Kapi Nganampa

Community water supplies in the Anangu Pitjantjatjara Lands, South Australia: sustainability of groundwater resources

A.R. Dodds, S. Hostetler, and G. Jacobson

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PO Box E11
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Telephone: (02) 6272 4282
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FOREWORD

Knowledge of the quality and quantity of our groundwater resources is critical for the longterm management of our supplies so that Anangu (the people) can live in their country and continue to derive health benefits.

This study gives us baseline data on the sustainability of our major production bores and again was carried out with a high degree of professionalism by the partners involved.

The Nganampa Health Council would like to thank ATSIC for funding the project and the Bureau of Rural Sciences and Department of Water Resources, South Australia for project design and the field work, compilation and analysis of the data.

Together with the previous report on the water quality, this information will now be used in the production of a water management plan/strategy for the Anangu Pitjantjatjara and Yankunytjatjara Lands increasingly now a necessary tool in the Anangu survival kit

Robert Stevens
Chairperson
Nganampa Health Council

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SUMMARY

Groundwater sustainability in the Australian arid zone

The groundwater supplies in the nine communities of the Anangu Pitjantjatjara (AP) Lands, northwest South Australia, are primarily derived from fractured rock aquifers. These aquifers are discontinuous and limited in extent. There is evidence of modern recharge into some of these systems, but several communities are abstracting old waters from fracture zones where there is little to no current recharge.

Water supply issues

Each remote community needs a minimum of two water supply bores with reasonable yields, and preferably three bores as a safeguard against bores drying up, or equipment breakdowns. Additional exploration to find an adequate water supply is needed at Mimili, Kalka, and Yunyarinyi.

Water quality issues

Water quality is relatively good, with five of the nine communities having water that meets the Australian Drinking Water Guidelines. However, the community supplies at Iwantja, Mimili, Kaltjiti and Amata are marginal to unacceptable in terms of salinity, and in some cases, fluoride and boron. Treatment, such as reverse osmosis or desalination, of community water supplies should be considered at Iwantja and Kaltjiti.

Regional water management strategy

This project forms the scientific basis for the development of a regional water management strategy for the AP Lands. Further development of the strategy will require consultation with the communities, and consideration of social, cultural, economic and institutional factors in water supply. It should be noted that water supply for mining, irrigation or pastoralism has not been covered in this investigation.

INTRODUCTION

This investigation of the sustainability of major community water supplies in the Anangu Pitjantjatjara Lands was initiated by a request from the Nganampa Health Council, the health arm of the Anangu Pitjantjatjara Council. The Council is running a long term health strategy aimed at improving the health status of the people called Uwankara Palyanku Kanyintjaku (UPK). The UPK strategy involves 9 Healthy Living Practices which are the practices identified most likely to reduce the high level of infectious diseases and give people an increased capacity to take care of their own health. Many of the practices involve the use of water. It seemed prudent then to attempt to map the sustainability of water supplies in the major communities given that there was already evidence of bores drying up, increasing salinity, and other water quality problems. The Council through other environmental projects had already determined water usage rates per household and the water use required for health (Pholeros, 1997). Under new South Australian legislation, the Anangu Pitjantjatjara communities need to develop a regional water management strategy, and this project is an essential step towards it. There is also an expectation amongst the Anangu communities that they will be able to continue occupation of their land into the future.

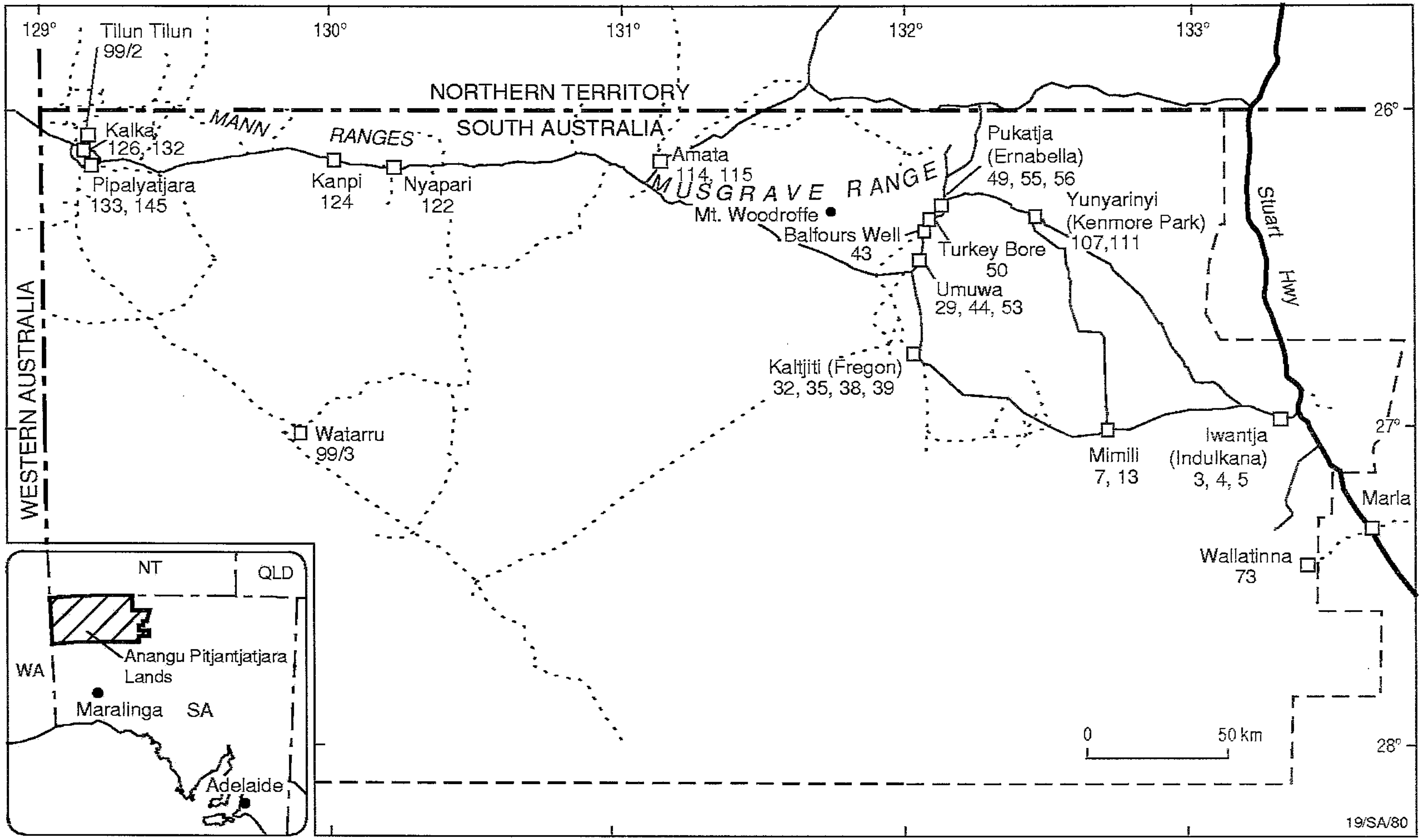
The AP Lands are located in the far northwest corner of South Australia (Figure 1). Topography is dominated by the E-W trending Musgrave and Mann Ranges along the northern border and the rolling dune country of the Officer Basin to the south. Rainfall is sparse, 250-350 mm/yr, and is generally an order of magnitude less than evaporation. The area has nine main communities and about 70 homelands (outstations) with a total population of around 3000.

Bores are typically shallow (20-30 metres) and are developed in the fractured basement of the Musgrave Block granites and granulites, Officer Basin metasediments, or alluvial aquifers. There are about 150 production bores in the region, and more are presently being drilled. Groundwater derived from bores is the only source of reticulated water in the AP Lands.

The project, undertaken from 1997 to 1999, aimed to evaluate the sustainability of groundwater resources for nine of the larger communities where there was concern for sustainability of water supply. These include 'at risk' settlements, where the water supplies appeared to be failing, and also settlements for which there were proposals for larger water supply systems which might not be viable with current bore yields. The investigation also assessed the potential for aquifer contamination at four of these communities.

The project was justified to the Department of Agriculture, Fisheries and Forestry Australia and the Aboriginal and Torres Strait Islander Commission (ATSIC) by: the need to provide a scientific basis for the Anangu Pitjantjatjara Council, as major landowners, to develop a regional water management strategy in response to new SA legislation arising from COAG water reforms; the need to improve community living conditions on a sustainable basis and in support of the homelands (outstation) movement; the need to minimise the future costs of infrastructure development; and the pressing need to improve the quantities and qualities of drinking water because of health concerns.

Figure 1: Location map of the Anangu Pitjantjatjara Lands



Pitjanjatjara Lands Boundary — *Sealed road* — *Unsealed road* - - - - *Track* — ◘ Kanpi 124 (sample location and number)

Location map and sample locations, Anangu Pitjantjatjara Lands

TERMS OF REFERENCE

The project objectives were stated as:

1. Provide a comprehensive assessment of the sustainability of the nine main community groundwater supplies in the AP Lands in order to present options for community decision-making with respect to water supplies.

2. Provide a scientific basis for advice to communities and regional groups on appropriate systems of water allocation and water pricing, as a contribution towards a regional water management strategy.

3. Provide a basis for the communities to consider options for alternative technologies to conserve or supplement water supplies, including wastewater re-use, artificial recharge, and water treatment.

4. Assess the potential for aquifer contamination, in view of the position of wastewater and other facilities in relation to the siting of the water bores, and provide the information for the communities to consider the need for aquifer protection measures.

5. Recommend appropriate data collection and monitoring programmes for consideration by the Pitjantjatjara Council, to fill in gaps in knowledge.

Response to Terms of Reference

In response to the Terms of Reference, the project team has:

1. Provided an assessment of the sustainability of the nine main community groundwater supplies in the Anangu Pitjantjatjara Lands in order to present options for community decision-making with respect to water supplies. The present report summarises this assessment and is supplemented by several more detailed scientific and technical reports (see References, below).

2. Provided a scientific basis for advice to communities and regional groups on systems of water allocation and water pricing. Although the scientific information is now available (see present report and supplementary reports), this aspect requires community consultation and further consideration towards a regional water management strategy.

3. Provided a basis for the communities to consider options for alternative technologies to conserve or supplement water supplies, including stormwater harvesting and artificial recharge, rainwater harvesting, and water treatment possibly including desalination. Some specific recommendations are made in the present report but further studies of these options, especially rainwater harvesting, are needed in particular communities.

4. Assessed the potential for aquifer contamination, and provided information for the communities to consider the need for aquifer protection measures. This has

been done for four communities (Plazinska, 2000) and the work could be extended in the future.

5. Recommended appropriate data collection and monitoring programmes for consideration by the Pitjantjatjara Council, to fill in gaps in knowledge. This aspect is covered briefly in the present report, and in more detail in a fuller report to be published shortly (Dodds and Sampson, 2000).

PROJECT PARTNERS AND STAKEHOLDERS

The project was a collaborative study between: the Pitjantjatjara Council Projects Division[1]; Nganampa Health Council[2]; the Department of Water Resources South Australia (DWR)[3], the Division of State Aboriginal Affairs (DOSAA)[4] in the South Australian Department of Environment, Heritage and Aboriginal Affairs; the Bureau of Rural Sciences (BRS)[5]; and the Aboriginal and Torres Strait Islander Commission[6]. The project has been overseen by a Steering Committee, consisting of a representative of each of the project partners. In the latter stages of the project, liaison has been maintained with the Arid Areas Catchment Water Management Board.

In this project, DWR installed water level monitoring systems on 30 bores in eight communities. This provides continuous monitoring of water level, rainfall, and water use at these remote localities and is a considerable technical achievement of great benefit to future water resources studies. They also undertook geophysical well logging of production bores to ascertain the production zones.

BRS undertook: radioisotope studies to determine approximate age and recharge of the stored groundwaters; specialised groundwater quality sampling at four communities to determine pollution risk; and seismic refraction surveys at three communities to enhance information related to aquifer storage and future drilling targets.

This joint DWR/BRS report summarises the significant results for each of the nine communities - Iwantja (Indulkana), Mimili, Kaltjiti (Fregon), Umuwa, Pukatja (Ernabella), Yunyarinyi (Kenmore Park), Amata, Pipalyatjara, and Kalka. Recommendations are given below.

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[1] The Projects Division of the Pitjantjatjara Council drills and equips bores for homelands water supplies across the AP Lands. It also maintains a regional database on groundwater resources.

[2] The Nganampa Health Council is the health arm of the Pitjantjatjara Council, and has responsibilities for environmental health. The Council has expressed concern about the vulnerability of the community water supplies in the AP Lands which are based entirely on discontinuous aquifers in fracture zones.

[3] DWR have supported these community groundwater investigations, have an overview of the hydrogeology of the region, and maintain the State groundwater database.

[4] DOSAA has the responsibility for major community water supplies in the region.

[5] BRS is the science agency within the Commonwealth Department of Agriculture Forestry and Fisheries - Australia and is concerned with land and water issues including the sustainability of arid-zone water supplies.

[6] ATSIC provided seed funding for the project

COMMUNITIES

Iwantja (Indulkana)

The location of Iwantja (Indulkana) is shown on Figure 1. Most of the bores are in fractured sandstone of the Officer Basin sequence; they are typically 60-80 m deep.

Bore I-25 has been the greatest and most consistent water supplier, and overall has supplied over half of the community's water usage. Other bores have contributed to the water supply at times, such as I-19 and I-19A between January and March 1998. Two bores in the Indulkana Range, IR-1 and IR-2, came on line in the winter of 1999 but were not fitted with monitoring equipment until October.

The available yield and water quality of the Iwantja bores is (Clarke, 2000):

I-19 ....300 KL/month	1110 mg/L TDS
I-19A .....300 KL/month	780 mg/L TDS
I-25 ....800 KL/month	1500 mg/L TDS
I-26 ....600 KL/month	1000 mg/L TDS
I-27 ....300 KL/month	3000 mg/L TDS
IR-1 .....4000 KL/month	1900 mg/L TDS
IR-2 .....3600 KL/month	1500 mg/L TDS

Thus the total amount of groundwater available is about 10,000 KL/month but much of this is more than 1000 mg/L TDS and thus unacceptable for human consumption. The two new bores in the Indulkana Range should supply the community's water needs for some time although the supply should still be used with caution to preserve the viability of the community. However, any significant increase in water use by Iwantja needs to be preceded by further investigation of the Indulkana Geosyncline.

Water-level monitoring shows a rise in standing water level (SWL) in bore I-19 indicating some recharge during recent rainfall events (Figure 2). However radioisotope studies show old waters in three of the production bores (Figure 3), with chlorine/chlorine-36 ratios of 141–177 x 10^{-15} (<30,000 years) and radiocarbon contents of 15-30% relative to modern carbon (10-20,000 years) (Cresswell and others, in press). The rise in SWL was confined to bore I-19 and does not occur with every large rainfall event, suggesting recharge through a localised fracture zone. In any case, the volume of water recharged to the aquifer is thought to be small relative to abstraction levels.

The salinity of two Iwantja bores sampled in the 1997 water quality survey was 780 and 1110 mg/L TDS, with nitrate concentrations of <1mg/L and fluoride concentrations of 0.4 mg/L. There were high iron (3.9-5.7 mg/L) and radionuclide concentrations in these groundwaters (Fitzgerald et al., 2000) and also high iodide concentrations in two bores. These groundwaters are marginal to unacceptable in terms of the Australian Drinking Water Guidelines (1996).

Sampling and analyses from the 1997 water quality investigation also detected total coliform counts in one bore.

Conclusions: Groundwater quality at Iwantja is marginal to unacceptable and will require treatment if it is to be used for drinking water. A dual reticulation system or full water treatment (desalination) is necessary for the supply to meet drinking water guidelines, and feasibility studies of this have been undertaken (Taylor, 1998). Recent drilling has confirmed that groundwater supplies are adequate as regards quantity (Clarke, 2000) but the longevity of these supplies should not be taken for granted; continued monitoring for signs of aquifer stress is necessary.

Mimili

The location of Mimili is shown on Figure 1. The community bores are developed in weathered and fractured granite of the Birksgate Complex (Watarru Gneiss and Kulgera Suite Granite).

Monitoring shows that the community water supply comes from two bores, M-1 and M-3. From November 1998 to March 1999 usage exceeded 2800 KL/month (~345 L/person/day) from these two bores; the maximum abstraction was in January 1999 and was 3800 KL (~470 L/person/day).

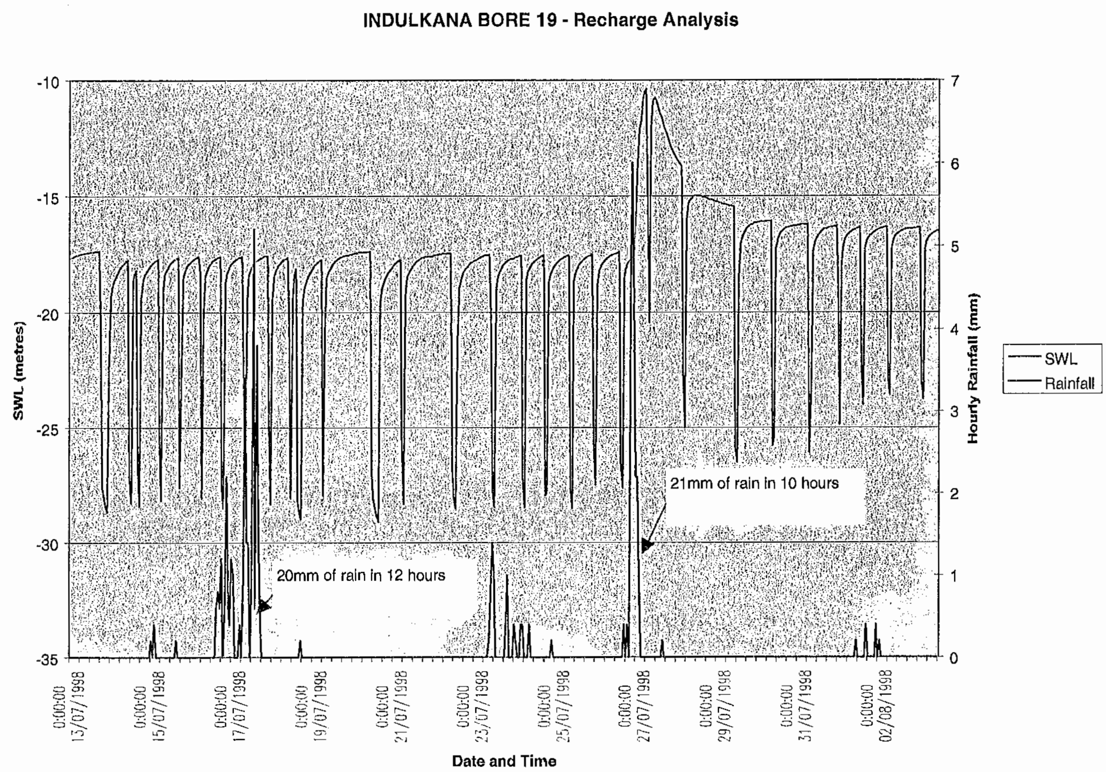
Neither bore has shown any longterm lowering of the water level during the period of bore monitoring, although there are reports of bores drying up. The radiocarbon content of 74-77% modern carbon suggests waters a few thousand years old. Chlorine 36 values for Mimili are generally indeterminate (less than 30,000 years), and support the age indicated by the radiocarbon (Figure 3). The low $^{36}Cl/Cl$ value for Bore M-3 is probably due to remobilisation of salts containing dead chloride (Cresswell and others, in press).

The salinity of these groundwaters is 1050-1090 mg/L TDS with nitrate concentrations of 73-83 mg/L and fluoride concentrations 1.9-2.3 mg/L. These concentrations exceed the levels suggested in the Australian Drinking Water Guidelines (1996).

The 1997 water quality investigation detected total coliform counts in the two community bores that were tested (Fitzgerald et al., 2000). When re-tested in 1999 the microbiological quality of water supplied by bore No. 1 was very good (Plazinska, 2000). Bore No. 3 had low level contamination indicated by total coliform levels, possibly from biofilms in the bore installations. Samples from both storage tanks showed no contamination suggesting that chlorine levels were sufficient to maintain adequate microbiological quality of water.

Water is also treated with the water softener, Calgon, added automatically at regular intervals to water entering the reticulation system from the overhead tank. A reverse osmosis (RO) system is used to desalinate water supplied through a separate reticulation line to the clinic and school.

Conclusions: This is a mildly vulnerable community as regards water supply. Two bores are producing an adequate supply for the community and show few problems regarding the reliability of supply or the life expectancy of the borefield. However, the water quality is poor to marginal and the water quantity would be restrictive should either bore fail. Some form of artificial recharge may be feasible here and an expanded search for additional water supplies is also recommended.



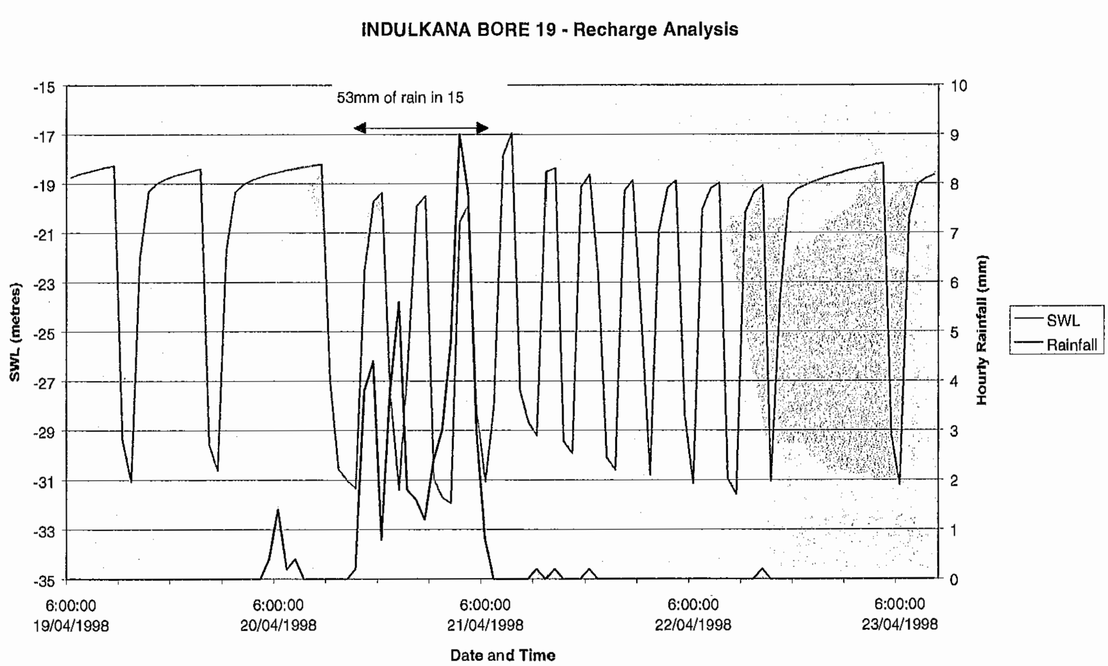


Figure 2: Hydrographs from Indulkana Bore 19 showing variable responses in the SWL to major rainfall events, suggesting recharge by fractures or other preferred pathway.

Kaltjiti (Fregon)

The location of Kaltjiti is shown on Figure 1. The community bores are in weathered granite and schist of the Birksgate Complex.

Community water usage has ranged from 3000 to nearly 10,000 KL/month (~875 L/person/day) during the monitoring period (Figure 4). There are four producing bores and their capacity is sufficient for these demands. However the water quality is poor, with all the bores producing water above 1000 mg/L TDS, the upper limit for potable water by WHO (1993) standards, and water from FRG-4 now exceeding 1500 mg/L TDS (salinity has increased from 1130 mg/L in 1972 to 1511 mg/L in 1997) (Dodds and Sampson, 2000).

Water levels in all wells have remained virtually constant over the monitoring period and in some cases have risen since the drilling of the well. From rainfall statistics we suspect that recharge of the aquifer occurs with rainfall events of more than 100 mm. However radioisotope studies (Figure 3) indicate old waters in this borefield. Radiocarbon contents are 58-67% modern carbon (3-4000 years) and the chlorine-36 ratio is 161-195 x 10^{-15} (indeterminate age) (Cresswell and others, in press). These data suggest a mixture of older waters with some component of modern recharge. These samples were taken from groundwaters in fractures at depths of 20 m or more.

The bore FRG-1 should be cleaned out to clear roots that endanger equipment and supply. Otherwise all the bores are in satisfactory condition.

The salinity of these groundwaters ranges from 1050 to 1820 mg/L TDS with nitrate concentrations of 37-50 mg/L and fluoride concentrations of 1.3-1.4 mg/L. This water is deemed unacceptable in terms of the Australian Drinking Water Guidelines (1996) and poor to unacceptable according to WHO Guidelines (1993).

The 1997 water quality investigation detected the presence of total coliforms in the supply lines (Fitzgerald et al., 2000). Follow-up studies found that all the production bores supply water of good quality microbiologically: no contamination was found except for total coliforms detected by the presence/absence Colilert test (Plazinska, 2000). This low level of contamination could be due to the presence of biofilms on the bore installation surfaces.

Conclusions: Kaltjiti is well supplied with water as far as quantity is concerned. However the quality is poor and water treatment (desalination) is recommended for the community water supply.

Umuwa

Umuwa is the administrative centre of the AP Lands (Figure 1). The bores supplying the community are developed in weathered and fractured granite of the Birksgate Complex.

Groundwater levels are not presently monitored at this community but radioisotope studies show modern recharge (Figure 3). The isotopic signatures in all the community bores are modern with groundwaters from two of the three bores sampled in Umuwa indicate bomb pulse recharge containing elevated levels of radionuclides associated with the nuclear tests of the 1950s (Cresswell and others, in press).

There are three operating supply bores: two solar-pumped bores (B1 and B2) and one diesel-pumped bore which is generally used as a backup. The community's

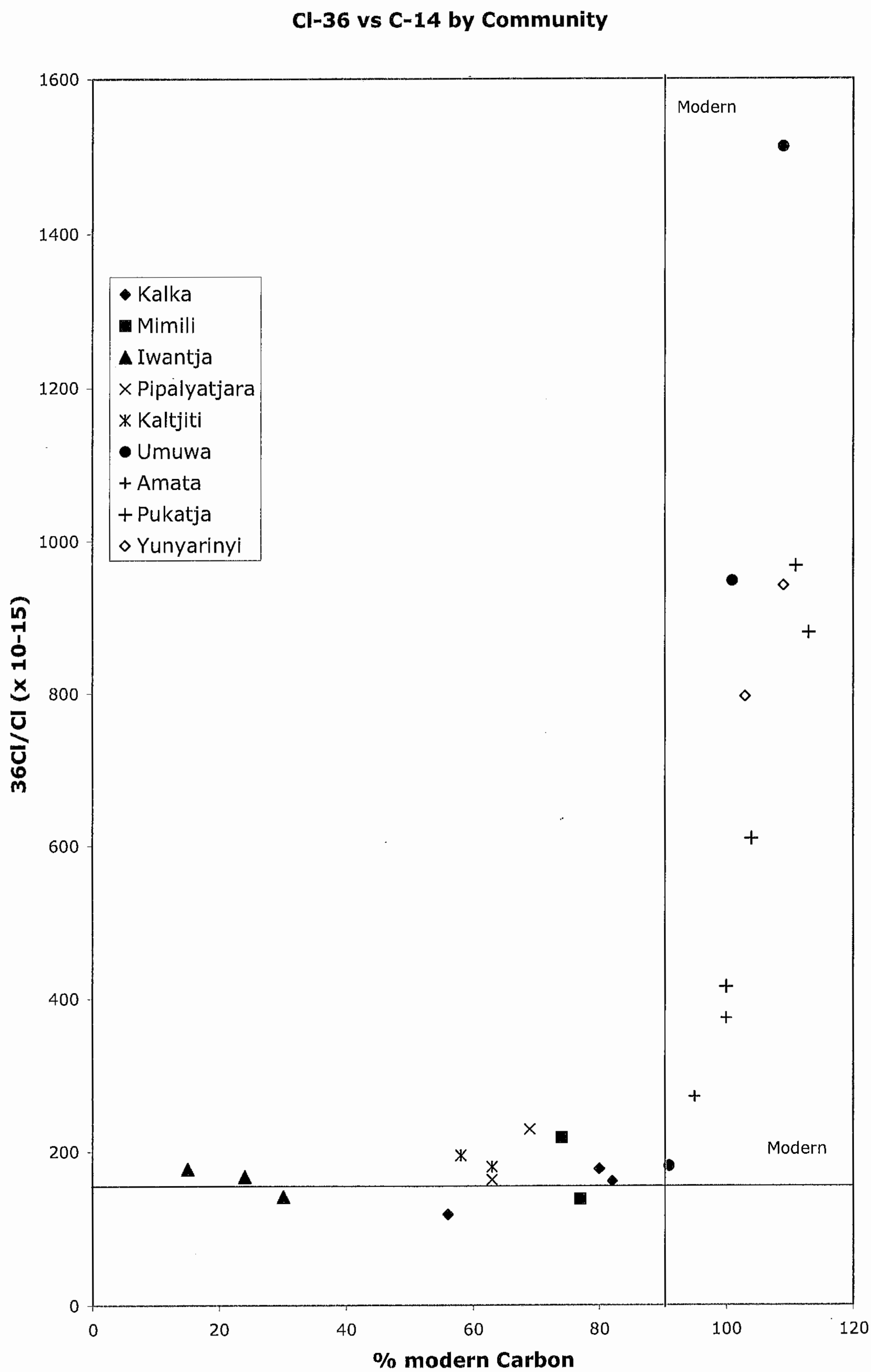


Figure 3: 14C plotted against 36Cl/Cl ratio for each community. 14C values greater than 90 pmC and 36Cl/Cl ratios greater than 180 x 10-15 indicate modern recharge.

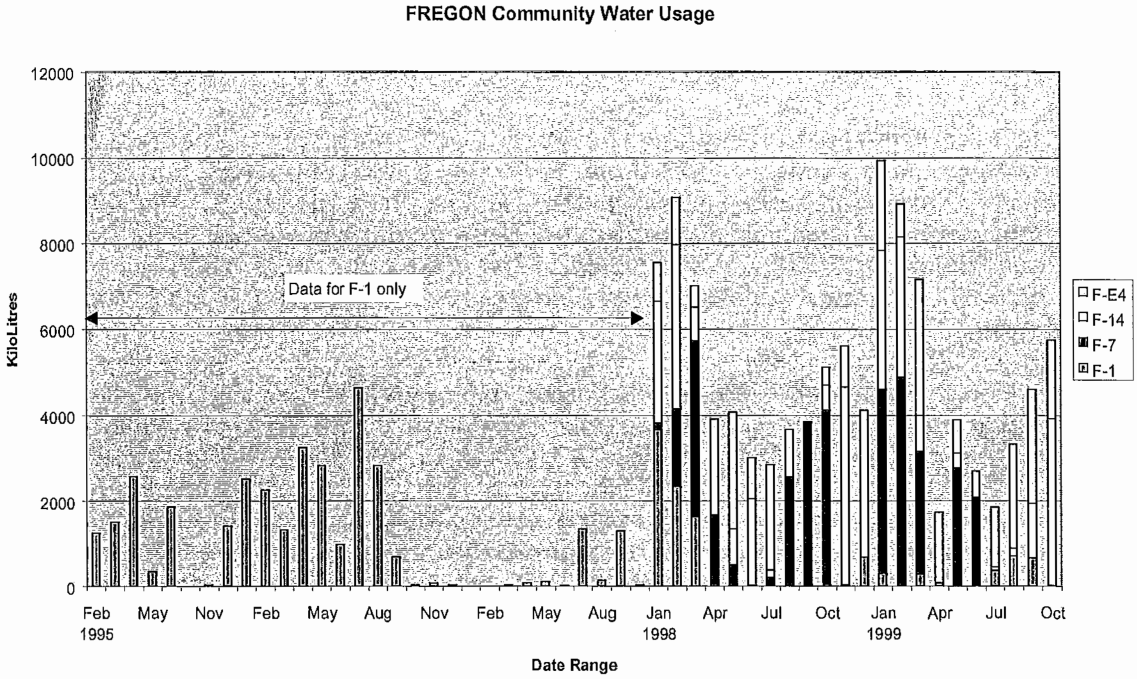


Figure 4: Graph showing the variable use of water for Kaltjiti (Fregon). Water usage varies during the year, peaking in summer due to the use of evaporative air conditioners. The graph also shows the rotation of the town supply bores to prevent dewatering of any one bore.

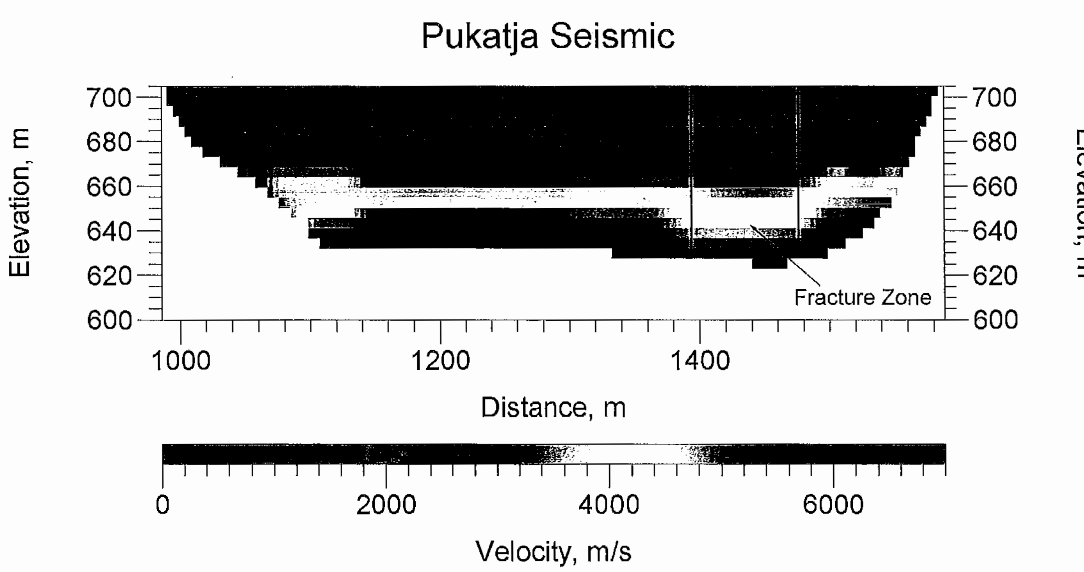


Figure 5: Processed seismic refraction line near Pukatja. Red colour indicates a high seismic velocity typical of unweathered granitic bedrock. The fracture zone shows up as an increase in the depth of weathering in the basement. The fracture zone correlates with a lineament swarm on the surface along which several high yielding bores have been drilled.

water use is believed to be about 60 KL/d (1800 KL/month). The regional groundwater quality study in 1997 found that the three community bores had good quality water with 390–670 mg/L TDS (Fitzgerald et al., 2000). However, two additional bores sampled at the Umuwa campground were more saline with 1520 and 1800 mg/L TDS, and also had elevated fluoride concentrations. This level of salinity is unacceptable according to the Australian Drinking Water Guidelines (1966).

Microbiological investigation in 1999 showed that both bore B2 and the diesel bore supply water that is quite clean microbiologically, with no thermotolerant coliforms or faecal streptococci and a low level of non-coliform bacteria (Plazinska, 2000). However, groundwater from bore B1 contained total coliforms; the coliform presence may result from the development of a biofilm on internal surfaces of the bore installations. The sample from the diesel bore contained *Clostridium perfringens* spores, which suggests some contamination with faecal matter in the past, but too long before sampling for other indicator organisms to survive. A potential source of contamination to the aquifer is the periodical disposal in the bush of sewage from the town's septic tanks.

In the 1999 investigation, water samples from two hand pumps located at Umuwa camping grounds showed a high level of faecal streptococci and also the presence of *Clostridium perfringens* spores (Plazinska, 2000). Both hand pumps are located within the camping grounds that are used, at times, by large numbers of people. The absence of thermotolerant coliforms indicates that the contamination may have occurred some time before sampling.

Conclusions: The bomb pulse signature in Umuwa groundwaters indicate some modern recharge to the groundwater system. Microbial contamination of the aquifer supplying the drinking water is possible because of the method of sewage disposal, and this should be reviewed and monitored. At the time of sampling in 1999 the quality of water from supply bores was generally good but the presence of *Clostridium* spores in one of the bores suggests the possibility of prior contamination. Water in the storage tanks should be chlorinated. Water from the handpumps at the camping ground should not be used for drinking without treatment. We also recommend that the water-level monitoring bore network should be extended to include this community.

Pukatja (Ernabella)

The location of Pukatja (Ernabella) is shown on Figure 1. The borefield is in fractured granite of the Birksgate Complex that is, in places, overlain by alluvium derived from Officer Creek. The seismic cross-section (Figure 5) shows a zone of deeper weathering of the basement along the lineament that the bores were drilled.

The town supply bores are widespread, and monitoring shows that the present water supply is sufficient for the needs of the community (Dodds & Sampson, 2000). In 1997/8 the bore E12 supplied an average of over 4000 KL/month, or more than all other bores put together. E-45 has also been a major producer for this community, and until April 1999 these two wells produced virtually all of the water used. Since April much of the demand has been taken up by the two Pupalyatjara bores, E-97B and E-97L. The contribution of the other three bores, E-01, E-42 and E-44, is minimal and their use now is primarily for monitoring the water table. E-42 and E-44 originally yielded large supplies but now have quite meagre yields.

For the future, E-97B and E-97L appear capable of supplying at least 13,500 KL/month, based on pump test data and limited monitoring. This is considerably more than the community used before these bores were installed. However, it is important to monitor the effects of extraction on the water table and this could best be done by monitoring observation bores that are not being pumped; these include E-97A, E-97D and E-97G. Moreover, experience at Pukatja (E-42, E-44 and E-45) and at Itjinpiri 10 kilometres further north shows that wells that were originally generous water suppliers may fail with time. Although Pupalyatjara is lower in the aquifer than these wells, and therefore less prone to such effects, caution and close monitoring are advisable.

A study of this area has indicated that groundwater levels are currently dropping, and that this depletion is a result of natural drainage rather than water abstraction (Clarke, 2000). Radioisotope studies indicate that the community bores are recharged to some extent in modern times (Cresswell and others, in press). Bomb-pulse isotopic signatures were obtained in three community bores and also in New Turkey Bore and Balfours Well. The reasons for the bomb pulse occurring in these groundwaters in the Musgrave Ranges, may be meteorological or may relate to the shallow water table in these fractured granite aquifers, with infiltration to 9 metres depth in 45 years.

The salinity of the Pukatja groundwaters ranges from 420 to 860 mg/L TDS with nitrate concentrations of 5-16 mg/L and fluoride concentrations of 1.4–1.8 mg/L. These parameters are generally within the Australian Drinking Water Guidelines (1996) although fluoride is marginal.

The 1997 water quality investigation detected Total Coliform counts in two bores (Fitzgerald et al., 2000). Follow-up microbiological investigation in 1999 showed that two production bores, E-12 and E-45, supplied water which was clean microbiologically (Plazinska, 2000). However, water from bore E-42 showed the presence of coliforms and faecal streptococci; possible sources are considered to be a camping ground 50-70m from the bore or an old rubbish dump several hundred meters from the bore. Since the bore E42 yield has decreased significantly, it should be considered whether further use of this bore is desirable.

Water from the new bore 97B was positive for total coliforms using a presence/absence test, and faecal streptococci were also present. At the time of sampling bore 97B was not fully equipped - the area around the bore was not sealed and was accessible to dogs and horses. Bore 97B should be monitored for some time to determine whether the contamination was an one-off during installation or whether there is a ongoing source.

Because Pukatja is located close to the Musgrave Ranges the thickness of the weathered material/alluvium is relatively thin ranging from 20 to 30 metres. Most of the useful bores have been developed in alluvial deposits influenced by fracture/fault patterns. These deposits are relatively thin in cross-section, 30 m wide and 40 metres deep, but are thought to be well developed along the groundwater flow direction. The major difficulty is that the relative thinness of the aquifer combined with drainage means that the aquifers are prone to dry out.

Conclusions: The bomb pulse signature in Pukatja groundwaters indicates modern, ie. post 1950s, recharge to the groundwater system. There appears to be natural drainage of groundwater via the valley alluvium of Ernabella Creek; bores around Pukatja are higher in the groundwater flow system and tend to dry out. Use of E42 should be discontinued. New observation bores are needed near Turkey Bore, lower in the flow system; there are some available for this purpose, and equipment could be transferred from some of the older, disused, bores. If additional bores are needed in the region then new seismic information is available to guide the drilling (Hostetler, in prep.). It would be advantageous to drill on the seismic line, Ernabella 11 (Figure 5), to assist the understanding of the aquifer configuration.

Yunyarinyi (Kenmore Park)

The location of Yunyarinyi (Kenmore Park) is shown on Figure 1. The bores are sited in weathered and fractured granite of the Birksgate Complex. They are low-yielding and drilled into rock.

Monitoring results show failing water supplies in this community; Yunyarinyi is highly dependent on bore KP-6 for its water supply. The total water usage in 1998/9 came mainly from KP-6 with small contributions from KP-7 and KP-98 (Dodds and Sampson, 2000). Consumption reached a monthly high of over 3400 KL in January 1999, and exceeded 1800 KL for each of the six months September 1998 to March 1999 (Figure 6).

Because Yunyarinyi is located near the top of the Musgrave Block drainage system the aquifer tends to dry out quickly. Without additional recharge, the natural drainage will dewater bore KP-6 in about 7 years. While recharge from a major rainfall event might extend this, the supply is fragile and should be supplemented by additional bores if consistent supplies of over 1500 KL/month are required.

Radioisotope studies indicate that the community bores are recharged to some extent in modern times (Cresswell and others, in press). Bomb-pulse isotopic signatures were obtained in two of the community bores.

The salinity of these groundwaters is 540–670 mg/L TDS with nitrate concentrations of 22-44 mg/L and fluoride concentrations of 1.5 mg/L. Salinity is within the Australian Drinking Water Guidelines (1996) although water quality with respect to fluoride is marginal. The 1997 water quality investigation detected total coliform counts in two of the bores possibly indicating the presence of biofilms in the bore casing which will need to be cleaned out (Fitzgerald et al., 2000).

Conclusions: Monitoring data show that water supplies are failing in this community; there is one main production bore with an estimated life of seven years. Although there is some evidence of modern recharge to the groundwater system, water levels in the main production bore are falling owing to natural drainage and pumping. Yunyarinyi needs additional bores to secure the water supply for the foreseeable future.

Amata

The location of Amata is shown on Figure 1. The aquifers are in fractured gneiss of the Musgrave Block (Fitzgerald et al., 2000).

For the period January 1998 to October 1999, water usage ranged from 3000 KL/month in July 1998 to 8200 KL/month (~615 L/person/day) in January 1999 (Figure 7). Three operating bores contributed to this total. The life of the borefield is estimated as at least 20 years. It is slowly being dewatered (Figure 8), probably because of natural drainage with little impact due to pumping observed.

While rainfall was appreciable over the summer of 1998-99 (33-68 mm each month), no indication of recharge in the aquifer could be inferred from the

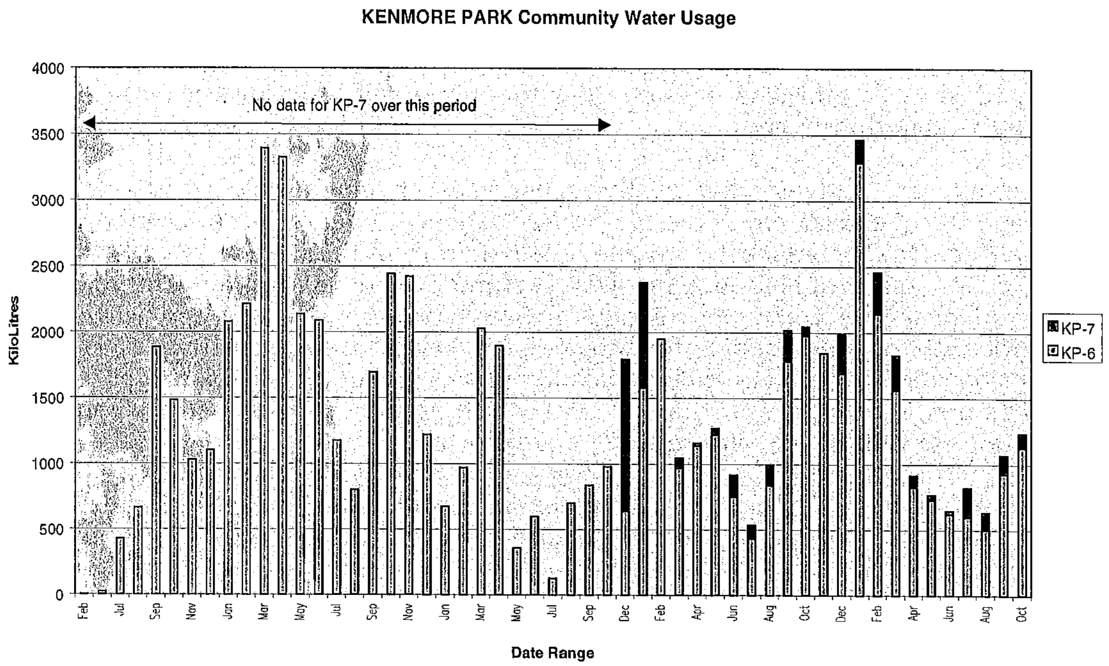


Figure 6: Graph showing the variable usage of water in Yunyarinyi (Kenmore Park) over several years. Water use peaks during the summer months due to an increased usage of evaporative air conditioning

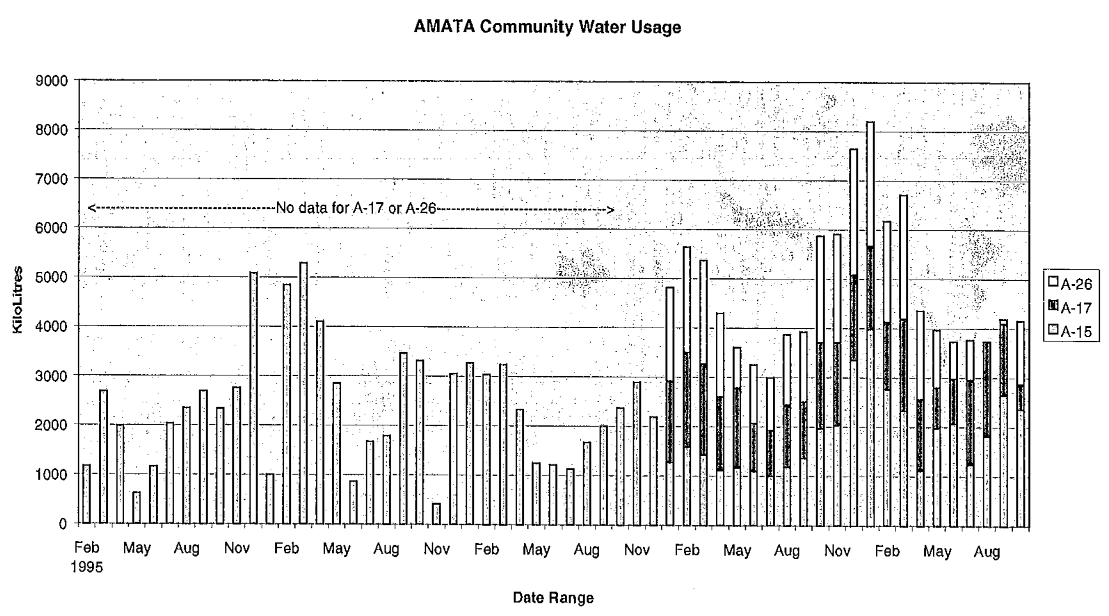


Figure 7: Graph showing the variable usage of water in Amata over several years. Water use peaks during the summer months due to an increased usage of evaporative air conditioning. Water is supplied mainly from bore A-15, although A-26 and A-17 also contribute significant water.

hydrograph at this time (Figure 8). However, there have been historic rises in water level which may have resulted from recharge. Nearly 1000 mm of rain was recorded in 1974 and it is possible that this has been the only recharge event during the past thirty years.

Monitoring data suggest that all three bores are being dewatered, by natural drainage or by extraction, and have a life of about 20 years. If dewatering is by natural drainage, as suggested by the steady nature of the decline in water level, then based on probable aquifer water storage and the extraction volume, recharge must be occurring or the aquifer would have run dry long ago. However, the prognosis of water supply for the wells in this area is speculative, since the dimensions of the aquifer that serves them are unknown. Thus the potential water storage capacity of the aquifer, which is an essential component to predictions of future well performance, is unknown.

The casing of all three bores is in poor condition and should be rehabilitated. Ten other bores have been drilled in this general area, with little success. The geology of the bores has generally not been recorded, but it is likely that they are in fracture zones in basement. To locate these zones requires both skill and experience to integrate all of the indications (topography, geology, vegetation, remote sensing data) to optimise the chance of finding water.

Radioisotope studies confirm the likelihood of modern recharge at Amata (Figure 3). The values of the chlorine-36 ratio were 271 x 10^{-15} and 374 x 10^{-15} (bombpulse) for the two bores analysed, and these values equate to radiocarbon contents of 95 and 100% (bombpulse) modern carbon.

The salinity of Amata groundwaters is 710-1070 mg/L TDS, with nitrate concentrations of 17-33 mg/L and fluoride concentrations of 0.9-1.4 mg/L. The salinity is marginal in terms of the Australian Drinking Water Guidelines (1996). The 1997 water quality investigation detected total coliform counts in the supply lines (Fitzgerald et al., 2000).

Amata groundwaters are very hard, in the range 360-530 mg/L calcium carbonate. Trials of a water softening technology were conducted in Amata in 1998-9 (Downing, 2000). Water conditioning units were installed in a house and on the town water supply and appeared to be successful in removing and preventing scale buildup in the pipes and fittings.

Conclusions: Two bores can supply the winter needs of the community, but some constraint is needed in summer. There is probably modern recharge to the aquifers. Replacement of casing is recommended. Aquifer storage investigations are needed in the long term, to assist in sustainability assessment. Continuation of the water softening regime will be advantageous for the community and it is recommended that a magnetic water conditioner that does not use external cables be installed.

Pipalyatjara

The location of Pipalyatjara is shown on Figure 1. The water bores are developed in fracture zones in the Birksgate Complex granulite and overlying Quaternary alluvium. The groundwater at Pipalyatjara is much higher in magnesium than groundwater derived from fractured granites around Pukatja (Figure 9). This suggests, that the primary groundwater storage is in fractured gabbro of the Giles Complex on Dulgunja Hill.

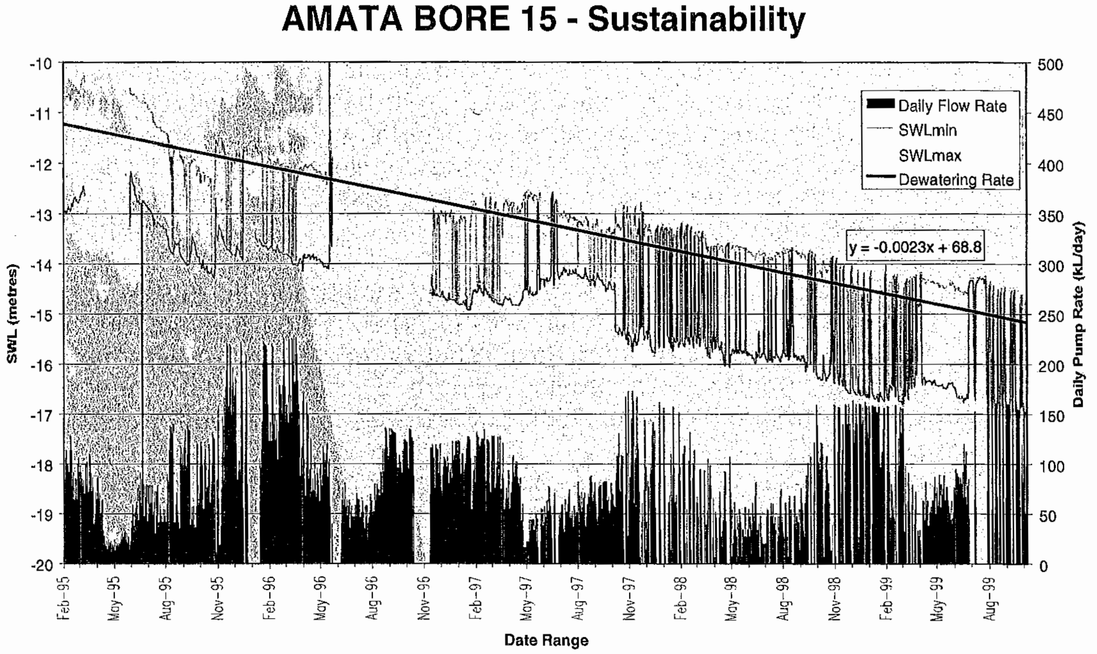


Figure 8: Hydrograph of bore A-15 showing decline in SWL of about 1 metre per year for the last 4 years. The decline is linear and does not seem to be affected by increases or decreases in pumping rate suggesting natural drainage of the aquifer.

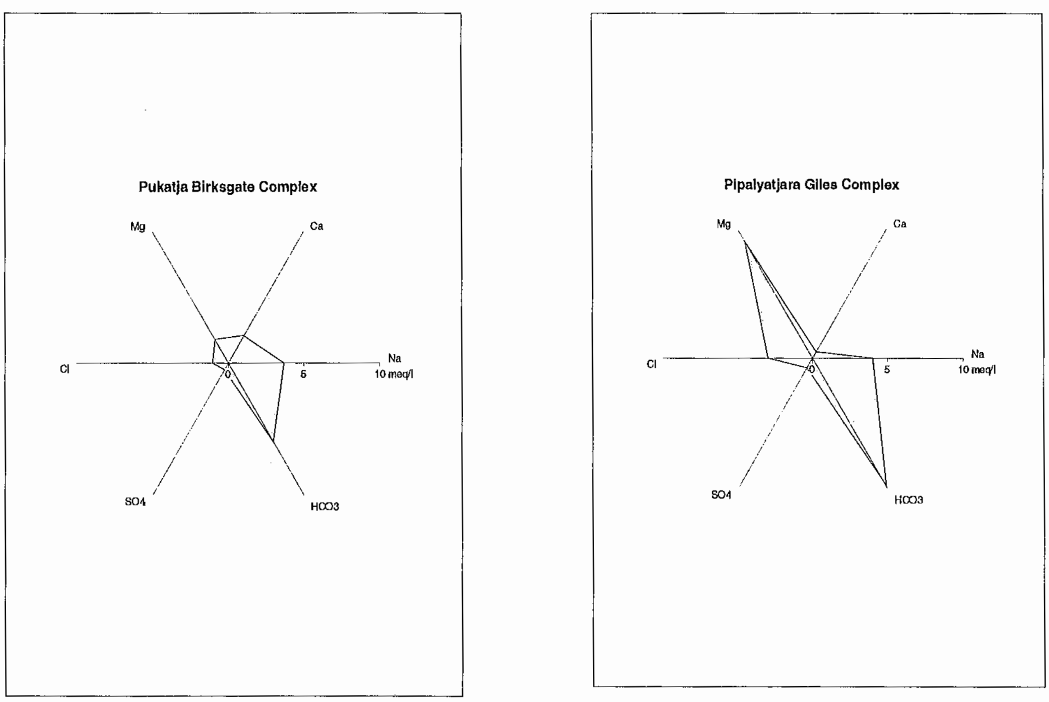


Figure 9: Radial hydrochemistry diagrams from the granitic Birksgate Complex at Pukatja and the gabbroic Giles Complex at Pipalyatjara. The two sources are easily distinguished by the high concentration of magnesium in the ultrabasic Giles Complex

The Quaternary alluvium ranges from 15-20 metres in depth and consists of rock fragments, sand and sandy clay. A seismic refraction survey across the bore field also revealed the presence of a zone of deep weathering associated with the Pipalyatjara Fault. Along this zone depth of weathering increases from 30 metres to over 50 metres. The presence of calcrete and conglomerate in the bore logs may indicate that the fracture zone may represent part of the drainage system associated with Dulgunja Hill (Hostetler, in prep).

No groundwater recharge has been evident during monitoring in 1998-9 despite over 100 mm of rain in January-February 1999. The decline in water levels is consistent with natural drainage from the groundwater system rather than the effects of pumping. Radioisotope studies (Figure 3) indicate 63% and 69% modern carbon (indicating an age of 3000-5000 years) in the groundwater from the production bores, and chlorine-36 ratios of 163 x 10^{-15} and 229 x 10^{-15} (indeterminate age). We speculate that there are older groundwaters in fractured rock on Dulgunja Hill draining via buried valleys as indicated in a seismic refraction survey (Hostetler, in prep), with some modern recharge superimposed on the system. The elevated groundwater levels may reflect decline in head after a 1-in-50 years rainfall event.

Water use has ranged from 1200 KL/month in July 1998 to 3300 KL/month (~530 L/person/day) in December 1998. Usage in September 1999 was exceptional at 5800 KL, for reasons unknown (Figure 10). This supply has come equally from the two main bores PIP-95 and PIP-96. Monitoring data suggest that the maximum production rate for bore PIP-96 exceeds the summer consumption for the community and that either of these two bores could supply the community for some time to come (Dodds and Sampson, 2000).

The salinity of these groundwaters is 640–770 mg/L TDS with nitrate concentrations of 30-35 mg/L and fluoride concentrations <1 mg/L. These values are all within the Australian Drinking Water Guidelines (1996). The 1997 water quality investigation detected total coliform counts in the supply lines (Fitzgerald et al., 2000).

Conclusions: Pipalyatjara has a good quality water supply that is sufficient for current usage rates for at least 5 years, and the community also has a reserve capacity that includes an additional bore, MD-13. Both operating bores could benefit from some cleaning of the slots by jetting. There may be some contamination of the supply line or storage tanks and microbiological monitoring is necessary. For future expansion of the borefield, seismic information on the location of the deeper weathered fracture zones is available.

Kalka

The location of Kalka is shown in Figure 1. The community bores are sited in fractured gabbro. High levels of magnesium in the groundwater indicate that groundwater flow originated from the ultrabasic Giles Complex composing Dulgunja Hill (Figure 10).

Monitoring since January 1998 shows that the water level is declining slowly, and the borefield may have a 40 year life (Dodds and Sampson, 2000). Water usage at Kalka is 1100-2200 KL/month (~700 L/person/day) during the summer, and 800-1100 KL/month in winter (Figure 11). Over this period the bore KA-3 supplied at least two-thirds of the water used. The bores at Kalka can probably supply 1750 KL/month in the long term, with higher yields available for short periods of a week or two.

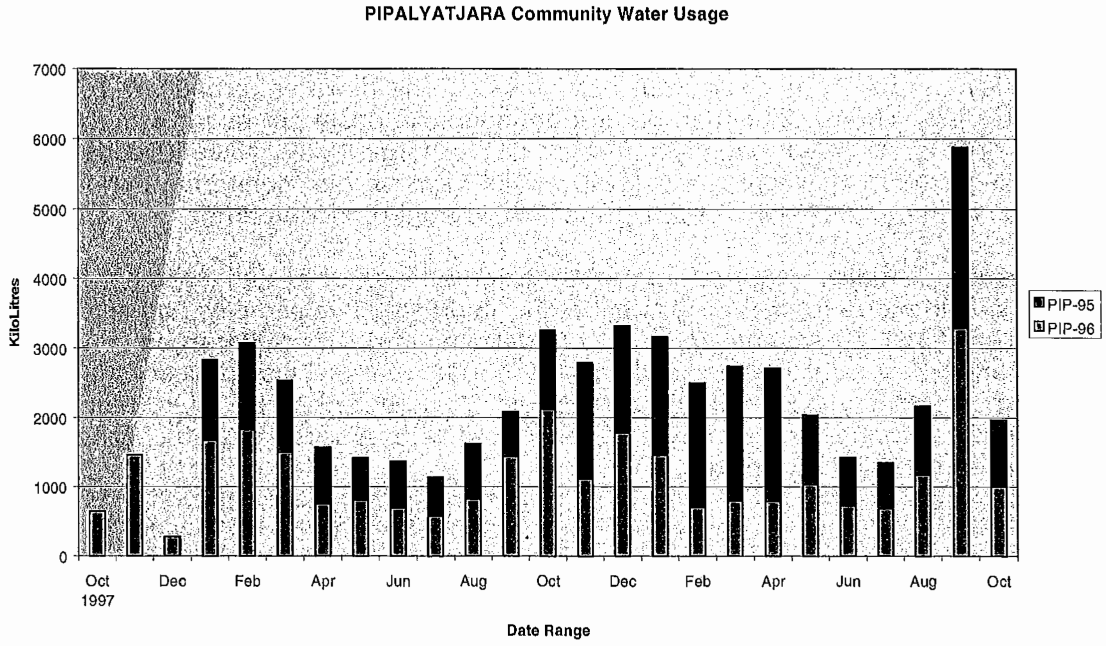


Figure 10: Graph showing the change in community water use over several years. Peak usage mainly occurs in summer months do to the use of evaporative air conditioners. Water supply comes fairly equally from both production bores.

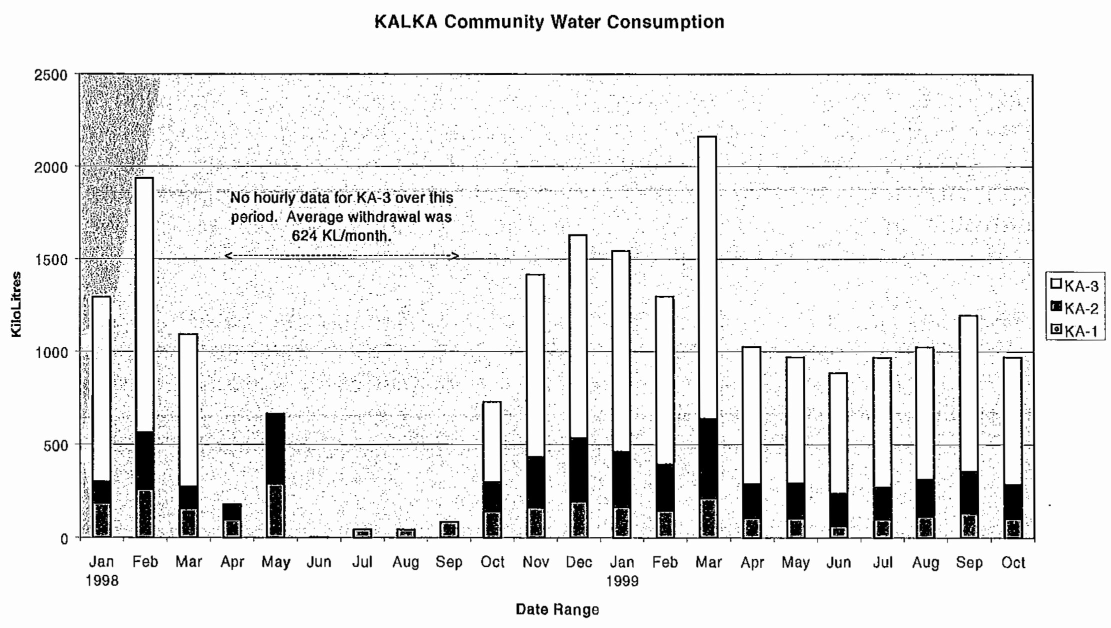


Figure 11: Graph showing the change in community water use over several years. Peak usage mainly occurs in summer months do to the use of evaporative air conditioners. Water supply comes mainly from bore KA-3. Kalka is considered 'at risk' because it has no suitable backup to KA-3 in case of breakdown or failure.

There is evidence of aquifer dewatering (decline in water level) for KA-2 (5-15 year life) and KA-3 (40 years) but not for KA-1. The dewatering appears related to water extraction rather than natural drainage. An observed rise in water level since drilling for KA-1 suggests that some recharge takes place (Dodds and Sampson, 2000). However the biggest rainfall event in the monitoring period, 88 mm in February 1999, did not affect the SWL in the production bores.

Radioisotope studies (Figure 3) suggest that groundwaters at Kalka are not being recharged in modern times (Cresswell et al., in press). Two samples had chlorine-36 ratios of 161 x 10^{-15} and 177 x 10^{-15} (indeterminate) with radiocarbon contents of 82 and 80 percent modern carbon (1000-3000 years). This suggests that the groundwaters may be 1000-3000 years old. A bore at nearby Tilun Tilun has bombpulse chlorine-36 which may be associated with river recharge by occasional flood events in modern times.

The salinity of these groundwaters is 540–580 mg/L TDS with nitrate concentrations of 22-34 mg/L and fluoride concentrations of 0.8-1.0 mg/L. These parameters are within the Australian Drinking Water Guidelines (1996). The 1997 water quality investigation detected Total Coliform counts in one of the bores and *E. coli* in part of the reticulation system (Fitzgerald et al., 2000). The condition of the casing is fairly good in all three wells, although KA-1 and KA-2 could benefit from some slot cleaning (Dodds and Sampson, 2000).

Five other bores have been drilled in the immediate vicinity, without success. It is evident that the location of the drilling is paramount, and it is likely that fracture zones in basement control the aquifers.

Depth to basement is variable depending on the presence of fracture zones associated with Dulgunja Hill and the Ewarara Mountains. Within the Kalka valley the alluvium is 30-40 m deep extending to over 60 m in the fracture zones. The fracture zones provide localised zones of deeper weathering 60-80 m wide, which may also tend to channel recharge from Dulgunja Hill away from the centre of the valley. The fractures funnel groundwater flow westwards eventually leading into the Pipalyatjara system. The search for additional groundwater supplies should be concentrated in the fracture zones near the Ewarara Range or to the west of Kalka at the foot of Dulgunja Hill (Hostetler, in prep).

Conclusions: Kalka is highly dependent on bore KA-3 for its water supply. The provision of an alternative supply bore is highly desirable. Seismic information is available to guide new drilling and there are possibilities of successful drilling in the area between bores 2 and 3.

GENERAL CONCLUSIONS OF THE AP LANDS GROUNDWATER SUSTAINABILITY STUDY

1. The output of this project is directed towards the nine communities in the AP Lands. They now have a better understanding of their groundwater resources, and can assess the sustainability of the resources under given uses. Models and prognoses of safe water yields and pumping rates can now be developed for production of water of given qualities.

2. Monitoring equipment has been installed in borefields in eight communities and is providing high quality data relating to water abstraction and recharge. It is important that this system be maintained and monitored for at least 10 years. The appropriate agency for this work is DWR. Extension of the monitoring system to other communities is needed. It may also be desirable to relocate some equipment to more critical areas or observation bores.

3. Rain gauges have been installed and linked to the borefield monitoring systems in eight communities. High quality rainfall data will be available from DWR for future groundwater recharge, rainwater catchment, stormwater and other hydrological and water management studies.

4. The nine communities have groundwater systems in weathered and fractured rocks: these are mostly granitic rocks, although the Pipalyatjara and Kalka borefields are in gabbro and the Iwantja borefield is in quartzite. Of the central communities Kaltjiti is lower in the Officer Creek flow system and has more saline, and older groundwaters than the other communities.

5. In general the fractured rock aquifers in the AP Lands contain a reservoir of older groundwaters (no modern recharge) with a small additional component of modern recharge (ie. last 50 years) in the Musgrave Ranges. There is some evidence of older waters being extracted from deep fractures with a topping up of modern recharge. This matter will become clearer when more data are available, particularly related to heavier rainfall events.

6. These remote communities need a minimum of two water supply bores with reasonable yields, and preferably three bores as a safeguard against bores drying up and against equipment breakdowns. Additional exploration to find drilling sites is needed at Mimili, Kalka, and Yunyarinyi (Kenmore Park).

7. Seismic investigations have been undertaken at three communities (Pipalyatjara, Kalka and Pukatja) and these seismic profiles, indicating the depth of weathering and presence of fracture zones are now available to aid future water search and locate drilling targets.

8. Two forms of aquifer depletion have been differentiated on observation bore hydrographs: that arising from recent groundwater abstraction; and natural drainage from higher water levels in the past. Where the latter is shown to be taking place, some form of recharge must have occurred in the last 50 or so years.

9. Five of the nine communities have water quality that meets Australian drinking water standards as regards chemical quality. However, the community supplies at Iwantja, Mimili, Kaltjiti and Amata are marginal to unacceptable in terms of salinity and, in some cases, fluoride. Treatment, such as reverse osmosis or desalination, of community water supplies should be considered at Iwantja and Kaltjiti.

10. Microbiological studies at four communities indicate that care is needed to avoid pollution of the bores. Field test kits are now available for regular microbiological monitoring. There is a need to insure that water supplies at Umuwa are chlorinated.

11. The hardness of groundwaters is a widespread regional problem affecting domestic hot water and other installations deleteriously. The water softening trial at Amata appeared to be successful and the technology is available for other communities. There is an issue about whether water softening technology should be used for discrete water units or for the larger community supply. The trial of a range of technologies for water treatment in remote communities is an emerging national issue.

12. The outcome of this project is the scientific basis for the development of a regional water management strategy for the AP Lands. Further development of the strategy requires consultation with the communities, and consideration of social, cultural, economic and institutional factors in water supply. It should also be noted that possible water supplies for mining, irrigation or pastoralism have not been covered in this investigation.

RECOMMENDATIONS

1. The regional water management strategy should consider the scientific results reported here in conjunction with community aspirations and social, economic, political, and institutional factors. The responsibility for the strategy is likely to be with the new Arid Areas Catchment Water Management Board. The strategy should also consider likely water supply needs for economic development including pastoralism, mining or irrigation, also future needs for outstations.

2. We recommend that the bore monitoring program be continued for 10 years to provide the water use and water level data on which management of the borefields must be based and to determine the effect of recharge events on these groundwater systems.

3. The monitoring program needs some extension and changes: water level data is required for the borefields at the emerging communities of Watarru, Kanpi, and Nyapari; and some unpumped bores should now be monitored to obtain information on recharge without the complication of pumping (there are observation bores at Pukatja, Turkey Bore, and Iwantja available for this purpose). Creek flow should also be monitored with staff gauges in selected locations where groundwater recharge is dependent on creeks.

4. Water search leading to additional drilling is recommended for Mimili, Kalka, and Yunyarinyi (Kenmore Park) and is probably also needed at Watarru.

5. Water treatment (desalination) is recommended for community water supplies with unacceptable water quality such as those at Iwantja (Indulkana), Mimili, Amata and Kaltjiti.

6. Rainwater options should also be explored for the communities where groundwater quality is marginal to unacceptable. Rainwater can be a valuable source of drinking water, supplementing the supply of water from the bores. Stormwater harvesting, although probably less viable, should also be explored.

7. Our observations indicate the necessity of regular water quality monitoring especially for bacteria, and that appropriate field test kits are now available. The agency responsibilities for water quality monitoring need to be clarified.

8. Field trials of water conditioning at Amata carried out over 18 months appeared to successfully remove and prevent scale buildup in domestic installations. Use of this or similar units will reduce the high cost of maintenance and replacement of domestic hotwater and other installations in these remote communities. There is a need for more extensive field trials of water treatment technologies for remote communities.

ACKNOWLEDGMENTS

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APPENDIX: SUMMARY OF METHODOLOGIES

1. Monitoring systems (from Dodds and Sampson, 2000).

DWR have installed monitoring systems in eight communities to record data automatically each hour. These data are: the rate at which water is being pumped; and the standing water level (SWL) in each bore. In addition, one bore at each community is equipped with a rainfall gauge, with a record made of each 0.4 mm of rain that falls. The data are stored on a data logger and the contents downloaded onto a computer at least every 6 months. At the time of download the equipment is checked, and any faulty units are repaired or replaced. The SWL measurement is also calibrated by comparing the automatic depth to water level with one taken manually.

This results in nearly 9000 data points, comprising date, time and two or three parameters (SWL, pump rate and sometimes rainfall), for each bore every year. While these hourly data are sometimes significant, overall analysis is made easier by reducing this to 5 daily parameters for each well: the maximum instantaneous pump rate; the total of water pumped; the maximum SWL (usually when the pump is not operating); the minimum SWL (usually with the pump operating); and the total rainfall.

Four plots are then prepared for each bore: a 'Drawdown' plot, which shows the instantaneous pump rate matched to the maximum and minimum SWL figures; a 'Sustainability' plot, which shows the total daily water extraction matched against the two SWL figures, and thus takes into account the duration of pumping each day; a 'Recharge' plot, which shows the daily rainfall and the maximum SWL; and a 'Monthly Pump Rate' plot, which shows the monthly water extraction from the bore. On a community basis, a combined plot shows the total amount of water extracted from all bores and the distribution between bores (eg Figures 6, 8 & 9). The monthly rainfall for the area is also plotted (eg Figure 7).

A plot of the total monthly withdrawal of water at each community, and the water supply contribution from each bore, assists in the analysis of total community water supplies and their vulnerability. It highlights those communities that are dependent on one bore and those which have a reserve capacity to cover such emergencies as the failure of a bore. It also shows variations in demand which may be seasonal, or may result from fluctuations in local population, such as occurs on special gatherings.

A detailed report on the DWR monitoring network has been published (Dodds and Sampson 2000).

2. Seismic investigations (from Hostetler, in prep.).

Seismic refraction traverses were undertaken at Kalka, Pipalyatjara and Pukatja (Ernabella). The location of the seismic lines were chosen to either cross major valleys or to intersect lineaments chosen from aerial photos. Lines were cleared and sighted by hand using a Brunton compass and GPS to maintain direction.

Based on depth to bedrock obtained from water bores, a geophone spacing of 10 metres was chosen to maximise depth and resolution.

A Smartseis seismograph with 24 channels was used with a 10 µm delay and a record length of 1024 µm. The seismic source used was a Betsy Gun M3 with a Seismic Blaster HVB-1 chosen as the most cost effective method of obtaining useful data over the distance although sometimes 10 shots were needed to obtained sufficient resolution.

For each unique geophone array up to three shots were fired forward (10 m offset), reverse (10 m offset), and mid (midpoint of line). The line would be then be moved 120 m along allowing overlapping coverage to increase the reliability of the results.

Firstpicks were chosen using Viewseis software and final processing done via Seisopt@2D.

Seismic refraction specifications

- Seismograph: Smartseis (24 Channel)
- Channels: 24 with 10 m spacing
- Geophones: 8 hz
- Source: Betsy Gun M3 firing 21mm Remington seismic shells (Seismic Blaster HVB-1 used as detonator)
- Processing software: Seisopt@2D and Viewseis

An example of a seismic cross-section at Pukatja is given above (Figure 5) and a detailed report is in preparation (Hostetler, in prep.).

3. Groundwater quality investigations (from Fitzgerald et al., 2000).

Sampling of groundwater from about 120 water bores and 30 domestic taps in the AP Lands was undertaken in 1997. Sampling protocols included filtration, freezing or acidification of particular aliquots. Certain parameters were measured in the field. Tests for faecal indicator bacteria were performed with a presence/absence test kit. The water samples were then analysed in the laboratory for a wide range of naturally occurring elements. Some sampling and analysis of water treatment products in the region was also undertaken.

Chemical analyses were undertaken as follows: Total Dissolved Solids (TDS) by evaporation; major and minor cations by Inductively Coupled Plasma (ICP); alkalinity by titration; major anions by Ion Chromatography; fluoride and iodide by Ion Selective Electrode; trace metals by ICP Mass Spectrometry; and dissolved organic carbon by Non Dispersive Infrared Spectrophotometry. Nutrients were determined by several different methods, including ammonia-N by the Flow Injection Salicylate Method; nitrite-N and Total Nitrogen by the Flow Injection Cadmium Reduction Method; and phosphate by spectrometry (colorimetry).

Alpha and beta radiation were determined by evaporation/gas flow proportional counting. The stable isotopes of water - deuterium and oxygen-18 - were measured by Isotope Ratio Mass Spectrometry to provide information relevant to groundwater recharge studies in the region. The full results and description of this study have already been published (Fitzgerald et al., 2000).

4. Radioisotopic sampling (from Cresswell et al.).

Thirty-one of the 150 production bores across the AP Lands were sampled for the radioisotopes chlorine-36 and carbon-14 as well as stable isotopes and major and minor elemental chemistry. These 31 bores are from the main communities in the AP Lands and are mostly from shallow aquifers 5-70 m below the ground surface in weathered and fractured rocks (Table 1). The recorded groundwater levels range from 4 to 35 m below the ground surface except for a single flowing bore, AP 5. In addition one surface water sample was taken.

The groundwater samples were generally taken from operating bores, or else standing water was purged from the bore casing before sampling. For chlorine-36 determination, silver chloride was precipitated by the addition of silver nitrate at acid pH, and this was then purified to lower the sulphur content. The water content of the precipitate was reduced by drying, and the precipitate was pressed into silver bromide masks in copper holders. Samples of the precipitate were measured using accelerator mass spectrometry on the 14UD tandem accelerator at the Australian National University (Fifield et al., 1987). Complementary samples were collected for ^{14}C determination, geochemistry and stable isotopes. Five samples were also analysed for tritium.

Because of the low level of chlorine-36 in groundwater, results are reported as the measured $^{36}Cl/Cl$ ratio, which varies naturally from a few parts to a few hundred parts in 10^{15} of stable chloride. The bomb pulse resulted in $^{36}Cl/Cl$ ratios up to 10^{-12} in groundwaters. Independent measurement of the chloride content of the groundwaters then allows us to determine the total number of ^{36}Cl atoms per litre of groundwater. Results are tabulated here (Table 1) and a supplementary report on the interpretation of these results is to be published (Cresswell et al., in press).

5. Microbiological sampling (from Plazinska, 2000).

Monitoring for the presence of specific pathogens in water supplies is difficult and a more indirect approach is adopted using the presence of indicator bacteria. Presence implies some degree of faecal contamination (Plazinska, 2000). The coliforms are generally used as indicator organisms; they are defined as: "aerobic and facultatively anaerobic, Gram negative, non-sporeforming and rod shaped bacteria that ferment lactose with acid and gas production at 35–37 °C within 48 hours" (APHA, 1995). The coliform group also includes thermotolerant faecal coliforms which are defined as being able to ferment lactose at 44 °C.

Coliforms are detected using Endo-type media containing lactose, at an incubation temperature of 35 °C. Samples shown to contain total coliforms are further examined for the presence of thermotolerant coliforms. The presence of coliforms (total and thermotolerant) is widely used as the indicator of faecal pollution of potable water, and is the main microbiological parameter in most water quality standards (ADWG, 1996; APHA, 1995). Thermotolerant coliforms can be detected using enriched lactose medium and an incubation temperature of 44.5 +/- 0.2 °C. The presence of thermotolerant coliforms generally indicates that faecal contamination has occurred, but their presence in water does not always imply a health hazard. It is now widely accepted that the use of *E. coli,* may be more appropriate than using the presence of thermotolerant coliforms, for routine surveillance of drinking waters. According to the Australian Drinking Water Guidelines (1996) no sample of drinking water should contain thermotolerant coliforms (minimum sample volume 100 mL).

Table 1: Bores sampled for radioisotopes

Sample no AP #	Cl (mg/L)	^{36}Cl/Cl (x 10^{-15})	^{36}Cl (x 10^6 atoms/L)	^{3}H T.U.	^{14}C (pmC)	SWL (m)	Bore Depth (m)	Aquifer depth (m)	Aquifer type	Name
124	388	118	778		56	8.3	37	8.3-35.7	Granulite	Kanpi
13	322	138	755		77	11	60	40,54	Granite	Mimili 3
4	366	141	877		30	15.6	68	55-60	Sandstone	Indulkana 19
99/3	283	151	727		n.d.	33	63	54-60	Gneiss	Watarru Solar 2
122	125	152	323		86	21.7	41.3	30-34	Granulite	Nyapari
99/1	31	159	83		n.d.	-	-	-		Pond (surface water)
132	95	161	260	<0.3	82	28-31	60	29-60	Gabbro	Kalka 2
38	483	161	982		67	11.6	21.5	11.6-20	Calcrete	Fregon 1
133	142	163	393	<0.3	63	17.4	60		Gabbro	Pipalyatjara 10
3	282	167	800		24	35	79	74	Sandstone	Indulkana 19A
126	99	177	298		82	15-19	40	24-30	Gabbro	Kalka 3
5	324	177	974		15	0	48	9-42	Sandstone	Indulkana 26
39	435	180	1330		63	12	48	39-45	Granulite	Fregon 7
44	462	181	1420		91	4.3	8	4.5-8	TQ Sediments	Umuwa Campgr.
73	209	192	682		59	9.5	19.2	19.2	TQ Sediments	Wallatina 96C
35	359	192	1171		n.d.	9	36	18-30	Granulite	Fregon 14
32	625	195	2070		58	11.5	35	20	Wthd schist	Fregon 4
7	311	218	1152		74	15.7	34.3	26	Gneiss	Mimili 1
145	184	229	716		69	17-21	36.8	22-36	Gabbro	Pipalyatjara 4
115	308	271	1418	1.1	95	8	35	25-35	Granulite	Amata 17
114	185	374	1175		100	8.6	36	30-36	Granulite	Amata 15
43	180	415	1269		100	5.9	12.6	37231	Granulite	Balfours Well
50	190	609	1965		104	9.4	39.3	30-39	Ademallite	New Turkey
107	55	796	744		103	9.2	36	26	Granulite	Kenmore 7
49	76	880	1136	2.2	113	9.2	29.1	9.2-24	Ademallite	Ernabella 45
111	54	941	863		109	7.2	30	17.5	Granulite	Kenmore 94B
53	56	947	901	1.7	101	6.9	45	27-39	Granulite	Umuwa diesel
56	102	967	1675		111	9	21	12-18	Ademallite	Ernabella 42
55	36.2	n.d.			114	9	18	11-18	Ademallite	Ernabella1
29	29	1512	745		109	6.5	24	12-21	Granulite	Umuwa solar 1
99/2	82	1564	2171		n.d.	25.3	42.3	32-39	Granulite	Tilun Tilun

The faecal streptococci include the genus *Enterococcus* and two species of *Streptococcus*, *Str. bovis* and *Str. equinus*. These organisms are mainly found in animal faeces. Faecal streptococci have certain advantages over coliforms as pollution indicators: they rarely multiply in water; they are more resistant to environmental stress and chlorination than coliforms; and they generally persist longer in the environment. However their value as an indicator of faecal contamination of drinking water is limited because: they are less numerous than coliforms in human faeces; there is a lack of standard methodology for their selective enumeration; and the group includes species that have different levels of sanitary significance as well as biotypes ubiquitous in nature. Nevertheless, they can serve as a valuable additional indicator in specific situations.

Clostridium perfringens is an anaerobic, spore-forming, Gram-positive microorganism of exclusively faecal origin. Clostridial spores are highly resistant to a range of environmental conditions and can survive in water much longer than either coliforms or streptococci. Sulphite-reducing *Clostridium perfringens* is consistently found in faecal wastes, and may be used to provide supplementary information about faecal contamination of water, eg. occasional or intermittent pollution.

Membrane filtration enables the enumeration of microorganisms present in samples of water. A measured volume of water is filtered through a membrane composed of cellulose esters. The pore size of the membrane is such that the microorganisms are retained on or near the surface of the membrane. The membrane is then aseptically transferred to either a solid medium or to an absorbent pad saturated with the liquid medium. On incubation at a specific temperature for a specific time, growth will occur. Colonies of characteristic morphology and colour, are counted and the number of organisms per 100 mL calculated. The results are expressed in colony forming units per 100 mL (CFU/100 mL).

In this investigation, all samples from supply bores and tanks were tested for coliforms and thermotolerant coliforms, faecal streptococci and *Clostridium perfringens* spores using membrane filtration methods. The volumes of the filtered samples were 10, 50 and 100 mL, as recommended for drinking water (100 mL) and groundwater (10, 50, 100 mL) by the American Public Health Association in "Standard Methods for the Examination of Water and Wastewater" (APHA, 1995). The volume used for *Clostridium perfringens* enumeration was 1000 mL.

Other tests used in the microbiological study of AP Lands groundwaters were the presence/absence (P-A) Colilert test. In the P-A test a volume of water sample (50 or 100 mL) is incubated in a single culture bottle containing an appropriate medium. It provides qualitative information on the presence or absence of microorganisms in the tested sample. The Colilert test employs the principle of defined substrate technology: substrates (chromogenes and fluorogenes) produce colour and fluorescence respectively upon cleavage by a specific enzyme. Further details and a comparison of the various tests have been published (Plazinska, 2000).

Sampling procedure

1. Sterile plastic bottles (1 L) were used for collecting water samples from supply bores and storage tanks.
2. Sterile, Whirl-pak bags (500 mL) were used to collect tap water and rain water samples.

3. All samples were processed within a maximum of 3 hours after collection at a field laboratory set up at the power station in Pukatja; in the meantime samples were stored at 4 °C (in the refrigerator).
4. Samples (1 L) for *Clostridium perfringens* analyses were stored at 4 °C, then transported to AGSO's Canberra Groundwater Microbiology Laboratory for processing.
5. The majority of supply bores were operating continuously at the time of sampling. Water was usually collected through taps installed at the pump head; water was run for 5-10 minutes and 70% ethanol was sprayed over the tap prior to sampling, to achieve external disinfection. Bores that were not operating at the time of sampling were pumped for at least 30 minutes before sampling.
6. All storage tanks had access from the top (lockable hatch); samples were collected by dipping 1 litre sterile bottles into the water using a long wire handle fastened around the bottle. The surface of the sample bottle and the wire handle were sprayed with 70% ethanol before being dipped into the water.
7. All household taps were tested for the presence of coliforms and *E. coli* on the outside and inside surfaces of the taps. It was anticipated that such contaminants could be present due to either poor hygiene or the presence of bio-films on the internal surfaces of the taps. Sterile plastic sticks with cotton end buds were used to swab the surface and then placed in sterile vessels. 100 mL of sterile water and Colilert reagent were added and vessels were incubated at 35 °C for 24 hours. The samples were then examined for colour (presence of total coliforms) and fluorescence (presence of *E. coli*).
8. Tap water samples were collected after water was run for 5 minutes and the tap was sprayed with 70% ethanol.
9. Rainwater samples were collected from taps either directly outside the tank or from the taps inside the house, using the same technique as described above.
10. Total and free chlorine tests were performed for all chlorinated samples. A Hach DR 2000 spectrophotometer was used with DPD Free Chlorine and DPD Total Chlorine test kits in a form of powder pillows. The detection range for both tests is 0-2.00 mg/L.