Arid-zone groundwater recharge and palaeorecharge: insights from the radioisotope chlorine–36

Gerry Jacobson[1], Richard Cresswell[2], John Wischusen[1], & Keith Fifield[2]

AGSO's collaborative 'Western water' study (*Wiluraratja kapi*; AUS.GEO News 30, October 1995, p. 9), of groundwater resources in Aboriginal lands in the southwest Northern Territory arid zone, has applied the radioisotope ^{36}Cl to investigate the sustainability of community water supplies drawn from shallow aquifers in the Papunya–Kintore–Yuendumu area (Fig. 11). The ^{36}Cl results have important implications for groundwater management throughout the arid zone, because substantial recharge occurs only during favourable, wet, interglacial climatic regimes. Most of the community water supplies depend on 'old' stored water.

Location, geology, and hydrogeology of the study area

The Papunya–Kintore–Yuendumu area of 60 000 km^2 includes seven major Aboriginal communities and a number of outstations. It has an irregular annual rainfall of 250 mm, and annual evaporation of ~3000 mm. The Aboriginal communities are totally dependent on groundwater, which is extracted from about 200 water-bores drilled to depths of 60–200 m. Groundwater salinity, a major constraint on present and future development in this area, exceeds the accepted drinking water standard limits (1500 mg/L total dissolved solids) in about half the water-bores tested. An additional constraint is the long-term sustainability of these water resources — especially for the major communities, in which several hundred people have a modern lifestyle and average water consumption is ~500 L/person/day.

The main aquifer types (Fig. 12) are:

- Cainozoic fluvial/lacustrine and alluvial-fan sandy deposits, up to 150 m thick, associated with relict palaeodrainage systems and containing surficial Quaternary calcrete;
- porous and fractured sandstone and basalt in the Proterozoic–Palaeozoic Amadeus Basin and Ngalia Basin sequences; and
- fractured igneous and metamorphic rocks of the Arunta Block.

Most of the area is part of an unconfined to semiconfined elongate groundwater basin draining towards a chain of playa lakes (including Lakes Bennett and Mackay) with a general westerly gradient (Fig. 12).

Recharge has occurred directly through rainwater infiltration to many of the surficial aquifers, and by stream-water infiltration through stream beds. The almost flat potentiometric surface over much of the area suggests that groundwater movement is slow; indeed, groundwater may be locally ponded over an irregular basement topography. Head decay from earlier wetter climatic conditions may also influence the low groundwater gradient.

The amount of recharge to the regional aquifers used for the main community water supplies, and therefore the sustainability of these supplies, is questionable. According to hydrographic evidence, a fractured-basalt aquifer at the Kintore settlement receives modern recharge (Wischusen 1994: in 'Papers, water down under', International Association of Hydrogeologists & Institution of Engineers of Australia, Adelaide, 343–349). However, monitoring of water-bores in the fractured-sandstone aquifer at Yuendumu, another large settlement, suggests that only 10 per cent of the extracted groundwater represents recharge — the remainder being 'old' water derived from storage (Berry 1991: Northern Territory Power & Water Authority, Report 07/1991).

In an attempt to elucidate the recharge characteristics, timing, and potential of the area's aquifers, we have integrated data from stable and radioactive (^{36}Cl and ^{14}C) isotopes with hydrochemical, and hydrogeological data. This contribution focuses on the ^{36}Cl component of the study.

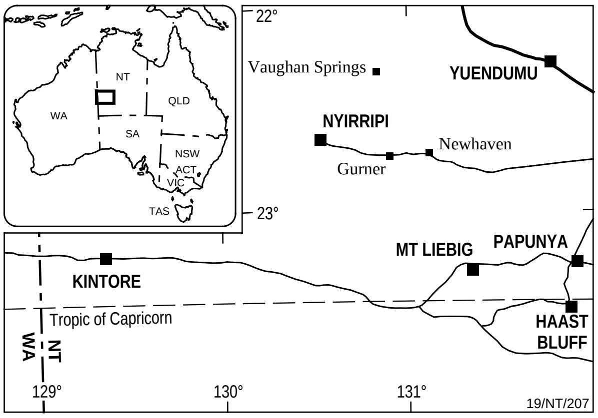

Fig. 11. 'Western water' study location map.

The ^{36}Cl technique for dating groundwater

Chlorine–36 is an unstable isotope produced from cosmic-ray interaction in the atmosphere (mainly with argon, and mostly at mid-latitudes) and with near-surface rocks, and by neutron flux arising from radioactive decay of actinides in the subsurface.

The atmosphere also contains stable chloride derived from sea-spray and remobilised terrestrial salts. The concentration of this chloride, which diminishes exponentially inland (Keywood et al. 1998: Journal of Geophysical Research, 103, 8281–8286), combines with a latitudinal dependence of ^{36}Cl fallout to give a ^{36}Cl/Cl ratio for any given location. This ratio can be measured by accelerator mass spectrometry from a few milligrams of silver chloride precipitated from groundwater, and varies in natural systems from a few hundred parts in 10^{15} of total chloride to a background of a few parts in 10^{15}. Thus, we measure the radioisotope at the attomole level from typically 250 ml of groundwater.

The hydrophilic nature of chloride makes it an ideal conservative tracer in groundwater systems, and the long half-life of ^{36}Cl (301 000 y) makes it particularly useful in systems with long flow paths. The ^{36}Cl/Cl ratio may be used to estimate ages of groundwater if three assumptions are made:

- that the only sink for ^{36}Cl in the aquifer is radioactive decay;
- that the only source for additional ^{36}Cl is normal deep subsurface production, or that additional sources can be identified and quantified; and
- that the production rate for ^{36}Cl is the same now as at the time of recharge.

The groundwater may then be dated from a standard radioactive decay equation.

Methodology

Eighteen groundwater samples were drawn from shallow aquifers in Cainozoic and Palaeozoic units via operating bores and, to a lesser extent, non-operating bores that were first purged of their standing water (Fig. 12). In addition, three samples were collected from the playa, Lake Ngalia: two surface crusts and one brine collected at a depth of one metre below the crust. For ^{36}Cl determination, silver chloride was precipitated from each sample by adding silver nitrate at acid pH, and 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 in the tandem accelerator at the Australian National University.

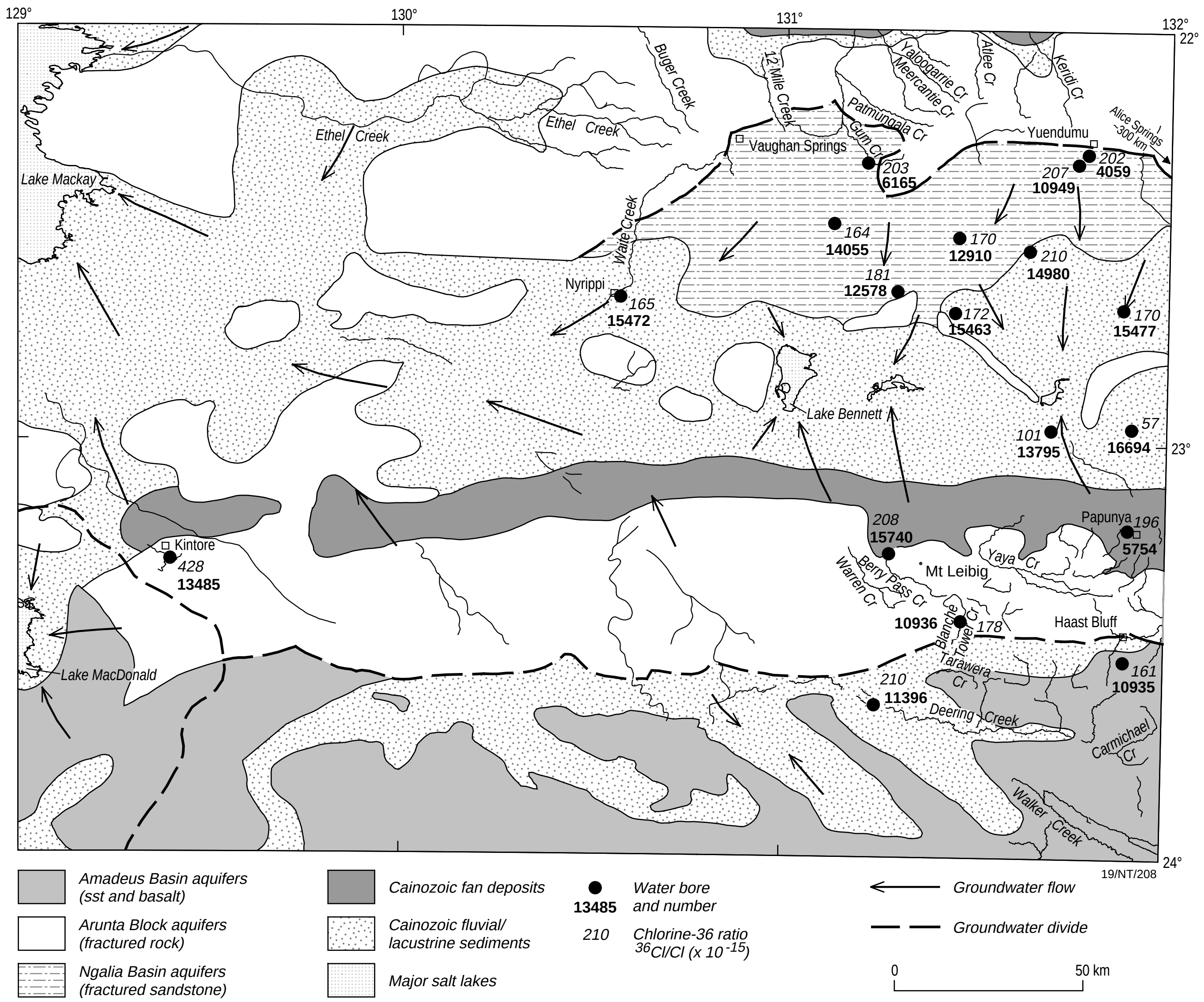

Fig. 12. General hydrogeology, groundwater flow system, bore locations, and major communities in the 'Western water' study.

Results and discussion

Spatial variations are apparent in both the geochemical data and ^{36}Cl/Cl ratios. Some of them may reflect an irregular subaquifer topography and attendant ponding of old water in localised depressions, as demonstrated for the smaller palaeodrainage system at Uluru (English 1998: 'Cainozoic geology and hydrogeology of Uluru–Kata Tjuta National Park, Northern Territory', AGSO Report). However, most of the ^{36}Cl/Cl ratios cluster about two values, which (together with other geochemical data) suggest that two basin-wide events have affected the ^{36}Cl contents of the samples.

To investigate the validity of this suggestion, we summed the individual ^{36}Cl age distributions and performed a Gaussian fit to the resulting data (Fig. 13). The statistical analysis shows that two ^{36}Cl/Cl ratios may account for 15 of the 18 data points: $170 \pm 7 \times 10^{-15}$ and $205 \pm 7 \times 10^{-15}$. Among the three other data points, a high-level sample with ^{36}Cl/Cl = $428 \pm 19 \times 10^{-15}$ from the fractured-basalt aquifer at Kintore also exhibits high ^{14}C (107% modern carbon); this site reveals hydrographic evidence for modern recharge, and the groundwater probably incorporates radionuclides due to bomb-testing. The lowest-level sample, from a Cainozoic aquifer close to the playa chain axis, has a ^{36}Cl/Cl ratio of $57 \pm 5 \times 10^{-15}$, similar to that measured from the salt crust and brine collected from Lake Ngalia. The third statistically distinct data point has a ^{36}Cl/Cl ratio of $101 \pm 7 \times 10^{-15}$.

On a ^{36}Cl/Cl ratio v. chloride plot (Fig. 14; together with lines representing appropriate trends for the processes indicated), the two dominant ^{36}Cl/Cl ratios plot as evaporation trends. The distinction between these two trends may be explained in terms of the duration of radioactive decay, and implies that ^{36}Cl input to the basin occurred during two distinct periods separated by 80 000 y. We infer that ^{36}Cl input coincided with substantial recharge, which would have happened only during wet climatic regimes.

The higher ^{36}Cl/Cl ratio (205×10^{-15}) logically records the most recent aquifer recharge. The long half-life of ^{36}Cl, and the associated analytical errors on the analyses (3%), sanction an interpretation of 'recent' in this sense to be as much as 20 000 y ago. Equally so, the higher ^{36}Cl/Cl ratio may represent early Holocene or pre-Holocene recharge water mixed with an insignificant amount of modern water.

Plotting the two ratios on the oxygen-isotope timescale (Imbrie et al. 1984: in Berger et al., 'Milankovitch and climate', NATO, ASI Series, Dordrecht, 269–305) puts the 80 000-y difference between them into perspective (Fig. 15). Wet climatic regimes coincided with interglacial periods. According to geomorphological studies, the wettest period in central Australia over the last full glacial–interglacial cycle, is thought to have been between 80 000 and 110 000 y ago (Kershaw & Nanson 1993: Global and Planetary Change, 7, 1–9). If the ^{36}Cl/Cl ratio of 205×10^{-15} records recharge during the current interglacial period, the $^{36}Cl/Cl$ ratio of 170×10^{-15} could represent recharge during the preceding interglacial, and the single-sample ratio of 101×10^{-15} may reflect recharge during an earlier interglacial.

Whereas the main settlement at Kintore appears to be tapping recently recharged groundwater, most of the other settlements are drawing water from a resource that is perhaps 80 000 y or more old. This could have serious implications for the future water security and sustainability of Aboriginal communities across the southwest Northern Territory.

Conclusions

- The $^{36}Cl/Cl$ ratios of groundwater in shallow aquifers of the southwest Northern Territory cluster in two groups: one, averaging 205 x 10^{-15}, records recharge probably during the current interglacial period; the other, averaging 170×10^{-15}, may represent recharge during the last interglacial. Without any intermediate values, the two ratios represent recharge separated by a dry interval of 80 000 y.
- The $^{36}Cl/Cl$ ratio of 428×10^{-15} of groundwater representing documented modern recharge in a fractured-basalt aquifer at Kintore probably reflects input of ^{36}Cl from surface nuclear-bomb testing.
- Low $^{36}Cl/Cl$ ratios observed in some groundwater close to discharge zones probably reflect either dilution by remobilised salt in the subsurface or particularly slow-moving groundwater flow.
- Recharge to the shallow arid-zone aquifers appears to have occurred entirely during wet interglacial periods. This has important implications for groundwater management in this area and elsewhere in central Australia, where many communities rely on groundwater from older (stored) water.

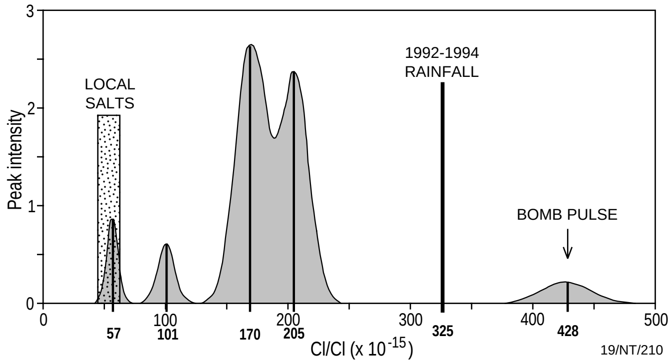

Fig. 13. Gaussian distribution of the $^{36}Cl/Cl$ ratio determinations for groundwater samples. Peaks indicate that most of the samples can be accounted for by two distinct ratios.

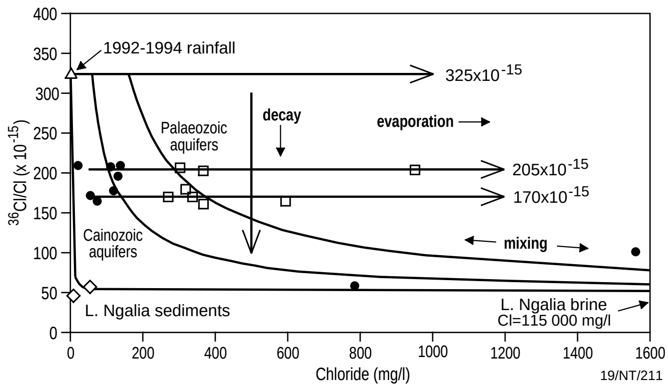

Fig. 14. $^{36}Cl/Cl$ ratio versus chloride for groundwater samples. Process trends are indicated by arrows.

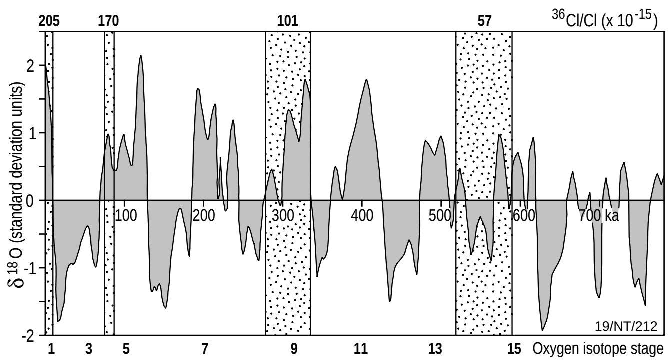

Fig. 15. The $^{36}Cl/Cl$ ratios, and their inherent errors, plotted on a time series defined by the SPECMAP $\delta^{18}O$ data (Imbrie et al. 1984: op. cit.). High positive $\delta^{18}O$ is correlated with global interglacial periods, which were wet in central Australia, and high negative $\delta^{18}O$ is correlated with global glacial periods.

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[1] Geohazards, Land & Water Resources Division, Australian Geological Survey Organisation, GPO Box 378, Canberra, ACT 2601; tel. +61 2 6249 9758 (GJ); fax +61 2 6249 9970 (GJ); email Gerry.Jacobson@agso.gov.au.

[2] Department of Nuclear Physics, Australian National University, Canberra, ACT 0200; tel. +61 2 6249 5179 (RC); fax +61 2 6249 0748 (RC); email richard.cresswell@anu.edu.au.