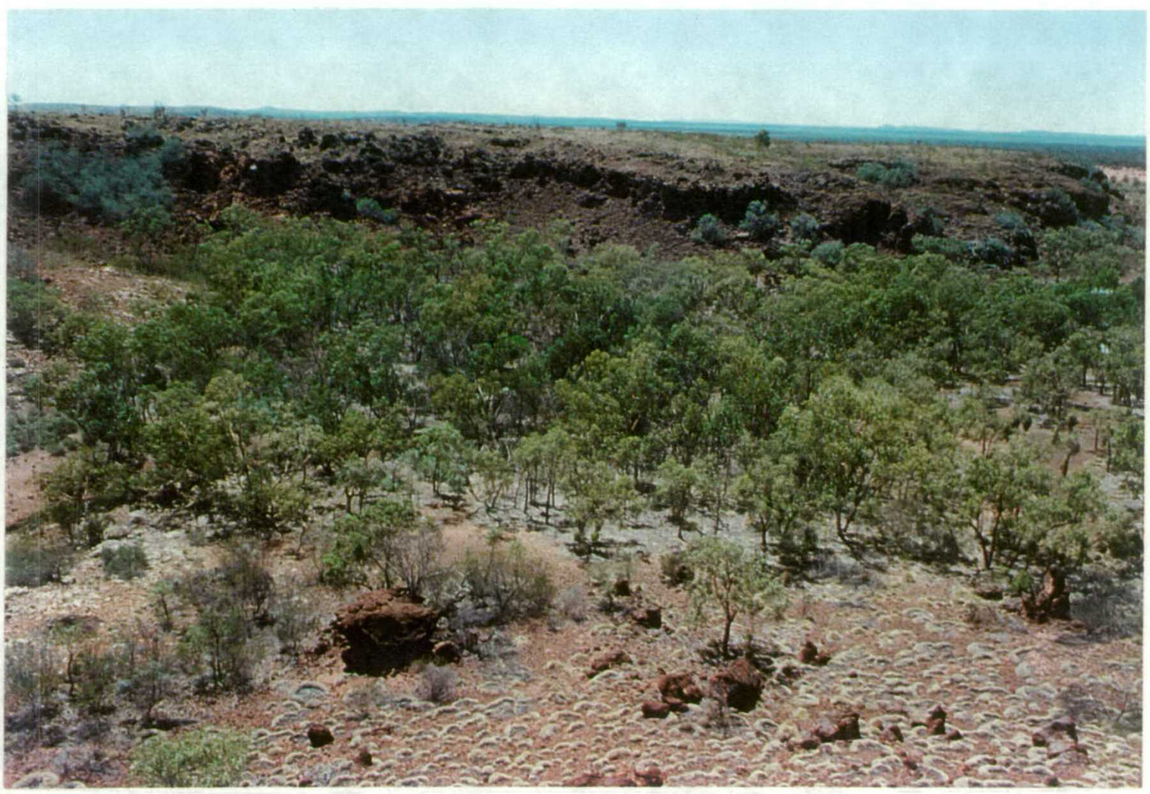
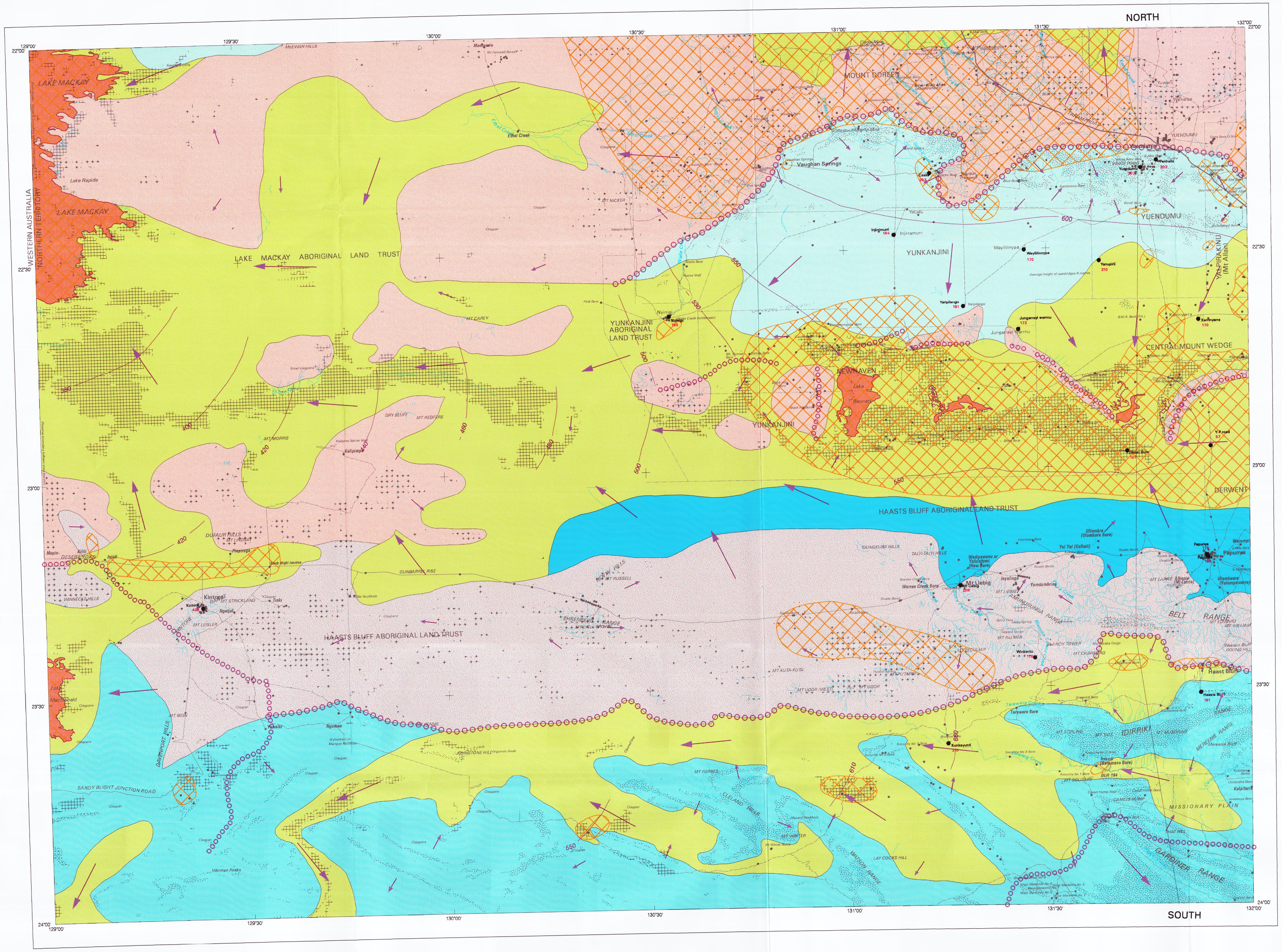


Photo 10. Vaughan Spring on the southeast flanks of the Truer Range. In the middle of the clump of trees, the spring discharges at a rate of about 2 L/s from laterite-capped Cainozoic gravels and sands. This spring is part of the Pikilyi Springs traditionally used by the Walpiri people.

Photo 11. Illpili Spring, Ehrenberg Ranges, in the South Arunta System. Permanent water is obtained by digging near the *Melaleuca* trees shown.

Photo 12. Putardi Spring at the base of Mt Putardi, in the South Arunta System.



MAJOR AQUIFER SYSTEMS OF THE PAPUNYA-YUENDUMU-KINTORE REGION

NORTHERN TERRITORY

Western Water Study *(Wiluraratja Kapi)*

1998

SCALE 1:500 000

10 0 10 20 30 40 50 Kilometres

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
LATITUDE OF ORIGIN: 0°. LONGITUDE OF ORIGIN: 129°
Australian Geodetic Datum 1966, Australian National Spheroid

AQUIFER SYSTEMS

Mountain Front Alluvial Fan System	*Permeable sand and gravel aquifers. Good supplies (1L/s median) of potable (922mg/L mean TDS) water expected from bores around 60m deep. Prospects are good with 71% of bores striking water*
Amadeus System	*Sandstone and limestone aquifers of the Amadeus Basin succession. Good supplies (1L/s median) of potable to brackish (1480 mg/L mean TDS) water expected from deep bores (130m median) in some lithologies. Only 46% of bores are recorded as having struck water, improved prospects may be possible by targeting the known aquifer formations ornamented*
Cainozoic System	*Sands, clays and calcrete aquifers. Fair (0.5L/s median) supplies of brackish to saline water expected (3178 mg/L mean TDS). Median depth of bores in this system is 38m, with 61% of bores striking water*
Ngalia System	*The arkosic Mt Eclipse and Kerridy Sandstone units of the Ngalia Basin are the main aquifers in this system. The low permeability of these sandstones is enhanced by fractures in some locations. Good supplies (2L/s median) of potable to brackish water (1774 mg/L mean TDS) is expected from deep bores (115m median) in this system. Prospects are good with 65% of bores striking water*
Playa System	*These playa lakes represent sites of groundwater discharge and are composed of pans of halite crust covering brine saturated clays. Playa surfaces are windows on the watertable*
North Arunta System	*Hard rock crystalline basement complex. Fine grained metasediments and schist lithologies in this system limit aqifer development. 61% of bores drilled are dry. When water is encountered fair (0.6L/s) supplies of brackish to saline (3656 mg/L mean TDS) water from shallow (45m median) bores typify results. Regions of highest metamorphic grade may offer the best prospects for potable supplies*
South Arunta System	*Hard rock crystalline basement complex. Fractured quartzose feldspathic gneiss and meta igneous rocks are the main aquifers in the system. Fair supplies (0.5L/s median) of potable to brackish (1017 mg/L mean TDS) water are found at shallow depths (36m median) from the 52% of bores that strike water. Regions of good recharge potential, such as where drainage courses run over faults or lineaments adjacent to areas of high relief, offer the best prospects for potable supplies*

Areas known to have groundwater salinity > 2000 mg/L

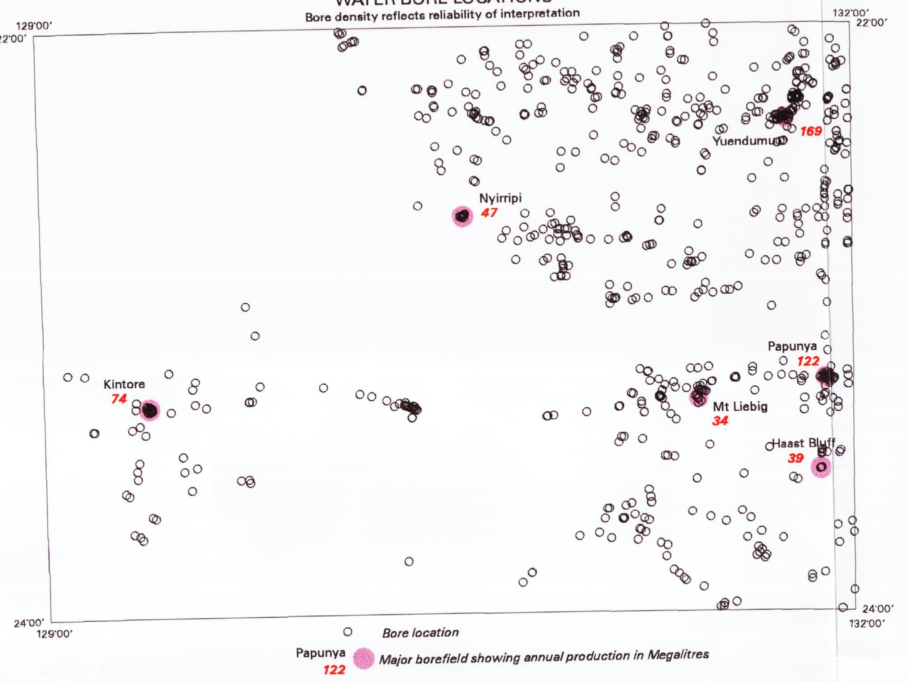
Areas of calcrete outcrop; these regions can represent the site of current or former groundwater discharges where evapo-concentration affects make shallow groundwater saline (5579 mg/L mean TDS). High groundwater salinity is particularly evident in the vicinity of playa lake systems. Small fresh water lenses may exist above saline groundwater at some locations

Areas of the main aquifer formations outcrop. This ornament highlights the formations known to have the greatest potential for groundwater development in this system

Areas where basement rocks outcrop. Apart from shallow basement (no overlying sediment or weathering products) these regions show where runoff may increase the likelihood of groundwater recharge (i.e. better potential for potable groundwater)

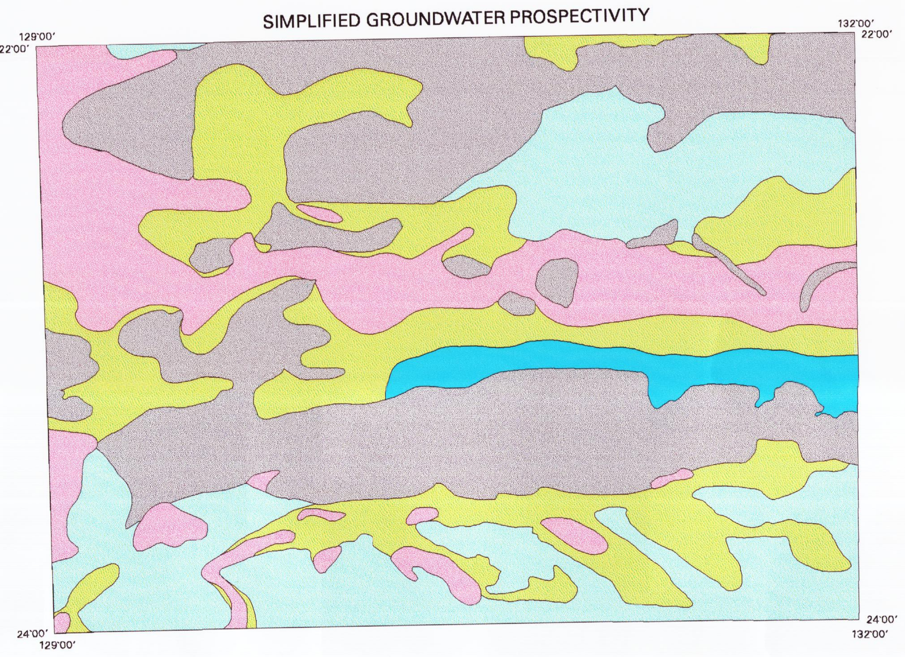
WATER BORE LOCATIONS

Bore density reflects reliability of interpretation



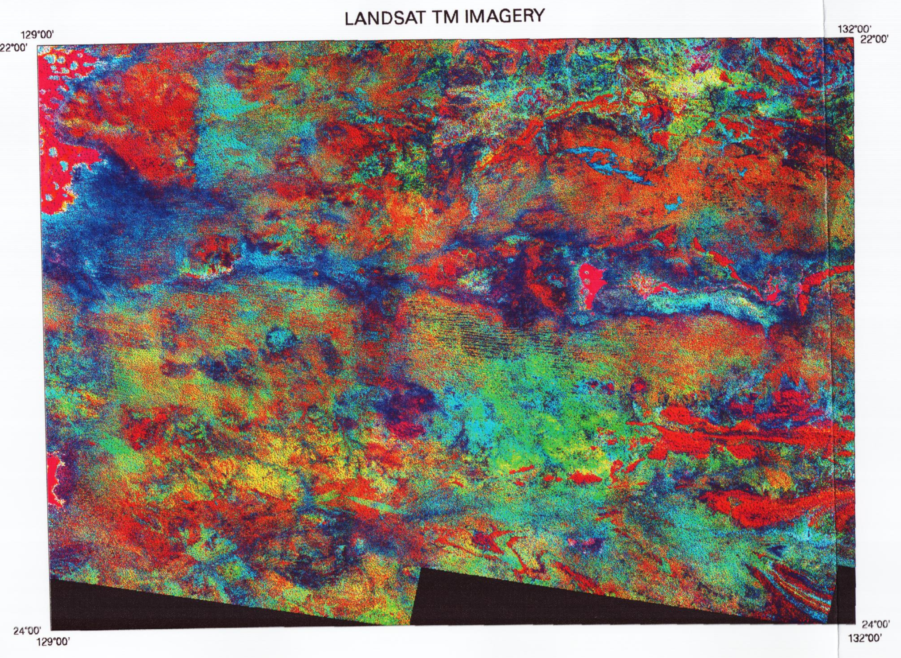
SCALE 1:2 000 000

SIMPLIFIED GROUNDWATER PROSPECTIVITY



SCALE 1:2 000 000

LANDSAT TM IMAGERY

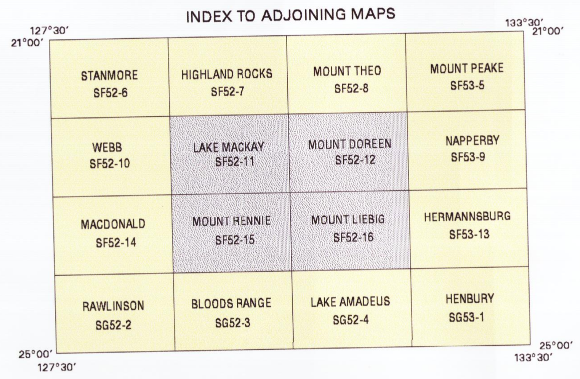


SCALE 1:2 000 000

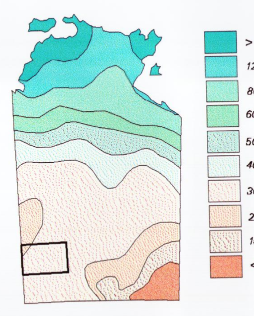
0 50kilometres

The image has been enhanced by spectral unmixing to highlight mineral content.
The image covers five scenes collected between 15 September and 10 October 1994.

INDEX TO ADJOINING MAPS

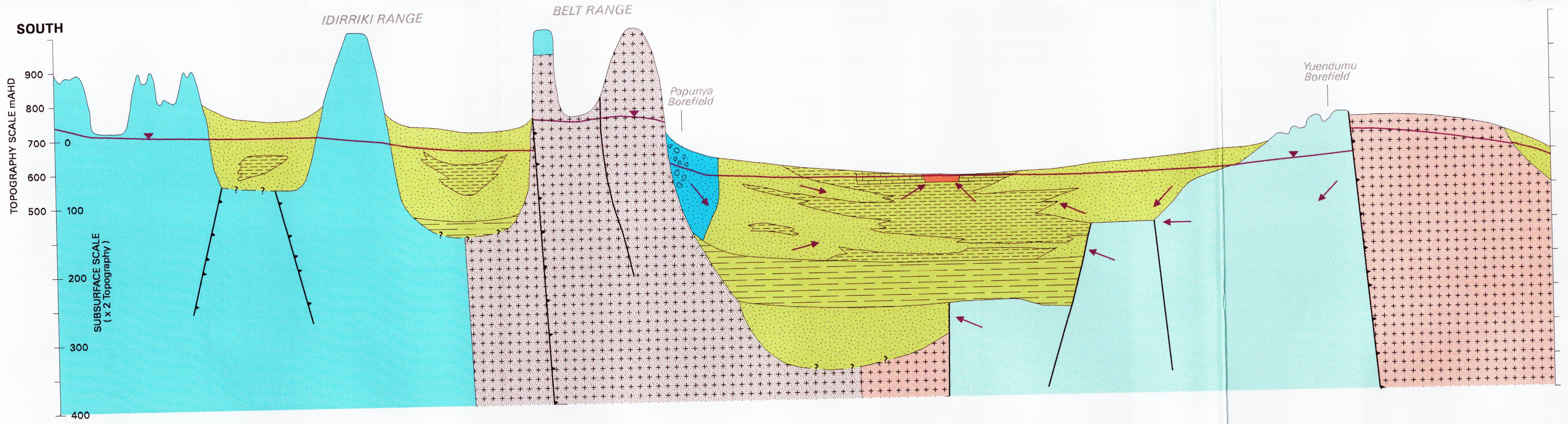


MEDIAN ANNUAL RAINFALL



MAP LOCALITY

Diagrammatic cross-section



Watertable
Playa
Mountain front alluvial fan system
Cainozoic Aquifer System: Calcrete; Sands, Clays (Miocene to Pliocene); Eocene clay
Amadeus System
Ngalia System
Arunta Block North
Arunta Block South

Hydrogeological boundary
Fault
Thrust fault
Groundwater flow direction
Potentiometric contour, in metres AHD
Groundwater divide
Waterbore
Location name of waterbore with chlorine 36 to chlorine ratio of groundwater ($x10^{-15}$)
Secondary road
Minor road
Vehicle track
River, mainly dry

Compiled 1996-1997 by J.D.H.Wischusen, J.E.Lau, L.G.Woodcock, G.Jacobson, AGSO; M.C.Jamieson, NTDLPE

Project leader G.Jacobson, AGSO; P.Jolly, NTDLPE; B.Rose, CLC

Surface geology from the published 1:250 000 geological series for Mount Doreen (1996), Lake Mackay (1971), Mount Rennie (1968), and Mount Liebig (1968)

Hydrogeology interpretation by J.D.H.Wischusen

New stratigraphic drilling 1995-1996 by Northern Territory Department of Lands, Planning and Environment (NTDLPE), supervised by M.C.Jamieson.
Geophysical soundings by J.Anning and G.Humphries, NTDLPE

Chlorine-36 determinations by R.G.Cresswell, L.K.Fifield, Nuclear Physics Department, Australian National University. Sample preparation E.Laing, AGSO

Waterbore and subsurface stratigraphic database for the project provided by NTDLPE and managed by M.Jamieson. Assistance from C.Garner, A.Wiegele, R.Darby, NTDLPE; A.Church, Alice Springs
Additional subsurface data selected by B.Calvert, Darwin and J.E.Lau from open-file company reports by Agip, Uranerz, and Central Pacific Minerals held by NT Department of Mines and Energy
Stratigraphic interpretation of subsurface data by J.E.Lau, J. Wischusen, AGSO; M.Jamieson, I Matthews, NTDLPE
Data integrity by Sonja Lenz, AGSO

Software to visualise waterbore data by R. Gallagher, GISolutions
GIS management and analysis by L.Woodcock

Cartography by G.A. Young, AGSO; additional graphics by A.Wiegele, NTDLPE

Produced by AGSO Spatial Information and Mapping Services using ARC/INFO System and may be suitable for transfer to other systems

MAJOR AQUIFER SYSTEMS OF THE
PAPUNYA-YUENDUMU-KINTORE REGION
NORTHERN TERRITORY
Western Water Study *(Wiluraratja Kapi)*

Central Land Council
The land is always alive

AGSO
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

WATER RESOURCES
NORTHERN TERRITORY
LANDS PLANNING ENVIRONMENT

ATSIC