Stanford University

Global Freshwater Initiative

Developing strategies to promote the viability of long-term freshwater supplies for people and ecosystems

Woods Institute for the Environment
Stanford University

February 2010

Research Prospectus: Global Freshwater Initiative

Date: February 9, 2010

Principal Investigator: Steven Gorelick, Environmental Earth System Science

Co-Principal Investigator: Barton Thompson, Jr., School of Law and Woods Institute

Co-Principal Investigator: Scott Rozelle, Freeman Spogli Institute and Woods Institute

Proposed Amount: $8.8 million over 5 years

Purpose: The Global Freshwater Initiative will develop implementable strategies to promote the long-term viability of freshwater supplies for people and ecosystems threatened by climate change, shifts in land use, increasing population, and decaying infrastructure. The initiative will be global in scope but regional in focus. In a carefully selected set of regional investigations, Stanford researchers and local collaborators will work together to understand freshwater resource issues and build quantitative policy evaluation models that account for both hydrologic processes and economic behavior. Through regional integrated models, the initiative will examine the efficacy of policy instruments aimed at reducing vulnerability and enhancing sustainability. The initiative will also conduct a variety of activities that cut across the regional investigations, including model-building workshops to generate a common analytic framework and an annual policy forum to compare water-resource sustainability strategies across regions. The initiative will 1) generate a set of policy evaluation models developed in conjunction with each regional investigation, 2) provide targeted analyses of viable policy interventions aimed at achieving freshwater sustainability, and 3) train the next generation of water resource experts. Project funds will support faculty, students, post-doctoral fellows, and visiting scholars, as well as allow project members to travel to regional investigation sites to build strategic partnerships, collect data, and construct regional integrated models.

1 The Threats to Global Fresh Water

Changes in human and natural systems will drive serious threats to freshwater resources in the 21st century. Multiple drivers of global change, ranging from increasing population to climate change, will put water resources at risk. An overarching challenge will be to create water systems that can sustain human well-being and natural ecosystems in the presence of rapid environmental and socio-economic change. A balance will be essential between water for direct human use and water to preserve natural ecosystems.

The impending "global water crisis" is not a single global water calamity, but rather a series of often interlinked regional problems with common themes. As a result, one silver bullet will not resolve all of the world's water issues. Instead, different regions will need locally relevant solutions focused on incentives, technology, conservation, markets, and trade. Solutions are likely to rely on modern engineering and information technologies combined with effective planning, policies, and institutions.

The increasingly interdisciplinary nature of the world's regional water problems presents an important opportunity for research to a) understand which regions are home to the most critical challenges in meeting the water needs of people and the environment, and b) identify effective planning and policy prescriptions.

1.1 Risks to regional water systems

Fresh water that supplies societal and natural systems can fail when water resources become physically or economically scarce.

- *Physical water scarcity:* As regions urbanize and industrialize, more and more water will be transferred from agricultural to urban uses. At the same time, as the world's population increases, more and more water is needed to grow food. To cope with the increased demand, many regions of the world are unsustainably withdrawing water and irreversibly destroying ecosystems. Climate change can exacerbate regional problems by altering hydrologic regimes, thereby shifting or shortening rainy seasons and decreasing the quantity available for use.

- *Economic water scarcity:* In some parts of the world, notably sub-Saharan Africa, water resources are plentiful, but the storage and distribution infrastructure is inadequate. In these regions, access to water is limited by the institutional and economic capacity of the region. This type of water limitation is often referred to as "economic water scarcity." The root causes of water crises in such regions differ from place to place: they may be policy related (over-subsidized water), economic (low income), institutional (unclear water rights), political (vested interests), and cultural (preference for water-intensive lifestyles). Even if a freshwater system as a whole is sustainable, individual groups or communities may be vulnerable to supply disruption because of an unequal distribution of income and other entitlements.

1.2 Risks to the global water system

Systemic global risks are superimposed on these regional water resources problems. Though water is generally too expensive to transport long distances, large amounts of water in fact move globally in the form of “virtual water” – water embedded in globally traded commodities. Consider the water required for food production. Because agriculture accounts for over 90 percent of the world’s consumptive water use, the interconnected global water system causes changes to agriculture and exports in one part of the world to be felt elsewhere; the entire global system is vulnerable to regional shocks in water supply.

2 The Global Freshwater Initiative

The Global Freshwater Initiative (GFI) at Stanford will research freshwater management in different regions of the world. This effort will have two objectives. The first will be to understand the nature and causes of water crises and their impacts on populations, economies, and ecosystems. The second will be to develop a unified analytic framework to explore policy interventions that make regional freshwater supplies both sustainable (viable in the long term) and less vulnerable (resistant to shocks) while maintaining the needs of natural systems.

2.1 Overview of Project Strategy

The GFI will conduct research centered on regional freshwater systems at the watershed to multi-watershed scale. All activities within the GFI will satisfy three strategic criteria:

1. **Solution-oriented academic research:** The GFI will conduct interdisciplinary scholarly research with an applied focus. Researchers will work with stakeholders and regional collaborators to inform policies and develop solutions in individual study regions. The GFI will identify solutions that can individuals, community groups, governments, or private companies can feasibly implement.

2. **Multiple driving forces:** The GFI will consider the combined effects of multiple stressors of water supply vulnerability. The project will focus on two types of global change: a) changes in the <u>frequency, timing, and magnitude</u> of water availability (e.g., more frequent or longer droughts), and b) rapid <u>rates of change</u> in water availability, quality, and use (due to groundwater depletion, salt-water intrusion, regional water-resource contamination, and urbanization). The project will concentrate on those changes that may have measurable economic, human, and ecosystem impacts in the generational time frame of 10 to 30 years.

3. **Global in scope but regional in focus**: The GFI will study diverse regions while facilitating learning across those regions. Recognizing the regional nature of water crises, the project will initiate a series of regional investigations (**RI**s). The project will carefully select the RIs to represent a diverse set of compelling and important problems involving water supply vulnerability and sustainability. The project will then unify across the RIs by developing a common analytic framework, global insights, and at least regionally generalized solutions.

2.2 Activities

As shown in Figure 1 and discussed in more detail later, the GFI will engage in four levels of activities: (1) Framework Development, (2) Regional Investigations, (3) Cross-cutting Studies, and (4) the development of a Global-Scale Water/Trade Model.

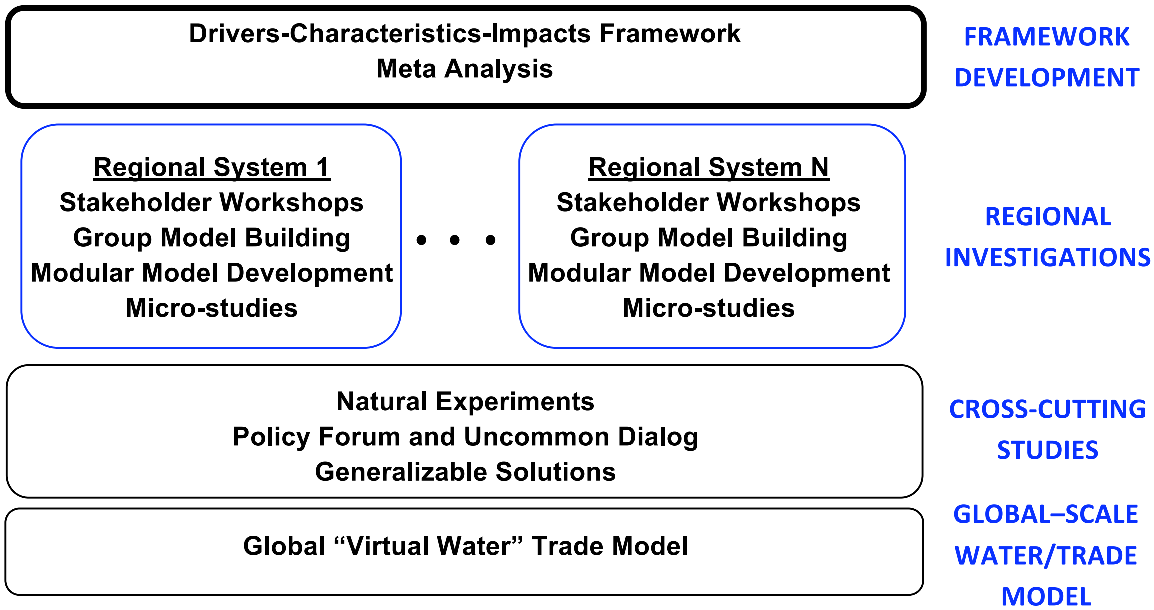


Figure 1: Proposed components and integrated approach of the Global Freshwater Initiative.

2.3 Impact Pathways:

The Global Freshwater Initiative will inform policy at multiple levels. In each Regional Investigation, the GFI team at Stanford will collaborate with local scholars, water managers, public and private decision-makers, and non-governmental organizations (NGOs) to identify viable policies. Across the Regional Investigations, the GFI will work with "boundary organizations" to disseminate research and policy insights to decision-makers elsewhere in the world. To facilitate the process, the GFI will invite representatives from the boundary organizations to participate in Uncommon Dialogues at various stages: initially to develop frameworks and metrics, and later to disseminate results.

2.4 Competitive Analysis

Freshwater vulnerability is a regional problem, influenced by institutional, economic and resource constraints. Policy is implemented at national, state, and local levels. Consequently, there are very few global-scale freshwater initiatives. Sharing knowledge *across* regions typically occurs through two means: multi-lateral organizations like the International Food Policy Research Institute (IFPRI), Food and Agricultural Organization of the United Nations (FAO), World Bank, and academic journals. Existing water programs do not generally integrate across disciplines and sectors, examine the combined effects of multiple stressors, or take a regionally-specific, but globally integrated approach. For example, multi-lateral organizations produce excellent policy-relevant research, but their focus is often sector-specific. IFPRI, as an illustration, is well-equipped to deal with food-security challenges, but not ecosystem or urbanization impacts.

A few recent initiatives have attempted global-scale freshwater initiatives, but do not seek to achieve the full strategic vision of the GFI: The Global Water System Project (GWSP) has established a network of independent research projects whose objectives are consistent with GWSP's broad framework. The GWSP is relatively decentralized in its approach, and the voluntary nature of participation makes generating comparative results a challenge. The International Water Management (IWMI) is supported by the Consultative Group on International Agricultural Research, a network of 60 governments, private foundations, and international organizations. IWMI engages in policy-relevant comparative research and focuses on regional studies. However, IWMI's applied focus does not favor innovative theoretical frameworks or rigorous research design.

In contrast, the GFI will combine scholarly research with significant long-term applied regional investigations. By careful selection of RIs and a scientific approach to research design, we hope to overcome the main challenges in developing a global freshwater initiative. The GFI builds on Stanford's world-class expertise in quantitative simulation of hydrologic processes, land-use, food security, water-supply systems, ecosystems, and policy disciplines. The Stanford team, including collaborators, is in a unique position to conduct interdisciplinary work that bridges hydrologic science, ecology, economics, and analysis of institutions.

3 Framework Development

In the first stage of its work, the GFI is developing a new framework for classifying freshwater systems and assessing their vulnerability and sustainability. The project will use this framework to choose its initial Regional Investigations. The "Drivers-Characteristics-Impacts" assessment framework is illustrated in Figure 2.

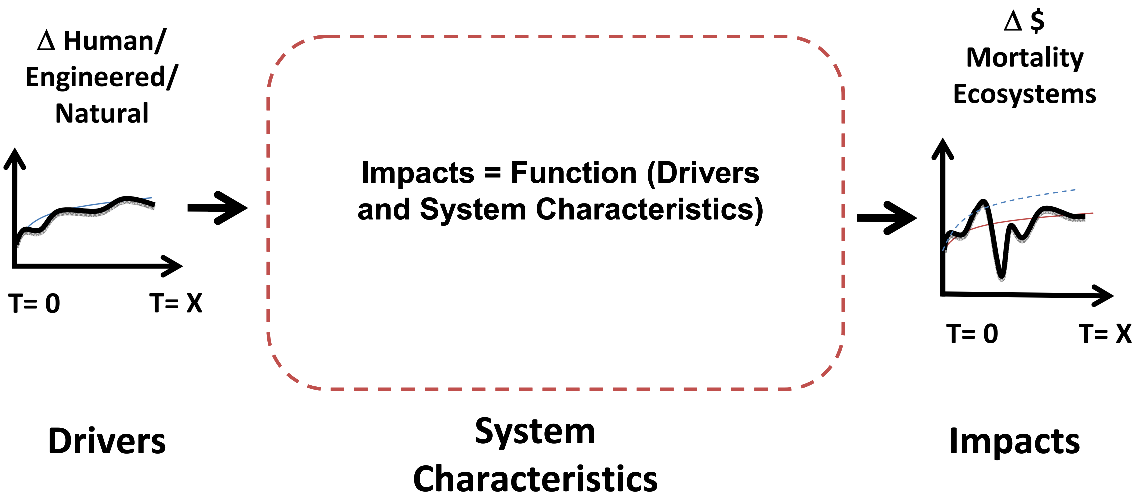


Figure 2: Drivers-Characteristics-Impacts Framework.

The GFI will use the framework to assess regions defined as either a watershed or a closely connected set of watersheds on the scale of several hundred to a few thousand square kilometers. As shown in Figure 2, the framework examines drivers, system characteristics, and impacts. **Drivers** are exogenous factors that are likely to change the supply and demand for water in terms of frequency, distribution, timing, and regional quality. **System characteristics** measure the ability of regions to adapt to the change(s) and thus amplify or attenuate the effects of the drivers. The interactions of drivers and system characteristics result in measurable **impacts** quantifiable in terms of income (or production/output), mortality, and ecosystem health, as well as the variance of each of these metrics. The evaluation of impacts along multiple dimensions (economic, human health, and ecosystem) allows us to consider monetary, health, environmental, and other values. In this respect, our approach differs from one relying on benefit-cost analysis alone.

The Drivers-Characteristics-Impacts analysis will provide a better understanding of the processes that govern susceptibility of different regions of the world to major impacts involving relatively rapid (decadal) changes in climate, land cover, population, regional water quality, infrastructural successes/failures, global trade, and the environment. This will improve our ability to develop and evaluate policy solutions (quantified using a set of integrated models) to reduce negative impacts on people and the environment. Policy prescriptions will target changes in water supply and demand, and proposed implementation will examine modifying infrastructure, offering economic incentives, and/or designing and implementing regulatory schemes.

The GFI will focus on two types of drivers: a) changes in the frequency, timing and magnitude of water availability, and b) rapid rates of change in water availability, quality and demand/use. As illustrated in Figure 3, the project will also examine the impact trajectories to determine the affect of the drivers on both vulnerability and sustainability. As defined in this project, ***vulnerability*** is the likelihood that a system or system component (community or ecosystem) will suffer a relatively sudden, possibly catastrophic, decrease in well-being driven by a short-term shock. ***Sustainability*** is the likelihood that a system or system component will not experience a decreasing trajectory of well-being over time.

The GFI seeks to develop policies that will yield both low vulnerability and high sustainability and thus improve human well-being and ecosystem health (the lower left quadrant in Figure 3). An agricultural economy may be highly sustainable yet highly vulnerable due to periods of drought (upper left). Competing high-intensity water uses, low streamflow, and frequent droughts may produce extremely high vulnerability such that agricultural production is sustainable only at a low level (upper right). If agriculture depends on deep groundwater that is being depleted while poor drainage causes soil salinization, the compound effects may reduce the ultimate sustainability of agricultural production (lower right).

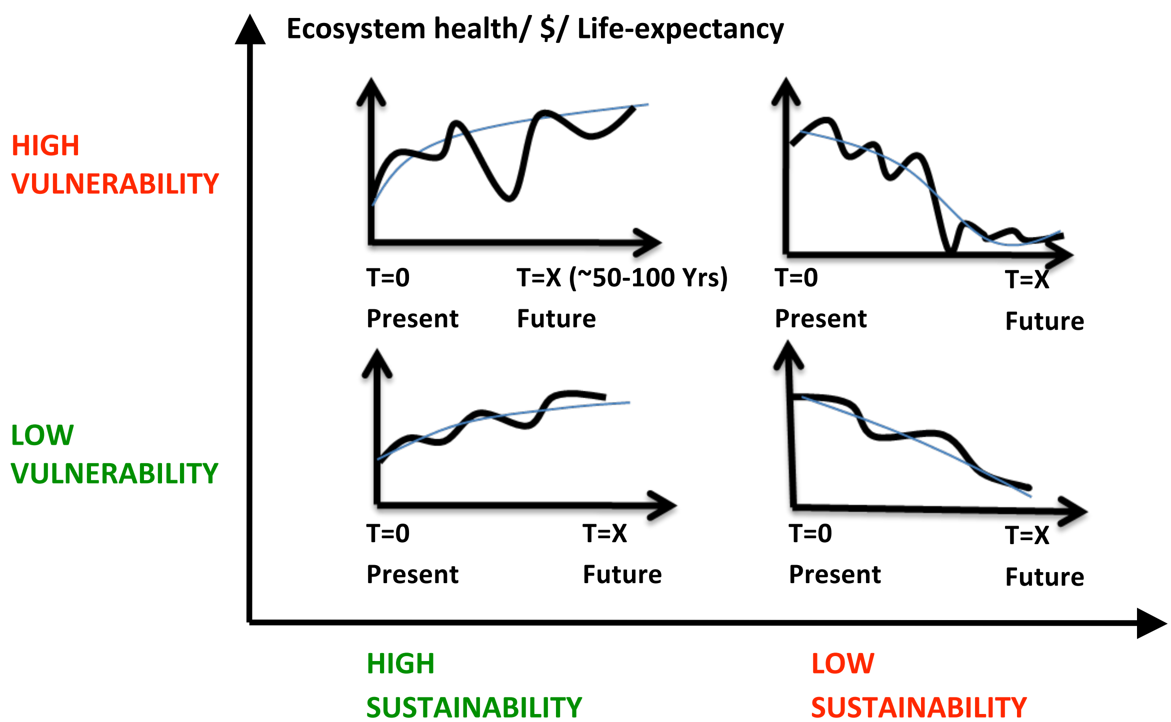


Figure 3. The state of freshwater systems is characterized by its susceptibility to short term effects (vulnerability) and its resilience over the long term (sustainability)

To illustrate what system characteristics may look like, Table 4 tentatively shows seven indicators of susceptibility. These characteristics are not by any means complete or final. We will improve on our list of characteristic indicators by conducting an extensive meta-analysis of the literature detailed (elaborated upon later in this proposal).

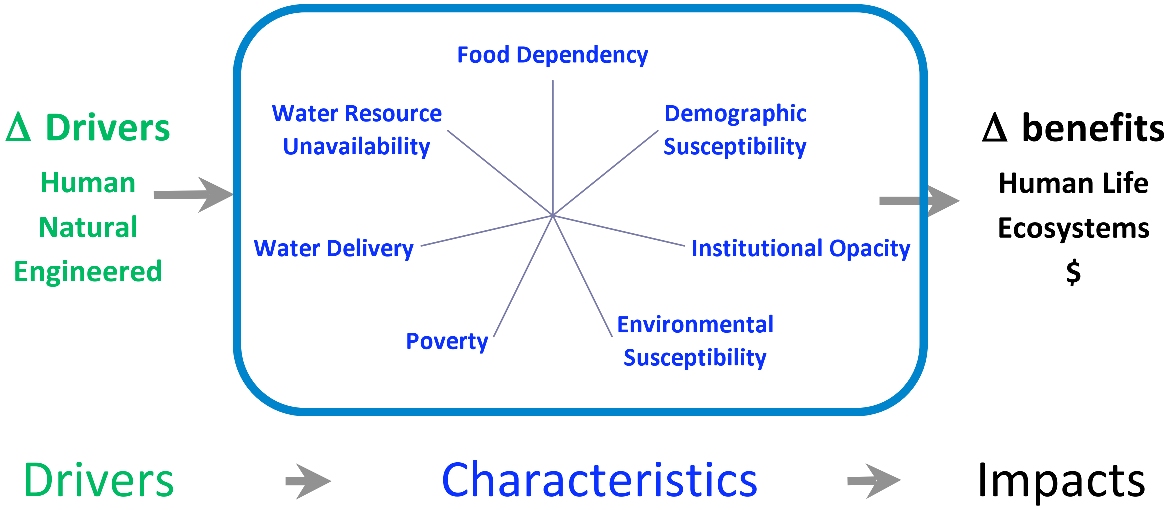


Figure 4: Characteristics of a potentially vulnerable freshwater system in a region.

A system does not need to be vulnerable along each axis shown in Figure 4, as high values of just one or two may indicate a system near the edge of vulnerability. Each axis goes from a scale of 0 to 1, where a higher value indicates a higher degree of regional system susceptibility.

Each of the seven characteristics shown in Figure 4 can potentially affect the impacts of particular drivers.

1. ***Food Dependency:*** While importing food alone does not make a region vulnerable in all situations, it might make a poorer region more vulnerable to price shocks or crises in the global economy. At the same time, a region insisting on self-sufficiency, may do so at the expense of stressing its natural resource systems beyond their limit. (Metric proposed is the fraction of calories consumed that are imported).[1]
2. ***Demographic Susceptibility:*** High density of population means high demand placed on scarce land and water resources, reducing the number of available options. (Metric proposed is population density – normalized across all regions).
3. ***Institutional Opacity:*** Poor governance, corruption and low institutional capability may result in poor management of water resources. (Metric proposed is the inverse of the Transparency International Corruption Index.)
4. ***Environmental Susceptibility:*** A large number of species are likely to become threatened by reductions in freshwater flows to the environment. (Metric proposed is the

[1] For an industrial region, our proposed alternate metric would be Water Dependent Economy: If a significant fraction of GDP is derived from industry, a disruption to the industrial economy due to lack of water would have large impacts. (Metric proposed is the fraction of water used by the industrial sector.)

fraction of species that are listed as "Threatened or Endangered" by the IUCN – normalized over all regions.)

5. ***Water delivery:*** If the "last-mile" of infrastructure is poorly developed or not functioning, access to water is limited. (Metric proposed is the fraction of population lacking access to freshwater and sanitation.)
6. ***Poverty:*** Low per capita GDP means the ability to pay for large infrastructure projects is limited. (Metric proposed is People/GDP in inflation adjusted $ – normalized over all regions.)
7. ***Water Resource Unavailability:*** Low freshwater availability per capita implies less water offered for all human uses. (Metric proposed is People/ cubic meter of annual renewable freshwater available – normalized over all regions.)

4 Regional Investigations

4.1 Regional Investigations Selection

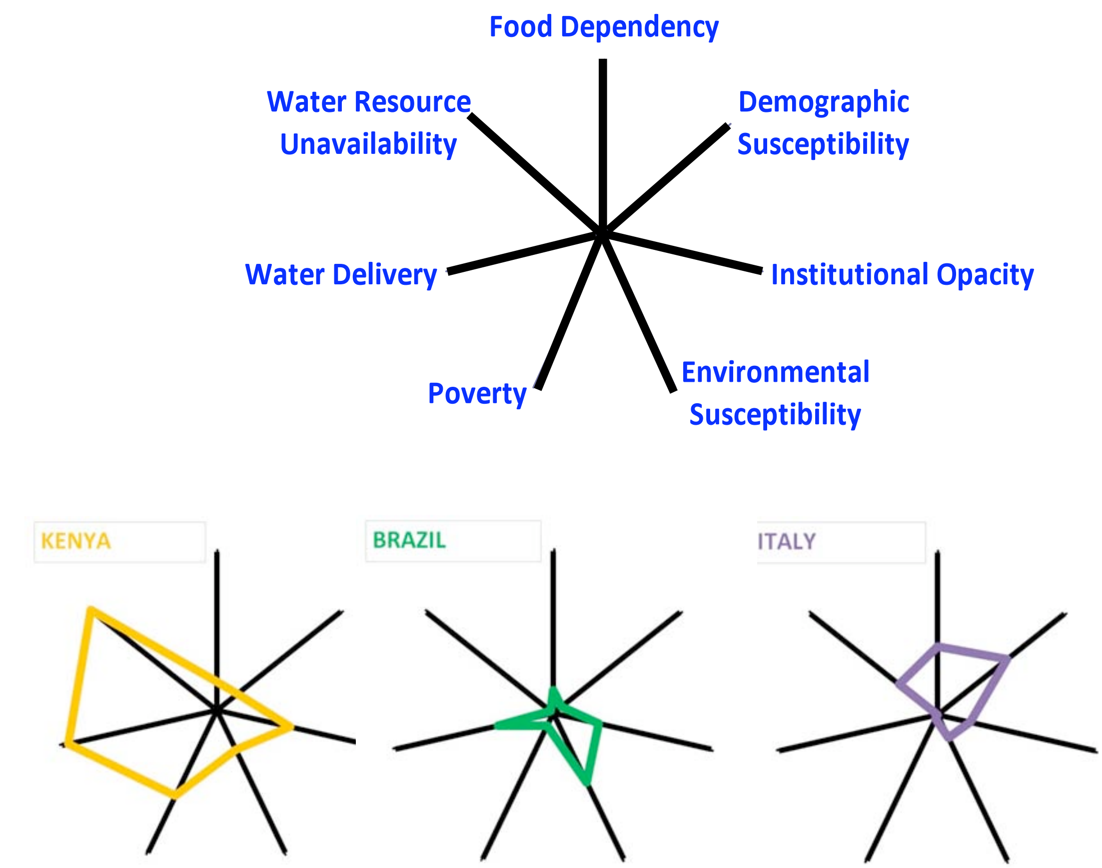
Once the Driver-Characteristics-Impacts framework is finalized, we will select regions for intensive multi-year investigations – the regional investigation (RIs). A team leader will head up each RI. Team leaders and participants will be in nearly continuous contact. Directors of the GFI will coordinate the efforts of the teams, and regular group conference calls and meetings will serve to unite the RIs by developing a common analytic framework, global insights, and generalized solutions.

Each RI will represent a system with a set of characteristics that is representative of various other regions. Figure 5 shows indicator characteristics for five countries (not regions), based on values obtained from the databases of a variety of international organizations (e.g., UN, FAO, and NGO). A high score along any axis indicates a higher degree of vulnerability (the origin is zero). We have used country-level data in Figure 5 because they were readily available. However, the goal of the GFI will be to represent more detailed information at the regional (multi-watershed/basin) scale.

The multi-axis plots form patterns that are quite distinct. The Asian economies have much higher population densities, environmental stresses, and agriculture dependency compared to Africa where poverty, weak institutions, and lack of access to water are the more defining characteristics. In contrast, while European countries (only one shown) have relatively high densities of population and are dependent on food imports, their populations are wealthier, the countries frequently have more reliable government institutions, and they are able to buy food on global markets. By using a multi-axis approach, we believe that results from regional investigations may be generalized to other regions displaying similar characteristics.

To discuss and refine our proposed approach, we invited a number of global water experts to a workshop in early 2009. Based on advice received at that workshop and our initial examination of the axes, we believe that the initial Regional Investigations may focus on China, India, Australia, Sub-Saharan Africa, and the western United States. This list is by no means a final selection. We will make selections only after finalizing the Driver-Characteristics-Impacts framework and engaging in careful deliberation and consultation.

Dealing with water quality problems is integral to the successful provision of freshwater to humans and natural ecosystems. The freshwater vulnerability characteristics will be expanded to include water quality indicators as necessary. The Global Freshwater Initiative will emphasize large-scale water quality issues that impact freshwater availability or ecosystems. For example, regional investigations may consider the problems of nitrate and other nutrients from agricultural runoff as they affect freshwater resources, regional arsenic as a constraint on groundwater use, rivers rendered unusable by pollution, and saltwater intrusion into coastal aquifers.



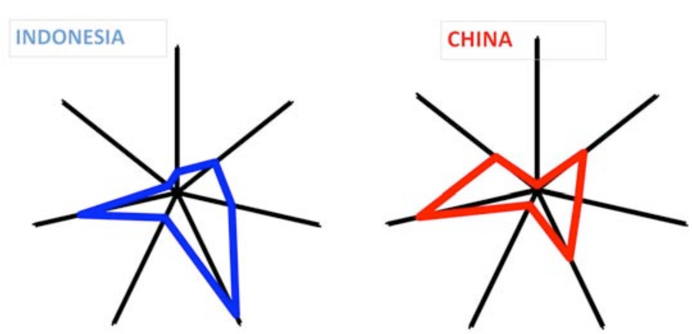


Figure 5: Potential freshwater vulnerability characteristics of five countries for which data were available. The multi-axis approach would be applied to regions in the Global Freshwater Initiative.

4.2 Common research protocol

Each regional investigation (RI) will analyze hydrologic, geographic, economic, and institutional systems in the selected region. Each RI will adopt a common research protocol that will include key components described below: modular models, group model building, stakeholder consultation, selected micro-studies, and common metrics for cross-regional comparison.

- **Modular Models:** RIs will quantitatively assess vulnerability, sustainability, and policy evaluations using integrated assessment models. The integrated assessment models will adopt a common research protocol, but each regional model will be unique and specific. The integrated assessment models will be organized into modules. Each module will encapsulate knowledge from different scientific and policy disciplines. The modules will be developed and calibrated independently using module-specific data first, then interlinked to include appropriate feedbacks. Modularity will allow the independent pieces to adopt spatial and temporal units appropriate to each discipline. A modular approach will also allow researchers to pursue research relevant to their discipline while at the same time highlighting the links that are most important to the system as a whole. For instance, the conceptual model shown in Figure 6 may be an initial starting point.

  Each component of each RI-system will be modeled using appropriate disciplinary tools, spatial and temporal units, and calibrated independently before integrating the modules to quantify feedbacks. The integrated modeling framework will be used to quantitatively evaluate combined influences of changes in driving forces, to assess the impacts of uncertainty, to compare regional systems, and to develop strategies to implement policy adaptations (e.g., tariffs, taxes, quotas, water-rental markets, and water-rights options).

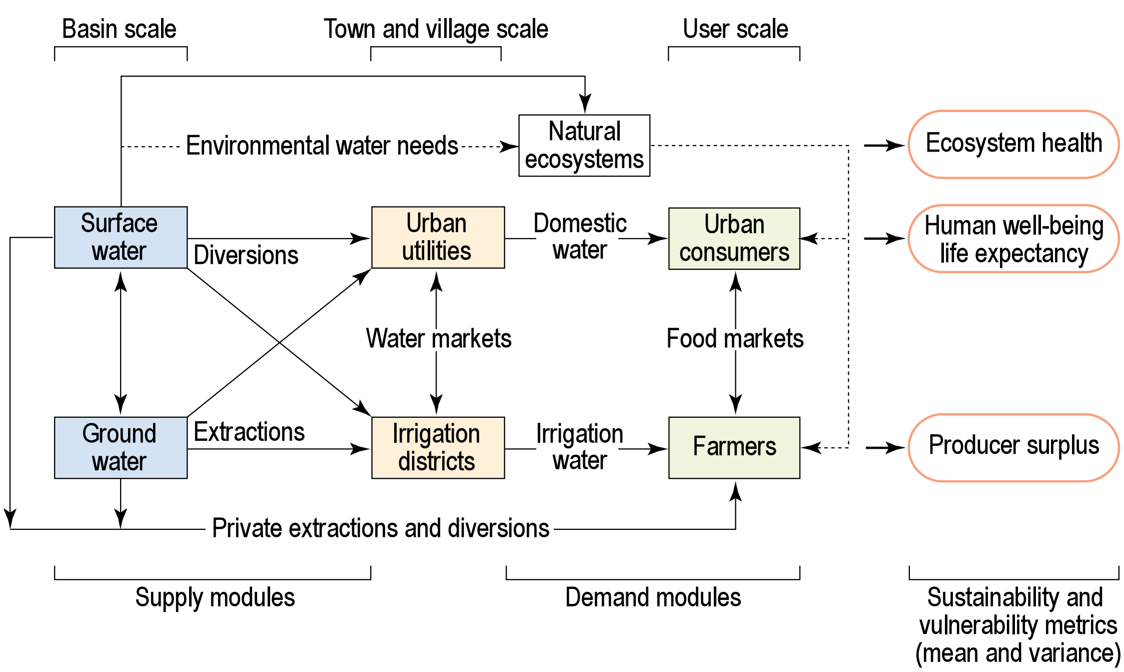


Figure 6: Hypothetical conceptual integrated modular model used in an RI.

- **Group Model-Building:** One of the challenges in integrated assessment environmental models is getting the different groups to agree on an overall conceptual model. We propose using "group model-building" techniques to get the collaborators in each of the RIs to agree on a conceptual model of the system: the key linkages, (unknown) variables, feedbacks, dimensions and scales that are important. The group model-building process will be informed by qualitative studies (narrative, historical, ethnographic, etc.). Involving participants from both social and natural sciences, and using qualitative studies will generate a model that is parsimonious while capturing crucial linkages and feedbacks.

- **Stakeholder consultation:** The RIs will be conducted in collaboration with local scholars, decision makers, and stake-holders so that the results are relevant. RI team leaders will be responsible for developing such collaborations through workshops and partnering.

- **Micro-studies:** The RIs will host "micro-studies" (e.g., the impact of electricity pricing on demand) where appropriate to fill in knowledge gaps about linkages in the system. Each RI will prioritize its micro-studies to focus on the most crucial linkages and feedbacks and will use appropriate disciplinary teams to conduct the research.

- **Policy Analyses:** The RIs will evaluate potential policies for addressing vulnerability and sustainability. Each regional model will be used to assess multiple policy scenarios.

- **Common metrics:** The results of the RIs will be standardized so as to make comparisons across regions. For instance, the RIs will use common definitions, metrics, and units for sustainability, vulnerability, and other outcomes.

5 Cross-cutting studies

The GFI will engage in cross-cutting studies to a) develop generalized insights across RIs, and b) examine a broad range of potential policy prescriptions.

5.1 International Policy Forum

The teams for the various RIs will come together in a yearly policy forum to discuss potential policy prescriptions. A vast array of water policy instruments have been developed, evaluated, and adopted in different regions of the world. Policy instruments have included supply-side measures, such as water markets and shortage sharing agreements, and demand management measures, such as rebates for water efficient equipment and block-rate pricing. The GFI will make it possible to coordinate water policy research across regions. One goal of the policy forum will be to formulate "policy experiments" across regions with similar hydrological and institutional regimes to understand variations in outcome by studying policies that vary in just one or two parameters.

5.2 Natural Experiments

The GFI will illuminate cross-regional comparisons by conducting natural experiments across regions with similar hydrologic and demographic regimes but very different institutional and political regimes and vice versa. For instance, this might allow us to better understand how institutions (say groundwater law) affect user behavior and hence impact the natural system.

5.3 Uncommon Dialogues

The Global Freshwater Initiative will also conduct annual "Uncommon Dialogues." These workshops will bring together researchers involved in the Regional Investigations, as well as external experts and funding liaisons, to facilitate learning across regions regarding: 1) data, model building, and project management, 2) lessons learned on policies and best water management practices, and 3) more abstract generalized insights and theories.

5.4 Models for Global Integration

Regional water sustainability can have global impacts (e.g., on food supply), and the Global Freshwater Initiative will help experts to better understand and model the potential impacts. For example, one of the Co-PIs on this proposal, Scott Rozelle, and his collaborators have been developing a global commodities trade model that can examine the effect of such changes as international trade agreements and the emergence of biofuels on global agricultural trade. The current model, however, does not include a realistic consideration of water resources. The results of the Regional Investigations will help Scott Rozelle and his collaborators to better integrate water resources into the model, which in turn will allow experts, for example, to predict the "impact pathways" of shocks in one part of the world, such as a severe drought in a major rice producing region, on another part of the world. The model, in turn, could then help in better understanding how such impact pathways can affect regional water sustainability.

6 Shovel-ready Projects

While the proposed Global Freshwater Initiative is a long-term 10-year effort, we have two 2-year projects that are shovel-ready and will be undertaken immediately.

6.1 Meta-analysis to classify characteristics of vulnerable water systems

In a preceding section, we described our framework of "Drivers-Characteristics-Impacts" to classify and identify systems susceptible to water crises in the future. The system characteristics presented are tentative, based on our combined expert judgment and available countrywide information rather than systematic regional-scale empirical data. In the first phase of this project, we will refine these system characteristics based on real-world analyses of regional water systems. We will derive a mutually exclusive, collectively exhaustive set that characterizes water systems by conducting an exhaustive analysis of the literature.

We will employ Qualitative Comparative Analysis or QCA, a new analytic technique to implement principles of comparison used by scholars engaged in the qualitative study of macro social phenomena. Scholars engaged in qualitative research typically examine only a handful of case studies at a time. However, their analyses tend to be both detailed (addressing many aspects) and integrative (examining how the different parts of a case fit together). By formalizing the logic, QCA makes it possible to combine the rigor of quantitative approaches and empirical intensity of qualitative approaches to derive general conclusions. QCA has been applied by scholars of complex environmental phenomena. We will collaborate with those who have expertise in QCA in extending these techniques to the study of water crises.

6.2 Integrated modular model of the Hai River Basin in China

Water scarcity is one of the key problems affecting the Hai River Basin in northern China, a key industrial/agricultural region producing about 10 percent of China's total grain output and 15 percent of the nation's industrial output. Hydrological data indicate that the Hai Basin is (by far) in the greatest water deficit of all of China's major watersheds (see Figure 7). Both irrigation and industrial/urban demand for water have increased substantially in the last 50 years and are likely to continue increasing in the future. However, past water projects have tapped almost all of the Hai River Basin's surface-water resources. Given the diminishing supplies of surface water, groundwater has played an increasingly important role in the region's economic growth. As a result, groundwater levels are declining. The combination of policy implementation challenges, complex hydrology, increasing demand and falling groundwater levels in a key economic/social/political region of China make the Hai River Basin a compelling study. We propose an initial study to pave the way for a potential full-scale RI.

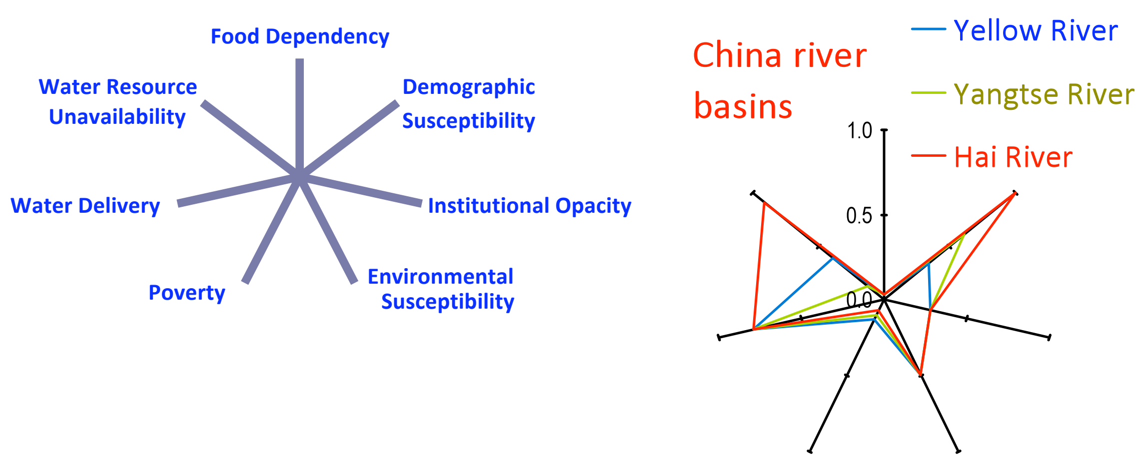


Figure 7: Characteristics of river basins in China.

Addressing the challenges of the Hai River Basin will require innovative approaches. Several concerns and knowledge gaps exist in devising and implementing effective management policies. One major concern is the potential impact of reducing water use on grain production; changes in water use may reduce grain production down to a level that threatens food security—at both the national and household levels. Secondly, there is a concern that simple policies may generate unintended consequences that may offset the original purpose of the policy. Finally, it is becoming increasingly known that the characteristics of each water resource being exploited affect both how water users behave and the effectiveness of policies. Therefore, it is essential to understand the feedbacks between water resource use and economics. The breadth of the issues involved offer a unique challenge: optimizing over different systems (hydrologic and economic) at different scales (user, village, province, and national) with potentially conflicting objective functions (profit maximization, food security, and environmental protection).

We propose a systems approach to the problem that will allow us to address the knowledge gaps as well as promote well-informed policy. One of the benefits of a systems approach is that it would provide insights into the types of "micro-studies" that need to be conducted to strengthen the overall policy prescriptions. A second benefit is that interventions at multiple scales can be compared – e.g., how do programs that pay farmers not to grow compare to a new pricing policy or a North-South water transfer project? Thirdly, a systems approach allows us to develop policies that meet goals and constraints at multiple scales, e.g., to explore the tradeoff between grain self-sufficiency at a province scale versus a regional sustainability objective where groundwater depletion is a problem.

Much of the initial data collections and local collaborations (with the Chinese Center for Agricultural Policy) for this project have been put in place by Co-PI Scott Rozelle.

7 Leadership and Collaborators

Because the meta-analysis is a necessary first step in selecting our Regional Investigations, we have not yet established formal partners in each region. However, the stage has been set for collaboration. As noted above, we feel comfortable beginning the China RI immediately. It will showcase the GFI integrative modeling process. The China RI leader will be Professor Rozelle, who will continue to spend about half his time in China and has already developed essential collaborative links. Professor Gorelick is prepared to lead an Australian RI, should one be selected there. He has numerous contacts in Australia, having spent 6 months in Perth during 2009. He has discussed potential collaborations with the Australian national laboratory (CSIRO), academia (University of Western Australia, and Curtin University), and regional water managers (Water Department). The GFI team will consist of a core-team based at Stanford. Each RI will be led by a principal investigator at Stanford with collaborators from other local universities and research organizations who will provide complementary expertise. Field research will be conducted by Stanford graduate students or students from the study region.

To ensure that the GFI proceeds in an orderly manner, we will initiate the RIs in stages. The China case study will begin in the first year. At least one other case study will then begin as soon as possible. The two initial case studies will be used to finalize the framework, metrics, and comparability across RIs. The remaining three RIs will begin over the first five years. Coordination will be centered at Stanford and will be the responsibility of the GFI PI team.

List of Proposed Directors, Participants, and Collaborators

Proposed Director: Steven Gorelick (EESS),

Proposed Co-Directors: Barton Thompson (Law/Woods), and Scott Rozelle (FSI/Woods)

Other Participants: Gretchen Daily (Bio/Woods), David Freyberg (CEES/Woods), Larry Goulder (Econ), Eric Lambin (EESS/Woods), Gary Libecap (Hoover), Pamela Matson (SES/Woods)

Post-doctoral Fellow: Veena Srinivasan (EESS)

Potential list of outside experts
Economics: Michael Hanemann, Isha Ray, (UC Berkeley), Richard Howitt (UC Davis)
Water Policy: Peter Gleick (Pacific Institute) Sandra Postel (Global Water Policy Project)
Systems Science: Claudia Pahl-Wostl (GWSP)
Hydrology: Ignacio Rodriguez-Iturbe (Princeton)
Water Resources Engineering: Asit Biswas (Third World Water Institute)

Other Related Programs within Stanford
Food Security and the Environment Program: Roz Naylor, David Lobell, Wally Falcon
Natural Capital Project: Gretchen Daily
Water and Sanitation Group: Jennifer Davis
Reducing Vulnerability to Climate Change (Proposed): Steve Schneider, Terry Root

Principal Investigators Bio-Briefs

Steven Gorelick, Cyrus F. Tolman Professor**,** Environmental and Earth Systems Science, Stanford University, and Director of the Global Freshwater Initiative.

Steven Gorelick is the Cyrus F. Tolman Professor in the Department of Environmental Earth System Science at Stanford. He is a hydrologist by training (Stanford '77, '81) with over 25 years of research and practical experience. His "hydro group" conducts research that combines hydrogeology with aspects of ecology, geophysics, operations research, and economics to study meadow restoration, wetland protection, water supply management in Mexico and India, and contaminated groundwater remediation methods. Major emphases of his research group during the past decade have been in the areas of ecohydrology and water allocation in developing nations. Professor Gorelick has co-authored over 100 papers, 3 books, and 3 patents. He is a Fellow of the American Geophysical Union and the Geological Society of America. He was awarded a Guggenheim Fellow ('05) for his work on global oil resources, and is a two-time Fulbright Senior Scholar ('97, '08) for research on freshwater resource problems in Western Australia.

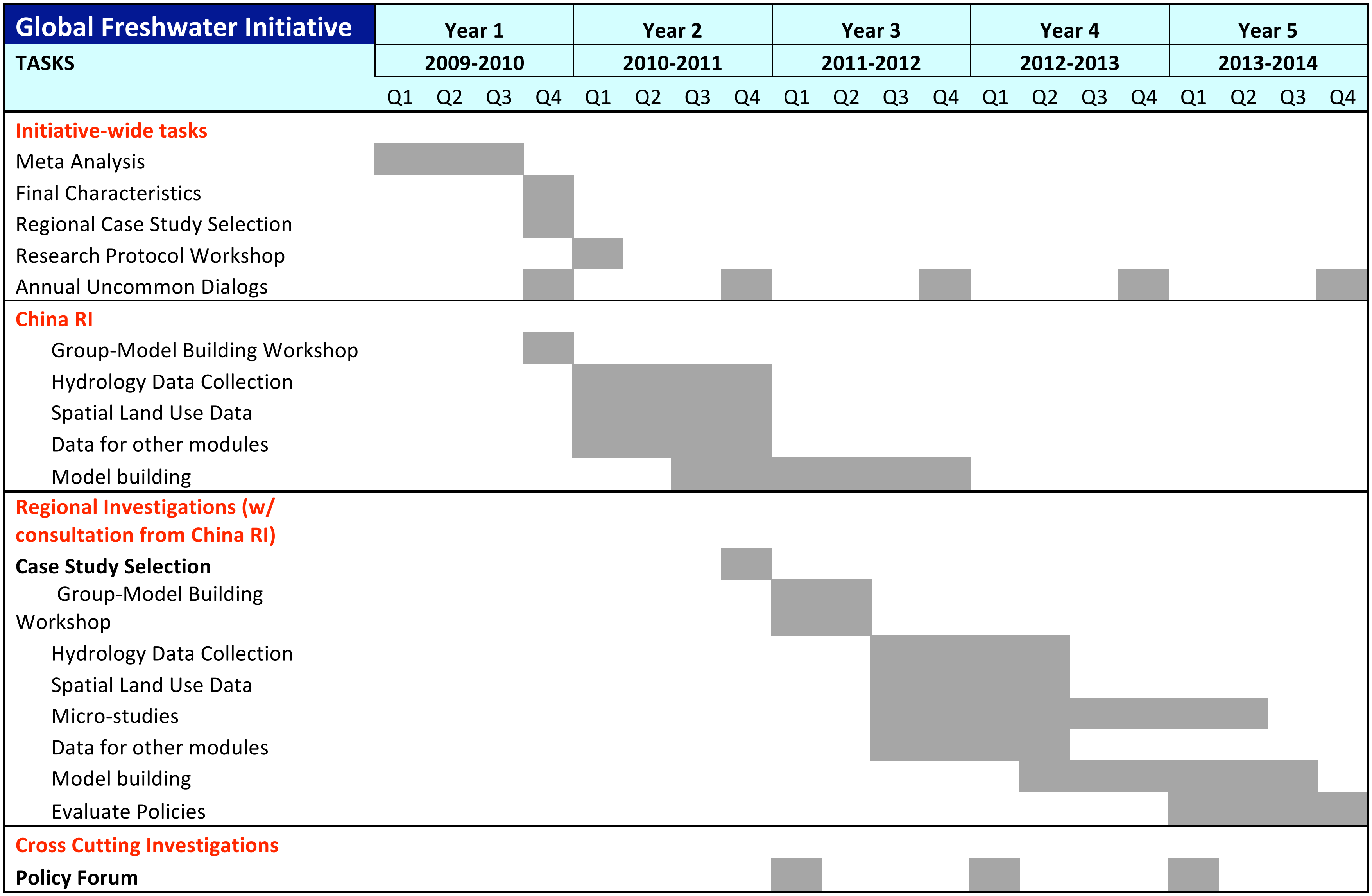
Barton Thompson Jr., Robert E. Paradise Professor of Natural Resources Law, School of Law, Stanford University, Perry L. McCarty Director of the Woods Institute for the Environment, Stanford University, Proposed co-Director of the Global Freshwater Initiative and co-PI

A leading expert in environmental and natural resources law and policy, Barton H. “Buzz” Thompson JD/MBA ’76 (BA ’72) is the author of both a leading textbook and dozens of articles on water resources. His research also focuses on institutional reform and the the use of economic and other alternative techniques for regulating the environment and natural resources. The Supreme Court of the United States has appointed him to serve as special master in Montana v. Wyoming, dealing with the waters of the Yellowstone River. He serves on the board of a number of environmental organizations and foundations and is a member of the Science Advisory Board of the United States Environmental Protection Agency. He holds degrees from Stanford in economics, political science, business, and law. He was a law clerk to the late Chief Justice William H. Rehnquist ’52 of the Supreme Court of the United States.

Scott Rozelle, Professor & Helen F. Farnsworth Senior Fellow, Shorenstein Asia Pacific Research Center, Freeman Spogli Institute. Stanford University, Proposed co-Director of the Global Freshwater Initiative and co-PI

Professor Rozelle is widely recognized as one of the best economist that works on China’s rural economy and rural resources. He has published more than 200 journal articles and several books on the economic, social and political issues in China. He was the Co-PI of the project that conducted the 2001/2004/2007 China Water Institutions and Management Survey and the 2004/2008 North China Water Resource Survey. He worked on designing the survey forms and training enumerators. He has written more papers on the economic of China’s rural water resources and water pricing than any scholar outside of China. In 2007, he was awarded the inaugural Chinese Academy of Science international collaboration award; in 2008, he was given the Friendship Award, the highest honor bestowed on a foreigner for collaborating in China; and in 2009 he was awarded the national science and technology research award.

Timeline


Global Freshwater Initiative
TASKS
Year 1
2009-2010
Year 2
2010-2011
Year 3
2011-2012
Year 4
2012-2013
Year 5
2013-2014
Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4
Initiative-wide tasks
Meta Analysis
Final Characteristics
Regional Case Study Selection
Research Protocol Workshop
Annual Uncommon Dialogs
China RI
Group-Model Building Workshop
Hydrology Data Collection
Spatial Land Use Data
Data for other modules
Model building
Regional Investigations (w/ consultation from China RI)
Case Study Selection
Group-Model Building Workshop
Hydrology Data Collection
Spatial Land Use Data
Micro-studies
Data for other modules
Model building
Evaluate Policies
Cross Cutting Investigations
Policy Forum

Bibliography

Global Water System

Allan J.A., 1998. Virtual water: a strategic resource, global solutions to regional deficits, *Groundwater* **36** (1998) (4), 545–546.

Alcamo J., C. J. Vörösmarty, R. J. Naiman, D. P. Lettenmaier and C. Pahl-Wostl, 2008. A grand challenge for freshwater research: understanding the global water system**.** *Environ. Res. Lett.* **3** 010202 (6pp) doi: 10.1088/1748-9326/3/1/010202.

Alcamo J., P. Doll, F. Kaspar and S. Siebert, 1997. Global change and global scenarios of water use and availability: An application of WaterGAP 1.0. Centre for Environmental Systems Research, University of Kassel, Germany.

Arnell N., 1999. Climate change and global water resources, Global Environmental Change, Volume 9, Supplement 1, October 1999, Pages S31-S49, ISSN 0959-3780, DOI: 10.1016/S0959-3780(99)00017-5.

Cai X., M.W. Rosegrant, 2002. Global water demand and supply projections, Part 1: a modeling approach. Water International **27**(2), 159-169.

Döll P., and S. Siebert, 2002. Global modeling of irrigation water requirements. *Water Resour. Res.* **38** 4 (2002), pp. 8.1–8.10 DOI 10.1029/2001WR000355.

FAO, 2000. New dimensions in water security — water, society and ecosystem services in the 21st Century. Land and Water Development Division, FAO, Rome.

Falkenmark M., 1997. Meeting water requirements of an expanding world population. Phil. Trans. Roy. Soc. London, B. **352,** 929–936.

Falkenmark M. and J. Rockstrom, 2006. The New Blue and Green Water Paradigm: Breaking New Ground for Water Resources Planning and Management. J. Water Resour. Plng. and Mgmt. 132, 129 (2006), DOI:10.1061/(ASCE)0733-9496(2006)132, 3(129).

Gallopin G.C. and F. Rijsberman, 2000. Three global water scenarios. *Water Resources Journal*, **211**, 1–14.

Gleick P. H., 1993. Ed., Water in Crisis: A Guide to the World's Fresh Water Resources (Oxford Univ. Press, New York, 1993).

Gleick, P.H., 2000. *The world's water 2000-2001, the biennial report on freshwater resources*. Washington, DC, Island Press.

Hoekstra A.Y. and P.Q. Hung, 2005. Globalisation of water resources: international virtual water flows in relation to crop trade, Global Environmental Change Part A, **15** (1), April 2005, Pages 45-56, ISSN 0959-3780, DOI: 10.1016/j.gloenvcha.2004.

Huntington T. G., 2006. Evidence for intensification of the global water cycle: Review and synthesis, Journal of Hydrology, **319** (1-4), 15 March 2006, Pages 83-95, ISSN 0022-1694, DOI: 10.1016/j.jhydrol.2005.07.003.

Meinzen-Dick R., and P. Appasamy, 2002. Urbanization and Intersectoral Competition for Water. In Finding the Source: The Linkage between Population and Water,. Washington D.C.: Woodrow Wilson International Centre for Scholars.

Pahl-Wostl C., 2002. Towards sustainability in the water sector––the importance of human actors and processes of social learning. *Aquat. Sci.* **64** (2002), 394–411.

Pahl-Wostl C., 2007. Transition towards adaptive management of water facing climate and global change. *Water Resources Management* **21**(1), 49-62.

Postel S. L., G. C. Daily, and P. R. Ehrlich, 1996. Human Appropriation of Renewable Fresh Water *Science* **271** (5250), 785. [DOI: 10.1126/science.271.5250.785].

Raskin P., P. Gleick, P. Kirshen, G. Pontius, K. Strzepek, 1997. Water futures: Assessment of long-range patterns and problems. Background paper Comprehensive Assessment of the Freshwater Resources of the World, Stockholm Environment Institute, Stockholm, Sweden.

Rogers P., H. Bouhia, and J. Kalbermatten, 2000. Water for big cities: Big problems, easy solutions? In *Urbanization, population, environment, and security: A report of the Comparative Urban Studies Project*, edited by Christina Rosan, Ruble Blair A. and Tulchin Joseph S. Washington, DC: Woodrow Wilson International Center for Scholars.

Seckler, D., U. Amarasinghe, D. Molden, R. de Silva and R. Barker, 1998. World water demand and supply, 1990 to 2025: Scenarios and issues. Research Report 19, Colombo, Sri Lanka, International Water Management Institute, 41 pp.

Shiklomanov I.A., 1997. Assessment of water resources and availability in the world. In *Comprehensive assessment of the freshwater resources of the world*. Stockholm, Stockholm Environment Institute. 88 pp.

Oki T., and S. Kanae, 2006. Global Hydrological Cycles and World Water Resources. *Science* **313** (5790), 1068. [DOI: 10.1126/science.1128845].

Vörösmarty C. J., P. Green, J. Salisbury, and R. Lammers, 2000. Global Water Resources: Vulnerability from Climate Change and Population Growth *Science* **289** (5477), 284. [DOI: 10.1126/science.289.5477.284].

Regional-Scale Investigations

Barnett T. and D. Pierce., 2009. Sustainable water deliveries from the Colorado River in a changing climate. *Proc. Natl. Acad. Sci. USA. May 5, 2009.* **106***(18), 7334-7338.*

Briscoe J., 2005. *India's Water Economy: Bracing for a Turbulent Future*, The World Bank, November 28, 95 pp.

Cai X., 2008. Implementation of holistic water resources-economic optimization models for river basin management - Reflective experiences, Environmental Modeling & Software, **23** (1), p.2-18, January, 2008 [doi>10.1016/j.envsoft.2007.03.005].

Letcher R. A., A. J. Jakeman, and B. F. W. Croke, 2004. Model development for integrated assessment of water allocation options, *Water Resour. Res.*, **40**, W05502, doi:10.1029/2003WR002933.

Marion W. J., J. R. Lund, R. E. Howitt, A. J. Draper, S. M. Msangi, S. K. Tanaka, R. S. Ritzema, and G. F. Marques, J., 2004. Optimization of California's Water Supply System: Results and Insights Water Resour. Plng. and Mgmt. 130, 271 (2004), DOI:10.1061/(ASCE)0733-9496(2004)**130**:4(271).

McKinney D. C., X. Cai, M. W. Rosegrant, C. Ringler, and C. A. Scott, 1999. Modeling water resources management at the basin level: Review and future directions, IWMI, Colombo

Moench M., E. Caspari, A. Dixit, 1999. *Rethinking the Mosaic: Investigations into Local Water Management*. Nepal Water Conservation Foundation and Institute for Social and Environmental Transition (ISET), Boulder, Colorado.

Rosegrant M.W., C. Ringler, D.C. McKinney, X. Cai, A. Keller, and G. Donos, 2000. Integrated economic-hydrologic water modeling at the basin scale: the Maipo river basin Agricultural Economics **24** (2000), 3346.

Ward, F., M. Pulido-Velazquez, 2008. Water conservation in irrigation can increase water use. *Proc. Natl. Acad. Sci. USA. November 25, 2008.* **105***(47), 18215-18220.*

Xu, Z. X., H. Takeuchi, H. Ishidaira, and X.W. Zhang, 2002. 'Sustainability analysis for Yellow River water resources using the system dynamics approach', *Water Resour. Mgmt.* **16**(3), 239–261.

Methods/ Definitions

Brooks N., W.N. Adger and P.M. Kelly, 2005. The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation, *Global Environmental Change* **15** (2005), pp. 151–163.

Forrester J. W., and J. N. Warfield, 1972. "World Dynamics," *Systems, Man and Cybernetics, IEEE Transactions,* **2**(4), 558-559, Sept. 1972.

Goodland R., 1995. The Concept of Environmental Sustainability. Annual Review of Ecology and Systematics 1995 **26**, 1-24.

Kasperson J.X., and R.E. Kasperson, (eds) 2001. *Global Environmental Risk*. United Nations University Press/Earthscan, London.

Parris T. M., and R. W. Kates, 2003. Characterizing and measuring sustainable development. *Annual Review of Environment and Resources* 28:559-586.

Ragin C.C. 2000. *Fuzzy-Set Social Science.* University of Chicago Press.

Rogers P.P. and M.B. Fiering, 1986. Use of systems analysis in water management. Water Resour. Res., **22**(9), 146S–158S.

Simonovic, S.P., and H. Fahmy, 1999. A New Modeling Approach for Water Resources Policy Analysis, *Water Resour. Res.*, **35**(1), 295–304.

Winz I., G. Brierley, S. Trowsdale, 2009. The Use of System Dynamics Simulation in Water Resources Management (2009) **23**, 1301–1323.

Young, O. R., E. F. Lambin, F. Alcock, H. Haberl, S. I. Karlsson, W. J. McConnell, T. Myint, C. Pahl-Wostl, C. Polsky, P. Ramakrishnan, H. Schroeder, M. Scouvart, and P. H. Verburg, 2006. A portfolio approach to analyzing complex human-environment interactions: institutions and land change. *Ecology and Society* **11**(2), 31.

Key Online References and Web Sites

FAO 2007. Comprehensive Assessment of Water Management in Agriculture.
http://www.fao.org/nr/water/art/2007/scarcity.html

Global Water System Project: http://www.gwsp.org/

International Water Management Institute: http://www.iwmi.cgiar.org