

## Hydrology of and Conflicts over Shallow Groundwater Use and Management in Low Coral Islands

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### Summary

Groundwater is the major freshwater source in coral islands. Its availability, quality, and management are central to sustainable development and poverty alleviation. Increasing populations, growing *per capita* demand and restricted land areas limit water availability and generate conflicts. Shallow groundwater in the Pacific is vulnerable in ENSO-related droughts and over-extraction causes seawater intrusion. Human settlements, animal production, and agro-chemicals coupled to very permeable soils, with limited water-holding capacity, result in rapid impacts on groundwater quality and human health. Coconuts, breadfruit, papaws, bananas and crops such as swamp taro, decrease groundwater supplies through direct evapotranspiration from the watertable. The trade-off between maximising and protecting groundwater resources and maximising overlying crop production presents a dilemma for island communities as does the tensions between the demands of an urbanised society and traditional cultural practices. This paper describes an UNESCO IHP project on the hydrology and hydrodynamics of shallow groundwater and the socio-cultural aspects of groundwater use in coral islands. The study was in Tarawa atoll, Kiribati in the central Pacific. A simple daily water balance model was used to suggest groundwater extraction strategies and management options. The lack of comprehensive water legislation and legal agreements between the government and landowners, combined with confusion over the responsibilities of government agencies and community vandalism to water supply infrastructure, are indicators of the tensions between the subsistence past and the urban future faced by many small island communities. The potential for using multi-agent systems to reduce conflicts is discussed.

### 1. Introduction

Groundwater has long been ranked as a high priority research area by small island nations in the Pacific. It is the major source of freshwater in many atolls and small islands and its

availability, quality, management and allocation are central to their sustainable development and poverty alleviation. Increasing populations and urbanisation, growing demand from all sectors and limited land areas decrease water availability and generate conflicts. Shallow groundwaters are also vulnerable in ENSO-related droughts when over-extraction causes seawater intrusion. Human settlements, animal production, the use of fertilisers and agro-chemicals coupled to very permeable soils, with limited water-holding capacity and often-poor nutrient retention, result in rapid impacts on groundwater quality. These soils, together with the availability and quality of groundwater for irrigation also restrict crop production in dry periods. In turn, permanent crops such as coconuts, breadfruit, papaws, bananas and long-term crops such as babai (swamp taro), decrease groundwater supplies through direct evapotranspiration from the watertable. The trade-off between maximising and protecting groundwater resources and maximising overlying crop production presents a dilemma for island communities.

## 2. Study location

This study was carried out in the Central Pacific Republic of Kiribati, on Tarawa Atoll. The water resources of Kiribati are predominantly groundwater in freshwater lenses on many of the 32 distinct coral atolls and reef islands. The watertable is typically within 0.8 to 1.6m below ground surface. Groundwater is supplemented by rainwater on most of these islands. South Tarawa is the capital and main population centre of the Republic. The water supply for the urban area of South Tarawa is pumped from horizontal infiltration galleries in groundwater protection zones or water reserves on Bonriki and Buota islands (Figure 1, Falkland, 1992). These currently supply about 1300m<sup>3</sup>/day, equivalent to about 30L/capita/day of freshwater, about 60% of the needs of South Tarawa communities. Rainwater, local private wells and a reverse osmosis desalination plant (100m<sup>3</sup>/day) supply the rest. The declaration of water reserves over privately owned land has led to conflicts, illegal settlements and vandalism of public assets.

Traditionally, land ownership also guaranteed ownership of groundwater and confers other subsistence rights. Water supplies to villages and individuals are unmetered. In an attempt to control demand, water is supplied over limited periods, however there are inequities in this system. There are significant administrative, social, economic and legislative issues regarding the use of private, traditionally-owned lands for public water supply purposes (White *et al.*, 1999; Crennan, 2001). There is no national water resource legislation, although a review of the Draft National Water Master Plan (Shalev, 1992) has been initiated.

Major issues and concerns over freshwater in Kiribati are (Falkland, 2001):

- Groundwater pollution associated with sewage systems, solid waste disposal and agriculture.
- Freshwater sustainability through droughts.
- Future water resource development for Tarawa, to supply the increasing population.
- Management of groundwater catchments to protect water supply sources and permit productive, conjunctive land use (Shalev, 1992; Metutera, 1994, White *et al.*, 1999b).
- No national water resources legislation (White *et al.*, 1999a).
- Insufficient use of rainwater for supplementary water (Shalev, 1992; Metutera, 1994).
- Insufficient demand management including leakage control and water conservation in urban water supplies (Metutera, 1994).

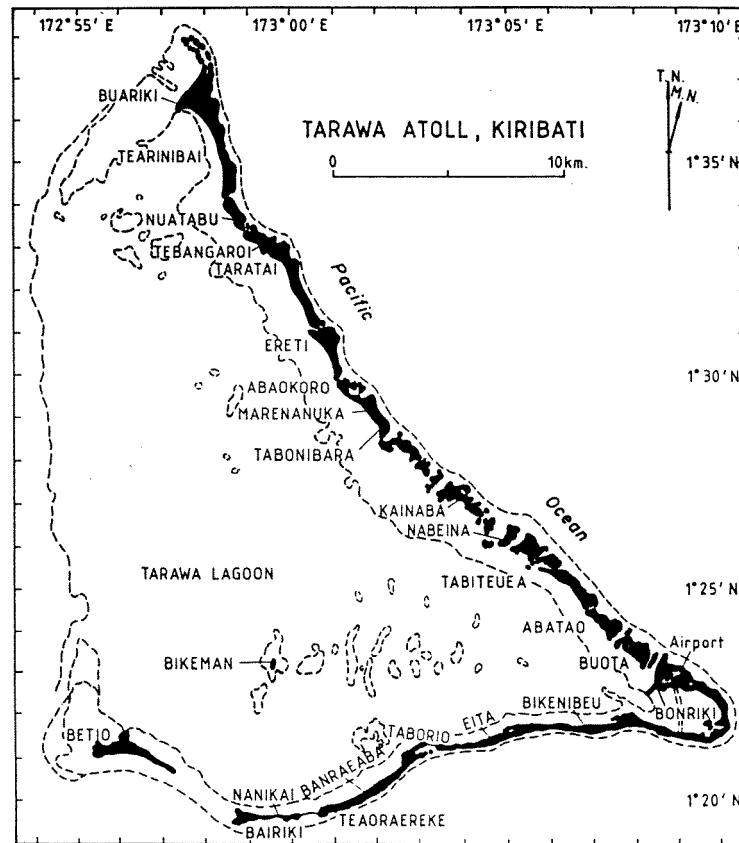


Figure 1. Tarawa Atoll. Bonriki and Buota islands are on the lower right of the atoll. Water from them is distributed 30 kms along South Tarawa to Betio on left of the atoll.

## 2.1 Climate

The climate is tropical, hot and humid but moderated by trade winds. Rainfall varies considerably from year to year. On average, annual rainfall in South Tarawa is close to 2000 mm. Very high rainfall is associated with El Niño episodes and long droughts can be associated with La Niña episodes. During the past 3 years, Tarawa, the capital and administrative centre, with over one third of the national population, has experienced its worst long-term drought since rainfall records commenced. This caused the death or severe die-back of mature breadfruit trees.

## 3. Groundwater in atolls and small islands

Groundwater in coral atolls and some small islands occurs as a relatively thin, shallow freshwater lens in coral sands "floating" over seawater in highly permeable karstic limestone (Wheatcraft and Buddemeier, 1981; Falkland and Brunel, 1993; Falkland and Woodroffe, 1997). Ground-water fluctuations, due to tidal forcing, mix freshwater and seawater at the base of the freshwater lens, so that a substantial, brackish, transition zone is produced (Volker *et al.*, 1984; Underwood *et al.*, 1992) making the freshwater lens thinner than expected from the classical freshwater lens model.

## 4. Study Results

### 4.1 Hydrology

The study in Tarawa atoll, Kiribati measured the components of the water balance on an island with sparse coconut trees (~ 20%). A simple daily water balance model was constructed which estimated interception, soil evaporation and groundwater transpiration losses and changes in soil moisture storage (Fig. 2, White *et al.*, 2001). This could be used to suggest extraction strategies and management options for water reserves that are yet to be tested. During the study period, estimated total evapotranspiration losses were 2/3 of potential evaporation, suggesting that equilibrium evaporation may be a more appropriate upper bound for small, low islands. This suggestion has yet to be rigorously tested particularly in areas with denser crops. Recharge only occurred after intense rainfalls in excess of 50 mm/d. It was found that severe droughts for large freshwater lens occur every 6 years and last on average about 12 months (White *et al.*, 1999b). The implications of this for groundwater and agriculture management have yet to be elucidated.

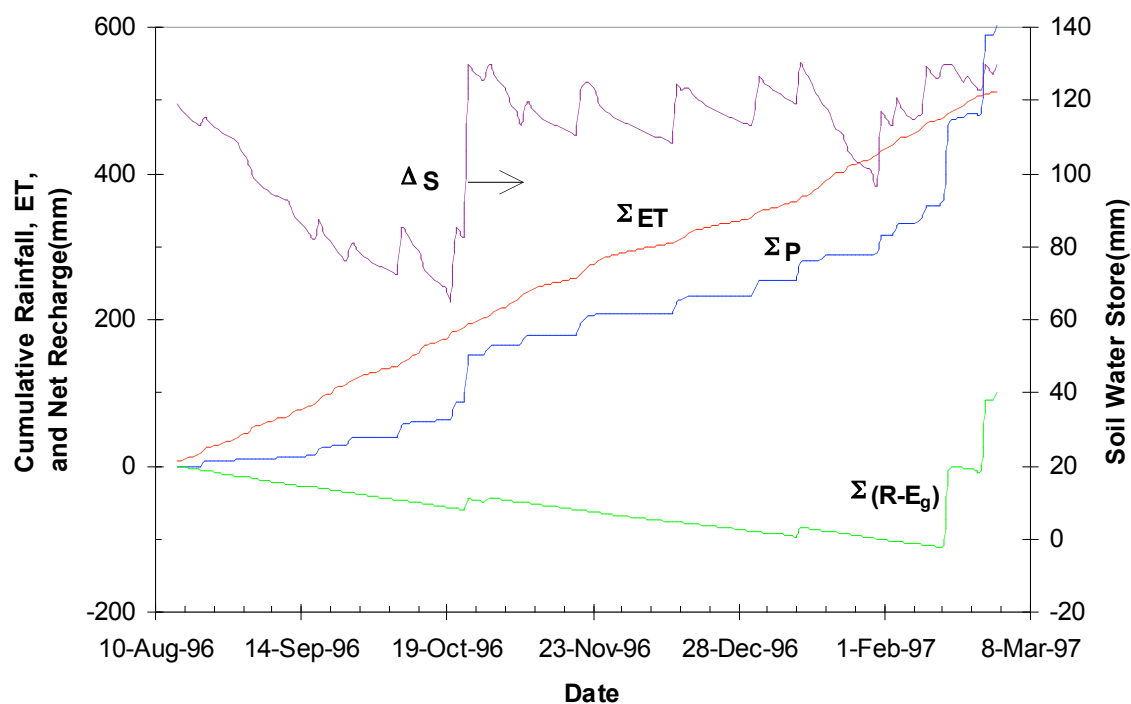


Figure 2: Daily water balance components for the island of Bonriki South Tarawa (excluding groundwater pumping) for the study period showing measured cumulative rainfall,  $\Sigma P$ , change in the soil water store to 1 m,  $\Delta S$ , evapotranspiration losses,  $\Sigma ET$  ( $=\Sigma[E_i + E_s + E_g]$ ), and net recharge,  $\Sigma(R-E_g)$ .

### 4.2 Social, cultural and institutional

A review of legislation and institutional arrangements for water resources in Kiribati revealed a lack of identified roles and responsibilities due to the absence of overarching water resource laws and of finalised leasing agreements with landowners from water reserves. Together, these suggest that the current and continued public use of water reserves to supply water via the reticulated water system to the wider public, are at risk.

The study (White *et al.*, 1999a) found that traditional resource ownership, land use attitudes and aspirations in developing, small islands states evolved in low density, subsistence communities. These are increasingly at odds with the planning requirements of high density, urbanised societies such as South Tarawa. The lack of comprehensive water legislation and legal agreements combined with a lack of clarity of roles and responsibilities of government agencies and community vandalism to water reserve infrastructure, are indicators of the tensions between the subsistence past and the urban future being faced by many communities on coral islands.

Responsibilities for the on-going protection of the water reserves and monitoring of the sustainability of groundwater extraction were key issues. These have been significantly compromised by continuing vandalism and unacceptable land use practices by the local landowners, which has been exacerbated by the fact that lease agreements between Government and landowners have not been finalised. The need for a community education program including school education on groundwater was identified. It was suggested that, instead of simple government compensation for the restricted land use of traditional owners, the water supplier could make regular payments to the local villagers as custodians and managers of the water reserve. Payment could be linked to mutually agreed performance indicators of appropriate land management. The removal of some coconut trees, that compete for freshwater, and their replacement in part of water reserves by sports fields was also suggested. It was concluded that safe conjunctive land uses for water reserves need to be researched.

## **5. The integration of social, cultural, economic and hydrogeological information**

Social rules and economic features such as land tenure and inheritance systems, religious or tribal faiths often outweigh technical aspects, especially in low-income agricultures found in small islands. Often, developed-world solutions to resource sharing are inapplicable in small island communities with traditional land tenure (White *et al.*, 1999a; Crennan, 2001). There is a pressing need to develop options that are socially, culturally and economically appropriate, which encourage a consensus approach to resource use and development and which reduce conflicts.

Faced with the threats to groundwater resources from surface contamination, some governments, such as that in Kiribati, have responded by declaring sources of water for reticulation as public water reserves, and proscribing certain activities (Metutera, 1993). This alienates traditional landowners and communities and restricts agricultural production. There is also the perception that groundwater pumping has decreased permanent crop production (White *et al.*, 1999a). In many small island nations land ownership and the associated property rights accompanying ownership are fundamental to the social, cultural and economic fabric of the community (Crennan, 2001). Centralised bureaucratic intervention cuts across the firmly held belief that private control over land and water resources is an ultimate right and fulfills an inherent need (Crennan, 2001).

The incorporation of information from social, cultural, economic and biophysical spheres and the inclusion of differing perspectives, aspirations and needs present major conceptual challenges (Thébaud and Locatelli, 1997).

Multi agent systems, MAS, (Bousquet, 2001) provide powerful tools for studying interactions between societies and their environment. They have the potential to greatly reduce conflict

over natural resource management and resource allocation. MAS require knowledge of the bio-physical processes governing the resource and of the social, cultural and economic rules controlling their use. In the future we intend to explore with island communities the use of multi-agent systems for equitable groundwater management in small islands. Systems will be researched that permit island communities to appreciate divergent views of and different strategies for using, allocating and managing groundwater. The experience gained from this project will have direct applications to other small island nations throughout the Pacific and Indian Oceans.

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