

Stanford University

Program on Water, Health and Development

Promoting safe, sustainable water supply and
sanitation for developing countries



WOODS INSTITUTE
FOR THE ENVIRONMENT
STANFORD UNIVERSITY

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THE STANFORD PROGRAM ON WATER, HEALTH AND DEVELOPMENT

Research Prospectus Executive Summary
February 2010

Executive summary

In the United States and other developed countries, virtually all households have access to high quality water supply and sewerage services, typically through individual connections to piped networks. By contrast, among developing countries in Asia and Africa, two out of every ten people have no improved water supply service, and half of the population lacks access to even the most basic sanitation services. The high cost of installing modern water and sewer networks means that efforts to expand access for these populations will rely principally on “non-networked” options, such as shared borewells and household latrines.

A variety of reliable and low-cost non-networked water and sanitation technologies exist, but their widespread use creates challenges for environmental, institutional, and public health planning from the household to the watershed scale. Such challenges include tracking and regulating usage and pollution of ground and surface waters across a large number of decentralized service points; identifying viable financing mechanisms for construction, operation and maintenance of infrastructure; creating and enforcing reasonable standards for service providers; and motivating household behavior change and investment in water, sanitation, and hygiene. These management challenges, in turn, are underpinned by fundamental knowledge gaps regarding the environmental, economic, and health impacts of large-scale, non-networked water supply and sanitation service delivery.

Applied research has the potential to address these knowledge gaps and identify solutions to these challenges. The proposed Stanford Program on Water, Health and Development will address pressing research needs related to non-networked water supply and sanitation service delivery; establish long-term partnerships such that outputs of research are translated into practice; and offer unique training and learning opportunities for faculty and students at Stanford and partner institutions.

The proposed Program will initiate activities in Cambodia, Mozambique, and Tanzania as first-stage locations, both because of the pressing need for progress in water, sanitation, and development, and also because of the strong partnerships that exist between Stanford faculty and collaborators in these countries. In Cambodia, Program researchers will work with partners to identify approaches for serving non-networked populations who are at risk of arsenic poisoning. In Mozambique, the Program and our collaborators will rigorously evaluate the impacts of a policy experiment to legalize water resale to non-networked populations. In Tanzania, researchers will investigate the changes in household water management and hygiene needed to realize health benefits of our government partners’ investments in community borewells. In each case, multi-scale, multi-disciplinary research is envisioned that has direct bearing on pressing environmental, health, and economic development policy debates.

Research can only make “real world” impact, however, if it is linked to decision-making and policy formulation. The proposed Program is premised on the belief that creating partnerships, and not simply

pursuing projects, is essential to have an impact on critical water and sanitation challenges in Asia and Africa. Initially we will build upon existing networks between Stanford faculty and government agencies, international development agencies, nongovernmental organizations (NGOs), and research institutions operating in Cambodia, Mozambique, and Tanzania so as to link research, training, and policy activities within each country program. At the same time, the Program will actively seek to disseminate research outputs across Asia and sub-Saharan Africa, where three quarters of those lacking access to improved water supply and basic sanitation live. Over time, the Program will scale out to establish new country partnerships in both regions.

Along with executing cutting-edge research that delivers impacts on the ground in Asia and Africa, the proposed Program will offer unique educational opportunities for Stanford students across a number of schools and departments. New course offerings on water, health and development will be offered by Program faculty, and a weekly seminar will engage a broad set of faculty and students both at Stanford and in other universities and research institutions. Stanford students will also have the opportunity to participate in summer fieldwork in Asia and Africa, reinforcing and applying their academic training alongside partners in Program field sites. At the same time, through collaborative research the Program will also build indigenous research capacity, thereby providing additional value and impact.

Despite its enormous capacity for leadership in the field of water, health and development, Stanford has been conspicuously absent from this arena. Establishment of the proposed Program will change that. Indeed, it will establish a new model for research-practice partnerships that links world class research with decision-making, provides unique training and learning opportunities, and improves the lives of people in some of the world's poorest countries.

THE STANFORD PROGRAM ON WATER, HEALTH & DEVELOPMENT

A research prospectus to the Woods Institute for the Environment
August 2010

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Vision

The Stanford Program on Water and Development will work with partners in low- and middle-income countries of Asia and Africa to (1) strengthen the scientific basis for decision-making in the water and sanitation sector, particularly with reference to non-networked populations, (2) enhance capacity within developing countries for sustainable water and wastewater management, (3) provide unique training and learning opportunities for faculty and students at Stanford and partner universities, and (4) improve the health and well-being of households in some of the world's poorest countries.

Funding request

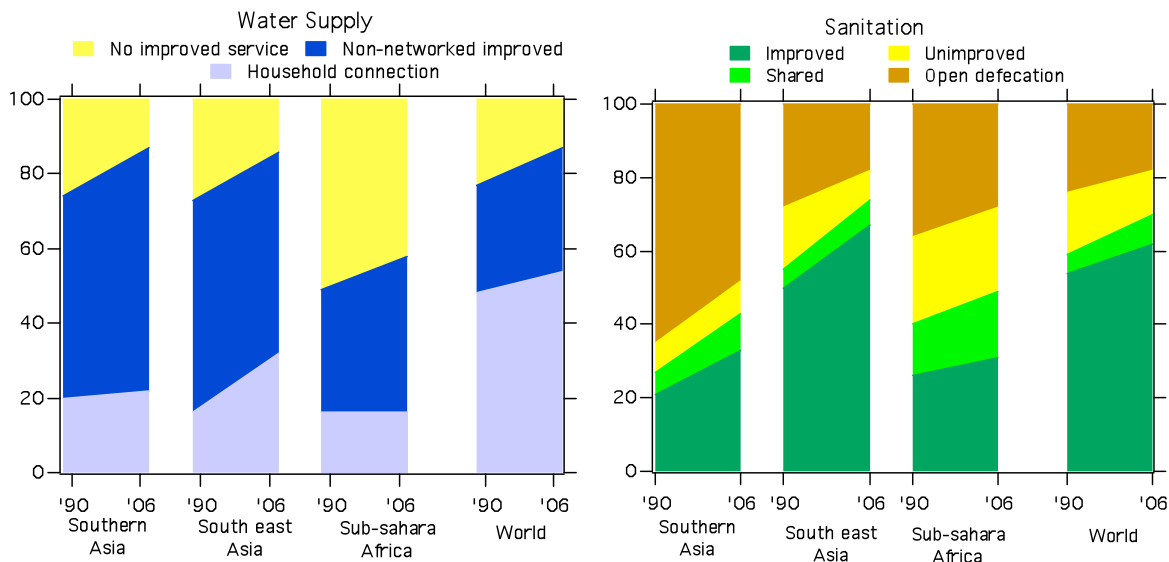
We seek support in the amount of \$2,723,150 over three years to launch the Program. These funds will be used to support a Program Director, two Postdoctoral Scholars, four graduate students (all Stanford affiliated); establish research-practice partnerships in at least three countries; enable participation of faculty and students from Asian and African universities in Program activities; carry out data collection and analysis for country-level research projects; engage with local communities, national policy-makers, donors, and academic audiences to share research outcomes and implications; and cover travel costs. Within this time frame we will solidify partnerships with in-country collaborators, execute "stage 1" research projects involving both Stanford and partner organization faculty and students, and hold regional workshops to disseminate learning to other countries, and to expand our partnerships and activities.

Motivation

Fresh water resources are central to the well being and economic development of populations around the world. The pattern and pace of development across the globe has been fundamentally shaped by the availability of fresh water for human needs. Throughout the 20th century, investments in large infrastructure projects moved water to the places where people wanted it for domestic, industrial, agricultural, and waste removal purposes. This "engineering era" in water supported the growth of the world's population from 1.6 to 6 billion people, as well as economic development that raised incomes, life expectancy, and quality of life around the world.

It is clear, however, that the 20th century approach to freshwater development has not yielded the same kind of success in low- and middle-income countries as compared to industrialized nations. Hundreds of millions of people still lack access to improved water supply, and more than 2.5 billion are without sanitation services, in less developed countries. Whereas the percentage of people in the developing world with access to an improved water source has gradually increased over the past 20 years (Figure 1), most of these gains have taken the form of shared point sources, such as taps, boreholes, and wells that are "non-networked"; *i.e.*, not connected to conventional pipe networks delivering water to households. Although 87% of the world's population was classified as having access to improved water supply services in 2006 by the World Health Organization (WHO), only 54% had piped connections in their homes or yards (WHO, 2008). Today almost 2.2 billion people obtain water for their drinking, cooking, bathing and washing needs from shared point sources.

Figure 1: Access to networked, non-networked water and sanitation services, by year and world region



Source: World Health Organization (2008)

With respect to sanitation, progress in extending access in developing countries has been much slower over the past three decades. In fact, construction of new facilities has barely kept up with population growth. In 2006, 38% of the global population lacked access to even the most basic form of sanitation services. In addition, more than 95% of new construction for sanitation services in low- and middle-income countries involves "on site" facilities such as pit latrines, rather than conventional sewer networks and sewage treatment plants. In short, almost all of the new construction of sanitation facilities in developing countries has been non-networked.

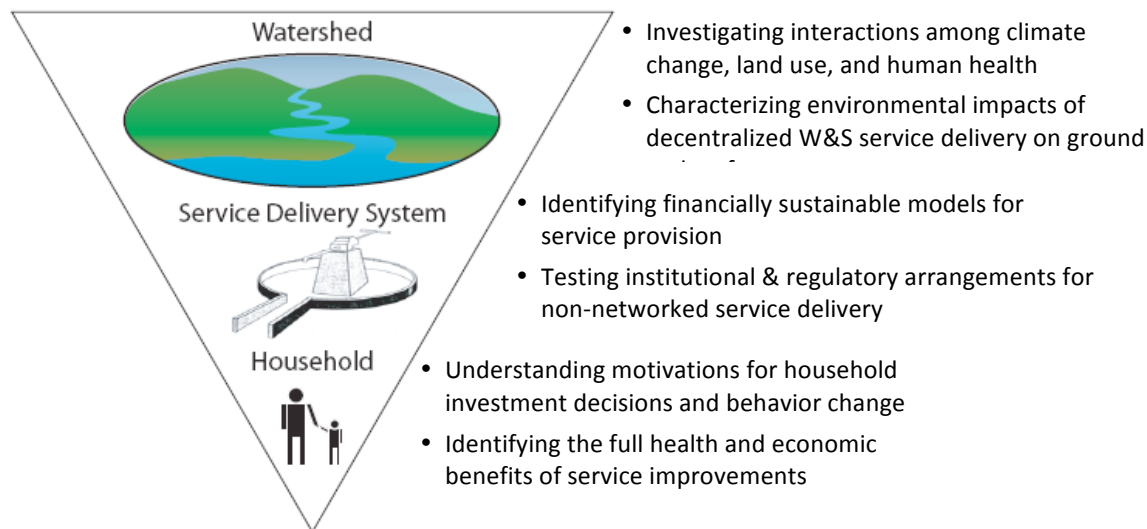
Such non-networked water supply and sanitation service options are common in developing countries because, it is commonly argued, they represent lower-cost strategies for providing water supply to the unserved. It is true that construction costs of a piped water system typically exceed those of multiple, shared point sources, and that conventional sewer networks are vastly more expensive to install as compared to simple pit latrines. Little is known, however, about the full costs and benefits of networked *versus* non-networked options. The full costs and benefits of these systems must account for human and

ecosystem health impacts, time savings, income generation and poverty alleviation, women’s empowerment, and system sustainability (e.g., averted rehabilitation costs). The proposed Stanford Program on Water, Health and Development seeks to improve the evidence base for decision-makers regarding these costs and benefits, so as to make the best use of limited resources.

Non-networked services also present a number of unique challenges within the water and sanitation sector, and rigorous research could make substantial contributions to addressing them in the following ways (see also Figure 2):

- *Identifying low-cost investments that realize substantial health benefits.* Whereas the health impacts of networked water supply and sewerage have been consistently documented (e.g., Cutler and Miller, 2006; Galiani *et al.*, 2007), the evidence regarding health effects of non-networked services is decidedly mixed (Fewtrell *et al.*, 2004). For example, even if shared points deliver relatively high quality water, they are often located at some distance from users’ homes (up to one kilometer by the WHO’s definition of “access”). Water can become contaminated during transport and storage, as demonstrated in numerous field trials (Faubion 1994, Han *et al.* 1989, Kittayapong *et al.* 1993, Quick *et al.* 1993). Also, households that rely on point sources use much less water per person each day, which can result in limited water availability for personal hygiene. As a result, researchers have found health improvements following non-networked water and sanitation improvements to be highly variable, ranging from none to substantial (e.g., Zwane and Kremer, 2007; Fewtrell *et al.*, *op cit.*). The key question is thus not whether water and sanitation service improvements are associated with better health, but rather, for a given setting what interventions will yield the majority of the possible health gains for the lowest total cost.

Figure 2: Research needs for improved sustainability, effectiveness of non-networked water supply and sanitation service delivery



- *Determining drivers of household behavioral change.* It is also the case that many of the health gains associated with non-networked water supply and sanitation require not only infrastructural improvements, but also sustained behavior change and/or investment on the part of users, e.g., safe water storage, good hand hygiene, or private expenditure on sanitation facilities. (Many efforts to develop new water and sanitation technologies for developing countries overlook this critical fact.)

A solid understanding of the drivers of household behavior change and decision-making are thus critical to effective water and sanitation planning and policy development.

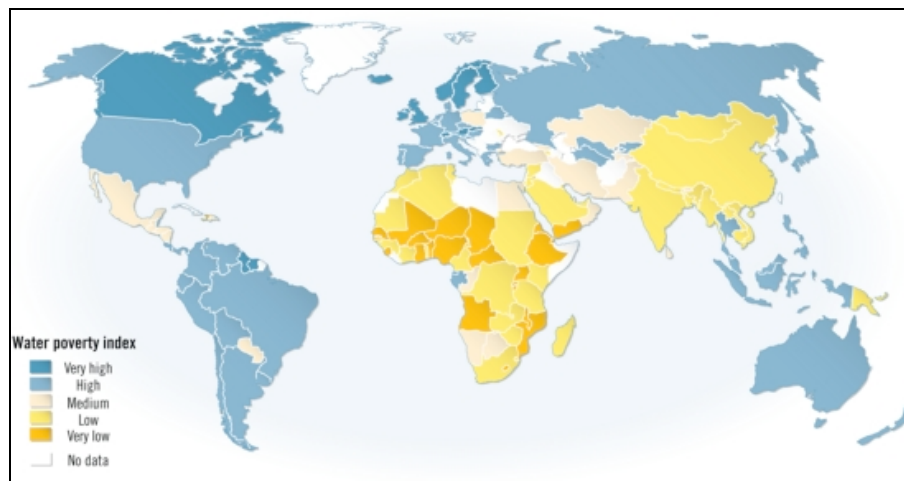
- *Regulating non-networked service providers.* Regulation of non-networked water and sanitation services is extremely challenging. Monitoring the quality of water from a large number of point sources, or compliance of on-site sanitation facilities with public health codes, requires resources and institutional capacity that are typically lacking in developing countries. Unlike piped water and sewer networks, which are generally the responsibility of public agencies, non-networked service delivery is often carried out by a diverse set of actors, many of whom are in the "informal sector," and this further complicates the regulatory burden. At the same time, the economics of water and sanitation service provision, along with political sensitivities regarding involvement of private-sector providers, translate into limited opportunities for using competitive pressures to regulate the quality and price of services.
- *Financing non-networked service delivery.* Challenges persist regarding the financing of non-networked water supply and sanitation. Precisely because such services are designed to be low cost, they are often perceived by households as not fully meeting their families' needs. Users are often unwilling to pay the fees needed to cover provision costs, threatening system sustainability. Research that assesses the costs and effectiveness of alternative financing mechanisms—including targeted subsidies, micro-credit, and private capital investment—would make a valuable contribution toward improving financial viability of non-networked services.
- *Minimizing adverse environmental effects.* Because non-networked water and sanitation options are highly decentralized and often poorly regulated, the full extent of users' environmental impacts is often poorly understood. The political imperative to ensure access to services in the short term often results in localized over-exploitation of groundwater resources, as well as the contamination of freshwater resources with domestic wastes. Multi-scale modeling and analysis can help illuminate these spillover effects, and can identify strategies to minimize negative impacts.
- *Planning for service delivery in a changing climate.* It is generally understood that one of the principal mechanisms by which global climate change will impact human well-being is *via* the water cycle. Broad impacts of climate change on precipitation will be felt most acutely in the agricultural sector, which claims the greatest share of fresh water. At the same time, to the extent that climate change increases the frequency of extreme weather events in the tropics, it is important to understand what kinds of investments will be needed to reduce vulnerability of water supply and sanitation service systems so as to reduce risks to human health.

Immense need, and opportunities for major impact

Three out of every four persons lacking access to improved water supply and basic sanitation live in South/Southeast Asia or sub-Saharan Africa. Among those who do have improved services in these regions, the majority are not connected to a water or sewer network. Three quarters of those with improved water supply use point sources; 90% of those considered to have access to sanitation have on-site facilities. Per-capita freshwater availability varies across both regions, yet countries in these areas consistently rate among the lowest values for the Water Poverty Index (WPI), a measure of the

aggregate impact of physical water scarcity and inadequate water provision on human populations (Figure 3).¹

Figure 3: Water poverty index, 2002



Water poverty index, by country in 2002. (2006). In *UNEP/GRID-Arendal Maps and Graphics Library*. Retrieved 20:55, May 8, 2009 from <http://maps.grida.no/go/graphic/water-poverty-index-by-country-in-2002>.

Program partner sites

We have selected Cambodia, Mozambique, and Tanzania as first-stage locations for our work both because of the pressing need for progress in water, sanitation, and development, and also because of the strong partnerships that exist between Stanford faculty and collaborators in these countries. Within Asia, the proposed Stanford Program on Water, Health and Development will initially focus our efforts on research to support the development of sustainable, cost-effective water supply approaches in Cambodia. Owing to 35 years of civil war, Cambodia is one of the least developed countries in the region (Table 1). Finally stabilizing in 1998, Cambodia has now begun a period of rapid development and land use change, intensification of farming, expansion of peri-urban areas, and urban growth. Given the limited investment in water supply infrastructure in the country, Stanford thus has an historic opportunity to help shape the course of water services development in Cambodia toward more effective and sustainable outcomes.

In Africa, the proposed Program will begin work with partners in Mozambique and Tanzania, two countries with some of the lowest levels of human development in the world. Like Cambodia, Mozambique is a post-conflict state whose current rate of economic and demographic transformation provides unique opportunities to shape policy development in the water sector toward more sustainable outcomes. Based on our interactions with key leaders in the Mozambican water sector, it is clear that they have a strong interest in both experimentation and evidence-based policy development, which creates openings for collaborative work with Stanford researchers.

¹ The WPI score is a number between 0 and 100, where a low score indicates water poverty and a high score indicates good water provision. The index was devised through an interdisciplinary approach that considers the diverse factors that affect water resource management, including natural resource endowment, infrastructure stocks, institutional capacity, user demand, and environmental requirements. For more information, see Natural Environment Research Council, Centre for Ecology and Hydrology. 2002. *The Water Poverty Index: International Comparisons*. Available on-line at: <http://www.nerc-wallingford.ac.uk/research/WPI/images/wdpaper.pdf>. Wallingford: Centre for Ecology and Hydrology.

Table 1: Focal countries for the Stanford Program on Water, Health and Development

	Cambodia	Mozambique	Tanzania
UN Human Development Index, 2009: Country score & global ranking among 179 countries	0.575 Rank: 136 th	0.366 Rank: 175 th	0.503 Rank: 152 nd
Per-capita GDP, 2009: US\$ & global ranking among 171 countries	\$818 Rank: 149 th	\$521 Rank: 157 th	\$465 Rank: 161 st
Infant / child mortality per 1000 live births, 2006: Rate & global ranking among 195 countries	89.4 / 1000 Rank: 150 th	118.4 / 1000 Rank: 164 th	163.7 / 1000 Rank: 176 th
Share of population with access to improved water supply, 2006	65%	55%	42%
Share of population with access to basic sanitation, 2006	28%	33%	31%

By contrast, Tanzania is a relatively stable country in the sub-Saharan region, with persistent challenges in expanding access to basic water and sanitation services. The recent election of a former Minister of Water & Irrigation to the office of President of Tanzania creates an unprecedented historical opportunity for the region. His Excellency Jakaya Kikwete’s highly publicized personal commitment to reducing infant and child mortality in Tanzania, along with his appreciation of the links between water, sanitation, and health, creates a unique opportunity to secure support for our research-practice collaboration at the highest levels of government.

In sum, our selection of Cambodia, Mozambique, and Tanzania as the first focal countries in the Program on Water, Health and Development is strategic in several respects. The Program will seek to tackle pressing water issues in some of the most resource-constrained countries on earth, making outputs from the work relevant to a large number of developing nations facing similar challenges. The three countries allow us to capitalize on existing networks while also fostering additional partnerships with a diverse set of collaborators. Finally, this set of countries affords the Program opportunities for comparative research, both across Asia and Africa and among countries of each region with different sociopolitical contexts.

Unique features of the proposed Program

Several universities in the U.S. have recently established, or are in the process of establishing, some form of a “water center” that includes work in the developing world. The most active U.S.-based water program with such a focus is the Center for Global Safe Water co-hosted by Emory, Georgia Tech, and the Center for Disease Control (CDC). Other water centers in the U.S. include U.C. Berkeley’s Water Center, University of Oklahoma’s WaTER Center, Harvard Center for International Development, Columbia University’s Water Center, John Hopkins University’s Center for Water and Health, and MIT’s ‘Safe Water for 1 Billion People’ initiative. In Western Europe, several universities have longer-standing centers that mesh research and practice in the field of water, sanitation and hygiene. The best known of these are the Hygiene Center at the London School of Tropical Hygiene and Medicine (LSTHM), Loughborough (UK) University’s Water Engineering and Development Center, Cranfield University’s Center for Water Science, and ETH Zurich’s North-South Centre.

Most of these water centers emphasize water and sanitation technology development. Several (*e.g.*, MIT, Berkeley) are focused on point-of-use water treatment devices for use at the household level. Others (*e.g.*, Emory) are developing new composting toilet designs. A few (*e.g.*, Georgia Tech, Cranfield)

are involved with the construction of large-scale infrastructure. Only the Hygiene Center (LSTHM) has an explicit focus on household decision-making and behavior. Loughborough is perhaps the group with the most experience in capacity building within developing countries, principally through degree and professional training programs.

Stanford, despite its enormous capacity for work in this area, has been conspicuously absent from this arena, but establishment of the proposed Program on Water, Health and Development will change that. Indeed, it will establish Stanford's contributions as being unique in the following four critical respects:

- 1) *Non-networked populations.* The proposed Program is unique in its explicit focus on non-networked populations in Asia and Africa.
- 2) *Research at multiple scales.* Research carried out within the Program will span and integrate learning from the household to the watershed scale, such that linkages between interventions and processes across these scales become a focus of study rather than being assumed away.
- 3) *Long-term partnerships with key local institutions.* The Program will forge linkages to planning and policy development through long-term research-practice partnerships in a manageable number of locations.
- 4) *Education and capacity building.* The program will also include in-country capacity building for research and practice among its goals, thereby providing additional value and impact. It will also provide unique learning opportunities for undergraduates and graduate students both at Stanford and in the countries in which the program operates.

Partnerships, not projects

The philosophy underlying the proposed Program's approach to research-practice partnerships deserves some elaboration, as we believe it is quite rare among university-based water research centers. The water and sanitation sector in developing countries is riddled with case studies of technical and institutional innovations that remain "islands of success" instead of realizing substantial impact at scale. The explanation for this limited scaling is rooted in the same reason that such innovations work in the first place—they are implemented in isolated, highly controlled settings that are disconnected from mainstream water policy and planning institutions and activities. In contrast, we have been deliberate in engaging fully with those policy and planning institutions and activities. Indeed, we view one of the most important keys to success for the proposed program as the establishment of meaningful and long-term collaborations with research and practice organizations in the developing world, particularly those linked to policy formulation. We view this strategy as being essential to avoiding project-by-project approaches that fail to achieve impact either in the long term or at scale.

Within the three first-stage Program sites, Stanford faculty have partners in universities, government agencies, donor organizations, and NGOs who have expressed their enthusiasm for working together on the kind of research-practice collaboration described in this proposal (Table 2). Our linkages with senior government officials in Cambodia, Mozambique, and Tanzania is another critical element of the Program, providing the opportunity not merely to influence policy development but to have architects of water sector and economic development policy personally engaged in an iterative dialogue with Stanford researchers. Our connections with the World Bank Group and United Nations agencies bring to the proposed Program on Water, Health and Development the influence of the international donor community's "thought leaders" in water. Our collaborations with engineering, planning, and public health departments in the universities of these countries enhance our ability to devise solutions that are

appropriate and sustainable within the local context. Moreover, such partnerships afford Stanford the opportunity to deliver another important type of impact, namely the strengthening of research capacity within the developing world.

Table 2: Existing research and practice partners in Cambodia, Mozambique, and Tanzania

	Cambodia / SE Asia	Mozambique	Tanzania
Universities & Research institutes	Royal University of Phnom Penh Bangladesh University of Engineering and Technology Independent University of Bangladesh An Giang University (Vietnam)	Eduardo Mondlane University (faculties of engineering and economics)	Muhimbili University of Health & Allied Sciences University of Dar es Salaam Ardhi University Ifakara Health Institute
Government agencies	Ministry of Rural Development	Direcção Nacional de Águas (national water agency) Águas de Moçambique (W&S utility) Conselho de Regulação do Abastecimento de Água (regulatory council)	Office of the President Ministry of Health District Commissioner’s office, Ilala and Kinondoni Dar es Salaam Water Supply & Sanitation Authority
Donor organizations	World Bank Water & Sanitation Program United Nations Childrens’ Fund (UNICEF)	World Bank Water & Sanitation Program The Bill & Melinda Gates Foundation French Development Agency (AFD)	World Bank Water & Sanitation Program UN-Habitat (Chief, W&S Infrastructure Branch) United Nations Childrens’ Fund (UNICEF)
NGOs	Resource Development International; International Development Enterprises, Cambodian Red Cross, Rainwater Cambodia	Water & Sanitation for the Urban Poor WaterAid Estamos Ascodesha	WaterAid Population Services International Health & Environmental Rescue Organization

Our group also has experience collaborating on applied research with NGOs. These organizations tend to have better information about and credibility within the kinds of under-served communities that the Program is targeting, and are thus important partners for our work. Such organizations are also interested in developing their analytical capacity through joint work with Stanford, thus providing another opportunity for the Program to deliver impact on the ground.

The proposed Stanford Program on Water, Health and Development is also ideally suited to bridge research and teaching efforts across all three of the Stanford Challenge Initiative areas: human health, international issues, and environmental sustainability. Indeed, the issues that the Program will tackle are situated at the intersection of these three Initiatives. We envision strong partnerships with the Global Health Group organized by the School of Medicine, the Center for Health Policy within the Freeman Spogli Institute, and several groups within the Woods Institute for the Environment. Indeed, it is worth noting that two Woods-supported initiatives have ongoing work in our focal countries, offering opportunities for synergistic collaboration. The Natural Capital project has a field site in the Eastern Arc

Mountains of Tanzania, a region that includes the catchments that supply water to several cities, including Dar es Salaam. The Program on Food Security and the Environment is working in Mozambique to examine the impacts on small-farmer livelihoods of the country's transition toward biofuel crop production, with considerable implications for water resources planning.

Key strategies

The broad approach of the Stanford Program on Water, Health and Development will be to (1) identify critical knowledge gaps in collaboration with our international partners in order to facilitate political support for rigorous research and direct links with planning and policy processes; (2) design and implement research that can help address those gaps; and (3) work proactively to encourage widespread uptake of the research findings within research communities, the host country, and across the region through dissemination workshops organized by the Program (Figure 4).

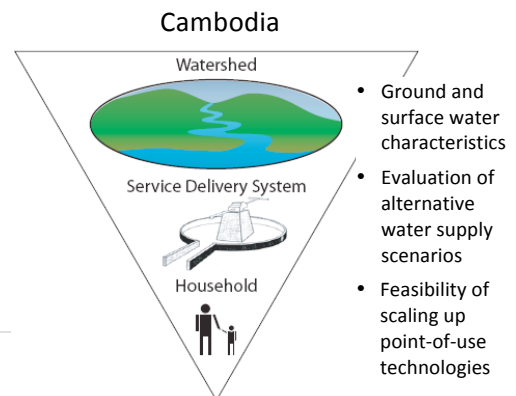
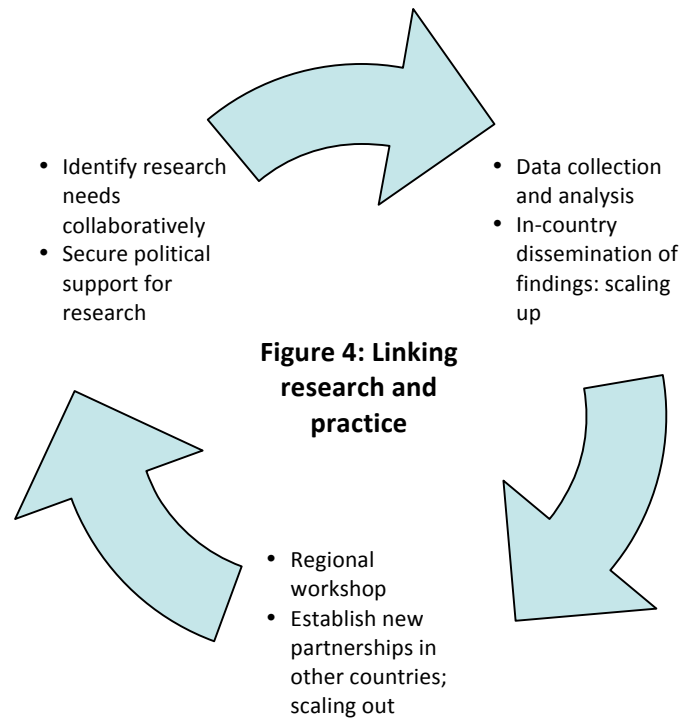
Given the proposed Program's focus areas, commitment to interdisciplinarity, links with planning and policy development, and capacity building, we have developed a preliminary research program for each country in collaboration with our partners.

Each country program is described below; see Appendix A for a 3-year timeline of Program activities.

Cambodia

During the 1970s and 80s, governments of South and Southeast Asia worked with international donor agencies to reduce reliance on surface water sources that had become highly contaminated with pathogens for drinking water supply. The installation of millions of deep borewells allowed households in these regions to shift from polluted rivers and ponds to groundwater sources that were largely free of biological contaminants. After two decades, it became clear that, while this water infrastructure investment strategy had indeed reduced water- and sanitation-related infectious disease in Asia, it had also exposed tens of millions of people to harmful levels of arsenic in the groundwater.

The arsenic crisis has received considerable attention in Bangladesh, where the effects of arsenic poisoning from groundwater were first documented. Research and policy responses there have largely focused on characterizing the sources, fate, and transport of arsenic in groundwater, and on developing technologies for arsenic removal from the household to the community level. Conspicuously absent from most initiatives in Bangladesh is an approach that



considers both alternative sources of water supply (*i.e.*, surface water sources and rain water collection), as well as the social and economic feasibility of scaling up technical solutions that are shown to be efficacious at the bench scale.

Our research on non-networked water supply planning focuses on Cambodia, another Asian country with high levels of naturally occurring arsenic in groundwater but with relatively less “sunk costs” in borewell infrastructure, and thus a greater ability and willingness to consider alternative infrastructure investment paths. We will focus initially on the Kien Svay district of Cambodia, an area that includes both rural and peri-urban settlements and lies downstream of Phnom Penh, the capital and largest city in Cambodia, as a representative area for this work. A variety of water sources are available for development in this district, each with its own health-related challenges. The Bassac River carries effluent from the Phnom Penh sewer system and is heavily contaminated with pathogenic viruses, bacteria, and protozoa. Groundwater in the district is contaminated with arsenic at levels greater than ten times the World Health Organization recommended level (10 µg/L). Other surface water sources (rivers, ponds, wetlands) vary in the type and extent of contamination.

The critical challenge for the Ministry of Rural Development is to map out a vision for water supply infrastructure investments for underserved districts such as Kien Svay that incorporates the costs, benefits, and risks associated with exploiting arsenic-contaminated groundwater, pathogen-laden surface water, and/or rainfall. The Ministry, along with donors such as the World Bank and UNICEF which are supporting water sector development in Cambodia, is keen to partner with researchers in a rigorous and systematic assessment of alternative pathways. Working together we will develop a framework that considers the costs, benefits, and sociopolitical and technical feasibility of different options for ensuring access to safe and reliable water supply, including a variety of water sources and treatment scenarios such as household-based point-of-use treatment and centralized treatment.

Ultimately we aim to generate a GIS-based decision support tool that allows the Government of Cambodia to devise an appropriate water supply strategy for Kien Svay (and, ultimately, for all districts in the country). Successful development and testing in Cambodia will also allow for the decision support tool to be transferred across the greater South and Southeast regions of Asia where similar conditions prevail. Specific objectives within this project include:

- Characterization and mapping of ground and surface water sources in terms of pathogen and arsenic contamination, respectively
- Evaluation of the efficacy of the most promising water treatment technologies available for the study area
- Characterization and modeling of household preferences for different water supply options, including willingness and ability to use multiple systems and/or water treatment technologies
- Cost-benefit analyses of alternative water supply strategies

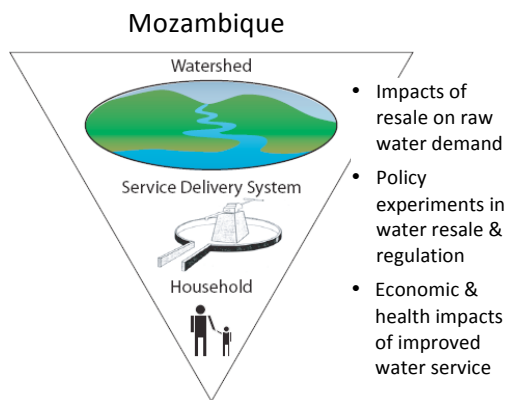
We will establish a small Technical Advisory Committee (TAC) with senior members drawn from the Ministry of Rural Development, the Phnom Penh Water Supply Authority, donor agencies, and universities in both Cambodia and neighboring countries to develop an implementation strategy (a linked to the institutional and regulatory arrangements noted in Figure 2). Not only will the TAC help link research outputs with decision-making in Cambodia, but we hope it will also spur interest in applying the framework to other countries in the region. Faculty and students from the Royal University of Phnom Penh (RUPP) will be directly involved as collaborators in the project; our research will be a critical aspect of their scientific development and degree advancement. Through an agreement with

Resource Development International, RUPP students conducting research with us receive graduate credit and the ability to use the research material for their graduate theses. Students will receive training on survey methodologies, surface and groundwater collection procedures, hydrologic analyses, pathogen assays, and chemical analyses. With these skills, they will help us fulfill our research objectives, and the students will be prepared to conduct research suitable for use in preparing graduate theses. The collaborative agreement is an optimal means to educate and train the local populous while also providing critical ‘in country’ support for our research efforts.

Initial planning for this project began in March 2009 during a Woods Institute-sponsored “Uncommon Dialogue” that was convened in Siem Reap. More than 60 researchers, government officials, and donor agency staff met to describe the current conditions, processes underlying the water problems, necessary future work, and possible solutions. The output from this meeting are several review papers currently being developed for publication in *Science* and *Nature Geosciences*; these articles describe the current health consequences, groundwater conditions, presently known causations, and future risks (particularly the vulnerability of presently ‘clean’ water to contamination). If funding can be secured, we are thus poised to mobilize quickly on the basis of the enthusiasm generated during the recent Uncommon Dialogue discussions.

Mozambique

Water utilities in sub-Saharan Africa typically provide water to only a small fraction of households living in the cities they serve. The majority of low-income households is non-networked and meets their water supply needs through standpipes or informal suppliers such as tankers and street vendors. Historically, infrastructure investment plans pursued by governments in this region (with support from international donor organizations) have focused on improving the financial position of water utilities so that utility networks could be extended into un-served peri-urban areas. Moreover, governments have typically relied on installing public standpipes for serving low-income households and for meeting the Millennium Development Goals (MGDs) for water supply. These strategies have yielded disappointing results; access to improved water supply services in sub-Saharan Africa has not even kept pace with population growth in recent years.



In Maputo, the capital and largest city of Mozambique, the water utility *Águas de Moçambique* (AdeM) is breaking away from this standardized approach to serving low-income peri-urban neighborhoods by experimenting with strategies such as the legalization of the currently prohibited re-sale of utility water by customers. This policy change is scheduled to take place in February 2010. Notwithstanding that water resale is currently illegal in Maputo, the Water Regulatory Council (CRA) and others have identified, since 2001, water resale from house connections as an important form of water services.

Moreover, a 2007 study in 20 neighborhoods conducted

by CRA found that 26% of the population in greater Maputo relied on water purchased from their neighbors, who were obtaining network water (often bypassing meters and thereby avoiding tariffs) and reselling it illegally.

Despite evidence of the significance of water resale, there are many unresolved questions: Why do some consumers prefer purchasing from water resellers compared to other types of service providers,

and what are the characteristics of these consumers? What characterizes households that resell water and why do they choose to resell? Under what conditions can water resale be a “first best” option for improving services to non-networked populations? What are the impacts of widespread resale on the price and quality of service offered by other providers, as well as on the financial viability of the public utility and the demand for raw water?

This research requires the collection of in-depth information at the household, community, and water system (utility) level, before and after water resale legalization takes effect. Repeated data collection with the same household and water resellers before and after the legalization will allow us to carry out before-after comparisons and estimate effects of water resale legalization under initial conditions existing in different types of neighborhoods. This type of experimental research design is exceedingly rare in the water sector. Prior studies of water resale (e.g., Crane 1994) have not employed before-and-after surveys to study the impact of resale legalization. Unpublished studies in Mozambique have either included a small area – often only one neighborhood (e.g., Boyer 2006) - or have focused on a limited number of households in a large number of neighborhoods (e.g., CRA 2007). This investigation is thus expected to generate considerable interest, both within and outside the southern Africa region.

To answer our research questions, we will:

- Collect and analyze information about the demand and the supply side of the water resale market, including socio-economic and other characteristics of households, resellers, and where relevant, various types of alternative providers.
- Rigorously evaluate the impact of water resale legalization on the consumers, resellers, and the utility using statistically-robust longitudinal surveys of household and water reseller across a sample of neighborhoods.
- Employ econometric and statistical procedures to assess (1) households’ perceptions of water resale *versus* other water supply options, (2) the financial viability of AdeM operations under legalized resale, and (3) the health and non-health costs and benefits of resale legalization at the household level.

This research will help to build long-term partnerships with government agencies and universities, thereby directly influencing policies and technical capacity in the areas in which we work. CRA and AdeM have both expressed high interest in the study, whose results will guide implementation of the legalization process in Maputo and the “scaling up” of legalization in other cities in Mozambique. In addition, two other organizations have expressed great interest in the study: WSP, an independent, donor-funded program administered within the World Bank, which is currently supporting CRA in defining the regulatory framework for water resale; and WSUP, Water and Sanitation for the Urban Poor, an NGO investing in water infrastructure improvements in ten neighborhoods in Maputo. Both organizations are active in a number of African countries, which further expands the scope of influence for the study’s results.

Field teams composed of students from the University of Eduardo Mondlane (Maputo) and Stanford University will carry out on-site data collection in a number of neighborhoods in greater Maputo under the supervision of Stanford faculty and advanced graduate students. Neighborhood guides will support the team in the identification of households. CRA, FIPAG, AdeM and the Municipal Council of Maputo will collaborate in designing and supporting implementation of the study. These arrangements were made during and after the July 2009, Woods Institute-sponsored “Uncommon Dialogue on Water, Health and Development” in Dar es Salaam.

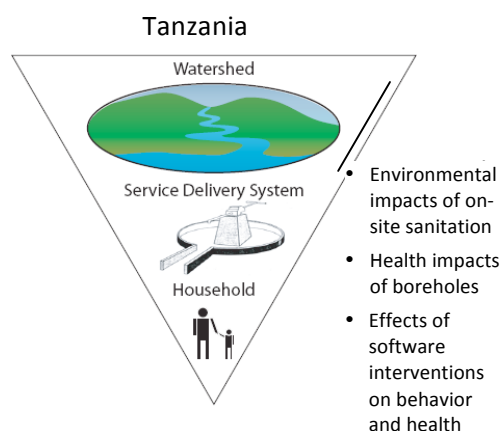
Key questions regarding water resale legalization concern: whether resale will be embraced by non-networked households as well as those able to resell; and how legalized resale influences water sellers currently used by non-networked households to obtain water. If many non-networked households purchase more water from neighbors connected to the utility’s network, they would buy less water from public standpipes or vendors in the informal sector. This would lead to shifts in the composition of the water supply market as a whole, with implications for household use as well as health and income levels. The water resource itself may be also be affected, for example, if there is increased demand for water from the utilities network -- water which is obtained from surface water supplies -- and decreased demand for water from vendors relying on groundwater sources. Our research will explore impacts from the household to the watershed level of the government’s resale policy experiment.

Tanzania

Dar es Salaam (“Dar”) is the largest city in the east African country of Tanzania. With an estimated 2.8 million inhabitants in 2006, Dar is also considered to be the 9th fastest growing city on the planet, with a population doubling time of just 16.4 years. Like Maputo, Dar is emblematic of the challenges facing municipal governments of African cities. Resource constraints preclude the extension of piped water and sewer networks to the majority of city residents. Instead, the Dar es Salaam Water Supply and Sanitation Authority (DAWASA) uses a strategy of supplying peri-urban households with shared taps for water supply.

Whereas the water delivered from these systems is of reasonably good quality at the tap, our preliminary research in Dar—which was initiated with seed funding from the Woods Institute and further supported by funding from the National Science Foundation—has demonstrated that stored drinking water supplies are highly contaminated. In addition, we have shown that the hands of both children and adults in these households have high levels of contamination with fecal indicator bacteria. These findings are consistent with evidence that DAWASA’s investments in borewells in peri-urban Dar have had little impact on the incidence of water- and sanitation-related illness. Improved infrastructure alone is insufficient to break the fecal-oral route of contamination; additional changes in water management and hand hygiene are essential ingredients for realizing the full health benefits of water supply improvements.

Our research in Dar has thus focused on understanding the extent to which water, sanitation and hygiene “software” interventions can motivate non-networked households to invest time, effort, and financial resources to reduce water-sanitation-related illness. “Software” includes both generic information regarding strategies to reduce risks of illness, as well as tailored messages regarding the level of contamination of stored water and on hands. This initial research has been carried out in partnership with DAWASA, the Muhimbili University for Health and Allied Sciences University (MUHAS), and the NGO Health and Environment Rescue Organization (HERO).



Our initial work has produced valuable insights regarding the effects of providing personalized information on water quality or hand hygiene on water-related behaviors, hygiene practices, and health. In addition to manuscripts developed from this work (Pickering *et al.*, 2009), policy briefings regarding

effective implementation of interventions to reduce water- and sanitation-related illness among children will be prepared for DAWASA, officials in the Ministry of Health, and the Office of the President. Our National Science Foundation funding will allow us to expand this research within Dar es Salaam by increasing our sample of households and the length of time over which we engage with them. In addition, we have been encouraged in recent exchanges with the Office of the President of Tanzania to expand the geographic scope of our research to include small town and rural communities, where the burden of water- and sanitation-related illness is even greater as compared to peri-urban zones.

We are also seeking to link our household- and system-level investigations with watershed-level analysis of the impacts of Dar's heavy reliance on non-networked sanitation technologies. An estimated 93% of households use pit latrines or toilets with septic tanks for their excreta disposal. Sanitation services for these 2.7 million people are completely self-financed and largely unregulated, with households and the private-sector pit and tank emptying services they contract acting as *de facto* fecal sludge managers for the city. Quantifying the public health and environmental costs of this policy, as well as of possible interventions such as wastewater reuse for urban agriculture, are important contributions that we seek to make in future phases of the project.

Educational merit

A growing literature on learning and education suggests that the teaching of skills and analytical methods is greatly enhanced by enabling students to apply these tools to “real world” problems that have salience for them (Buchan et al. 2007; Dale and Newman 2005; Perdan et al. 2000, Jucker 2002). Learning is further enhanced through dissonance, such as with the introduction of competing conceptual and analytical frameworks (Eagan et al., 2002; Wals and Jickling, 2002). With its emphasis on research-practice partnerships and multidisciplinary collaboration, the proposed Stanford Program on Water, Health and Development will offer graduate and undergraduate students these sorts of deep educational and training experiences.

Faculty in the proposed Program will develop a team-taught course on water, health and development that will be offered to students from all schools and departments. An additional seminar class will be organized for graduate students working as research assistants in the Program. It is also expected that, during each summer session, a group of undergraduate and graduate students will have the opportunity to participate in fieldwork in Asia or Africa. The principal investigators for this Program, Jenna Davis and Scott Fendorf, as well as other program-affiliated faculty, have extensive experience involving students in their field projects in developing countries.

Leadership

Leadership of the Program will be vested with two regional Research Directors (Asia and Africa), a Program Advisory Committee and an Executive Director. The two Research Directors will have principal responsibility for maintaining the research-practice partnerships established in their regions; ensuring that research conducted under the Program is both high quality and of practical import; and creating opportunities for faculty and students across Stanford and in research institutes in partner countries to become involved in the Program. Prof. Scott Fendorf and Prof. Jenna Davis will act as the Program's first Research Directors for Asia and Africa, respectively.

The Program Advisory Committee (PAC) will be constituted with faculty and students who are not directly involved in our research activities but who share common interests in sustainable development

and human health. The PAC will meet quarterly to provide guidance on the Program’s strategic direction and setting of research priorities, and to review progress in ongoing activities.

The Executive Director will be responsible for leadership in implementing the long-range program, carrying out organizational and financial planning; publicizing the activities and goals of the program; and developing and executing a fund-raising strategy. He or she will be recruited through a competitive search.

Several other faculty from an array of Stanford schools and departments have been involved in the development of the Program concept over the past year (see Appendix B for brief biographical sketches). They will continue to participate as research faculty in the Program (Table 3). In addition, a recurring seminar focused on water, health and development will be organized at Stanford to engage a broad set of faculty and students across the campus, as well as in other universities and research institutions.

Table 3: Research faculty, Stanford Program on Water, Health and Development

Faculty member	Relevant expertise	Affiliation(s)
Ali Boehm	Drinking water quality, public health microbiology, microbial risk assessment	Civil & Environmental Engineering
Jenna Davis	Water & sanitation planning and policy, public health	Woods Institute, Civil & Environmental Engineering
Wally Falcon	Natural resource economics, agricultural policy	Woods Institute, Freeman Spogli Institute, Food Security & Environment Program
Scott Fendorf	Water quality and pollution, environmental chemistry	Environmental Earth System Science, Woods Institute
Abby King	Health behavior theory and interventions	School of Medicine
Eric Lambin	Land use change and infectious disease, remote sensing	Woods Institute, Environmental Earth System Science
David Lobell	Agricultural production and climate change, GIS/remote sensing	Environmental Earth System Science, Food Security & Environment Program
Roz Naylor	Environmental and equity dimensions of intensive food production	Environmental Earth System Science, Food Security & Environment Program, Woods Institute
Leonard Ortolano	Environmental and water governance, water resources development	Civil & Environmental Engineering
Gary Schoolnik	Medicine, infectious disease	School of Medicine

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**Appendix A: Stanford Program on Water, Health and Development
3-year timeline for major tasks**

	Year 1				Year 2				Year 3			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Personnel and partnerships												
Recruit program director	█	█										
Establish MOUs with partner organizations	█	█	█									
Recruit postdoctoral scholars		█	█	█								
Country launch workshops					█	█						
Annual country meetings									█	█		
Research												
Form research teams; secondary data review		█	█									
Fieldwork site scoping, formative research			█	█								
Cambodia field work				█	█	█	█	█	█	█	█	
Mozambique field work					█	█	█	█	█	█	█	█
Tanzania field work				█	█	█	█	█	█	█	█	█
Data analysis						█	█	█	█	█	█	█
Dissemination												
Southeast Asia workshop												█
East Africa workshop												█
Southern Africa workshop												█

Appendix B: Stanford Program on Water, Health and Development

Biographical sketches of research faculty

Alexandria Boehm is a professor at Stanford University in the department of civil and environmental engineering. Her primary research area is coastal water quality, and a secondary area is sanitation more broadly. The work on coastal water quality is focused on understanding the sources, transformation, transport, and ecology of biocolloids - specifically fecal indicator organisms, pathogens, and phytoplankton - as well as sources and fate of nitrogen. This knowledge is crucial to directing new policies, and management and engineering practices that protect human and ecosystem health at the coastal margin. Projects focus on understanding both the influence of terrestrial runoff and submarine groundwater discharge on coastal water quality. The work on sanitation aims to gain a better understanding of how pathogens are transmitted to humans through their contact with water, feces, and contaminated surfaces. The goal is to design and test novel interventions and technologies for reducing the burden of waterborne disease. Current projects include a microbial risk assessment of rotavirus transmission to children via fomites, studies on water quality and health in Dar es Salaam, Tanzania and Papua New Guinea, and lab and field work to understand the efficacy of alcohol-based hand sanitizer and hand washing with soap in reducing bacterial levels on hands and reducing illness in developing countries.

Jenna Davis is an Assistant Professor in the Department of Civil & Environmental Engineering and a Fellow at the Woods Institute for the Environment with Stanford University. She holds a master's degree in public health and a PhD in environmental management and policy, both from the University of North Carolina at Chapel Hill. Professor Davis' research interests focus on the water and sanitation sectors, with particular emphasis on cost-effective, sustainable water supply and sanitation (W&S) service delivery in developing countries. Current research projects focus on decentralized, private-sector delivery of W&S services in several countries; synergies between sustainable sanitation planning and both economic development and environmental protection strategies; and the design of post-construction support programs for rural water systems. Prof. Davis teaches courses on water and sanitation planning, infrastructure privatization, the theory and practice of sustainable development, and research methods. She has conducted fieldwork in more than a dozen countries, including most recently Kenya, Colombia, and Mozambique.

Walter Falcon is deputy director of the Food Security and the Environment Program, former director of the Freeman Spogli Institute for International Studies (FSI), and Farnsworth professor of International Agricultural Policy at Stanford University (Emeritus). Specializing on agricultural policy in developing countries, Falcon provides a wide array of research experience as an analyst and consultant in international economic and environmental policy. His current research focuses on agricultural decision-making in Indonesia and Mexico, and on biotechnology, climate change, and biofuels. Falcon has consulted with numerous international organizations, and has been a trustee of Winrock International and chairman of the board of the International Rice Research Institute (IRRI). From 1978 to 1980, he was a member of the Presidential Commission on World Hunger and in 1990 he was named a Fellow of the American Agricultural Economics Association. Falcon became a Fellow of the American Association for the Advancement of Science in 1991. From 1996-2001 he served as chairman of the board of the International Corn and Wheat Institute (CIMMYT), and from 2001-07 served on the board of the Center for International Forestry Research (CIFOR). Falcon was awarded the prestigious Bintang Jasa Utama medal of merit by the government of Indonesia for twenty-five years of assistance with that country's development effort.

Scott Fendorf is Professor of Soil Biogeochemistry and Chair of the Earth System Science Department at Stanford. His research and teaching are directed at processes broadly related to water quality and nutrient cycling. He focuses on the chemical and biological processes that control the fate and movement of toxic trace elements such as arsenic within soils, sediments, and surface waters. A large focus of his research has been on deciphering processes responsible for arsenic levels and migration in groundwater of South and Southeast Asia, where more than one-hundred million people are drinking hazardous levels of this toxin. His research group has illustrated the importance of soil processes in liberating arsenic to pore-water that is subsequently transported down into the underlying aquifers, where it is subsequently tapped for human consumption. He is now engaged in helping to define means for providing safe drinking water to peri-urban and rural areas of South/Southeast Asia.

Abby King, Professor of Health Research and Policy and Medicine at Stanford University School of Medicine, has published extensively in the area of disease prevention and health enhancement. A recipient of the Award for Outstanding Scientific Contributions in the Area of Health Psychology from the American Psychological Association, Dr. King's research has focused largely on the application of behavioral science theory to the development, evaluation, and dissemination of public health and community-wide interventions aimed at disease prevention and health promotion, with a particular emphasis on the behavioral risk factor areas of physical activity, dietary behaviors, and stress. Her research has included work with younger and older adults, children, low-income minority adults, and other populations. She has served on a number of government taskforces focused on population-based health promotion and disease prevention throughout the U.S. and abroad, and has been the recipient of a number of National Institutes of Health research grant awards. She is an elected member of the Academy of Behavioral Medicine Research, and is currently serving as the Director of the Stanford Prevention Research Center. Dr. King was the first recipient of the Stanford Prevention Research Center's Divisional Teaching Award, and was the recipient of the Society of Behavioral Medicine's 2003 Distinguished Scientific Mentor Award. She is a member of the U.S. Secretary of the Department of Health and Human Services' Scientific Advisory Committee on National Health Promotion and Disease Prevention Objectives for 2020 (Healthy People, 2020).

Eric Lambin is Professor at the Department of Geography at the University of Louvain, Louvain-la-Neuve, Belgium. He was previously Assistant Professor at Boston University and Expert for the European Commission at the Joint Research Center (Ispra). He has been Chair of the Land-Use and Land-Cover Change programme of the International Geosphere-Biosphere Programme and International Human Dimensions Programme on Global Environmental Change. The research interests of Eric Lambin include the monitoring of land-cover changes by remote sensing, and the modelling of land-use changes and some of their impacts on coupled human-environment systems. He has published extensively in leading scientific journals in remote sensing, geography and environmental sciences. Professor Lambin will join the faculty of Stanford University as a Professor in Environmental Earth System Science and a Senior Fellow with the Woods Institute for the Environment.

David Lobell is an Assistant Professor at Stanford University in Environmental Earth System Science, and a Center Fellow in Stanford's Program on Food Security and the Environment. His research focuses on identifying opportunities to raise crop yields in major agricultural regions, with a particular emphasis on adaptation to climate change. His current projects span Africa, South Asia, Mexico, and the United States, and involve a range of tools including remote sensing, GIS, and crop and climate models.

Rosamond Naylor is director of the Program on Food Security and the Environment, professor of Environmental Earth Systems Science, William Wrigley Senior Fellow at FSI and the Woods Institute,

associate professor of economics by courtesy, and affiliated faculty at the Center on Democracy, Development, and the Rule of Law (CDDRL). Her research focuses on the environmental and equity dimensions of intensive food production. She has been involved in a number of field-level research projects throughout the world concerning issues of aquaculture production, high-input agricultural development, biotechnology, climate-induced yield variability, and food security. She currently serves as a member on a number of advisory councils, including at the Pew Fellowships Program in Marine Science, the Communication Partnership for Science and the Sea (COMPASS), and the Bill Lane Center for the American West. Naylor was named Fellow in the Aldo Leopold Leadership Program in Environmental Sciences in 1999 and Pew Fellow in Conservation and the Environment in 1994.

Leonard Ortolano, UPS Foundation Professor of Civil Engineering, is a specialist in water resources and environmental planning and policy, and has a particular interest in the implementation of environmental and water policies and programs. His research in the area of domestic water supply and sanitation includes studies of: factors influencing the long-term sustainability of village water supplies in Honduras, the relationships between citizen participation and the effectiveness of condominium sewers in Brazilian cities, and the effectiveness of subsidy programs for bringing water to the more than 400,000 Americans living without ready access to potable water on the U.S. side of the U.S.-Mexico border. His current work in water and sanitation concerns water supply in peri-urban areas within Mozambique. Ortolano teaches courses on environmental governance and sustainable water resources development. In addition to his research and teaching, Ortolano has had practical experience working as an environmental engineer, and as a consultant to numerous companies, agencies and international aid organizations, including the World Bank.

Gary Schoolnik is professor of Medicine, Microbiology, and Immunology at the Stanford Medical School, Associate Director of the Institute for Immunology, Transplantation, and Infection, Associate Dean of the School of Medicine, and an attending physician in infectious disease and internal medicine at Stanford Medical Center. His research employs molecular genetic and genomic methods and combines laboratory and field work (in Mexico and Bangladesh) to study infectious agents which are significant causes of disease in developing countries. A particular current interest is the molecular ecology of infectious agents in natural environmental habitats.