MADAGASCAR
Developing Water Supplies from Fractured-Rock Aquifers

Overall Goal

The project seeks to support ongoing water development efforts in southern Madagascar with isotope data addressing the recharge, storage, and vulnerability of local aquifer systems and build the capacity of the National Institute for Nuclear Science and Technology to support hydrogeological research.

Background

The Malagasy national program under RAF/8/029 involves groundwater investigations in two separate areas of southern Madagascar, each linked to ongoing village water supply programs (Figure 1). In the so-called 'socle' area of the southern interior, a region of crystalline bedrock, UNICEF has installed 150 boreholes equipped with hand pumps over an area of more than 15,000 square kilometers north and west from the town of Antanimora. The World Bank is financing an additional 500 boreholes over a larger area adjoining the 150 wells project, starting in the spring of 2001. The RAF/8/029 activities in the socle area are intended to supplement the geohydrological investigations conducted as part of the World Bank effort, building on findings from the existing UNICEF boreholes. In particular, a better understanding of the distribution and sources of salinity in the groundwater is sought to help target drilling on areas most likely to have fresh water, thus increasing the overall efficiency of the 500 Wells project. A similar program is being conducted with the UNDP to develop water supplies along the southwestern coastal strip.

Project Scope

The groundwater tapped by boreholes in the socle occurs in fractured granite, gneiss, and schist. Groundwater is found at relatively shallow depths but the useful extent of the aquifer is likely fairly limited, assuming that the density and transmissivity of fractures declines with depth. Water quality concerns are also likely to limit the useful depth of the aquifer. The basement rock has been regionally altered by highly saline brines, forming local deposits of uranium and other minerals. The brines associated with this deep alteration may also affect shallow groundwater quality, particularly in areas with less active recharge.

Groundwater quality varies widely between near-by wells and even between water-bearing fractures encountered in a single borehole. Overall, approximately 30% of the 150 UNICEF boreholes were too saline for human consumption and were plugged and abandoned. Salinity appears to increase with depth. UNICEF drilling records indicate that several wells that were abandoned because of high salinity had encountered good quality water in the first water strikes. As these strikes did not provide adequate flow, drilling continued and the next water strikes were saline. In at least two cases,

replacement boreholes were drilled within a few hundred yards of the abandoned saline locations and yielded adequate supplies of water with acceptable salinity. However, detailed information on the distribution of salinity in groundwater is not generally available.

Environmental isotopes are amongst the various geochemical tools being used to determine the source of the high salinity and assess correlations between salinity and groundwater residence time, rock type, location of recharge, etc. Isotope techniques being applied include deuterium and ^{18}O, tritium and ^{14}C, $^{87}Sr/^{86}Sr$, radon, and ^{15}N. In addition, standard hydrochemical and trace element analyses are being performed, including bromide analysis to assess potential influences of marine salts.

RAF/8/029 is also providing isotope input to a UNDP water supply project developing village water supplies along the southwestern coast between the Linta and the Onilahy rivers. Isotopes are being used to help define recharge, mixing, and sources of salinity in the coastal area. In contrast to the socle area, flow in the karst aquifer occurs on a regional scale, and large amounts of water are potentially available. Isotope data are playing an important role in developing an understanding of the hydrogeological systems involved and have been incorporated in a working conceptual model of regional groundwater/surface water interaction and flow.

Preliminary Results

Approximately 130 samples have been collected to date from the two project areas. Results for stable isotopes (Figure 2) show that the socle area groundwater composition clusters much more tightly than the coastal karst aquifer, reflecting the broader range of processes affecting the regional coastal system. Most samples lie somewhat beneath the global meteoric water line, reflecting a moderate degree of evaporation. The single sample with positive isotopic composition is from a highly saline lake that experiences extreme evaporation in a coastal environment.

While the socle area samples are somewhat evaporated, this is not the major source of the high salinity, primarily sodium chloride. Chloride content in the socle groundwater does not show positive correlation with ^{18}O, as would be expected if evaporative concentration were responsible for the salt loading in the aquifer. The changes in chloride content essentially independent of ^{18}O suggest that dissolution of salts in the formation or progressive reaction between the groundwater and the aquifer materials is responsible. The negative correlation between tritium content and chloride (Figure 4) indicates that groundwater acquires salinity progressively as its residence time in the aquifer increases, suggesting that gradual dissolution or reaction with aquifer materials is the dominant mechanism. While there is a general trend of increasing alkalinity in saline samples, the greatest increases in salinity appear unrelated to changes in alkalinity, suggesting that dissolution of sodium chloride rather than carbonic acid weathering dominates.

These data support a conceptual model of the socle aquifers where fresh water occurs only in areas of active recharge, such as along streams and rivers where fractures connect the bedrock system to alluvial deposits. Groundwater in areas with less active recharge, probably the great majority of the region, develops high salinity over time as the water gradually dissolves relict salts from the basement rocks. This model may not provide sufficiently detailed guidance to on-going drilling programs to improve success in well completion, but it clearly limits site selection to locations near alluvial channels and supports relatively shallow well completions. This model also suggests that larger water supply systems, such as have been established in some of the bigger towns, may need careful management to prevent degradation of groundwater quality. Finally, project activities have helped the INSTN develop the tools, skills, and resources needed to contribute to groundwater development in Madagascar.

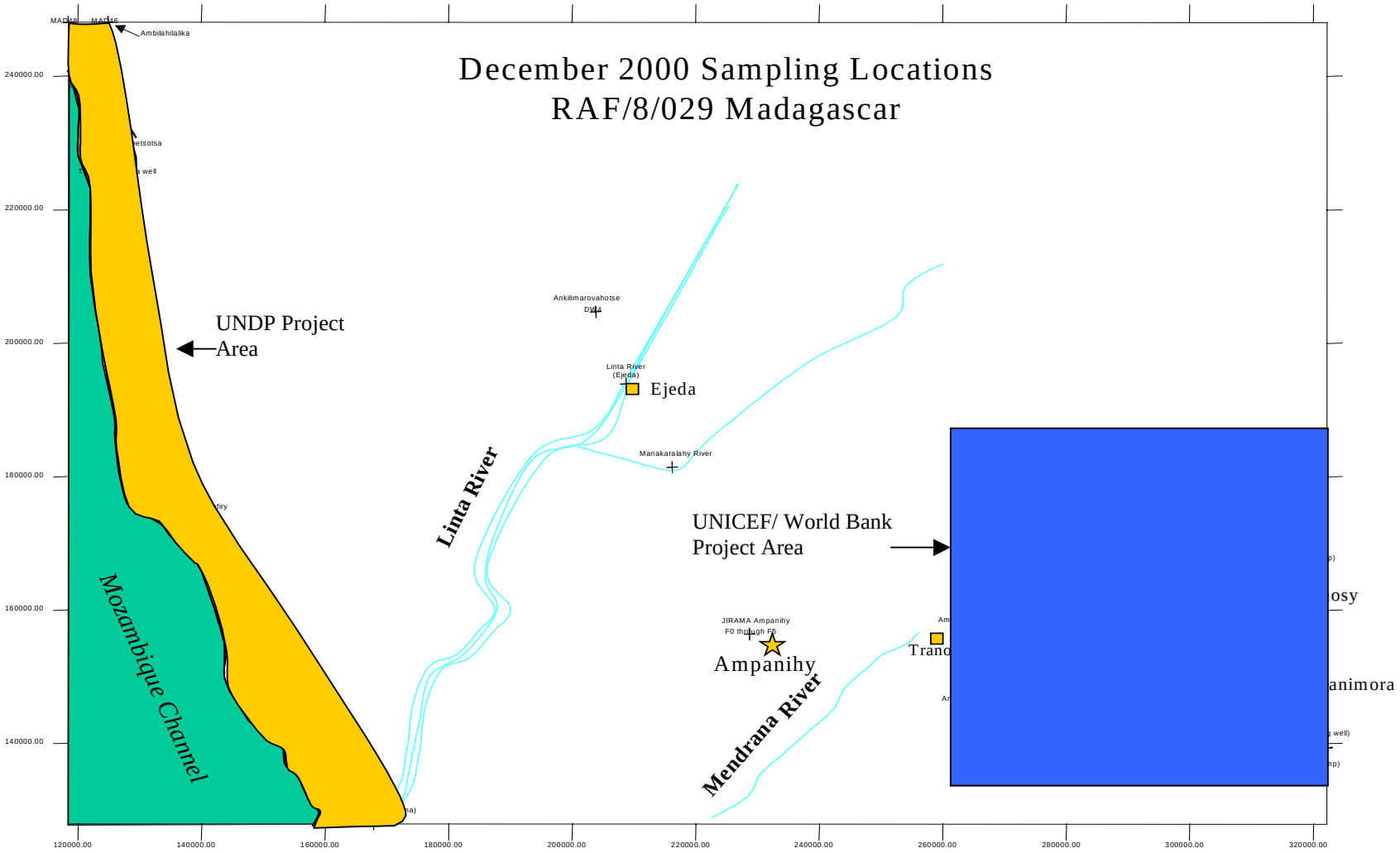
December 2000 Sampling Locations
RAF/8/029 Madagascar
Ambilahilalika
UNDP Project
Area
Ankilimarovahotse
DW4
Linta River
(Ejeda)
Ejeda
Manakaralahy River
Linta River
UNICEF/ World Bank
Project Area
JIRAMA Ampanihy
F0 through F6
Ampanihy
Mendrana River
Mozambique Channel
240000.00
220000.00
200000.00
180000.00
160000.00
140000.00
120000.00
140000.00
160000.00
180000.00
200000.00
220000.00
240000.00
260000.00
280000.00
300000.00
320000.00

Figure 2. Stable Isotopes in Groundwater, Southern Madagascar

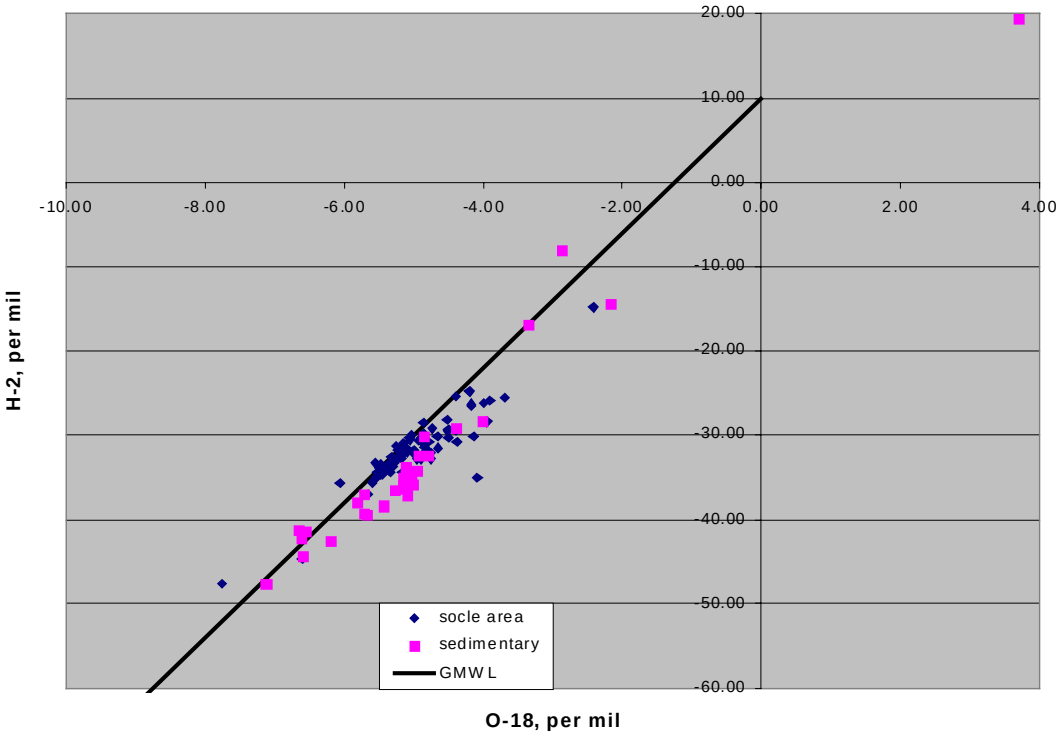

Figure 3. O-18 and Chloride in Socle Area Samples

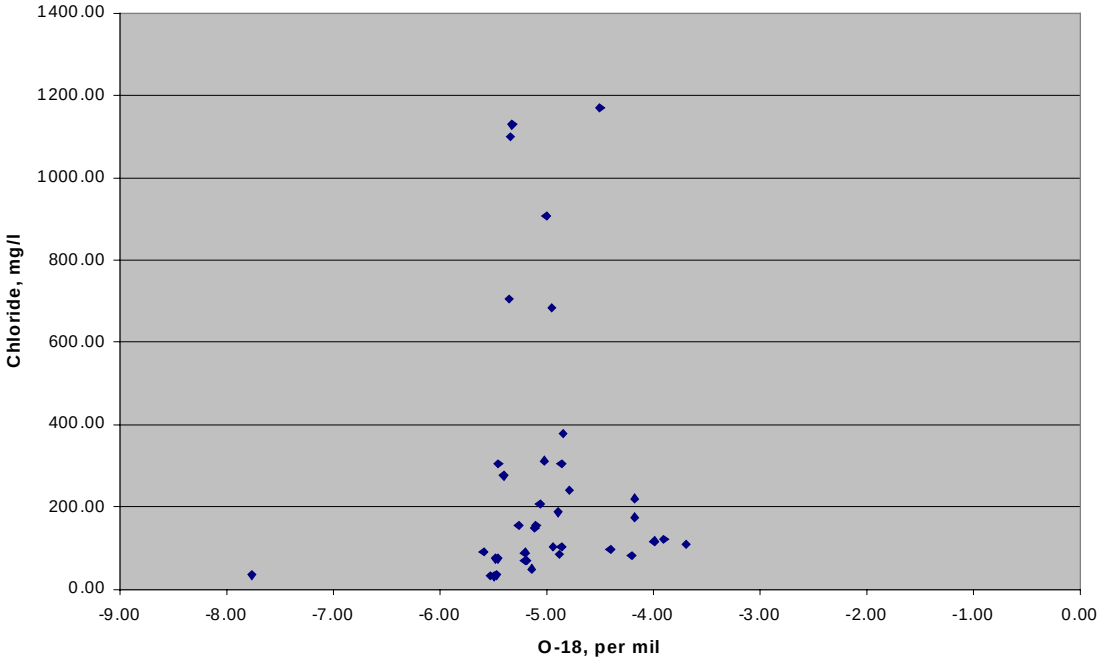

Figure 4. Tritium and Chloride in Socle Area Samples