AGSO

WESTERN WATER STUDY (*WILURARATJA KAPI*)

GROUNDWATER QUALITY IN THE PAPUNYA - KINTORE REGION, NORTHERN TERRITORY

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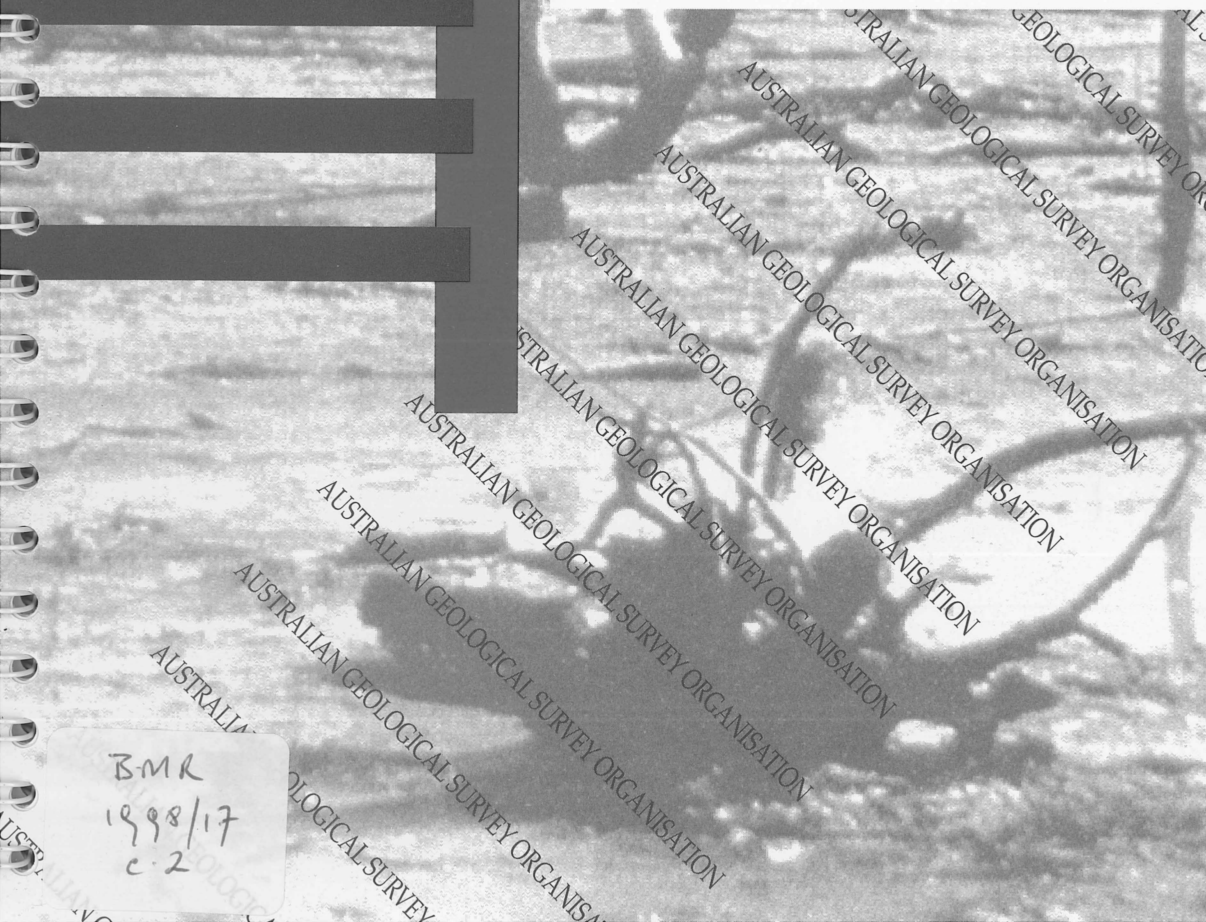
S. Hostetler, J. Wischusen & G. Jacobson

RECORD 1998/17



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1998

DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY

Minister for Primary Industries and Energy: Hon. J. Anderson, M.P.
Minister for Resources and Energy: Senator the Hon. W.R. Parer
Secretary: Ken Matthews

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Executive Director: Dr Neil Williams

ISSN: 1039-0073
ISBN: 0 642 27352 9

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ABSTRACT

The arid Papunya-Kintore region in the southwest Northern Territory contains shallow aquifers with little modern recharge, and groundwaters have long residence times, leading to the accumulation of elements deleterious to health. The Western Water Study *(Wiluraratja Kapi)* is a groundwater resources assessment program for Aboriginal lands in this region. The assessment is based on a GIS including all available regional geological and groundwater information. The GIS includes groundwater quality information for 479 water bores in the region. About two-thirds of these regional 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, while the high nitrate values are associated with shallow, unconfined aquifers. 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. There is a need for consideration of separate drinking water sources in the main communities of this region, which may involve water treatment or installation of rainwater tanks. 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.

INTRODUCTION

A decision-support system has been developed to facilitate groundwater management in central Australia (Fig. 1), and to improve access to groundwater information for Aboriginal people on their land. This is a collaborative project between the Australian Geological Survey Organisation (AGSO), the Central Land Council (CLC), and the Northern Territory Department of Lands, Planning and Environment (NTDLPE). The project has been supported by the Aboriginal and Torres Strait Islander Commission (ATSIC).

The study area, the Western Water Study *(Wiluraratja Kapi)* comprises 68,000 km^2 of arid central Australia. This is the Papunya-Yuendumu-Kintore region in the southwest of the Northern Territory. The available remote sensing, geophysical, geological, hydrogeological and groundwater quality datasets have been incorporated into an ArcInfo/ArcView Geographical Information System (GIS), and this has been produced as a CD-ROM to allow access and collaboration within the project (Wischusen et al., 1997). The GIS provides a means of compiling hydrogeology, as ready access and manipulation of groundwater data is possible. Analysis tools implemented with Avenue script enable the linking of the one-to-many relationships found in the spatial and depth datasets common to water bore data (Gallagher, 1996). The bore data can thus be interrogated for geological and hydrogeological analyses, which can be orientated to help local councils and community groups assess groundwater management issues. The database ARC format of this package allows the project partners to customise groundwater spatial analysis tasks as the need arises on Aboriginal land using either ArcView or ArcInfo, and it also provides a template for future expansion of this groundwater GIS in the Northern Territory.

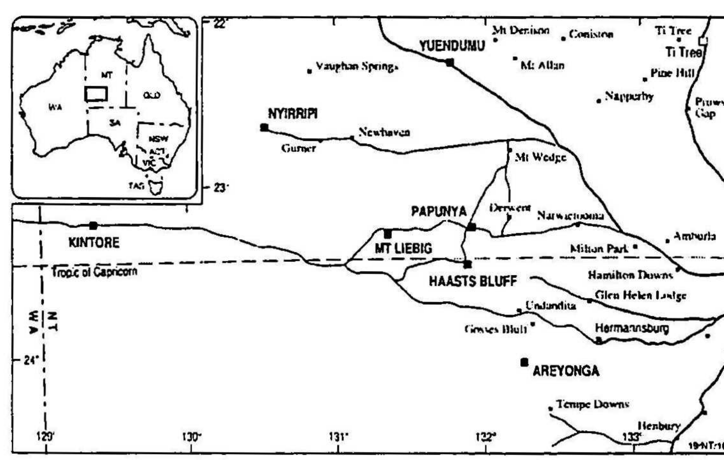


Figure 1: Study area location

This study applies the GIS to regional groundwater quality interpretation and associated issues using superimposed datasets,. The premise that the availability of clean, dependable supplies of water is a vital step towards health improvement for Aboriginal communities (eg. Hearn et al., 1993; Federal Race Discrimination Commissioner, 1994) has focussed much of the work undertaken for this project.

METHODOLOGY

The issues of groundwater quality discussed here were raised by Aboriginal communities in the region in early consultations about the Western Water Study, in 1994. There is a widespread awareness that radioactive waters exist in the region, as mineral exploration companies have been active. Complaints of poor-quality groundwater were also recorded in the ATSIC (1992) Infrastructure Study of these remote communities.

The previous groundwater database was held on paper files in the NTDLPE office. Waterbore data including the results of all chemical analyses have now been entered into the NTDLPE's HYDSIS database. This has a DBase format and from this the files have now been transferred to an Oracle database to enable spatial (GIS) analysis by the project partners.

A preliminary assessment has been made of the results of the chemical analyses of groundwater samples from 479 water bores (865 bores have been drilled, but there are only records for 479 bores). In order to obtain more information on minor elements 45 of these bores were resampled specifically for this project. The results of these additional analyses are given in Appendix 1.

The groundwater quality data has been compared with the Australian Drinking Water Guidelines (1996). Overlay of major ions with the hydrogeology has been undertaken in order to re-establish regional hydrochemical patterns. It is hoped to overlay population and health data in due course.

In this region, groundwater is used to supply Aboriginal communities and outstations. The sources are mainly shallow sand and gravel aquifers in Cainozoic basins, fractured sandstones of the Palaeozoic Ngalia and Amadeus Basins, or fractured granites and metamorphic rocks of the Arunta Complex.

RESULTS

Regional groundwater quality is such that in relation to the Australian Drinking Water Guidelines (1996), only 39 out of 479 water bores meet all the criteria (Table 1). The location of these bores is indicated in Figure 2. It should be mentioned that about 75% of water bores in this region were originally installed for cattle watering and are not considered as a source of drinking water for people.

The salinity of groundwater is the major constraint in present and future human development in this region. About two-thirds of bores tested (Fig. 3) exceed 800 mg/L total dissolved solids (TDS). The other major constraints are dissolved nitrate (Fig. 4) and fluoride (Fig. 5). About 25% of all bores tested contain less than 800 mg/L TDS but more than the recommended 50 mg/L nitrate and/or 1.5 mg/L fluoride.

Concentrations of major ions such as sulphate, chloride, and sodium show similar patterns to those of the TDS, although the relative proportions of the different ions vary between different aquifers (Table 1).

Concentrations of minor ions are generally low although there are rare occurrences of heavy metal contamination. Other ions of concern are boron (Fig. 6) and uranium (Fig. 7), which are known to be deleterious to health in excessive concentrations. Of the 45 bores resampled by AGSO, 11 showed high levels of boron (greater than 0.3 mg/L) and 5 had unacceptable amounts of uranium (greater than 0.02 mg/L).

Table 1. Bores exceeding Australian Drinking Water Guidelines (1996) listed by ion and aquifer

Aquifer	Total Bores	Bores within ADWG	Bores exceeding ADWG per ion Fl	SO_4	Cl	NO_3	Na	TDS
Tertiary sediments	124	6	41	63	88	31	78	86
North Arunta Complex	88	1	44	33	52	27	49	69
South Arunta Complex	81	12	27	17	19	34	25	33
Ngalia Basin	111	6	16	43	80	13	57	87
Lake	1	0	0	1	1	1	0	1
Alluvial	52	9	5	1	12	4	32	32
Amadeus Basin	22	5	1	5	6	1	4	9
Total	479	39	134	163	258	111	245	317
Bores used for human consumption	120	26	31	17	33	16	41	55

The results of screening for alpha and beta radiation activity are shown in Appendix 1. The guideline values are 0.1 mBq/L for gross alpha activity, and 0.5 mBq/L for gross beta activity after subtracting the contribution from potassium-40. After correcting the activity concentrations, additional sampling for specific radioisotopes was undertaken for water supplies where there was some concern. The results are shown in Table 2. These samples were taken from four water bores, and also from Mt Leibig and Yuendumu tapwaters.

Table 2. Radio-isotopes in regional groundwaters, concentrations in mBq/L.

Sample	Location	U-238	U-234	Ra-226	Ra-228	Th-232	Th-230	Pb-210	Po-210
10945	Yuendumu	262 (8)	1406 (42)	14.0 (0.7)	28.5 (2.7)	0 (0.1)	0.4 (0.2)	4.54 (0.58)	0.69 (0.28)
12578	Yaripilangu	118 (5)	203 (9)	9.9 (0.6)	31.5 (2.9)	0 (0.1)	0.5 (0.2)	3.04 (0.31)	0.67 (0.14)
12910	Wayililinypa	179 (16)	354 (31)	341 (13)	158 (14)	0.1 (0.1)	0.7 (0.2)	17.9 (0.7)	2.09 (0.21)
15740	Mt Leibig	82 (3)	255 (8)	13.1 (0.7)	40.9 (3.6)	0 (0.1)	0.5 (0.2)	2.15 (0.23)	0.57 (0.16)
Tap	Mt Leibig	67 (3)	203 (9)	6.7 (0.4)	28.3 (3.1)	0 (0.1)	0.2 (0.2)	1.51 (0.18)	0.41 (0.1)
Tap	Yuendumu	230 (10)	1241 (52)	10.4 (0.7)	20.5 (2.5)	0.1 (0.1)	0.2 (0.2)	0.64 (0.09)	0.27 (0.12)

DISCUSSION

In this arid region, a high proportion of the waterbores that have significant yield, are of poor quality in relation to the Australian Drinking Water Guidelines (1996). The generally high salinity and deleterious elements contained in these regional shallow aquifers, are related to: limited recharge in the modern climatic regime; high evaporation during the recharge process; and long residence times of groundwater in the flow system. The high salinity in many regional groundwaters is parallelled by high sodium concentrations. The exceedance of the guideline value for sodium concentrations in 41 out of 120 bores used for drinking water may be a health concern because of the link between excess sodium intake and cardiovascular disease (Hoffman, 1988; Tuthill and Calabrese, 1981).

The relative proportions of major ions, especially bicarbonate and chloride, reflect the position in the groundwater flow system (Fig. 9). The bicarbonate dominated groundwaters are noticeable in the recharge waters in the fractured basalt aquifer at Kintore (Wischusen, 1994), and in the alluvial fan aquifer at Papunya. Other aquifers such as the Ngalia Basin and the North Arunta Aquifer contain sulphate-chloride dominated groundwaters reflecting longer residence time.

Nitrate concentrations beyond the drinking-water limit of 50 mg/L are common in these shallow, mainly unconfined aquifers (Fig. 4). These nitrate-rich groundwaters were emplaced by episodic recharge events in an otherwise arid climatic regime. Nitrate has been flushed through the unsaturated zone which lacks denitrification activity. The nitrate originates in near-surface bacteria in termite mounds with the highest soil nitrate concentrations being found in the outer skin of termite mounds (Barnes et al., 1992). Bacteria associated with the termites appear to fix nitrogen, which eventually appears in inorganic form principally as ammonia. Nitrate is produced by bacterial oxidation of the ammonia, and is leached to the outside of the termite mound by capillary action. Recharge from extreme rainfall events then flushes this nitrate to the water table. Commonly, nitrate concentrations decrease with depth below the water table.

High fluoride concentrations in these regional groundwaters (Fig. 5) are particularly associated with intrusive granites of the Arunta Complex in the designated North Arunta and South Arunta Aquifers. High levels of fluoride in some Tertiary Sediments aquifers are probably associated with the sediments derived from the Arunta Complex. Excess consumption of fluoride can induce fluorosis and affect dental health.

High uranium concentrations in these regional groundwaters (Fig. 7) are associated with sandstone units of the Ngalia Basin sequence, the Tertiary Sediments aquifers, or with granites of the Arunta Complex. Enrichment of some of these units in radioactive elements is also demonstrated by airborne gamma spectroscopy of the region (Woodcock et al., 1997), and uranium mineral deposits are known in the Mount Eclipse Sandstone of the Ngalia Basin sequence (Wells & Moss, 1983). Most of the water bores have not been tested for the presence of uranium however, so the full extent of the problem remains to be determined. Concentrations of the radioisotopes radium-226 and radium-228 are below guideline values (0.5 mBq/L) in the water supplies where additional testing was done (Table 2).

High boron concentrations in these regional groundwaters (Fig. 6) are associated with granites in the North and South Arunta aquifers and with the Alluvial aquifer, which is derived from sediments of the Arunta Complex. High levels of boron can induce gastro-intestinal disturbances and depression (Australian Drinking Water Guidelines, 1996).

Concentrations of heavy metals are low in most of the regional groundwaters that have been sampled so far. The exceptions are two isolated instances of high lead levels which are probably associated with plumbing fixtures. Concentrations of arsenic in the regional groundwaters are low so far as yet analysed.

Several thousand people in this region may be affected by poor water quality. There is a high incidence of kidney and urinary tract stones in young Aboriginal children. The formation of stones is due to the supersaturation of urine with stone-forming salts, and dehydration is believed to be a major factor in this (Harris et al., 1986; Williams et al., 1996). In this region, both Harris et al. (1986) and Williams et al. (1996) have associated the high incidence of dehydration with the unpalatability of the available drinking water, especially under hot summer conditions. More specific health effects from high fluoride, nitrate, etc., are not yet documented in the region and may be masked by a spectrum of other health problems in these communities.

It appears that for 20 years of the homelands/outstations movement, Aboriginal people have needed to prove 'potable' water at specific sites in order to re-occupy their ancestral lands (ATSIC, 1996). The homelands movement has been underpinned by the availability of groundwater (Knott & McDonald, 1983). However, much of this water is now regarded as marginal or unacceptable as drinking water under the increasingly stringent Australian Drinking Water Guidelines (1996), although it may acceptable for hygienic and other purposes. There is a case for the introduction of dual water systems in the larger communities like Kintore and Yuendumu which have populations of several hundred people. Drinking water could be supplied by treatment, eg. Reverse Osmosis, or by supplementary rainwater tanks, and the untreated groundwater used for other purposes. There is also a need for water coolers to improve palatability of the drinking water in summer. There is also a need for research and development into small-scale water treatment technologies that are appropriate for outstations with populations of tens of people. Such appropriate technologies would assist Aboriginal people with increased access to the land and to the available water resources.

CONCLUSIONS

1. The Western Water Study GIS is an effective information base for future groundwater assessment. The groundwater quality data can be related only broadly to aquifer hydrogeology at this stage but some patterns are emerging to aid future bore siting.

2. The analysis shows that only 39 out of 865 water bores in the Papunya-Yuendumu-Kintore region completely meet the Australian Drinking Water Guidelines (1996). A high proportion of the water bores that have significant yields, are beyond the guideline values for salinity and for sodium.

3. A high proportion of water bores in this region are beyond the acceptable drinking water limits for fluoride or nitrate, and we have also documented some occurrences of high uranium and boron concentrations in the regional groundwaters.

4. There is emerging evidence of deleterious health effects due to unpalatable water, with a high incidence of young Aboriginal children having kidney and urinary tract stones, partly owing to dehydration.

5. There is a case for dual water systems at the larger communities that presently have water of poor or marginal quality, and this might involve water treatment or rainwater tanks for the supply of drinking water.

6. There is a need for research and development of appropriate small-scale water treatment technologies for outstations where there is no alternative to the available poor-quality groundwater.

ACKNOWLEDGEMENTS

We thank Michael Jamieson of NTDLPE, Lynne Woodcock, J.E. (Libbie) Lau, and Sonja Lenz of AGSO for their significant contributions towards developing the groundwater database for this project. The radio-isotope determinations were done by Gary Hancock at CSIRO Land and Water Division, Canberra. The GIS development for this project was partly funded by the Aboriginal and Torres Strait Islander Commission. We also thank Robyn Johnston for comments on the manuscript.

REFERENCES

ATSIC, 1992. National Housing and Community Infrastructure Needs Survey, preliminary report, stage 1, June 1992. Australian Construction Services, Brisbane.

ATSIC, 1996. Community infrastructure on homelands: towards a national framework. discussion paper, February 1996, 35 pp.

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

Barnes, C.J., Jacobson, G. & Smith, G.D., 1992. The origin of high-nitrate groundwaters in the Australian arid zone. Journal of Hydrology, 137, 181-197.

Federal Race Discrimination Commissioner, 1994. Water - a report on the provision of water and sanitation in remote Aboriginal and Torres Strait Islander communities. Australian Government Publishing Service, Canberra, 487 pp.

Gallagher, R., 1996. Visualising waterbore data with ARCVIEW2. Australian Geological Survey Organisation, Record 1996/18, 17 pp.

Harris , L., Knight, J., and Henderson, R., 1986. Morbidity patterns in a general paediatric unit in rural Western Australia. Medical Journal of Australia 145, 441-443.

Hearn, W., Henderson, G., Houston, S., Wade, A. & Walker, B., 1993. Water supply and Aboriginal and Torres Strait Islander health: an overview. AGSO Journal of Australian Geology & Geophysics, 14, 135-146.

Hoffman, C.J., 1988. Does the sodium level in drinking water affect blood pressure levels? Journal of the American Dietetic Association, v. 88, no. 11, 1432-1435

Knott, G.G. & McDonald, P.S., 1983. Groundwater for Central Australian Aboriginal communities. In Papers of the International Conference on Groundwater and Man, Sydney. Australian Water Resources Council, Conference Series 8, 3, 141-150.

Tuthill, R.W. and Calabrese, E.J., 1981. Drinking water sodium and blood pressure in children: a second look. American Journal of Public Health, v. 71, no. 7, 722-9

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

Williams, W.M., Nicholas, J.J., Nungurrayi, P.B. & Napurrula, C.R., 1996. Paediatric urolithiasis in a remote Australian Aboriginal community. Journal of Paediatrics and Child Health, 32, 344-346.

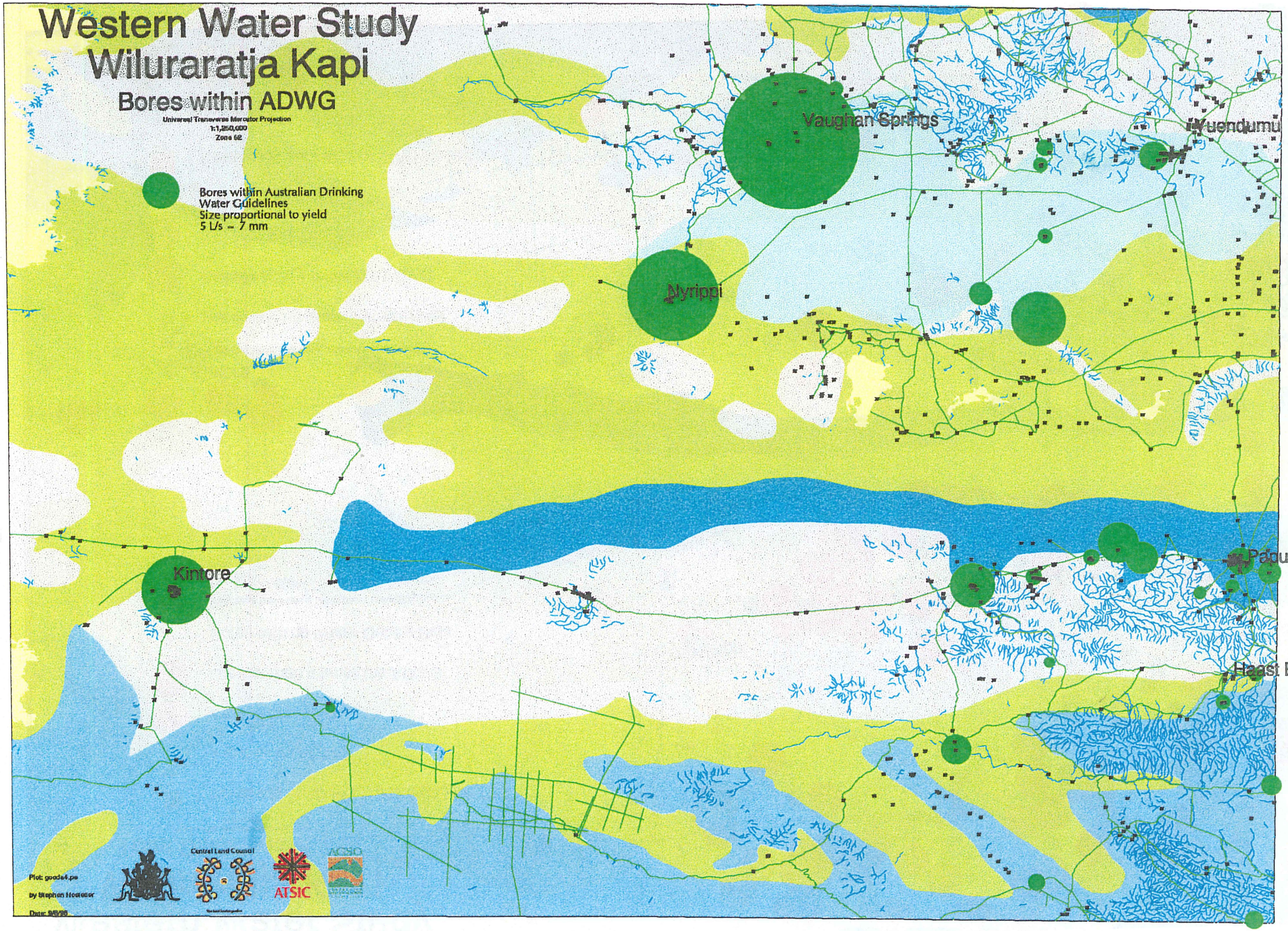
Wischusen, J.D.H., 1994. Sustainability of a hard rock aquifer at Kintore, Gibson Desert, Central Australia. International Hydrology and Water Resources Symposium, Adelaide, Preprints, 343-349.

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

Woodcock, L.G., Bierwirth, P. N. & 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.

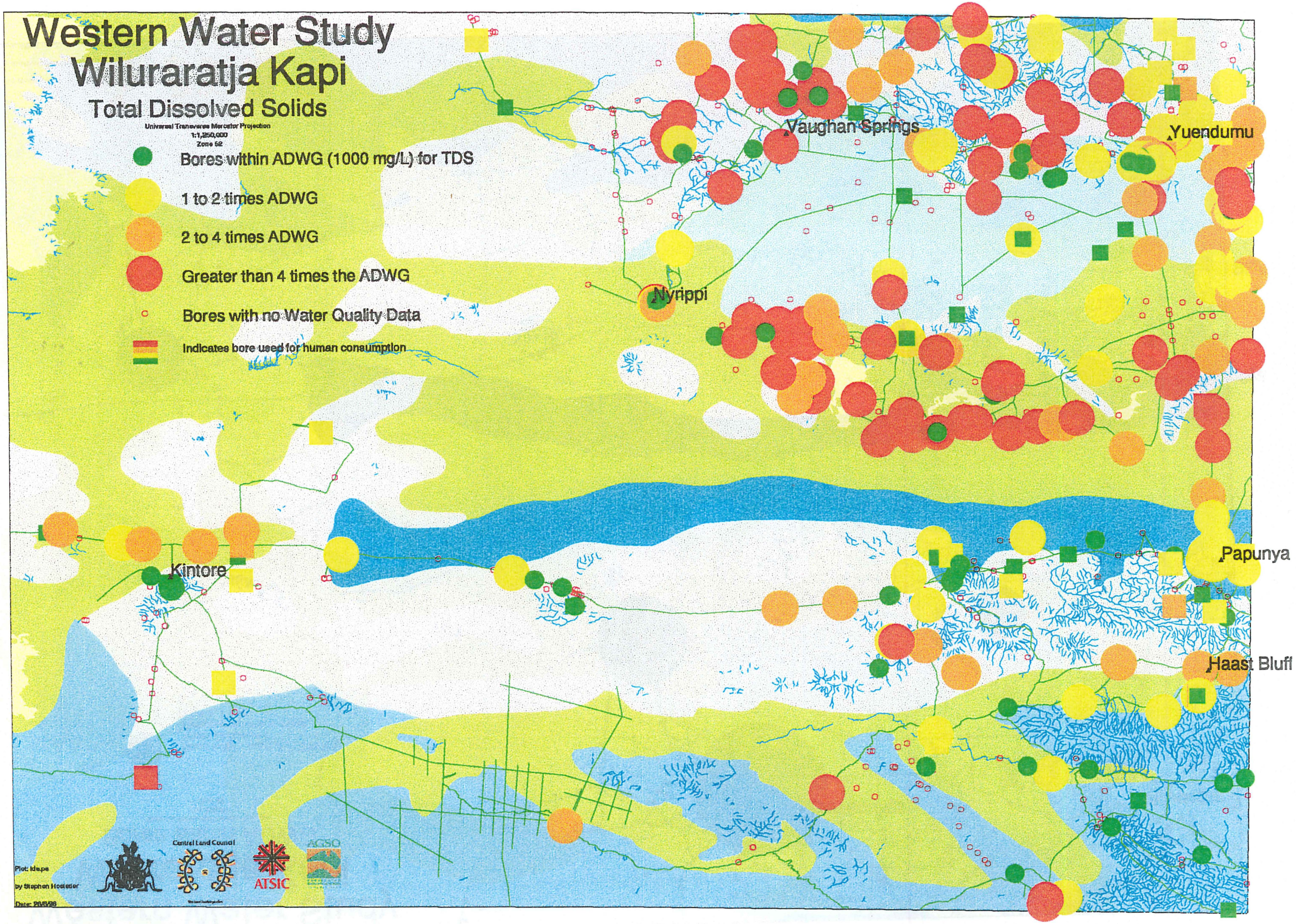
Appendix 1. Chemical analyses of groundwater samples for selected parameters

Bore	TDS	NO3	F	Gr_Alpha	Gr_Beta	Zn	Fe	Mn	Cr	Se	Pb	U	Cu	B
	mg/L	mg/L	mg/L	mBq/L	mBq/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
4059	1530	21	0			104	1250	1870	<1	<10	<1	14.4	6	
4316	75	1	0			56	<50	36	<1	<10	<1	<1	3	40
4334	905	51	2			65	<50	<1	<1	<10	<1	17	11	410
5754	833	11	1	0.2	0.41	11	<50	<1	1	<10	2	8.5	2	
6165	3175	13	1	1.14	2.67	36	<50	8	<1	<10	3	42.4	6	
7042	975	61	2			13	<50	4	<1	<10	<1	0.1	2	
10027	1920	14	0			23	450	9	<1	<10	1	18.7	1	
10935		14	1			12	<50	21	<1	<10	<1	9.2	2	
10936	575	29	1	0.04	0.57	981	<50	43	1	<10	<1	2.5	1	
10938	735	1	1			>1000	<50	7	2	10	2	25	<1	250
10945	1120	4	0	1.13	1.3	793	<50	4	<1	<10	4	19.5	6	
11174	1340	105	1			204			<1					
11175	866	49	1			108	<50	2	<1	<10	<1	11.5	7	
11384	426	11	4	1.91	1.45	238	<50	162	<1	<10	<1	76	1	
11396	745	33	1	0.16	1.16	39	<50	<1	<1	<10	<1	4.9	1	
11427	250	13	1			67	1000	45	3	<10	5	2	4	
11434	780	7	1			25	<50	8	<1	<10	<1	15.3	<1	
11631	730	1	2			176	<50	137	2	<10	<1	7	1	120
11806	693	26	2	0.06	0.22	29	>1000	703	<1	<10	<1	4.6	<1	
12578	1130	77	1	0.19	2.01	20	<50	6	<1	<10	<1	9.1	1	
12637	861	104	2			57	<50	2	<1	<10	<1	10	1	590
12641	756	38	2			58	<50	1	1	10	<1	3	<1	570
12645	1265	38	2			27	<50	2	2	<10	<1	14	15	410
12648	790	26	1			162	<50	<1	2	10	<1	6	12	220
12663	1260	29	1			78	<50	7	1	<10	<1	7	4	310
12910	1035	18	1	0.88	1.67	88	<50	6	<1	<10	<1	16	2	
13485	686	60	1	<0.05	0.06									
13795			0	0.43	1.84	11	<50	2	3	<10	<1	28.5	2	
13818	1340	2	2			318	<50	59	1	<10	<1	5	<1	900
13821	1470	82	1			81	<50	3	3	<10	<1	9	<1	570
13822	1510	51	1			70	<50	<1	1	10	<1	1	3	810
14055	3095	170	1	0.23	5.39	446	<50	67	<1	<10	<1	29.9	10	
14058			0			204	<50	<1	<1	<10	12	17	8	380
14300	109	1	0			>1000	<50	250	<1	<10	<1	<1	<1	60
14808	1295	85	2			37	<50	<1	2	10	<1	18	1	490
14875	1930	1	1	0.12	0.92	266	>1000	293	<1	<10	<1	0.1	3	
14980	380	10	3	0.18	1.11	17	<50	12	<1	<10	<1	6.2	<1	
15361	850	36	1			84	<50	1	5	20	<1	13	<1	240
15463	580	55	2	<0.05	1.05									
15472	614	26	1	0.2	1.2		<50	3	<1	<10	<1	10.3	2	
15477	1125	81	1		1.49	342	250	126	<1	<10	1	4.8	1	
15740	699	13	1	0.41	0.67	94	<50	2	2	<10	<1	6.5	2	
15854	930	27	3			7	<50	<1	<1	<10	<1	19	1	390
16027	1030	15	1			114	<50	<1	6	10	<1	10	1	270
16694		0	0	<0.1	0.8	20	<50	380	<1	<10	<1	10.6	1	



Western Water Study
Wiluraratja Kapi
Bores within ADWG
Universal Transverse Mercator Projection
1:1,250,000
Zone 52
Bores within Australian Drinking
Water Guidelines
Size proportional to yield
5 L/s = 7 mm
Vaughan Springs
Yuendumu
Nyirippi
Kintore
Papunya
Haast Bluff
Central Land Council
ATSIC
by Stephen Hostetler

Figure 2



Western Water Study
Wiluraratja Kapi
Total Dissolved Solids
Universal Transverse Mercator Projection
1:1,250,000
Zone 52
Bores within ADWG (1000 mg/L) for TDS
1 to 2 times ADWG
2 to 4 times ADWG
Greater than 4 times the ADWG
Bores with no Water Quality Data
Indicates bore used for human consumption
Vaughan Springs
Yuendumu
Nyirripi
Kintore
Papunya
Haast Bluff
Plot: Ida.ps
by Stephen Hostetler
Date:
Central Land Council
ATSIC
AGSO

Figure 3

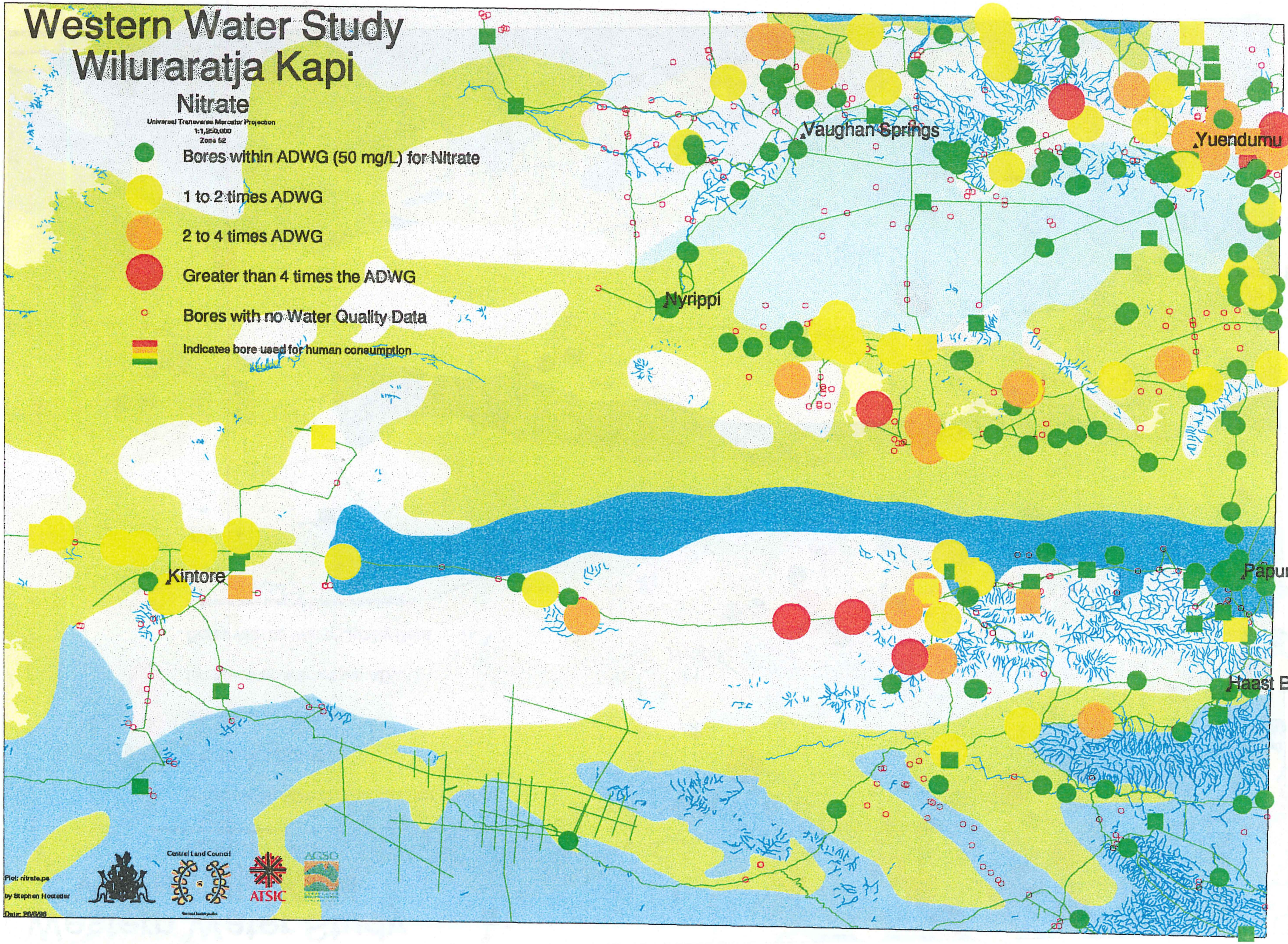
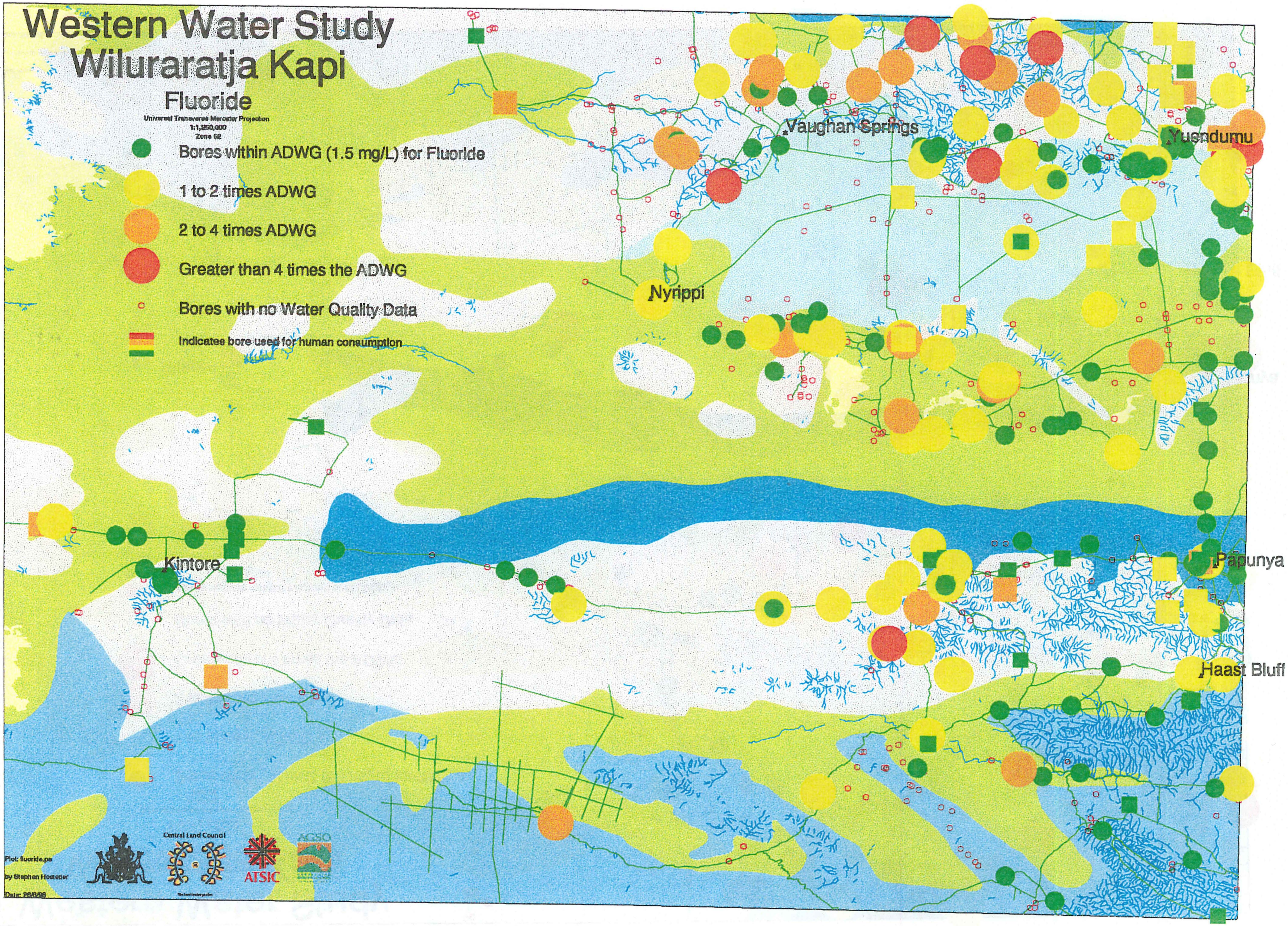

Western Water Study
Wiluraratja Kapi
Nitrate
1:1,250,000
Zone 52
Bores within ADWG (50 mg/L) for Nitrate
1 to 2 times ADWG
2 to 4 times ADWG
Greater than 4 times the ADWG
Bores with no Water Quality Data
Indicates bore used for human consumption
Vaughan Springs
Yuendumu
Nyrippi
Kintore
Papunya
Haast Bluff
Plot: nitrate.ps
by Stephen Hostetler
Central Land Council
ATSIC
AGSO

Figure 4



Western Water Study
Wiluraratja Kapi
Fluoride
Universal Transverse Mercator Projection
1:1,250,000
Zone 52
Bores within ADWG (1.5 mg/L) for Fluoride
1 to 2 times ADWG
2 to 4 times ADWG
Greater than 4 times the ADWG
Bores with no Water Quality Data
Indicates bore used for human consumption
Vaughan Springs
Yuendumu
Nyrippi
Kintore
Papunya
Haast Bluff
Central Land Council
ATSIC
AGSO

Figure 5

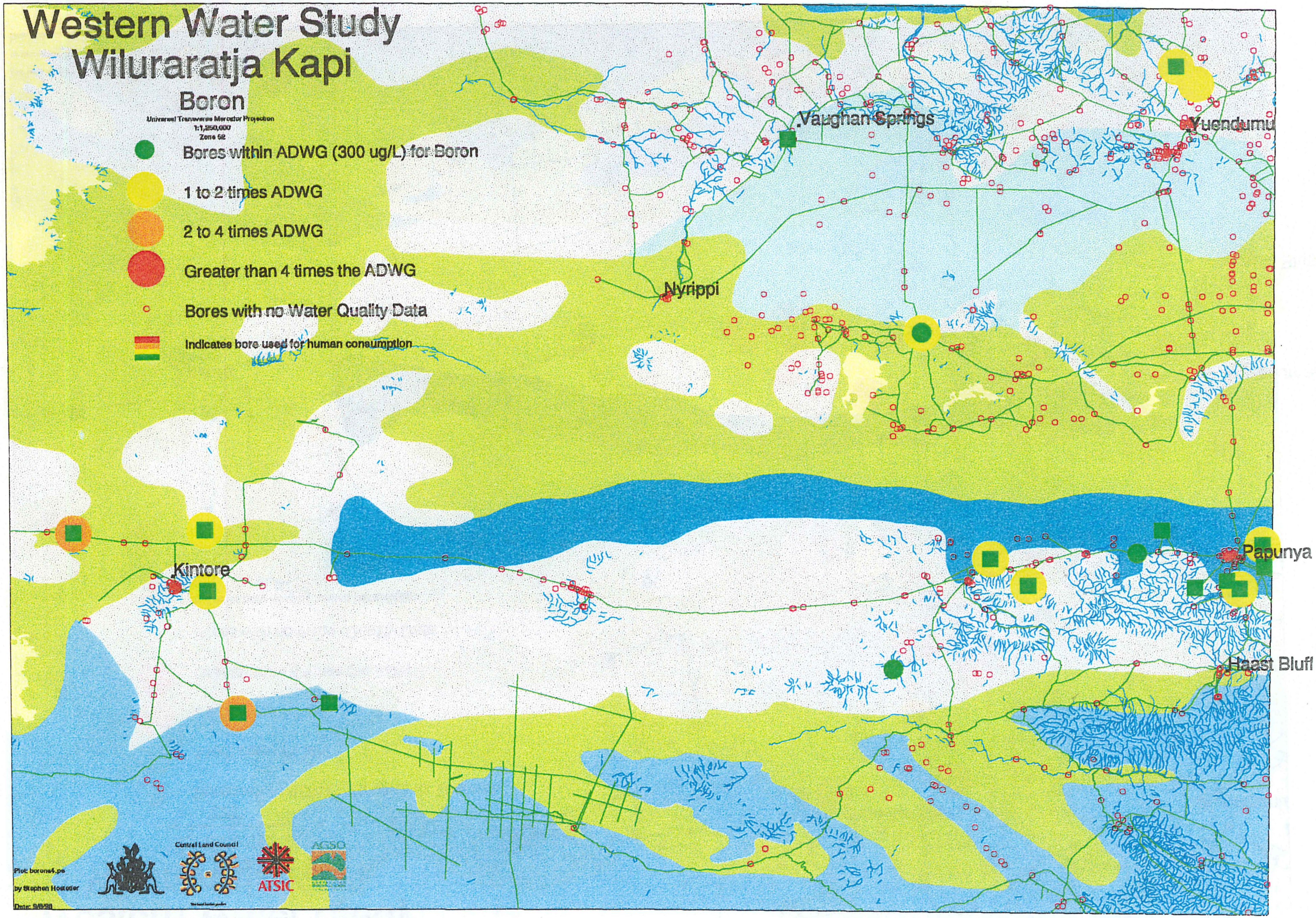

Western Water Study
Wiluraratja Kapi
Boron
Universal Transverse Mercator Projection
1:1,250,000
Zone 52
Bores within ADWG (300 ug/L) for Boron
1 to 2 times ADWG
2 to 4 times ADWG
Greater than 4 times the ADWG
Bores with no Water Quality Data
Indicates bore used for human consumption
Vaughan Springs
Yuendumu
Nyrippi
Kintore
Papunya
Haast Bluff
Plot: borone4.ps
by Stephen Hostetler
Central Land Council
ATSIC
AGSO

Figure 6

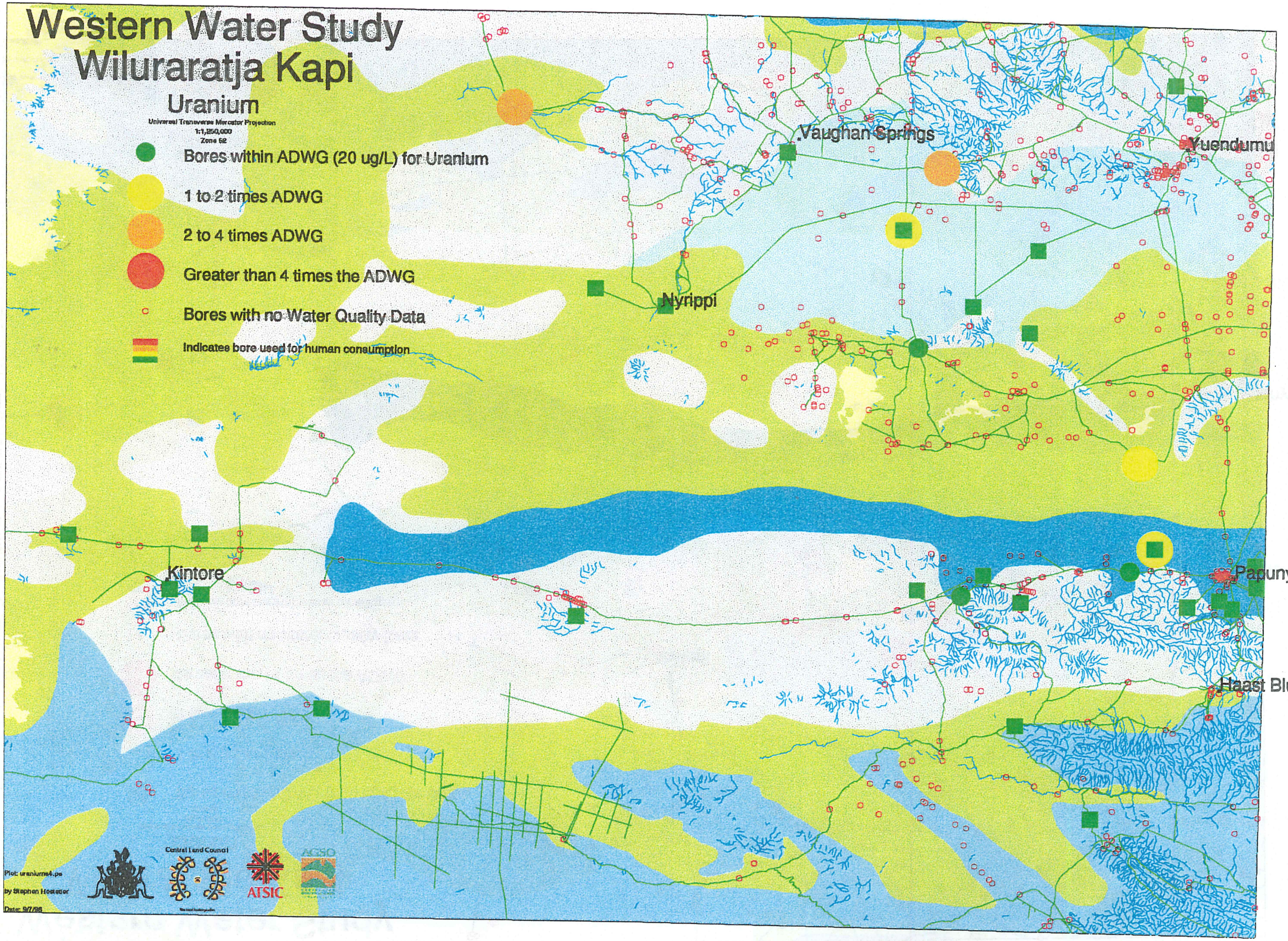
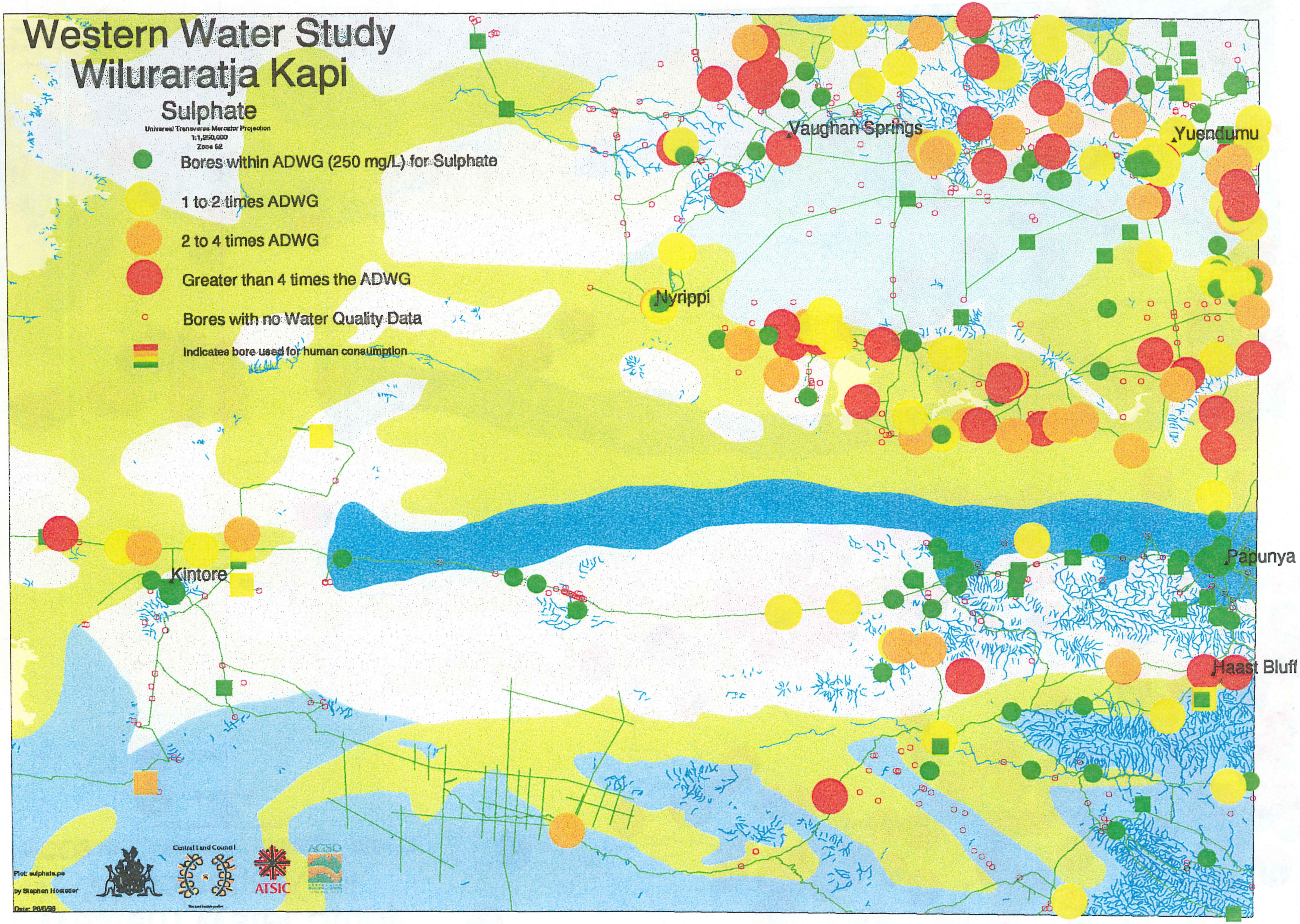
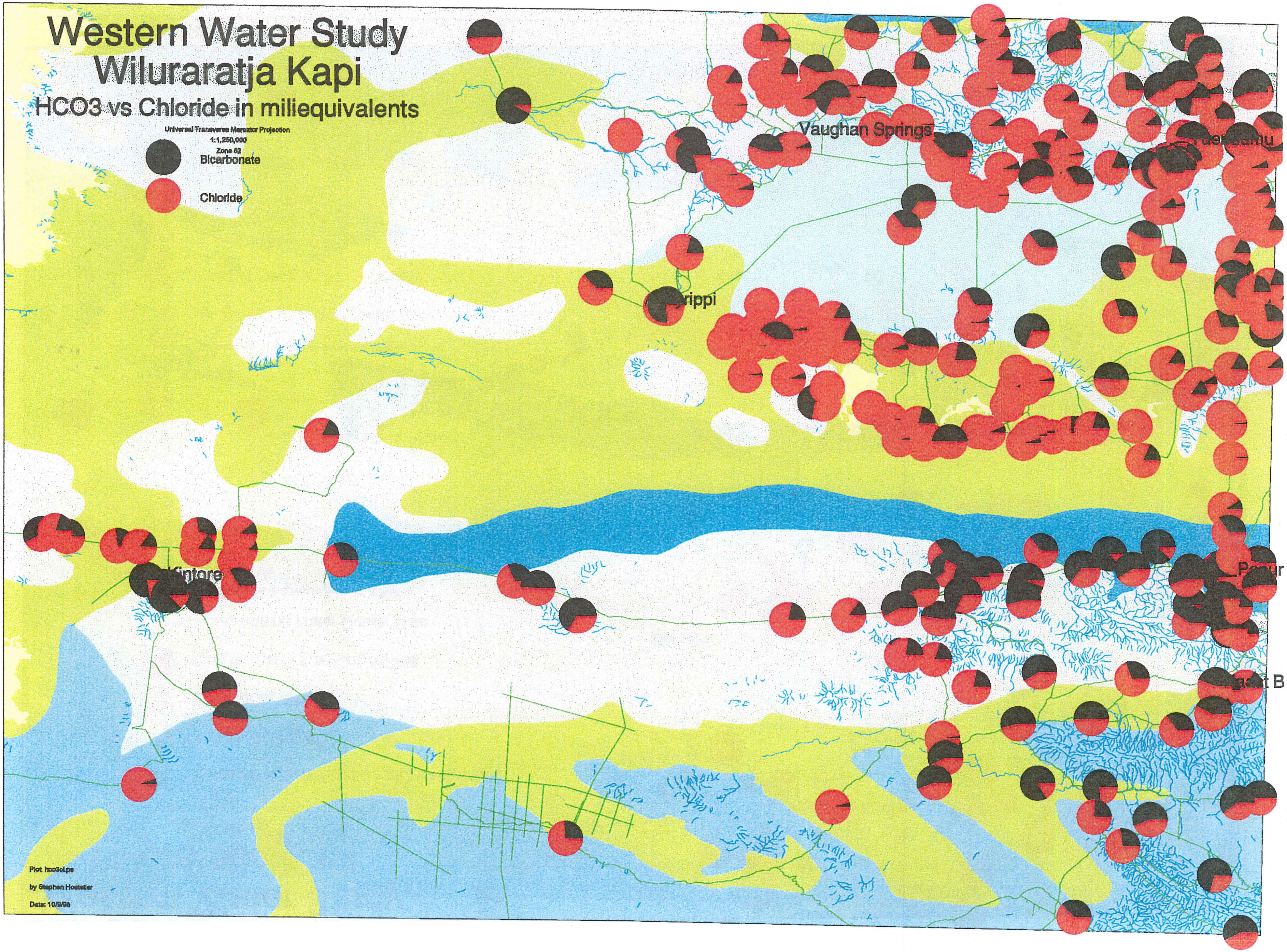

Western Water Study
Wiluraratja Kapi
Uranium
Universal Transverse Mercator Projection
1:1,250,000
Zone 52
Bores within ADWG (20 ug/L) for Uranium
1 to 2 times ADWG
2 to 4 times ADWG
Greater than 4 times the ADWG
Bores with no Water Quality Data
Indicates bore used for human consumption
Vaughan Springs
Yuendumu
Nyrippi
Kintore
Papunya
Haast Bluff
Plot: uraniums4.ps
by Stephen Hostetler
Date: 9/7/98
Central Land Council
ATSIC
AGSO

Figure 7

Figure 8



Western Water Study
Wiluraratja Kapi
Sulphate
Universal Transverse Mercator Projection
1:1,250,000
Zone 52
Bores within ADWG (250 mg/L) for Sulphate
1 to 2 times ADWG
2 to 4 times ADWG
Greater than 4 times the ADWG
Bores with no Water Quality Data
Indicates bore used for human consumption
Vaughan Springs
Yuendumu
Nyrippi
Kintore
Papunya
Haast Bluff
Plot: sulphate.ps
by Stephen Hostetler
Central Land Council
ATSIC
AGSO



Western Water Study
Wiluraratja Kapi
HCO3 vs Chloride in miliequivalents
Universal Transverse Mercator Projection
1:1,250,000
Bicarbonate
Chloride
Vaughan Springs
Kintore
Plot: hco3cl.ps
by Stephen Hostetler

Figure 9