SECURING WATER SUPPLIES FOR THE REMOTE ABORIGINAL COMMUNITY OF MILINGIMBI ISLAND, NT

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ABSTRACT

Groundwater pumping to supply water to the community on Milingimbi Island over the last thirty years has resulted in declining waterlevels and increasing groundwater salinity towards the end of the dry season. Recent studies have indicated that that the limited groundwater supply may not be capable of supplying future water needs of the community which is planned to grow significantly in the next few decades. This study used geophysical and hydrogeological methods to characterise the hydrological system on the island, constrain groundwater recharge rates and evaluate the rate of saltwater intrusion.

INTRODUCTION

For the 1600 Indigenous residents who live in Milingimbi, a remote island off the coast of Arnhem Land in the Northern Territory, drinking water is a scarce and precious resource that relies solely on fresh groundwater lenses (shallow aquifers) aquifers beneath the island. The population on the island is expected to grow to 2300 residents by 2030, and studies have shown the island's limited groundwater supply – which is already vulnerable to saltwater intrusion from the surrounding Arafura Sea – will not be capable of supplying the future water needs of the community. Solutions such as seawater desalination are commonly unfeasible.

The annual rainfall is high (1090 mm) but there is uncertainty as to what proportion replenishes the aquifers and how much is lost to evapotranspiration and lateral flow to the coast. Effective groundwater recharge of the freshwater lens takes place during the wet season between November and April with very little occurring during the dry season when water use is at its peak demand. Groundwater monitoring has shown that there has been a notable increase in salinity. Recent drilling investigations identified that there is interconnection between the more saline aquifer beneath the fresher shallower aquifer and that over pumping of the fresh aquifer could result in saltwater migration inland and/or contamination by the more saline aquifer below.

The aim of this project was to use geophysical and hydrogeological methods to increase the understanding of freshwater lens dynamics in a coastal environment and provide an improved conceptual model for the management of the water supply on Milingimbi Island. More specifically, determine:

(1) the extent and thickness of the fresh groundwater lens which is used as the town's water supply,

(2) the salinity distribution across the different aquifers and risks associated with inter-aquifer leakage,

(3) determine the effective groundwater recharge rate to the shallow aquifer system

STUDY SITE

Milingimbi Island (16 km^2) is part of the Crocodile Island group located in the far north of the Northern Territory in the Arafura Sea, Australia, 450 km east of Darwin (Figure 1). It is a low-lying plateau and its highest elevation is around 16 m above mean sea level in the central part of the island, which is surrounded extensively by mud flats. The island is situated in the dry tropics and receives the majority of its annual rainfall during the wet season between November and April.

The current conceptual hydrogeological model is based largely on the initial studies of Yin Foo (1982) and has recently been refined with more geological information from a drilling program in 2013 (Woodgate, 2014) (Figure 2). There are three aquifers separated by two aquitards at Milingimbi: an upper near-surface aquifer (sandy clay, clay, claystone and laterite, average thickness 10 m; too small and shallow to exploit), a first aquitard consisting of fine sand, sandstone, and clay (average 10 m thickness), a central aquifer consisting of sand, gravel and sandstone (current community water supply; average thickness 8 m), a second aquitard of clay and siltstone (average thickness 6 m), and a deep aquifer of fractured siltstone, chert, and siltstone (average thickness 13 m). The 5 aquifers/aquitards are spatially variable in depth and thickness; they often vary from less than 1 m up to 40 m thickness and vary as well in degree of weathering.

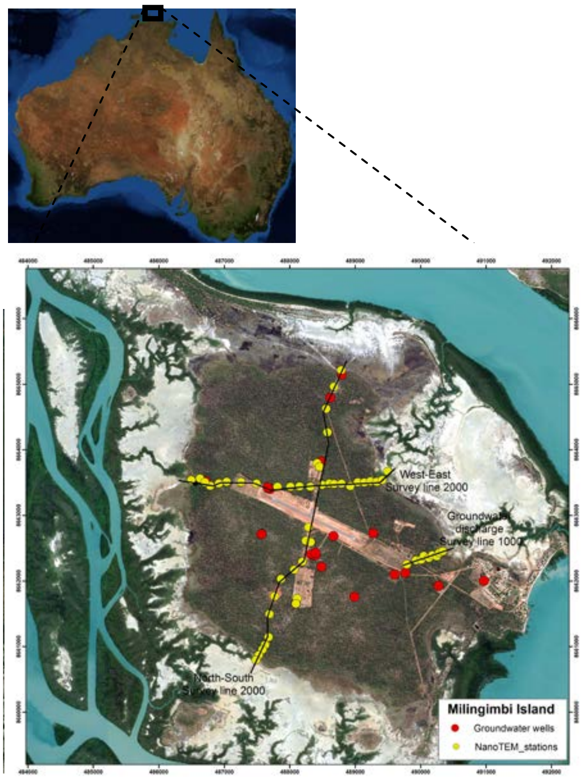

Figure 1. Location map of Milingimbi Island, Northern Territory, Australia and survey lines shown

The current knowledge is that the areal extent of the central and deep aquifers is limited to the central portion of the island. The two underlying aquifers are recharged by infiltration of highly variable seasonal rainfall through the overlying shallow aquifer (URS, 2011). Since production 30 years ago there have been declining water levels below mean sea level towards the end of the dry season and increasing salinity within the fresh groundwater lens, indicating that there is some risk of saltwater intrusion of the groundwater supply.

<u>METHODOLOGY</u>

Electrical resistivity (IRIS Switch Pro 96) and electromagnetic induction (Zonge NanoTEM, Geonics EM-34 and GF CMD Explorer) instruments were used to determine the extent of the freshwater lens, as well as the location of the freshwater-saltwater interface. Borehole logging (gamma and EM probes) was conducted on groundwater monitoring wells across the island in order to characterise the lithology and to provide calibration targets for the near surface geophysical surveys. Environmental tracers were used to understand the mixing dynamics between the different waters, geochemical processes and the apparent groundwater age. Groundwater samples, the billabong and local seawater were analysed for a suite of environmental tracers and included major ions, stable isotopes of water, chlorofluorocarbons (CFCs), sulfurhexaflouride (SF_6), tritium, radiongenic (^{14}C) and stables isotopes of carbon. Rock samples from a drill core that was retrieved during the 2013 drilling program were analysed for water content and pore water chloride using standard laboratory techniques (Rayment and Higginson 1992).

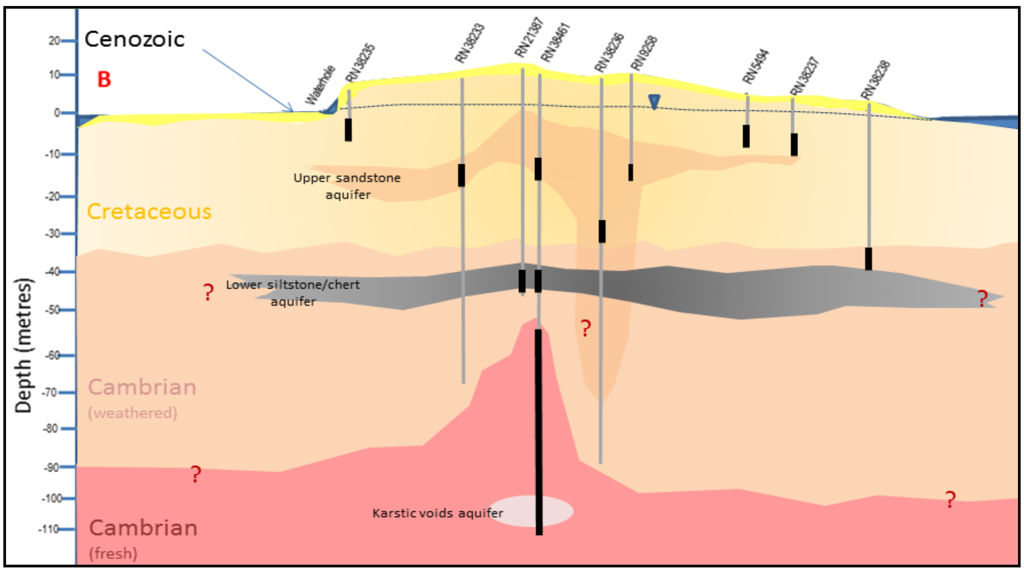

Figure 2. Hydrogeological conceptual model of Milingimbi Island [east-west] taken from Woodgate, 2014

RESULTS AND DISCUSSION

The electrical resistivity and electromagnetic geophysical surveys that traversed across the island identified the extent and geometry of the fresh groundwater lens and areas of the aquifer which may be at greater risk of saltwater intrusion (Figure 3- EM34 data and Figure 4- NanoTEM data). The interpolation of the EM34 data provided good spatial coverage of the soil bulk electrical conductivity (mS/m) across the entire island, but was limited by the instruments coil spacing of 20 metres and horizontal dipole orientation which could provide an effective penetration depth of approximately 15 metres. The two NanoTEM survey transects (north-south and east-west) clearly show more saline water intruding beneath the overlying fresher groundwater lens which extends down to about 40 m depth below the main part of the island. There is also a localised pocket of the fresher groundwater extending down to 80 metres depth which is supported by the hydrogeological conceptual model showing the upper sandstone aquifer extending down to this depth.

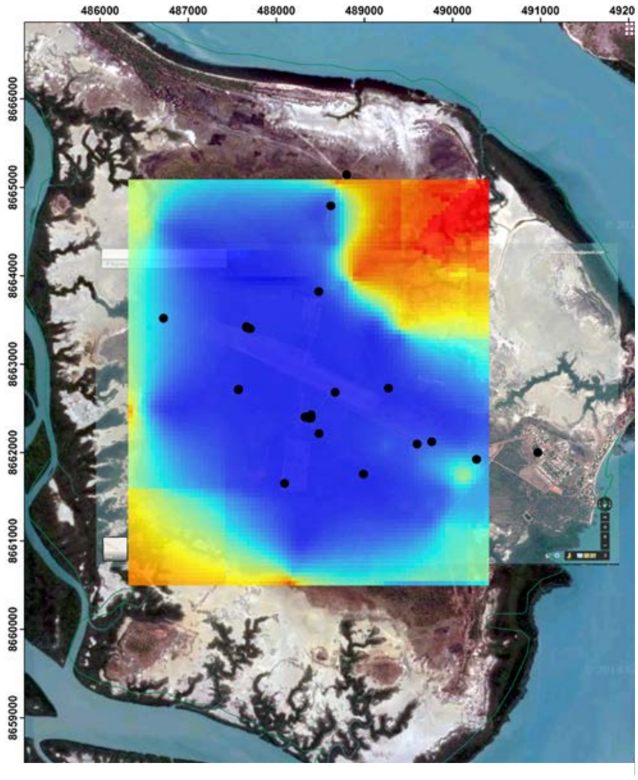

Figure 2 Soil conductivity map showing the extent of the freshwater lens in the middle of the island (interpolation based on EM34 survey 20 m coil spacing and in horizontal dipole orientation).

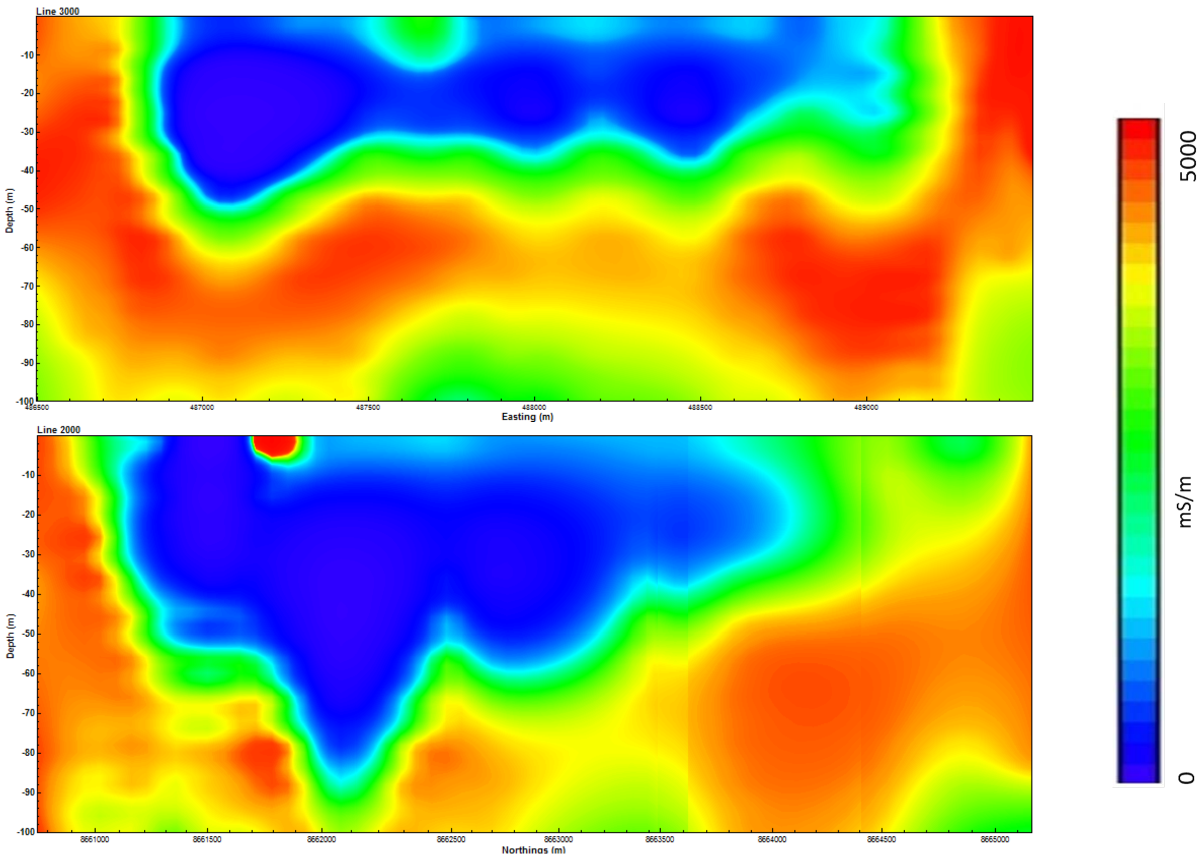

Figure 1: NanoTEM surveys showing the extent and thickness of the freshwater lens down to approximately 40 metres depth beneath the main part of the island and the dynamics of the freshwater/saltwater interface. west-east survey line 3000 (top), north-south survey line 2000 (bottom), Location of survey lines shown in Figure 1.

Soil porewater chloride analysed on the drillcore collected from one of the sites just north of the main airstrip and groundwater samples taken from the multinested piezometers completed at this site confirmed the geophysical results and showed the freshwater lens extending to about 40-50 metres depth below land surface. The soil porewater profile also revealed a steady increasing salinity trend beneath the lens to 110 metres depth towards the concentration of seawater (~19,000 mg/L) (Figure 5).

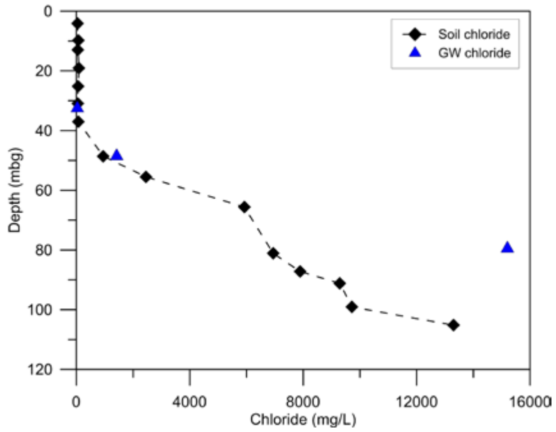

Figure 5: Soil pore water chloride analysed from the drill core and groundwater samples from the multi-nested piezometer completed within the cored drill hole on the island in mid 2013.

The stable isotopes of the water molecule and the chloride concentration results showed that the groundwater samples from the wells beneath the freshwater lens in the deeper aquifer plot between groundwater and seawater along an approximate mixing line beteween these two end members (Figure 6). The majority of the wells completed within the lens had chloride concentrations less than 1000 mg/L. The water from the billabong showed a distinct evaporative signature with a much greater increase in the stable isotope composition compared to the chloride ion.

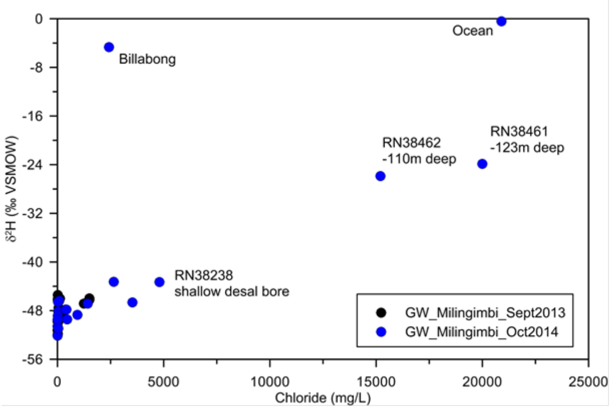

Figure 6. Deuterium versus chloride for the groundwater, billabong and ocean samples collected 2013-2014

The influence of the ocean on the groundwater aquifer system is also evident in the continuous groundwater level time series data showing the tidal signal in many of the monitoring wells (Figure 7). These three groundwater wells are located in the middle of the island adjacent the main production bore. The influence of the production bore is seen in groundwater well RN38463 which is completed within the freshwater lens to a similar depth (screen interval 26-29 metres below ground). The daily pumping schedule causes a one metre response in the water level of RN38643 and there also appears to be a slight decline in the water level over the short period of monitoring shown for October 2014. Groundwater well RN38461 is located in the deeper aquifer drilled down to 123 metres depth, whilst RN38464 is completed within the aquifer underlying the freshwater lens with a screen interval of 55-58 metres below ground. These two wells show a strong tidal signal and there is a much greater amplitude in the deeper well than the shallower one.

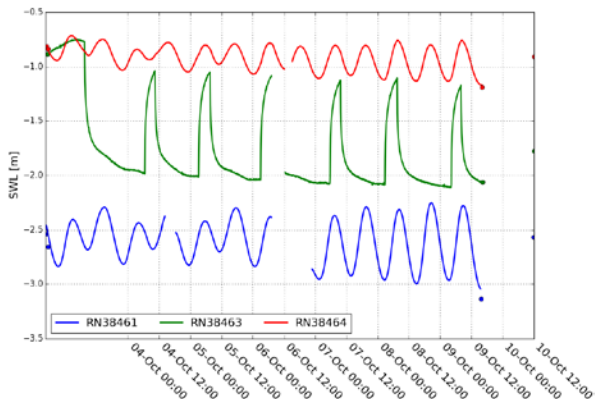

Figure 7. Groundwater level time series data of selected wells, October 2014, Milingimbi Island

Measurable concentrations of CFCs (indicator of young groundwater less than ~50 years old) were found in the aquifer and up to 60 metres below land surface. Using a simple Vogel type model (Vogel, 1967) whereby we assume that the unconfined aquifer is of constant thickness, uniform hydraulic conductivity, constant porosity (0.25) and receiving uniform recharge, it is possible to calculate an average groundwater recharge rate. Based on the CFC-12 apparent groundwater ages, the modelled recharge ranged between 25 to 150 mm/year which is up to 15 % of the annual rainfall (Figure 8). In comparison, the estimated recharge rate using the chloride mass balance method ranged between 10-160 mm/year.

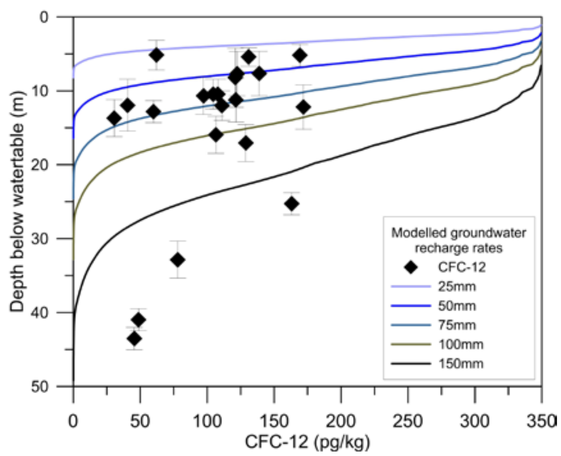

Figure 5: Chlorofluorocarbon (CFC-12) concentrations versus depth for sampled groundwater wells 2013-2014.

CONCLUSION

This study has highlighted the benefits of using multiple geophysical and hydrogeochemical techniques to investigate saltwater intrusion and groundwater dynamics beneath ocean islands. The near surface geophysical methods showed good agreement between what was observed at individual boreholes and provided greater clarity on the extent and geometry of the freshwater lens. Estimated average groundwater recharge rates using CFC and chloride concentrations were between 10-160 mm per year.

This information will prove invaluable in the development of a numerical groundwater model of the island and contribute to better decisions to sustaining a reliable water supply to a growing community.

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