Proceedings of the 2nd Asia Pacific Association of Hydrology and Water Resources Conference, Singapore 5-8 July 2004, Vol. II pp 345-356

SUSTAINABLE DEVELOPMENT OF WATER RESOURCES IN SMALL ISLAND NATIONS OF THE PACIFIC

IAN WHITE
Centre for Resource and Environmental Studies. Australian National University, Canberra ACT 0200, Australia

TONY FALKLAND
Ecowise Environmental, ACTEW Corporation, PO Box 1834, Fyshwick ACT 2609, Australia

PASCAL PEREZ
CIRAD, Montpellier, France and Resource Management in the Asia-Pacific Program, Research School of Pacific and Asian Studies, Australian National University, Canberra ACT 0200, Australia

ANNE DRAY
CIRAD, Montpellier, France and Resource Management in the Asia-Pacific Program, Research School of Pacific and Asian Studies, Australian National University, Canberra ACT 0200, Australia

MARC OVERMARS
South Pacific Applied Geoscience Commission, Suva, Fiji

This paper uses examples from the Pacific to discuss sustainable water management ìn small islands. Population centres in small islands have water supply problems that are amongst the most critical in the world. Limited land areas severely restrict surface water storages. Freshwater is extremely vulnerable to natural processes and human activities. Limited land areas also restrict freshwater quantities, particularly in frequent ENSO-related droughts. Demand for water is increasing due to both natural population growth and to growing urbanisation. There are few water professionals in many small island nations, policy and institutional frameworks are deficient and community participation in water management is minimal. Water use for agriculture competes with community water supplies. Limited resources and geographic isolation restrict the potential for irrigated crop exports so that reliance on aid is systemic. At the core of water management problems are land tenure and the conflict between the requirements of urbanised societies and the traditional values and rights of subsistence communities. Reforms of governance and the provision of knowledge to communities are critical. Long-term partnerships are needed which promote self-reliance. Multi Agent Systems offer potential for reducing conflicts over water. Regional organisations, able to foster self-support, can play a crucial role in developing island-adopted and owned solutions.

INTRODUCTION

Many Pacific small island countries have high rainfalls yet face water problems that are amongst the most critical in the world [1] especially in urban and peri-urban coral atoll communities. The harvesting and storage of freshwater is constrained by small land areas, atoll geology, pressures of human settlements [2], conflicts over traditional resource rights, capacity limitations, frequent droughts and inundation by the sea during storms [3], [4]. Traditional crops, coconuts, swamp taro, breadfruit and pandanus, compete directly with humans for freshwater [5]. In rapidly growing urban atoll communities, human health is paramount. In such situations where land is scarce, the potential to alleviate poverty through irrigation or tourism is restricted. Here we examine the nature of freshwater in atolls, its vulnerability, demand and management, governance, water-related poverty alleviation and examine mechanisms for addressing threats to atoll water supplies and communities.

UNIQUE NATURE OF FRESH GROUNDWATER IN ATOLLS

Freshwater in most atolls is supplied from rain tanks, domestic wells, or, in urban areas, from reticulation systems sourced mainly from groundwater. Several islands augment these with seawater desalination. Freshwater importation, used recently in Nauru, is expensive. Atoll soils are mostly coarse coral sands. Surface runoff is minimal with little opportunity for surface storage. Groundwater and stored rainwater are therefore predominant sources of freshwater [4]. Groundwater occurs as a thin lens of freshwater 'floating' over seawater in coral sand and limestone aquifers (see Figure 1).

Coconut and pandanus trees tap into and transpire shallow groundwater at rates of approximately 150 L/tree/day [6]. Groundwater is also extracted using domestic wells and groundwater pumping schemes (see Figure 1). Fresh groundwater also discharges into the surrounding sea. Geologically recent coral sands and gravels are deposited on older, karstic limestone seawater aquifers [7]. These aquifers transmit tidal pressures beneath atolls and groundwater lenses rise and fall in a lagged response to the tide, mixing fresh and seawater [8]. This forms thick, brackish, transition zones between freshwater and seawater below the lenses (see Figure 1). Fresh groundwater in low atolls is balanced between episodic rainfall replenishment and continual depletion by evpaotranspiration, extraction and outflow to and mixing with seawater.

The quantity of fresh groundwater depends on atoll width, recharge rate and the ease of transmission of freshwater through the aquifer. Wider islands with high recharge rates and less permeable aquifers generally have thicker freshwater lenses, good sources for reticulation systems. Narrow atolls with transmissive aquifers, as in Tuvalu, have limited potential for viable fresh groundwater and raintanks are used [4].

Small land areas in atolls restrict freshwater supply to mainly basic human needs. Flushing toilets consume 30 to 40% of water supplies and there is little scope for

freshwater sewerage systems[4]. Majuro and South Tarawa have saltwater sewerage systems. Elsewhere, composting toilets have been trialed [9].

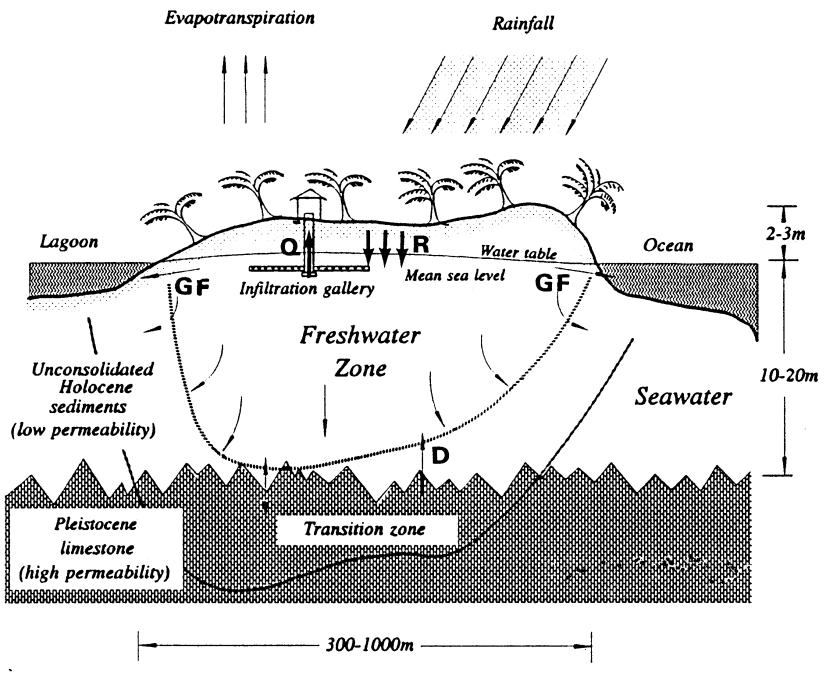

Figure 1. Vertically exaggerated cross-section through a low coral island showing the fresh groundwater lens surrounded by seawater. R is recharge from rainfall, Q is extraction by pumping, GF is discharge to the sea or lagoon and D is loss due to tidally-forced mixing with underlying seawater.

Sustainable groundwater extraction and rainwater use to maintain freshwater throughout droughts is a critical issue for urban areas. This requires data on recharge rates, demand and the response of freshwater lenses to losses. Sufficiently long monitoring records are available in only a few atolls [4]. Surrogates such as temperature and rainfall inferred from coral cores, provide useful guides to past extreme events [10].

VULNERABILITY OF FRESHWATER IN ATOLLS

Natural Threats

Fresh groundwater in low coral atolls is vulnerable to natural processes and human activities [11]. Drought, storms and climate change affect both quantity and quality of groundwater in atolls. Annual rainfalls in many atolls exhibit large variability due to

frequent ENSO-related droughts. Droughts decrease the thickness of freshwater lenses (see Figure 2) and increase salinity.

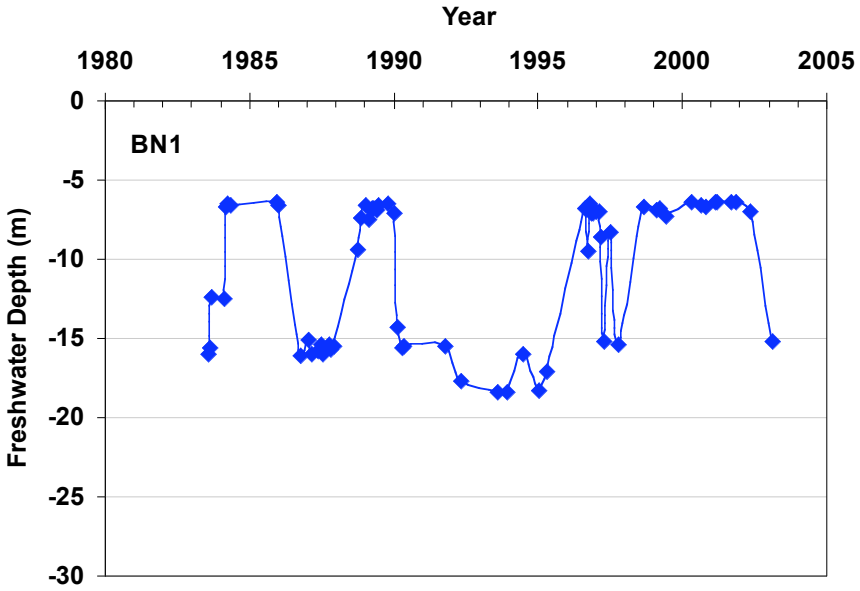

Figure 2. Change in the freshwater depth at the edge of a large freshwater lens Bonriki island, Tarawa atoll, Kiribati. Droughts in 1984, 1989, 1996 and 1998-2002 are evident.

Roof catchments and tanks are small and are vulnerable during droughts. Severe droughts have forced the evacuation of some atoll communities in the Pacific. The prediction of, planning for and response to droughts are priorities in small islands [11], [12].

Inundation of low atolls by waves during storms salinises shallow groundwater. Predicted climate change impacts, particularly sealevel rise, therefore causes anxiety. Migration of the Pacific warm pool across the central Pacific already produces sealevel rises around 0.25m. Preliminary estimates of climate change impacts on atoll groundwater indicate that change in rainfall is the most important factor. Small sealevel rises with current mean rainfall may slightly increase quantities of groundwater [13].

Threats associated with human settlement

Overpumping of fresh groundwater and inappropriate extraction wells can salinise atoll groundwater. However, biological and chemical pollution of drinking water and its impact on human health are of more concern. Groundwater contamination caused by sewerage, pigs, crop production, spillage of petroleum products, and seepage from waste dumps occurs in many small islands [9].

The most critical factor influencing groundwater contamination is the depth from the surface to the watertable [14]. In atolls this thickness is often less than 2 metres, and surface contaminants can reach the groundwater in under two hours. Swamp taro pits, excavated into watertables, are significant sources of pollution. Faecal contamination of groundwater is a major source of gastroenteritis in atoll communities, causing high infant mortalities and outbreaks of diseases like hepatitis, typhoid and cholera. Domestic wells close to dwellings and pit latrines are especially vulnerable [9]. Domestic wells and rain tanks in low population density islands are less vulnerable. Protection of water supplies from contamination remains one of the greatest challenges for small island urban centres.

PROTECTION OF GROUNDWATER SOURCES

In atolls with freshwater reticulation systems, some governments have created groundwater reserves in attempts to exclude settlement and restrict landuse. Increasing encroachment, however, has forced the abandonment of groundwater reserves in some atolls (see Figure 3).

Figure 3. Betio, Tarawa atoll, Kiribati where expanding population with densities as high as 15,000 people/km^2 have forced the abandonment of freshwater reserves.

Land ownership and traditional landuse rights are central issues in the establishment of water reserves. Many island families have long-established interests in land and most rely on their lands for subsistence, even in urbanised areas. Land provides groundwater, food,

attendant fishing rights and cash income from copra harvesting [15]. Traditional land ownership involves ownership of groundwater, a fact seldom appreciated when water reforms are proposed. Declaration of water reserves by governments generates conflicts with landowners and users, sometimes resulting in infrastructure vandalism [5]. Payment of adequate compensation and restricted landuses are continuing contentious issues. Wider communities regard designated water reserves as common property and resources can be plundered. Squatting, market gardening and pig-raising also occur..

It has been suggested that governments should pay reserve landowners as custodians of reserves and settlement could be permitted around the perimeter of water reserves where groundwater discharges seawards (see Figure 1) to reduce conflicts and address land shortages. Conflict resolution and negotiation support strategies using multi agent systems are also being developed [16]. A novel solution for crowded atolls is the creation of water reserves on artificial islands formed using dredged lagoon sediments [3].

DEMAND AND ITS MANAGEMENT

Per capita consumption in the Pacific is increasing. Past designs for freshwater reticulation systems in atolls used 50L/capita/day as the demand estimate [4]. Growing expectations in larger villages suggest 100-150L/capita/day as a more reasonable estimate. Leakage from reticulation systems is endemic with rates of 50% not uncommon. Leakage control increases water availability and reduces costs substantially [1]. Some reticulation systems are unable to meet demands and losses and water is supplied for only a few hours per day as *de facto* demand management. Urban communities supplement water supplies using domestic wells and small rain tanks. During droughts these are quickly exhausted or contaminated.

Resettlement of communities to uninhabited atolls is planned in some countries to lower population pressures. Few governments, however, have sufficient resources to make this attractive for people drawn to towns. Metering and charging for water supplies, a long-recognised demand management tool, is successful in some small islands [4]. Where poverty is significant, there is reluctance to introduce metering, or it has been abandoned in favour of flat fees, containing no conservation message. Water revenues, where collected, are mostly inadequate to cover operation and maintenance [17]. A novel approach to demand management is being trialed in Kiribati. Small, single dwelling storage tanks are filled continually from the reticulation system by a slow trickle feed, sufficient for a day's demand. Conservation of water then becomes a household responsibility. Behavioural change is fundamental for conserving and protecting water and education and awareness programmes have increased in the Pacific [18].

POLICY AND INSTITUTIONS

Water is usually treated as a common-pool resource in the Pacific. Property rights and responsibilities are often undefined. Over the past decade, institutional reforms have

swept developed world water sectors. There, the State usually owns water. There is a general reluctance in the Pacific to adopt national policies and pursue developed world institutional reforms because land tenure often implies customary 'title' to water [7].

The notion of water as an environmental resource seems not in tune with water-related public-health concerns in small islands [19] As well, reforms such as the separation of supplier and regulator are impractical in small islands with two or three water professionals. Water reforms raise constitutional, ethical and social issues, issues of community-concern. Many small island states are reluctance to entrain communities in the debate [19]. Aid donors seldom recognise the protracted period required for community consultation in atoll communities.

Because of limitations or non-existence of national water policies or comprehensive water and sewerage laws, government agencies involved in water and wastewater management often have no clearly defined roles and responsibilities. Existing institutions frequently inherited responsibilities for water from older legislation and past administrations. Overlaps in responsibilities and roles persist, and uncertainties in water management result. Agencies are reluctant to cooperate and share information [18]. Urban and rural water supplies are frequently under different organisations but urban water suppliers have the concentration of water expertise and resources.

Water utilities across the Pacific identified insufficient institutional capacity, lack of government support, insufficient community support and widely scattered multiple island states as constraints to achieving sustainable water and wastewater management [20]. Common regional concerns such as limited land area, competing land use, increasing demands, poverty, large distances and lack of coordination between donors and international organisations also emerged. Because of common problems and restricted national capacities in small island countries, regional water organisations such as the South Pacific Applied Geoscience Commission, the Pacific Water Association and the South Pacific Regional Environment Programme can play key roles in building self-reliance in small island countries. In the past, aid donors have overlooked the potential of such regional organisations. To be successful, regional organisations need to build long-term relationships and be adequately resourced.

There is no single reform process applicable to all small island nations in the Pacific. A number of national building blocks have been identified that may be useful [19]: water sector assessment; broadly-based water vision; water action agenda and plans; design of capable institutions; integrated investment plans; regional support; dialogue with investors and donors. Awareness raising and genuine consultation with island communities are central to any reform process. Water reform is a complex, long-term process in which Pacific-generated and owned solutions are required.

POVERTY, WATER AND AID

Extreme poverty reduction is a critical world goal and water plays an important role in poverty alleviation [21]. However, benefits of increased growth from water infrastructure

projects are reduced by inequitable income distribution [22]. Donor agencies in the past have funded large water infrastructure projects in small island communities resulting in the loss of householder responsibility for water conservation and protection [18]. Widespread criticism of aid projects has led to calls for 'pro-poor' growth assistance with emphasis on improved management efficiency, institutional reforms and community participation.. Poverty in Asia-Pacific has been claimed is claimed to stem from institutional weakness and policy failures that prevent countries from taking advantage of the opportunities of globalisation and coping with its risks [22].

Other regions in the world rely on freshwater both for subsistence and poverty alleviation. In the Mekong, six factors could cause relative poverty to increase [22]: continuing deterioration of natural resources, on which the poor depend; the conflict between national laws and customary rights; spending of public resources on large infrastructure projects rather than on social investment; inherent inability to transfer the opportunities of globalisation to the poor and its relation to property rights; institutional failures, conflicting jurisdictions and agendas between government agencies; and reluctance to empower community participation in natural resource management. Many of these factors are apposite to Pacific atoll nations, however the potential for small island communities to participate in the benefits of globalisation through irrigation are limited by restricted land areas, acute water shortages during dry times and distances to markets. Some niche markets exist, such as the production of squash pumpkins in Tonga, but these are mainly confined to larger, higher, volcanic islands with fertile soils. Tourism could reduce poverty in atolls, however it has high per capita water demands.

While the potential for high-value crop exports from atolls is limited, production of fruit and vegetables for local urban markets is an important source of cash income for the poor. Frequent hand irrigation is required because of the permeable nature of the coral soils and the use of pig manure or mineral fertilizers threatens groundwater. Water and nutrient efficient hydroponic vegetable production is being trialed by some atoll communities (see Figure 4). Its long term viability during dry periods when supply water salinity increases may be a problem.

Aid addressing institutional weakness, policy failure, property and customary rights, community empowerment and the deterioration of water and associated land resources together with providing the broad community with appropriate knowledge and information may provide the greatest benefits [22]. These, however, require long-term commitment and partnerships with regional and non-government organisations.

CONCLUSIONS

Sustainability problems faced by Pacific Island Countries also occur in other developing regions. Poverty, deterioration of water resources, institutional failures, knowledge and information access, restricted capacity and conflicting jurisdictions and agendas between government agencies are common. Three central issues are also shared. These are the tensions between the demands of urbanised societies and the traditional values, customs

and rights of subsistence communities, land tenure and its attendant customary rights and genuine community participation in debate and decision making [22], [23].

Figure 4. Hydroponic vegetable production Bikenibeu, South Tarawa Atoll, Republic of Kiribati.

The extremely limited land area in atolls, their geographic isolation and hydrogeology, however, pose unique problems that constrain sustainable development and poverty alleviation and threaten water supplies as populations increase. Regional pooling of expertise through partnerships with adequately resourced, long-lived regional organisations has the potential to overcome capacity limitations in small island countries.

The *Pacific Regional Action Plan on Sustainable Water Management* [24] addresses issues of water management, island vulnerability, awareness, technology, institutional arrangements and finance. Developed-world water policies and reforms that conflict with traditional rights and values of small island countries will only be adopted when the need for them is recognised and they are adopted and owned by island communities. Behavioural change at all levels is fundamentally important for conserving and protecting water in small islands but requires provision of appropriate, appreciation of cultural, social, economic and geographical contexts and long-term commitments.

Acknowledgements
The authors are grateful for support from the Australian Centre for International Agricultural Research, The Pacific Biological Foundation, UNESCO IHP, the Australian Academy of Science, the Embassy of the Republic of France, and Ecowise Environmental.

REFERENCES

[1] Capenter .C, Stubbs J., and Overmars M. (eds) , *Proceedings of the Pacific Regional Consultation on Water in Small Island Countries,* Sigatoka, Fiji Islands, 29 July-3 August 2002, Asian Development Bank and South Pacific Applied Geoscience Council, (2002).

[2] Ward R.G., "*Widening Worlds, Shrinking Worlds, the Reshaping of Oceania"*. Pacific Distinguished Lecture 1999. Centre for the Contemporary Pacific, Australian National University, Canberra, (1999).

[3] Falkland A., "Tropical island hydrology and water resources: Current knowledge and future needs", In *Hydrology and Water Resources Management in the Humid Tropics. Proc. Second International Colloquium,* Panama, Republic of Panama, 22-26 March 1999, UNESCO-IHP-V Technical Documents in Hydrology, No 52, UNESCO Paris, (2002), pp 237-298.

[4] Falkland A., "Theme 1. Water resource management", In *Proceedings of the Pacific Regional Consultation on Water in Small Island Countries,* Sigatoka, Fiji Islands, 29 July-3 August 2002, C. Capenter, J. Stubbs, and M. Overmars (eds), Asian Development Bank and South Pacific Applied Geoscience Council, (2002).

[5] White I., Falkland A., Crennan L., Jones P., Etuati B., Metai E,. and Metutera T., "Issues, Traditions and Conflicts in Groundwater Use and Management", UNESCO-International Hydrological Programme, Humid Tropics Programme. IHP-V Theme 6. Technical Documents in Hydrology No. 25. UNESCO, Paris.

[6] White,I., Falkland,A., Etuati,B., Metai E., Metutera T, "Recharge of fresh groundwater lenses: Field study, Tarawa atoll, Kiribati"**, I**n *Hydrology and Water Resources Management in the Humid Tropics. Proc. Second International Colloquium*, Panama, Republic of Panama, 22-26 March 1999, UNESCO-IHP-V Technical Documents in Hydrology, No 52, UNESCO Paris, (2002), pp 299-322.

[7] Falkland A. and Woodroffe C. D., "Geology and hydrogeology of Tarawa and Christmas Island, Kiribati", Chapter 19, In HL Vacher, and TM Quinn (eds), *Geology and Hydrogeology of Carbonate Islands, Developments in Sedimentology* 54, H.L. Vacher, and T.M. Quinn (eds), Elsevier, Amsterdam, (1997).

[8] Wheatcraft S.W. and Buddemeie, R.W., "Atoll island hydrology"*, Ground Water*, Vol. 19, (1983), pp 1–320.

[9] Crennan L., and Berry G., "Review of community-based issues and activities in waster management, pollution prevention and improved sanitation in the Pacific

Islands region". Prepared for the International Waters Programme, South Pacific Regional Environmental Programme, Samoa, (2002).

[10] Fairbanks R.G., Evans M.N., Rubenstone J.L., Mortlock R.A., Broad K., Moore M.D., and Charles C.D., 'Evaluating climate indices and their geochemical proxies measured in corals', *Coral Reefs*, Vol. 16, Suppl., (1997), pp S93-S100.

[11] Scott D., 2002, "Theme 2. Vulnerability and dialogue on water and climate", In *Proceedings of the Pacific Regional Consultation on Water in Small Island Countries,* Sigatoka, Fiji Islands, 29 July-3 August 2002, C Capenter, J Stubbs, and M Overmars (eds), Asian Development Bank and South Pacific Applied Geoscience Council, (2002).

[12] White I., Falkland A., and Scott D., *Droughts in Small Coral Islands: Case Study, South Tarawa, Kiribati*, UNESCO IHP-V, Technical Documents in Hydrology, No. 26, UNESCO, Paris, 1999, 55 pp.

[13] Alam K., and Falkland A., "Vulnerability to Climate Change of the Bonriki Freshwater Lens, Tarawa", Report No HWR97/11, for Ministry of Environment and Social Development, Republic of Kiribati, April 1997, ECOWISE Environmental, ACTEW Corporation, Canberra, (1997).

[14] Dillon P., *Groundwater pollution by sanitation on tropical islands*, UNESCO IHP V, Technical Documents in Hydrology, No. 6, UNESCO IHP, Paris, (1997).

[15] Jones P., 'The Impact of the Socio-Cultural Order on Urban Management in the Pacific: A Case Study of South Tarawa, Republic of Kiribati', PhD thesis, Depart. of Geographical Sciences and Planning, Uni. of Queensland, (1997).

[16] Perez P., Dray A., White I., Le Page C. and Falkland A, "AtollScape: Simulating Freshwater Management in Pacific atolls. Spatial processes and time dependence issues", in *Proceedings MODSIM, International Congress on Modelling and Simulation* July, 2003, Townsville. Modelling and Simulation Society of Australia and New Zealand, Inc., (2003), pp 514-518.

[17] Walker I. "Theme 6. Financing", In *Proceedings of the Pacific Regional Consultation on Water in Small Island Countries,* Sigatoka, Fiji Islands, 29 July-3 August 2002, C. Capenter, J. Stubbs, and M. Overmars (eds), Asian Development Bank and South Pacific Applied Geoscience Council, (2002).

[18] Crennan L.,, "Theme 3. Awareness" In *Proceedings of the Pacific Regional Consultation on Water in Small Island Countries,* Sigatoka, Fiji Islands, 29 July-3 August 2002, C. Capenter, J. Stubbs, and M. Overmars (eds), Asian Development Bank and South Pacific Applied Geoscience Council, (2002).

[19] Hill D., "Theme 5. Instutional arrangements legal, planning and policy and institutional strengenthening", In *Proceedings of the Pacific Regional Consultation on Water in Small Island Countries,* Sigatoka, Fiji Islands, 29 July-3 August 2002, C. Capenter, J. Stubbs, and M. Overmars (eds), Asian Development Bank and South Pacific Applied Geoscience Council, (2002).

[20] Dworsky M., "Theme 4. Technology'" In *Proceedings of the Pacific Regional Consultation on Water in Small Island Countries,* Sigatoka, Fiji Islands, 29 July-3

August 2002, C. Capenter, J. Stubbs, and M. Overmars (eds), Asian Development Bank and South Pacific Applied Geoscience Council, (2002)..

[21] AusAID 2003, *Making every drop count: Water and Australia Aid*, AusAID, Canberra.

[22] Kaosa-ard M., "Poverty and globilisation", in *Social Challenges for the Mekong River,* Kaosasd-ard, M. and Dore, J. (eds), White Lotus, Bangkok, (2003), pp 405-440.

[23] Dore J (2003), 'The governance of increasing Mekong regionalisation', *In Social Challenges for the Mekong River,* Kaosasd-ard, M. and Dore, J. (eds). Chiang Mai University, White Lotus, Bangkok, p 405-440.

[24] SOPAC and ADB 2003, *Pacific Regional Action Plan on Sustainable Water Management.* SOPAC and ADB, Suva, Fiji.