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The place of rural, remote and least-wealthy small islands in international water development: the nexus of geography–technology sustainability in Chuuk State, Federated States of Micronesia

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Many least-wealthy, rural, remote and resource-poor small island communities are unlikely to benefit from high-profile global water improvement initiatives. Their small landmasses, geologic composition, geography, social and technological isolation, colonial history, and weak educational and financial resources constitute significant barriers to improving access to safe drinking water. This paper discusses the relatively unique position of such island societies in the international community, providing a case study of the Federated States of Micronesia that integrates data and information pertaining to water resources management and governance, spanning from the island village to national scale. A vision is offered regarding the interaction between small island human and biophysical water systems, manifesting ways to pursue water resource development to improve public health which are constructed to be economically, physically and culturally sustainable.

KEY WORDS: Micronesia, Pacific Islands, capacity building, environmental education, watershed management, water, small islands, sustainable development

Introduction

Areas of small island countries, such as the Federated States of Micronesia (FSM), exceed well over 5000 mm of precipitation annually (Smith Jr 2003). These communities are in some of the wettest places on earth. Nevertheless, their geologic and geographic settings, technology, government capacity, village-scale governance and knowledge base can still make accessing safe drinking water exceedingly difficult. Despite billions of dollars in aid, labour, and local spending, inadequate progress has been made in recent years in much of the least-wealthy realm in improving access to safe drinking water. Some regions have regressed, and if percentages of coverage improve somewhat, total numbers of persons lacking access may still increase (Smith Jr 2003). There are over 1 billion people without safe water, over 3.4 million deaths occur annually, 2.2 million of which are of children – with suffering and economic loss not quantifiable. Some 14 000–30 000 die each day from consuming contaminated water or food (Gleick 1999; UNESCO 2006; WHO 1993 2000 2006). Because of variable access to water, broad trends in development policy, and profit seeking, alternatives to traditional forms of water management have gained momentum. The two main forces in reforming water policy are privatisation and sustainability.

Human rights, sustainability, and development

An important dimension of discussions regarding power, policy and equity in accessing safe water at adequate volumes has been the rise of the 'human right to water' (hrH2O) movement in support of fulfilling basic needs (McCaffrey 1992; Swyngedouw 1997; Jolly 1998; UNESC 2000; UN General Assembly 2000; Petrella 2001; Abrams 2001; COHRE *et al.* 2007). Sanitation is linked to water quality, so it is logical to extend the hrH2O to include sanitation,

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and with conservation rates increasingly being implemented to enhance the sustainability, and climate change impacting on supply, it is notable that Smith Jr (2008) and Smith Jr and Wang (2008) connect equitable access to water to demand-side modelling. In these scenarios, water is conserved during drought to protect supply, ecology, low-income consumers and purveyors.

The hrH2O movement has evolved since the 1970s, partially as a response to privatisation, and partly due to limited progress in water and sanitation improvements. Global civil society has advanced arguments that insist on essential levels of water being provided regardless of ability to pay, or personal or geographic characteristics. This is a 'right' supported in UN documents, one some civil society members believe is endangered by profit-oriented models (UNESC 2000 2002; Barlow 2001; International Forum on Globalization 2001). Thus, some insist on yet another redirection in water development policies towards building national capacity, rather than on promoting international concessions. This stance is buoyed by the failure of privatisation in Manila. Here privatisation has resulted in the loss of pressure, even in previously adequately served areas like Project 8.

This conflict over the governance of resources has led to public clashes in which company heads have criticised NGOs for undermining their efforts, and have threatened to disengage from the process (*The Economist* 2004). Nevertheless, many pro-privatisation advocates contend that privatisation through multinational corporations, in forms such as public–private partnerships, offers the technical expertise and capital necessary to enhance access to water (Uitto and Biswas 2000; Water Policy International 2004; Water, Engineering and Development Centre 2007). However, critics argue that such partnerships create a model that fosters conflicts of interest between serving the needs of stakeholders and stockholders, and that there is hypocrisy in such engagements, as most northern nations achieved adequate water with public systems (Hall 2000 2002; Shiva 2002; Smith Jr 2003).

These debates dominate recent international water development discourse. However, their focus on the impact of privatisation and burgeoning urban mainland communities does not address rural, remote and least-wealthy (RRLW) conditions. Even if the neoliberal wave holds promise in urban areas, there is little incentive for companies to privatise water supply on hundreds of scattered islands inhabited by few people with very limited financial resources. Also, the remoteness of urban and rural mainland areas is less than that of islands surrounded by vast areas of often rough ocean, and this makes business difficult to conduct in places like the Pacific – although global networks draw in even 'unconnected' places (Tsing 2005). Rural places on the mainland also have larger populations and basins, multiple viable aquifers, and more established flows of ideas, technology and capital.

Another RRLW small islands' issue is that injecting resources on a state scale, when governance of many small islands in places like the Western Pacific remains at the village and family scales, can be wasteful and can create highly uneven development. It may mean putting faith in a government that is not effective, perhaps not having a daily presence. This creates opportunities for corruption. Additionally, fragmented island geography makes centralised water systems impossible, except in tiny areas of concentrated capital. However, the goal of the Millennium Declaration and the hrH2O is an equitable and broad distribution of safe water, regardless of geography or affiliations.

'Sustainable development' has arguably become a mainstream feature in water policy, albeit predominantly in an industrialised world context (Smith Jr and Wang 2008). The normal components of this approach are a harmonising of economics, ecology, supply and equity through the integration of supply and demand-side techniques, so that water resources can be utilised wisely for 'multiple generations' (UN 1987). The discussion is often framed in a context of 'competing users' and industrial era pressure on resources.

This vein of water resources development discourse has some value when applied in least-wealthy countries, because this can encourage communities to balance short-term economic gain against ecological and public health considerations. However, inherent in this approach is an emphasis on water conservation and high technologies for sophisticated monitoring, especially for costly 'adaptive management'. Whereas, persons in least-wealthy countries most often struggle with fundamental water quality concerns, such as preventing human and other animal waste from entering their water supply, and their water resource management and fiscal resources are not at an industrial scale.

More closely related to 'on-the-ground' concerns in the FSM are the principles of 'project sustainability', which share the concern of sustainable development that management regimes should follow a multigenerational perspective. However, another major concern is making certain that water projects do not collapse after outside 'aid-workers' leave. Key elements are to be sensitive to the need for local (i.e. village) ownership of projects, capacity building, financial stability, wise choices in technology, and healthy partnerships. Sometimes public–private partnerships are seen as the way to finance such endeavours, at least until capital builds up, although

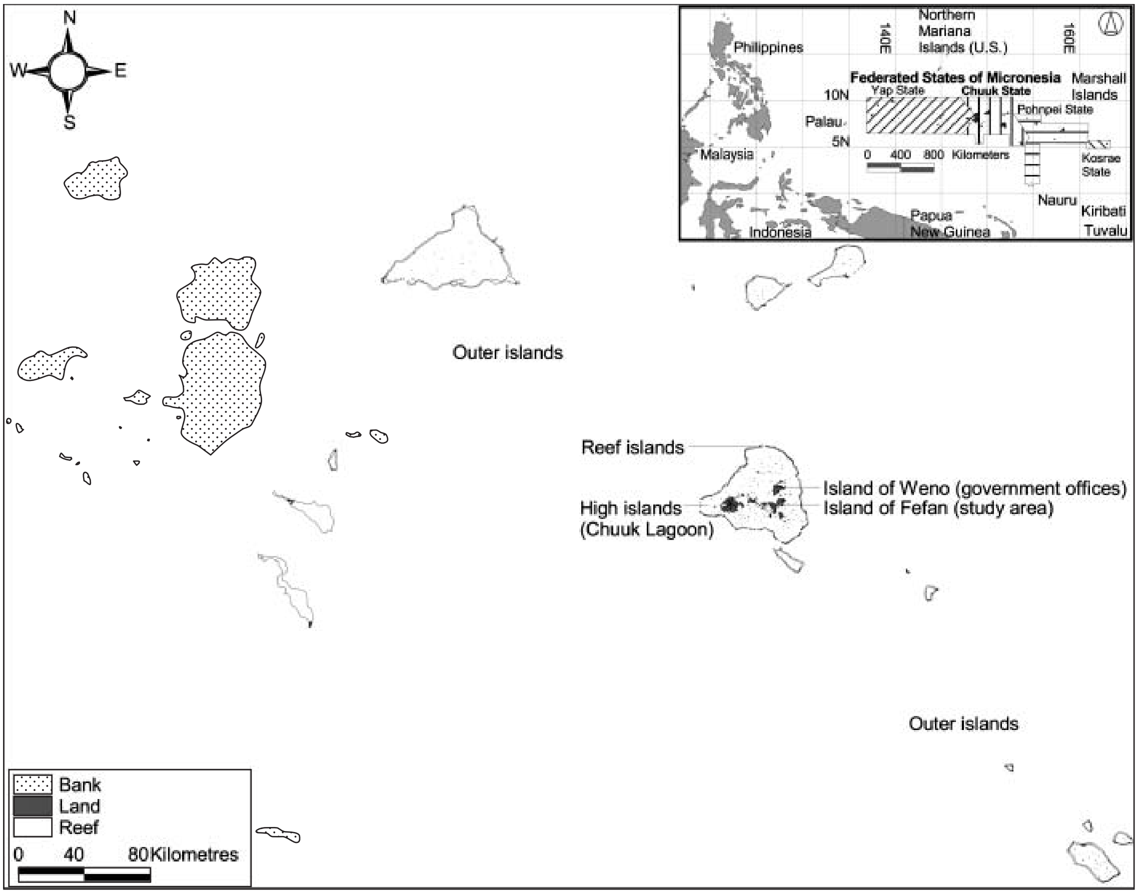

Figure 1 Chuuk State, Federated States of Micronesia

this may be critiqued as cutting local staff and management capacity, something which is difficult to reverse. Discussions regarding privatisation, sustainable development, and especially project sustainability are valuable. However, small island scenarios are sufficiently unique as to require a more customised treatment, and generally are not well suited to mainstream sustainable development or neoliberal paradigms.

Rural, remote and least-wealthy small islands

RRLW small islands remain impacted by their physical geography and relative lack of exchange of information and technology with the outside world. This lack of connectivity, together with minimal human, economic and natural resources, necessitates strategies that assume almost no 'high' technical capacity (Keating *et al.* 1984). Operating in such a limited and isolated environment requires an intimate knowledge of culture, particularly governance, at multiple scales, and a highly selective eye for methods and technologies that fit island village life.

The communities discussed here may be only a few hundred people on small basalt (high) islands or tiny coral (low) atolls, surrounded mostly by millions of square kilometres of ocean (Figure 1). In some cases, larger high islands may exist, but the distance between islands across often tempestuous water, sometimes many hours away by ship, may prevent daily political–economic activity. In such cases, isolation is the norm. This dramatically impacts the implementation and maintenance of technologies, efficacy of national policies, governance regimes and communication.

Some specific field observations made in the FSM while pursuing this research include a lack of infrastructure and poor communications, except on those parts of islands where tourists and officials stay. The physical geography of many tiny islands scattered across the sea disallows expensive centralised (piped) systems typical of Northern/Western models. Additionally, underground storage of water is frequently limited by the shape, scale and geology of small islands (Falkland 1990). Most people do not have paid employment, and usually any income comes from kindred in the family network that have government jobs – as the private sector is weak or non-existent. Sharing resources within the extended family is expected, and this may impact on governance. Most people live a sustainable agricultural and fishing existence and this paradigm of living results in little global influence, despite possessing large territories (mostly ocean). However, global issues can impact on the islands, often inequitably, as is the case with fisheries' pressure and climate change, despite the island's small carbon consumption 'footprint'.

In the FSM, most young children attend school, but may have to leave their island to do so after elementary education. Technology and environmental health education lack support, and in the few places where a 'college' exists, offices are very poorly funded, sometimes closed, and extension programmes are weak or absent. In such settings, introducing technologies can have unexpected results. Even in isolated cases where a 'technical fix' is successfully introduced, without educational outreach, source water protection may suffer, endangering health. For instance, in Pohnpei, FSM, after a water treatment system went on-line, villagers assumed they could do whatever they wished to the river (e.g. dump rubbish), and moved near intakes (W. Raynor, Country Director, FSM, The Nature Conservancy, 1 June 2001, personal communication).

'Parachuting' in high technology and only working with senior government officials to transfer it in a 'turn-key' scenario holds little promise, as relying on changes in behaviour requires internal motivation and local participation at a village scale to sustain it (Winter and Stephenson 1981; St Martin 2001). Highly uneven technology applications can create jealousy, as was observed in one Micronesian case, in which a small solar pump on an atoll required the trimming of a coconut tree. This led to tension because of the refusal to trim the tree to improve solar collection.

Outreach strategies and technologies

Capacity building should not be completely driven by outsiders or funding agencies, or it may not be appropriate or adopted, as it will not reflect local priorities. Cultural and long-term economic appropriateness, not simply physical fit, are essential factors in technology selection. There are some specific characteristics to which to aspire in selecting technologies for the Western Pacific. These include the ability to withstand tropical conditions that cause rapid degradation, the utilisation of cheap yet durable local or widely available materials and parts for ease of maintenance and upgrades, and the use of local talent and systems that are simple enough to be widely understood. The efficiency level should be based on what is sufficient to do the job, even if not judged 'efficient' by Northern standards, accompanied by higher capital costs. Technology should be scaled to fit the local demand and physical setting, as opposed to a factory-set scale. For instance, a problem in the energy field has been plants run by multinational corporations that are guaranteed a certain revenue based on a hypothetical demand that is never reached.

Equity in terms of spatial distribution of technology is important. If each time funds are available to pursue water improvement, and the approach is through a typical centralised high-technology and high-cost system, then the project will likely gravitate to the most wealthy and influential island, often that with government officials and/or tourists. This violates the hrH2O as defined by UNESC (2002) in terms of distributional equity. Decentralised, sustainable, low-tech and low-cost approaches, such as those highlighted by the Water, Sanitation and Hygiene for all, or 'WASH' (Water Supply & Sanitation Collaborative Council 2006), 'SAFE WATER' (Centres for Disease Control and Prevention and CARE Health Initiative 2001), and Participatory Hygiene and Sanitation Transformation, or, 'PHAST' programmes (WHO 1998b) should be considered.

Falkland (1990) provides a thoughtful set of appropriate water management technologies for small islands. The Small Island Developing States programme and the Internet links from it are also good resources (see also Small Island Water Information Network 2006; UN Program of Action for the Sustainable Development of Small Island Developing States 2006; UNDEASA 2006; The Alliance of Small Island States 2006). Whyte's (2001) research on best management practices in the Pacific is a quality complement to such information.

The hidden nature of 'low-cost' approaches

Low-cost approaches may incur a high cost in community effort and sacrifice (Winter and Stephenson 1981; Whyte 2001; White, Bradley and White 1972 2001). For example, altering locations of point and non-point pollution sources, so that they are lower in a basin and below water intakes, may cost little money, as does the creation of vegetation buffers to filter runoff. However, even if local persons are convinced of the worth of such endeavours, this requires significant personal sacrifices of time, effort and maybe even some of the precious island land, as well as negotiating contentious changes in land use patterns. Time, obtaining permission to pass or act on private or common lands, coordinating labour, and adaptation to community priorities that may not resonate well with scientific ones, all consume the time and energy of partners (Gadgil 1998). In fact, many that pass through such remote locations are doing 'Big Science' on large grants that are not designed with the priorities of villages in mind.

Having local partners from specific villages, rather than just from anywhere in the country, is important to avoid conflicts in technology placement (Winter 2000). Winter and Stephenson (1981) note that one key thing to decide is whether local partners and villagers are to be paid, and what resources (stakes) they are committing. Outside researchers can be surprised, perhaps even offended, to find that villagers will not work even on 'their own aid projects' if they develop jealousies and/or expectations of payment that are not dealt with upfront, or that disenfranchising passive donor–recipient relationships can form. Unfortunately, the way in which many grants are administered, the researcher is pressured to build a given research project quickly and produce timely 'outputs', well before supporting relationships can be formed.

The Pacific way

Understanding local culture and taking cues from it does not ensure a successful collaboration, but without this, success is improbable (Hezel 2004). The 'Pacific way' is a term that is used to describe how cultures in the region try to avoid large numbers of small conflicts in these small spaces. This protocol is important for outsiders to understand, so as not to undermine their collaboration efforts. Generally speaking, despite the 'warrior tradition' of places like Chuuk State, FSM, and the occasional disruption, sometimes fuelled by alcohol, the repercussions of being insensitive to neighbours in such spaces are generally too great to ignore (Marshall 1979 2004). This is relevant to those wishing to intervene in such cultures, as persons providing 'aid', yet insensitively disregarding community members impacted by their work can set off reactions that are difficult for outsiders to anticipate. In addition, if outsiders have shown arrogance in the past, then researchers must cope with their legacy. Showing extra respect for a local leader, through the way one approaches and works with a particular village, may be important. In places in the Pacific this may historically be the Melanesian 'big-man', the Polynesian Chief, Pohnpei's Soumas and Nahnmwarki, etc., although in places such as Chuuk, governance has been greatly decentralised. In addition, understanding indigenous knowledge and uses of technology and resources is also important for avoiding conflicts and inefficiencies (Shutler *et al.* 1984; Stephenson and Kurashina 1983; Hunter-Anderson 1987).

Local politics and unexpected barriers

Understanding local politics is essential for avoiding 'unexpected barriers'. For example, Winter and Stephenson (1981) note how dating habits and jealousy ruined water improvement projects in the Western Pacific. In one instance, Winter thought, 'logically', that building a simple system to bring water to a village would be widely appreciated. What he did not realise was that the need to walk into the high island's upper watershed for water had traditionally provided an opportunity for young women and men to get together without family being present. The young men reacted to this intrusion on their culture by hacking up the pipes with machetes. In another case, PVC pipes ran across a small section of a villager's land, but did not provide the owner with a connection. The neglected stakeholder took dried coconut shells and set them on fire around the pipes.

Arranging a form of contract with communities well ahead of time for a given project is frequently helpful. However, determining who to approach, and how many commitments would constitute sufficient 'consensus', can be challenging. This is especially true if indigenous political hierarchies have become weak; if they have not become weak, simply applying Northern/Western assumptions regarding the virtues of democratic governance, and not appreciating the traditional power vested in local hierarchies, may undo plans regardless of how well intentioned, 'logical' or 'scientifically valid' to outsiders.

Chuuk State

The case of Chuuk State, FSM illuminates the RRLW issues (Figure 1). FSM is one of the last places to be settled on earth and has a physical, biogeographical, historical and cultural geography inclusive of the subcultures of the States of Yap, Chuuk, Pohnpei and Kosrae (Denoon *et al.* 1997).

The US Department of State (1996) notes the FSM land area to be 699 km^2 over four major island groups, encompassing 607 islands and stretching 2897 km east to west. Chuuk State has a land area of only 127 km^2, but is surrounded by approximately 2.5 million km^2 of water (US Department of the Interior 1997). Of its 290 islands, 40 are inhabited. Island geology and topography vary from relatively large and mountainous basalt islands to tiny low

Table 1 Population density for federated states of Micronesia: 1994 and 2000

	1994					2000				
	Total	Yap	Chuuk	Pohnpei	Kosrae	Total	Yap	Chuuk	Pohnpei	Kosrae
Population	105 506	11 178	53 319	33 692	7317	107 008	11 241	53 595	34 486	7686
Land area (km^2)	702	119	127	342	111	–	–	–	–	–
Land area (sq. miles)	271	46	49	132	43	–	–	–	–	–
Density (per km^2)	150	94	420	99	66	152	94	422	101	69
Density (per sq. mile)	389	243	1088	255	170	395	244	1094	261	179

Source: Calculated from data from the Division of Statistics, FSM (2002)

coral atolls. Weno is the location of the Chuuk airport, hosts government facilities, contains a small urban centre on approximately one-third of the island, and is one of Chuuk's 19 high volcanic islands, enclosed by a coral ring composed of 87 small and low coral islets forming a lagoon. Chuuk Lagoon, and the relatively large basalt islands left over from previous extrusions and differential weathering, are easily seen inside the coral tracing of what used to be the mouth of a volcano. For a discussion of the links between small island vulnerability and geography see Smith Jr (2008).

Islands are categorised locally into three groups. First are the 'high islands', which are volcanic and are only located in Chuuk Lagoon; second are the low coral-based 'reef islands' of Chuuk Lagoon; and third are the low coral-based 'outer islands' that exist in extreme isolation, up to approximately 14 h from Chuuk Lagoon. For 'low island' issues and geography, see Smith Jr (2003). Chuuk accounts for 50.1% of FSM's population, whereas Pohnpei, Yap, and Kosrae represent 32.2, 10.5 and 7.2%, respectively (Division of Statistics, FSM 2002) (Table 1). However, because Chuuk has a strong mariner culture and steep slopes, the population is highly concentrated along the coasts, and population pressure is greater than statistics portray. It was not until around 1880 that the resistant 'warrior culture' of Chuuk had regular contact with the European powers (Hezel 1973). This may have led to far higher population density in Chuuk than its neighbouring states, due to less contact with diseases from whalers, missionaries, etc. Population density has clear ramifications for water, sewage and land use.

Climate, water and infrastructure

Temperature varies little in this area, approximately 7° north of the equator, and relative humidity normally ranges from 55 to 100% (Hamlin and Takasaki 1996). During El Niño periods, drought can have devastating effects, but there is no true dry season. January–March brings about half the mean annual rainfall of 356 cm (Karolle 1993).

On the high islands, compacted volcanic material results in a shallow (unconfined) ground water lens (Takasaki 1989; Anthony *et al.* 1993). Thus, what occurs on the surface rapidly impacts water quality below, hence rooftop catchments are attractive. However, the research team found that shallow wells and springs dug-out by hand are often used (Plates 1–5). Thus, given the presence of livestock, it is emphasised that source water protection should be a priority. These broad characterisations apply to our study area on the island of Fefan.

Across the FSM, most housing units were built between 1988 and 2000. The only centralised and treated water is found on the western and southern sides of the island of Weno, where a couple of small hotels (re)treat the water. This system also reaches parts of Weno, where government officials live (Cowan 1980 1982). Drinking non-hotel water is not advisable. Weno also has a limited sewage collection network, but no treatment, and raw waste is piped into the lagoon just off the airport for 'mixing'. Electric power is also selectively available on Weno, but it is periodically lost due to problems at the old and small power plant.

Capacity

Environmental analysis and management capacity is poor. Major fiscal and resource constraints, combined with a physically fragmented and rugged landscape strewn across sometimes treacherous water, often make it practically impossible for environmental managers to travel to places at a distance easily achieved in most continental areas. This is one reason that simplified GIS-based desktop analysis holds promise (Jensen 2002). However, technical needs assessment, strategic purchasing and maintenance, supplies, training (over significant time, not ad hoc workshops), preparation of trainers,

Plate 1 (left) PVC drains from stream with rocks holding pipe in dug-out bed and forming a small check dam
Plate 2 (upper right) PVC drains to tank at F02
Plate 3 (lower right) PVC drains from covered spring hole at interview site F04

Plate 4 (left) Interview site F09 with separated systems
Plate 5 (right) Rooftop catchment water only for consumptive purposes in the left-hand tank, spring water for non-consumptive uses like bathing and washing clothes on the right

Plate 6 (upper left) A northeast view of Fefan from Southern Weno
Plate 7 (upper right) Northwest coast including study area of the Island of Fefan
Plate 8 (lower left) Study basin including villages of Onongoch, Fein and Fogen
Plate 9 (lower right) A study basin home

and oversight of applications in the field, are all currently lacking. For example, the Chuuk State Environmental Protection Agency had no mapping capacity (before this research) or a functioning water quality laboratory, merely one staff member located only on Weno for the entire state.

Linking objectives in a multi-scale framework

The researchers employed a 'multi-method' approach to collect and study sub-basin data. McKendrick (1999) notes that in applied environmental work, in which both scientists and non-scientists participate and data are scarce, such approaches can help to capture and combine the most relevant and diverse types of knowledge. Work took place at two scales. The first scale revolved around building Chuuk State level managerial capacity in the areas of environmental analysis, technology, water improvement strategies and environmental health outreach. The second scale focused on village/sub-basin scale analysis, low-tech and low-cost source water protection, and environmental education and outreach. Strategies were implemented at both scales simultaneously to allow lessons from the work at each scale to inform the other early enough to make meaningful adjustments.

The author delineated all basins for the first time for Chuuk (and all land cover and reef). Basins were delineated from rim to the reef in the indigenous Hawaiian Ahupua'a tradition (Save our Seas 2006). To prepare for outreach regarding waterborne diseases, local staff had to be trained in basic GIS and global positioning system (GPS) skills over several visits using local examples and photos, not just satellite imagery, which is harder for locals to

Table 2 Village water, sanitation and hygiene

A	B			C	D	E	F	G	H
	1	2	3						
F1	■							■	■
F2	■			■	■		■		■
F3	■			■	■			■	■
F4		■		■	■			■	■
F5		■		■	■			■	■
F6		■			■			■	■
F7		■			■			■	■
F8		■			■			■	■
F9			■		■				

A – primary families interviewed; B – water for drinking, cooking, food preparation, brushing (1 stream, 2 well, 3 rooftop); C – always boil water and store with a cover; D – always boil water before drinking; E – always boil water before using for food preparation; F – always boil water before brushing teeth; G – have a water-sealed toilet; H – dump household waste in a pit or near water. F1-B – untreated; F2-G – cesspool; F5-B – previously untreated; F9-H – in taro patch; fills a second tank with stream water for drought. All have battery or kerosene power. No pesticides or chemical fertilisers

interpret. Land cover for the high islands was derived from 4 m colour and 1 m panchromatic IKONOS satellite data. Landsat 7 ETM+ imagery was also used for land cover and for mapping reefs for all Chuuk State. The mapping process took approximately 1000 h, including interviewing, training and outreach.

Some studies of water quality and resource management have been conducted in Chuuk in the past, mostly on Weno (Moen), many around 25 years ago (Clayshulte and Zolan 1980; Clayshulte 1983; DeWolfe *et al.* 1991). Fontaine (1987) found unsafe water to be a primary cause of FSM's poor public health. In the FSM, more than 30% of all diseases are directly connected to inadequate access to safe water. For example, Pohnpei, Chuuk's easterly neighbour, experienced a cholera outbreak in 2000, and almost 3000 people were hospitalised, and at least 21 deaths were recorded (Khosrowpanah and Heitz 2003). In the 1980s, Chuuk experienced a cholera outbreak that the US government assisted the then 'Trust Territory' in coping with the outbreak, through the construction of rooftop catchments, although the systems subsequently fell into disrepair.

The FSM/UN group (1995) pointed out that not only is safe water important, but diseases known as 'waterwashed' diseases can be caused by a lack of water for basic hygiene and hydration. The same literature notes that hospital records reveal that 20% of patients in 1993 and 1994 had diseases potentially caused by poor water quality or insufficient water. Very high levels of total and fecal coliforms were reported in source water (Smith Jr 2003).

Island of Fefan research sub-basin

The following represents our inventory of the research sub-basin in Northwestern Fefan, within which the villages of Onnongoch, Fongen and Fein are located. The area was selected partially because it is home to Chuuk EPA staff and research team member Juilta Albert. Having a local partner from the sub-basin was essential for establishing rapport and access in this pilot study. The study area is a sub-basin with a perimeter of 4281 m and an area of 0.96 km^2 (Plates 6–9). The population lives in a mostly forested basin, with the exception of the coastal area, and economic practices include fishing and sustainable farming.

Inventory of point and non-point sources of contaminants

Our field research agenda was pursued in two stages. In stage one, we surveyed and at the same time collected GPS data for the mapping of survey locations, source water and potential contaminants. In stage two we again surveyed and collected GPS data, but in this case mapped culturally important places, consumption, and secondary and unmapped tributaries.

The surveys included 89 people across three villages in the study sub-basin. Our goal was to understand at a grassroots level the interaction between biophysical and human systems related to water, in order to ascertain the levels of vulnerability of the populations to waterborne disease. This meant researching and characterising the climate, surface flow, characteristics of the ground water lens, potential local pollutants, technologies for obtaining and storing water, and water uses. A summary of some key findings of the surveys is found in Table 2 (shaded boxes represent affirmative answers). We systematically travelled up into the basin through the forest and underbrush and across the creeks with our guide. We had a translator, but interviewees were unevenly responsive. Overall, villagers were friendly, curious and gracious, no doubt in part due to our local guide helping with introductions and our attempts to be friendly rather than having an intimidating air of the 'expert'. Sometimes an entire family wished to be interviewed, and sometimes just a representative of the family would answer questions, while others of all generations observed.

We marked waypoints utilising our GPS to map the features previously discussed. Our freeware (Minnesota Department of Natural Resources 2007) allowed us to upload an outline of the study area delineated from re-rectified old topographic maps, rectified photos and IKONOS imagery, placing this image on our GPS screens. This allowed us to know if we were conducting interviews in the correct sub-basin.

Technological hazards

It is noteworthy, that in previous studies by Delay *et al* (1989), that all wells were found to have total and fecal coliform bacteria contamination. We found pig cages next to and spanning streams, and untreated human waste in close proximity. Infectious disease, especially cholera, is a concern. Interviewees at sites F03, 04, 05, 06, 07 and 08 all recalled the cholera episodes of the 1980s which led the US to bring in groups to construct limited rooftop catchment systems. Education for local maintenance and construction, as well as for coping with growth in population, appears not to have been accounted for, so the sustainability of these systems has been jeopardised. As is evident in the case of site F08, these rooftop systems can degrade, especially in humid and salty tropical island conditions. Thus, it is important to consider whether the damaged system can introduce harmful elements to the water, especially given assumptions that such systems provide the most consistently 'safe' water (Winter 1983). At a minimum, disrepair encourages the use of less safe sources of water like streams or springs, either alone, or combined with rooftop water in tanks, creating an illusion of safe water.

Chuuk's island landscapes manifest how even well-intentioned provision of 'assistance' can lead to unsustainable technology and waste hazards. For evidence, one can witness massive abandoned water tanks, and the buried (once openly piled) tens of transformers from the power plant breaking down at Weno just uphill from root crops. Water containers must be safe to use, and the family at F03 had a 208 litre tank that was previously used for another purpose, possibly military. This deserves follow-up because of potential contamination from its former contents.

Sanitation and household waste

Sanitation varies, as interviewees F01, 03, 04, 05, 06, 07, 08 utilised 'water sealed toilets' likely connecting to the shallow water lens. Interviewee F03 represented a rare situation, as the family had a toilet inside, which is convenient, though perhaps less sanitary. At the site of F05, the mud from Super Typhoon Chataan filled in the original metal drum waste repository (not all have drums). Thus, it is worth considering whether overflow during storm events can mobilise waste products as runoff into streams and water intakes. (It seems wise to advise disconnecting PVC pipes carrying water from streams to storage tanks during and after large events until runoff diminishes.) Similar concerns exist for site F02, where the facility is an overland type of toilet, with no flushing or water seal, forming a cesspool.

Interviewee F09 had a relatively elaborate site, and utilised a water closet connected to a septic tank. Waste flows through a pipe by gravity down a mild gradient to a septic tank within about 24.4 m of a stream that passes first uphill, then curves alongside and below the tank. There is no equipment for pumping out septic tanks on Fefan, and this location is obviously problematic, especially as the tank fills up. The stream is so near the coastline that no neighbour below has PVC water intakes that will be impacted, but contact with waste while swimming in the coastal waters, or through consumption of near-shore marine products, is a concern.

Hazardous waste, including that from generators and batteries, was dumped by interviewee F05 along stream banks and covered with soil to create what were perceived as small flood control structures. This results in pollutants entering tiny PVC intake pipes in the small streams that deliver untreated water by gravity to homes below for household consumption. Consequently, efforts were made by some villagers to position intake pipes high enough into streams to reach above settlements, though not necessarily banana and taro agricultural plots.

Collection techniques

Community water collection has been altered since early times (Hunter-Anderson 1987; Winter 1987a). Techniques evolved from travelling to streams to eat and drink at the source, or to collect water to bring home, to using the trunk of a banana tree, and eventually PVC pipes, for delivery by gravity to homes. Water is gathered by pipe from streams or at springs that are at times dugout by hand and lined with rocks (for 'protection') and a removable metal cover (Plate 3). In some cases, rooftop catchments are used, but at homes such as the one at site F08, the system was broken and raw stream water has been combined with any rooftop water available. It is worth noting that Dillaha and Zolan (1985) found fecal contamination in 'many catchments' in their Micronesian survey, and thus recommended disinfection of rooftop catchment water before drinking, but found only 38% of those surveyed did so. In 1983, Winter stated that the Water and Environmental Research Institute of the Western Pacific found 25% of its samples failed fecal coliform standards.

Interviewee F09 utilised a fibreglass rooftop catchment. It contained 100% rainwater for drinking, with another concrete tank inside the house in a screened-in area that was also 100% rainwater, but in case of concerns about drought conditions it can connect to a stream-fed pipe to fill up (Van der Burg 1986). Another tank uses stream water for non-consumption uses, with the sanitary area being downhill and away from the domestic water supply. This is the best example that we encountered in the field of family and water catchment scale planning to mitigate contamination and to prepare for drought. This represents a potential model on which to build, for if all places in the study area maintained the same type of system, vulnerability from waterborne and waterwashed diseases would be reduced, and the highest quality water would be assigned efficiently to the most appropriate uses.

Interviewee F08 also utilised a system of rain and stream water, but sources were always blended. This home utilised piping from a stream, pouring water directly into a shower area with no tank, as well as into a fibreglass tank for domestic consumption. The tank also receives water from a rooftop catchment, but it is severely damaged and corroded. Thus, 'safe' water is combined with, and potentially polluted by, impaired water, resulting in a confidence that is not warranted. The tank is adjacent to the shower, and it shares a space only 1.5 m from the toilet. Here, rooftop technology has not mitigated vulnerability.

It has been observed that leaks in the delivery system are typically dealt with by merely piling relatively large rocks over holes. Some islanders made an effort to run pipes high up the stream channels, splitting them off when necessary. Yet, a leak in a pipe running down over land where animal or human waste exists allows pollution to flow directly to communities downstream from storm water events – pipes should be elevated.

Containers

Some homes had storage tanks. Around 11 000 litres of water can be stored in most concrete or fibreglass storage tanks, and some larger ones can handle up to 37 000 litres (Plate 3). It is clear that some families, such as the one at site F09, clean their tanks from time to time, but a systematic programme is lacking. F06 was a well-manicured site. The toilet was on the far side of the property, away and downstream from the point of water storage and distribution (by bucket), and the shower. This sort of positive spatial arrangement in the catchment, like that of F09, can be encouraged through education and by participation in catchment management, but the radically fractured island physical and political geography makes sharing best practices a challenge.

Any storage cooler, pot or drum needs to be made of non-toxic materials. Lids are important, and storage time is not infinite. However, because many common vector-borne diseases generally appear not to be a major threat, concerns regarding lids, location of containers inside homes, and stagnant water may not be crucial. However, filiarisis is reported, and there are anecdotal reports from Pohnpei which create uncertainty regarding the prevalence of vector-borne diseases. Recontamination through poor hygiene appears a primary threat (WHO 1998a 1998b).

Consumption

Water is not boiled before storage in larger tanks, and therefore needs to be boiled before storage in smaller containers such as pots and coolers. The surveys showed that boiling water is often not undertaken in the study area. However, interviewee F02 boils water in the preparation of sashimi, and interviewee F04 prefers to use water from the spring instead of its outside storage tank for this purpose because 'it's better'. Interviewees F01, 03 and 05 'sometimes' boil water for this purpose. Such responses reflect an uneven understanding of the basic principles of water, sanitation, hygiene and germ theory. Brushing of teeth can obviously involve swallowing water and cutting gums if there is enough irritation. However, while interviewee F09 uses rain water that is not boiled, and interviewee F02 claims to use boiled water for that purpose, a group including F01, 04, 05, 06 and 07 say they sometimes use treated water, and F08 and 03 indicate they do not. Respondents used the same sources of water for drinking, cooking, food preparation, brushing teeth and non-consumptive purposes in the majority of cases, be it from a stream, spring or rooftop source. The safest water is generally not separated and saved for meeting basic consumption needs. An exception to this assertion, family F09 uses its intelligent, but low-tech and low-cost arrangement for reducing vulnerability by conserving rainwater for drinking, cooking, food preparation and brushing teeth, while spring water is used for bathing and washing clothes. With an annual precipitation of 3500 mm of rain, reasonably distributed in non-drought years, the system functions well. However, interviewee F01 served as an example at the opposite extreme, as the respondents said they only 'sometimes' boil their water before drinking, and not for other purposes.

Treatment techniques in the study area consist only of boiling. To our knowledge there is no use made of chlorination, iodine, solar or filter using local sand. However, tanks are cleaned in some cases 'when they need it'. It should not be assumed that full-time chlorination would be appropriate until the possible detrimental effects of trihalomethanes, caused by using chlorine in turbid stream water, are explored. However, it seems reasonable to provide tank cleaning and hygiene products, as necessary at a low cost, and to a large portion of the population, as well as disinfection tablets for emergencies. To examine techniques for water collection, storage and distribution and suggested methodologies for the islands, see Stephenson and Kurashina (1983), Winter and McCreary (1985), Winter (1986 1987b), Falkland (1990), and the Water and Environmental Research Institute of the Western Pacific (2004).

Outreach

Given the plethora of complex and varied on-the-ground experiences of these RRLW islanders, a simple and flexible set of guidelines regarding risk in relation to potential sources of water, and cross-listed by pollutant, is useful for stakeholders. The outreach we provided was based upon our family-scale surveys, local and scientific knowledge, and accessible technology. It is also based on observed sources of water and potential contamination, and of island systems used to collect, treat and store water for consumption. Our outreach details the best local sources and treatment options based on a realistic evaluation of the resources present, and makes clear which choices are best by categorising in simple language what is risky, least risky, etc. (Table 3).

The idea is to illuminate a simple set of sustainable options that are flexible to the diverse set of circumstances on the ground, rather than insisting unrealistically that everyone have the 'best' science and technology. In this way, each resident in the relatively unique RRLW small island setting can, in theory, have an equal opportunity, and no one is neglected through focusing on only those who can afford the superior technology. In addition, this approach takes into account the on-the-ground experiences of villagers, making space for their local voices, perceptions and knowledge, and adding to it, rather than simply replacing it with outside expertise. The research team included with this flexible set of community guidelines, a set of posters and brochures created in both Chuukese and English for schools and community workshops (Gundry and Heberlein 1984). For those unfamiliar with how to conduct education and workshops, Niedermeyer (1992) offers an accessible generic methodology for critiquing such tasks.

Historically, communities are expected to adapt to technology, not the other way around, but 'Big Science' and technology may be out of place in these settings, likely not matching local agendas well, and, if nothing else, they can be intimidating to locals (Noble 1983; Bazin 1986; Esteva 1992). Schumacher (1999) first introduced much of the Northern world to the concept that small, local and sustainable technologies and production are especially worth nurturing. Appropriate technologies, cartoons, games, pictures (for those not literate) and posters do not represent 'cutting-edge' science, but they may be more appropriate for improving conditions in such settings (Winter and Campbell 1995; Mejia-restrepo 2002).

The first poster we produced is a general land–water and environmental health poster created for use by local Chuuk EPA and civil society team members. It contains general suggestions for land management to guard environmental health, and flexible guidelines for the treatment, storage and consumption of water. A shared basin identity is stressed (Neville 1999; Sanger 1997). A second poster was created specifically for the study community. It combines basin-oriented education, pictures of local places and interviewees, recommended land management practices, and flexible guidelines for the treatment, storage and consumption of water. The message is positive, avoiding long 'do not do' lists.

The research team used our outputs to conduct workshops in communities, and for meetings with both students and teachers. Laminated versions of the materials were hung in public places, while non-laminated versions were donated after workshops for indoor use. The team also presented our work to the Governor, who has displayed them in the main waiting room to his offices to share them with other officials. Producing these outreach materials improved Chuuk EPA mapping and basin analysis capacity by enhancing hardware, software, data and human skill-sets; improved the ability to turn this technical capacity into public outreach regarding water and health for villages; enriched communities and schools with environmental education support; and improved people's understanding of the importance of spatial analysis in such projects.

Discussion

The fieldwork reveals a need for a greater focus in RRLW small islands on sub-basin or village-scale spatial analysis capacity, environmental health education, participatory catchment-level source water protection, and the construction and maintenance of rooftop catchments and other 'appropriate technologies'. Given local constraints in such settings, it may be possible to address some of the factors which make populations vulnerable by using low-tech and low-cost methods – but only through participatory methods will changes be sustainable, as federal

Table 3 Generalised source water risk and local options

Techniques	Major local pollutants and level of vulnerability to them				
	Animal waste	Detergent	Dirt/erosion[a]	Hazardous household waste[a]	Human waste
1. Rooftop catchment water only, with a clean system and container	Almost no risk	No risk	No risk	No risk if system is clean	Almost no risk
When boiled and stored and served in a clean container	No risk	No risk	No risk	No risk if system is clean	No risk
2. Rooftop catchment combined with spring water in the same tank	Sometimes risky	Little risk	Little risk	Little risk	Sometimes risky
When boiled and stored and served in a clean container	No risk	Little risk	No risk	Little risk	No risk
3. Rooftop catchment combined with stream water in the same tank	Risky	Risky	Risky	Risky	Risky
When boiled and stored and served in a clean container	No risk	Risky	No risk	Risky	No risk
4. PVC pipe bringing water from spring with a vegetation buffer and cover	Sometimes risky	Little risk	Little risk	Little risk	Sometimes risky
When boiled and stored and served in a clean container	No risk	Little risk	No risk	Little risk	No risk
5. PVC pipe bringing water from streams	Risky	Risky	Risky	Risky	Risky
When boiled and stored and served in a clean container	No risk	Risky	No risk	Risky	No risk
6. Drinking water at springs directly without any treatment	Sometimes risky	Little risk	Little risk	Little risk[c]	Risky
7. Drinking water at streams directly without any treatment	Extremely risky	Risky	Very risky	Risky	Extremely risky[d,e]

[a]Boiling will kill germs in dirt, but leave the soil itself, but it is difficult to predict the effect of boiling on reducing a variety of household wastes and detergent.
[b]Under the ‘animal’ and ‘human’ waste categories reduced travel time for pathogenic microorganisms is assumed to increase risk; this is in comparison to water that is piped and then stored before use.
[c]Springs are assumed to be less vulnerable to the second, third and fourth categories due to no ‘upstream’ use and a vegetative buffer (though the freshwater lens is thin).
[d]No technique is safe and avoids risk if good hygiene such as washing dirty hands with soap and water is not practiced when handling water before using it, and the container it is placed in must be clean.
[e]Boiling all water for drinking, cooking, food preparation and brushing teeth, even rooftop catchment water, is the safest strategy, as it will kill pathogenic microorganisms in the distribution system and storage tank.

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and state legislation and regulation has little influence over village scale governance. This means significant time has to be spent at the appropriate scales building positive relationships, not just proving technologies or developing methods, and this also entails a strong understanding of small island culture and its relatively unique human and physical geographic interface.

Focusing education on the impacts of different types of land use practices should support environmental health, and fostering understanding of how island basins function, and how pollution moves through them, impacting ecology and vulnerability, is key. It is also important to remember that small island and continental hydrogeology differ. From the contact lens-like shape of low island aquifers lying on top of salt water, to the shallow lens in compacted basalt formations described earlier, traditional continental models simply do not apply.

Another area worth pursuing is the alteration of spatial arrangements between pollutants (i.e. dumps, pigs, toilets), and places where water is collected, within a village-scale sub-basin management framework. The emphasis should be to reduce contact between source water and sources of pollution (as interviewee F09 did) in a way that requires significant family level planning and participation, but little in terms of finances. This approach should be combined with a basic understanding of when and how to capture and treat water for drinking, cooking, food preparation and brushing teeth, as well as rooftop catchment repair and hygienic practices to prevent contamination. In this way, community vulnerability could be reduced significantly in a culturally, materially and economically sustainable way. Such a holistic approach is best supported by interdisciplinary and intercultural medium- to long-term partnerships, and reciprocating flows of knowledge across multiple scales. Local government and NGOs need tools and the will to coordinate this process, to do fundamental analysis, and to focus on outreach materials and fostering partnerships, rather than to do 'science' *per se*. This way, participatory sub-basin management can be emphasised. If not treated as a means unto itself, GIS may help in this regard. Because of these needs, we developed the first GIS/GPS system and training for Chuuk to be tailored to address the issues above (Britton 2000; Craig *et al*. 2002; Kyem 2004). With the new layers of data and skill sets, it is possible to incorporate stakeholder issues and knowledge into the process of building capacity for state-scale spatial analysis of environmental health, and for outreach to villages. Of course, if there is little internal motivation to maintain such a programme once researchers are gone and external funding is spent, then the system will not be sustained.

It is important to work simultaneously at multiple scales in such settings. This is done in order to ensure that, from very early stages, governmental and village capacity building inform one another's development, and that the motivation exists because efforts are geared towards local concerns and missions. Winter (1996) makes an interesting point when he states that of all the outside institutions to come to Chuuk, only the church has maintained its presence. Thus, perhaps working through the church has potential in areas such as training to construct and maintain rooftop catchments or participatory mapping.

Effective analysis of the nexus of geography–hazards–vulnerability, as it relates to water resource development in the less-wealthy world, requires a multidisciplinary approach. Geographers have a history of doing interdisciplinary work across cultures. Gilbert White's classic literature on water and sanitation, *Drawers of water*, tackled issues related to the research discussed here decades ago, albeit without incorporating small island dimensions (White, Bradley and White 1972; White and Bradley 2001). White's work highlighted the daily struggles of people in difficult conditions as they tried to acquire fresh water and reduce vulnerability, and contextualised these struggles in their particular physical environment. Such an approach will likely hold more relevance for RRLW small island communities than the 'hot' modern water development debates regarding privatisation.

The conditions in Chuuk do not exactly mirror every RRLW small island community, and there are differences between low and high islands. Nevertheless, this research underscores that differences in scale and distance between such tropical small islands and continental regions have broad impacts. Impacts are observed in the areas of perception, flows of communication and knowledge, hydrology and technology. Researchers should be aware of these issues when they work in such regions. Many researchers come from continental areas, and are trained in how to use models that function well at relatively large scales, such as the river basin, but not smaller spaces, easily walked around, connected to reefs, and surrounded by ocean. Additionally, researchers may come to the field with assumptions about the hierarchy of law and policy – with the nation dominating the state, the state dominating the local, etc. This social organisation, as has been demonstrated here, is turned upside down in many small island societies. In addition, in places such as the US, much effort is placed on translating science into national and state-scale policy – again, an ineffective resolution at which to aim one's efforts in RRLW small islands.

Conventional wisdom about the same 'public' always attending public participation meetings is compounded in such settings (Paulson 1999). This is due to the fact that in places such as Chuuk State, the vast majority of persons have not visited most of even the physically close surrounding islands. Just because they are close on a map, or are close by continental standards, does not make them close in practice, nor do data travel between islands any easier than people, especially when there is no electricity, internet clearinghouse mechanism, university or highly globalised economy.

In terms of technological regimes, two major sub-themes emerge from this research that have global relevance. First, there is a need to consider how to define what makes for a 'sustainable' technology. The second issue focuses on the idea of centralised technologies. Most people from continental areas are trained to develop centralised systems. A major reason for this is the economy of scale benefits of a larger facility, such as a water treatment plant. However, the vision of one treatment plant distributing water in pipes stretched across churning ocean should suffice to manifest the ill-fit of many centralised systems to fragmented island geography. Scale, fragmentation and remoteness impact on what is 'appropriate technology', and assumptions of what is reasonable to expect in terms of training, 'trickle-down' of knowledge and self-sufficiency are also challenged.

When researchers engage in small island research, they must significantly adapt or throw out many of their familiar geophysical and technological models and, at the same time, develop multi-scale knowledge of island culture, or risk the implementation of inappropriate models and technologies, wasteful programmes and inconsequential policy. When working in a small island society, the reality is that one will engage with many people living surprisingly separate village and island-oriented lives – communities with great economic and geophysical fragmentation, and perhaps different languages, with some members more marginalised than others. In that sense, even with small populations and small landmasses, diversity is the rule, even if everything looks the same to the outsider.

When it comes to researchers doing hazards work, the very structure of grants within which persons in academia must often work can force researchers to create 'outputs' before strong partnerships can be formed. Yet, strong partnerships need to be built first, in order to overcome key barriers, and so understanding can be garnered about potential pitfalls in a given setting. Regardless of the particular type of research project or specific island, researchers must guard against importing continental knowledge without paying close attention to the relatively unique biophysical, political and economic scales and interactions associated with RRLW small islands. In this regard, it can be important to identify local NGOs and learn from them, rather than have outside researchers constantly 'reinventing the wheel' – which can tire local partners and is inefficient.

The *United Nations Decade of Education for Sustainable Development* was launched in 2005. In the small island settings discussed here, we found that it is essential that environmental education for behaviour modification, not simply cutting-edge technology, provide the foundation for improving access to safe drinking water. However, education should not be a one-way flow from researcher to villager. Rather, researchers must be open to learning about, and adapting their methods to, the unique geographies of such small island communities. Small island networks, such as the 'Small Island Developing States Network', and the UN's 'South–South Cooperation' groups may help to extend understanding of such settings, and also to provide venues for evaluating appropriate technologies. Technologies moving from South to South, such as the sari material touted by Huq *et al.* (1996) as an effective simple filtration method to mitigate cholera in South Asia, may sometimes hold more promise than expensive Northern high technologies, and perhaps even create useful markets. This is an example of a technology that would be light to ship, simple to use in a decentralised manner, easy to clean by hanging in the sun, and simple to dispose of without hazardous waste.

Creative non-traditional thinking, combined with indigenous knowledge, and enhanced by sharing of best global South and island practices, can perhaps be integrated with appropriate Northern science and technology for beneficial and sustainable results – but only if applications are socially and geographically contextualised and partnerships are healthy. Such an endeavour is a daunting challenge, but it is also an opportunity, as small islands in the Western Pacific, such as those that comprise Chuuk, offer remarkable opportunities to comprehend the condition of similar RRLW small island communities around the world.

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