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innovations

TECHNOLOGY | GOVERNANCE | GLOBALIZATION

Clear Necessity

Addressing Global Water and Sanitation Challenges

ENTREPRENEURIAL SOLUTIONS TO GLOBAL CHALLENGES

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Organization of the Journal

Each issue of *Innovations* consists of four sections:

1. Lead essay. An authoritative figure addresses an issue relating to innovation, emphasizing interactions between technology and governance in a global context.

2. Cases authored by innovators. Case narratives of innovations are authored either by, or in collaboration with, the innovators themselves. Each includes discussion of motivations, challenges, strategies, outcomes, and unintended consequences. Following each case narrative, we present commentary by an academic discussant. The discussant highlights the aspects of the innovation that are analytically most interesting, have the most significant implications for policy, and/or best illustrate reciprocal relationships between technology and governance.

3. Analysis. Accessible, policy-relevant research articles emphasize links between practice and policy—alternately, micro and macro scales of analysis. The development of meaningful indicators of the impact of innovations is an area of editorial emphasis.

4. Perspectives on policy. Analyses of innovations by large scale public actors—national governments and transnational organizations—address both success and failure of policy, informed by both empirical evidence and the experience of policy innovators. The development of improved modes of governance to facilitate and support innovations is an area of editorial focus.

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John Briscoe

Water Security

Why It Matters and What to Do about It

Hydrology matters. People depend on having an adequate supply of water to grow their food, produce their energy, and sustain their bodies. Rich and poor countries face different hydrological challenges (see figure 1, next page): rainfall in most rich countries is moderate and predictable, whereas many poor countries suffer more frequently from droughts and floods and face higher levels of uncertainty. Compounding the "bad hydrology" problem, most poor countries face a rapid growth in water demand, have small endowments of water infrastructure, have fragile institutions, and confront ever greater variability as the world climate changes. The result is growing water insecurity and more conflicts within and between countries, with the gravest challenges in and between poor countries.

The glass is certainly half empty. But it is also half full, as there is emerging evidence (a) that societies with adequate stocks of infrastructure and robust institutions can adjust to major climatic shocks relatively harmoniously and with modest economic consequences, and (b) that there is huge potential in the development of a new generation of "smart technologies" (involving infrastructure, biology, chemistry, information, finance) for getting greater economic return from constrained supplies.

In short, faced with unprecedented water-security challenges, there is an urgent need for all countries, and especially poor ones, to develop suites of institutions and technologies that are adapted to their cultural, historic, natural, and financial realities and which can bring their people improved and more harmonious development.

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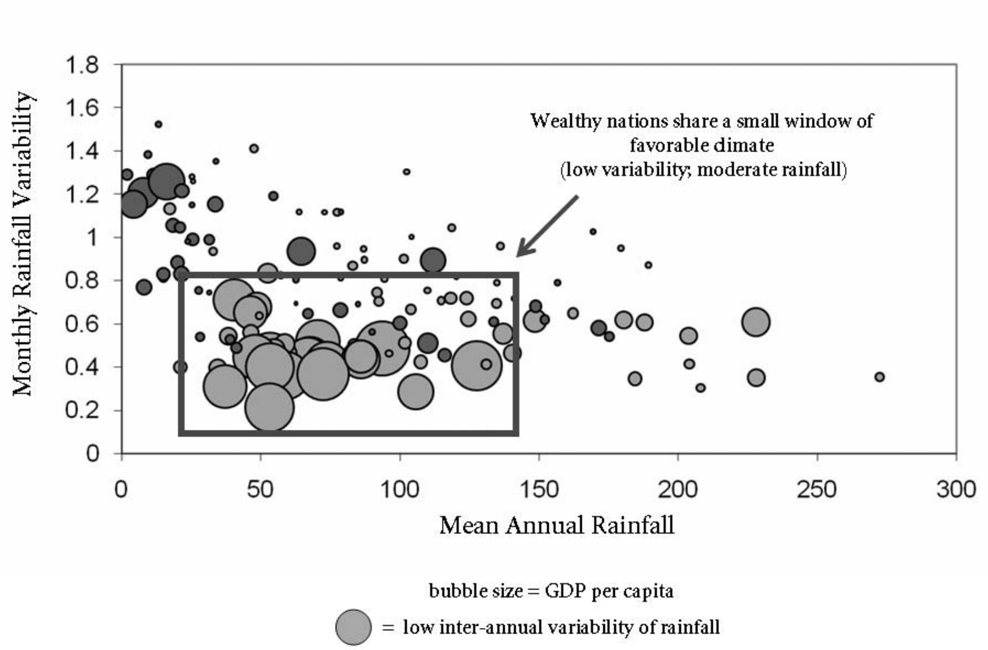

Figure 1. Rainfall Variability and GDP
Source: Brown and Lall, 2008

WATER SECURITY AND ECONOMIC GROWTH

A central challenge for many developing countries facing the "bad hydrology" shown in Figure 1 is to devise and implement a set of interventions that will mitigate the effects of hydrological variability on the lives of their people. Figure 2 provides a typology of such interventions.[1] Type 1 interventions are broad-based water-resources interventions, including dams and canals, that provide national and regional economic benefits to all, including the poor. Type 2 interventions improve water-resources management, such as watershed projects in degraded environments, in ways that directly benefit poor people. Type 3 interventions improve the performance of water-service utilities, which benefits everyone, including the poor. Type 4 interventions provide targeted services, including water and sanitation, irrigation and hydropower, to the poor.

Type 1 Interventions: Broad policies and investments that affect the development and management of water resources. Countries faced with extreme climate variability that do not have "insulating infrastructure" incur large opportunity costs in adapting to the effects of water-induced shocks to the economy. Figure 3 shows how the economy of Ethiopia, for example, depends directly on rainfall. As articulated by a finance minister of India, "Every one of my budgets was a gamble on rain."[2] An obvious and historic response to this rainfall variability is to mitigate the effects by investing in water storage. An informative example comes from

		Nature of intervention	
		Broad	*Poverty Targeted*
Affecting water…	*Resource development & management*	Type 1 Broad region-wide water resource interventions	Type 2 Targeted water-resource interventions
	Service delivery	Type 3 Broad impacts through water service delivery reforms	Type 4 Targeted improved water services

Figure 2. How Water Interventions Affect Poverty
Source: World Bank, 2003

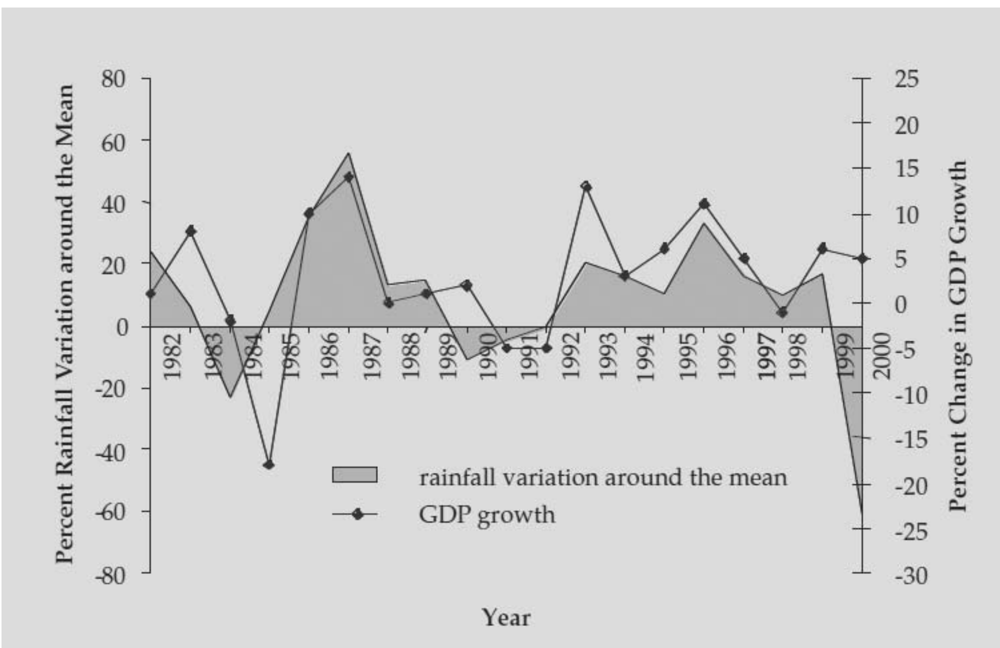

Figure 3. Rainfall Variability and GDP in Ethiopia
Source: World Bank (2006) Ethiopia: Managing Water Resources to Maximize Sustainable Growth, Washington DC

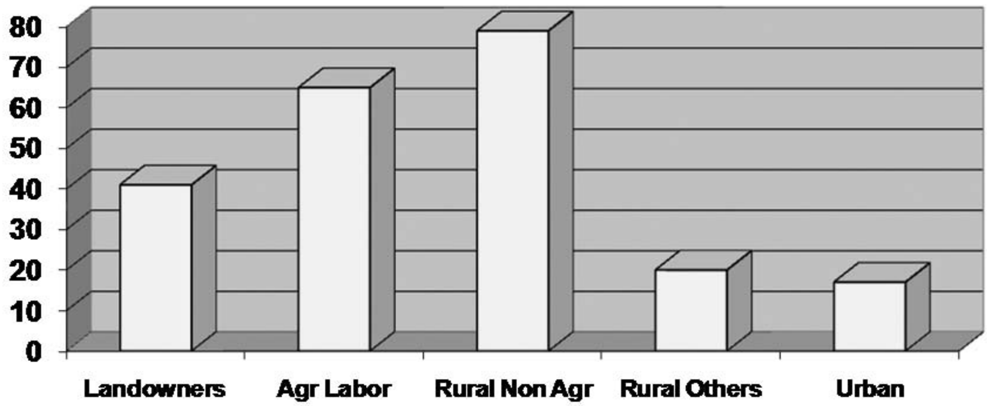

Figure 4. How the Bhakra Dam in India's Punjab Benefits Poor Households
Source: Bhatia et al (2007)

Europe. In temperate Europe, rainfall is relatively regular, and there is natural regulation through lakes, groundwater storage, and wetlands. This natural regulation means that more than 40 percent of runoff is available for productive uses. In the semiarid Iberian Peninsula, the situation is dramatically different, with less than 10 percent of runoff available through natural regulation. The responses have been logical and quite different—the countries of the Iberian Peninsula have 150 times more storage capacity per person than do France, Germany, and the United Kingdom.

Major water-resources projects often form the basis for broad regional development that has significant direct and indirect benefits for poor people (and others). Such projects in Brazil, India, Malaysia, and the United States show large direct benefits—for example, from irrigation and hydropower—and indirect benefits that are typically twice as large. In many cases, poor people benefit enormously from this economic activity. In Petrolina in Northeast Brazil, for example, water infrastructure has been the basis for the development of a dynamic rural economy.[3] This has created a large number of high-quality, permanent agricultural jobs, 40 percent of which are held by women. And for every job in agriculture, two jobs have been created in the supporting commercial and industrial sectors. These opportunities have meant a reversal in the historic pattern of outmigration, with the benefiting districts growing at twice the state average. Similarly, in India, water infrastructure has evened out the seasonal demand for labor, with the poor, who do not benefit directly, being the greatest overall beneficiaries of these investments (Figure 4). The tentacles of such projects reach deep—irrigation infrastructure, for example, has had a major impact on the returns to investments in education in India. The return to five years of primary schooling versus no schooling in Indian districts where agricultural conditions were conducive to the adoption of Green Revolution technologies was high (32 percent), whereas in districts where conditions were not conducive, estimated returns to schooling were negative.[4] This multitude of direct and indirect effects has a striking impact on poverty: in unirrigated districts, 69 percent of the people are poor, while in irrigated districts, poverty drops to 26 percent. It is these broad, systemic effects that have made water-related infrastructure an essential building block for regional and national development in many OECD (Organisation for Economic Co-operation and Development) countries (Japan, the Netherlands, Norway, Spain, the western United States, and others) and in some developing countries (among them Brazil, Egypt, Mexico, Pakistan, South Africa, and Thailand).

Type 2 Interventions: Poverty-targeted policies and investments that affect the development and management of water resources. Better management of water resources requires greater attention to management of the land-water interface. Services provided by hydraulic infrastructure are dependent on how land in the catchment is managed, and communities living in vulnerable land-water environments, such as eroded mountains, salinized plains, and the floodplain, can benefit from the improved opportunities that arise when local land and water resources are managed more effectively. Projects that improve the quality of the land and water resources simultaneously increase the livelihoods of poor people (who constitute a large proportion of the population in these degraded environments).

Most poor countries face a rapid growth in water demand, have small endowments of water infrastructure, have fragile institutions, and confront ever greater variability as the world climate changes.

Two projects in the Ganges Basin are outstanding examples of the success of such approaches. The Shivalik Hills Watershed Management Project reduces erosion from these young mountains, simultaneously increasing groundwater recharge and improving the livelihoods of poor people. The major investments are in building terraces, establishing check structures in eroded ravines, planting vegetative cover on denuded hills, building small dams, and digging wells and canals that make better use of the preserved water resources. The Uttar Pradesh Sodic Lands Reclamation Project on the plains works with poor people living in areas where land has been degraded by salinization. The project organizes groups of landless farmers into small cooperatives and provides technology and advice on land reclamation. A notable feature of the project is that while the men in the farmers' cooperatives failed to manage the important credit component, women's microcredit groups have filled the vacuum and constitute an indispensable element in the overall success of the project. Finally, early efforts at better management of ecological flows from dams have had impressive results for poor people. Fishers below the Manantali Dam on the Senegal River in Mauritania, for example, saw their annual catches increase from 10 tons a year to 110 tons after the operating rules for a hydropower dam were changed to allow for artificial floods. The bottom line is that there are many opportunities for simultaneously improving resource management and the lives of poor people.

Type 3 Interventions: Broad policies and investments that affect the development and management of water services. Poor people suffer most when water services—water supply, irrigation, and hydroelectric power—are managed poorly. In city after city in the developing world, unserved poor people pay ten or more times the price for a liter of water than do their fellow citizens who are served by formal supplies. The corollary is that poor people benefit immensely when they live in a town where water is supplied by a modern, accountable, and financially viable utility that can extend services to a large number of users. To cite just one case, the concession contract in Buenos Aires meant that 1.5 million more people (most of them poor) gained access to piped water and that 600,000 more people (most of them poor) gained access to sewer connections. Put simply, effective water-utility reform—whether in the public sector (as in Uganda) or the private sector (as in Chile) or, increasingly, through a combination of public and private actions (as in Sao Paulo, Brazil)—means substantial benefits for poor people. The irrigation story is more complex, because water services are just one of several critical inputs, along with seeds, fertilizer, information, credit, and marketing. A particularly interesting case is the irrigation projects in Northeast Brazil, where the initial model—five-hectare lots to poor farmers—was ostensibly pro-poor but in fact meant that expensive infrastructure was being used for subsistence agriculture, because the poor farmers were unable to solve endemic technology, credit, and marketing problems. An apparently anti-poor change in policy (auctioning off 50 percent of new areas to commercial farmers) ushered in a growth-stimulating and poverty-reducing cycle. The commercial farmers were able to address the issues of technological innovation, credit, and marketing, and poor farmers benefited in two ways. First, the poor farmers piggybacked on the opportunities created by the commercial farmers, often becoming their subcontractors. Second, the poor farmers benefited by finding employment in the industries that grew up to supply inputs (land, machinery, seeds, fertilizers, pesticides) and process the products of this now-dynamic agricultural sector. The key conclusion is that reforming the way water services are provided can help stimulate growth for all.

Reforming the way water services are provided can help stimulate growth for all.

Type 4 Interventions: Poverty-targeted policies and investments that affect the development and management of water services. Poverty-targeted policies and investments are the classic and most obvious ways water projects reduce poverty. Those who are excluded from formal services—always poor people—typically pay much more for water than those who receive formal services—always the better off. Poverty-targeted rural and urban water and sanitation projects are thus very

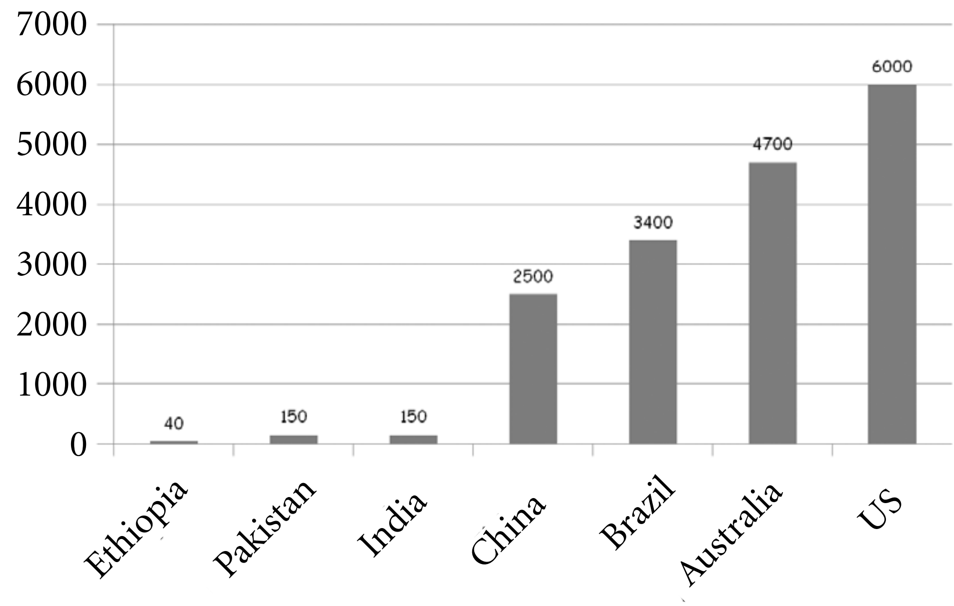

Figure 5. Endowments of Water Infrastructure (cubic meters of water storage capacity per capita)
Source: World Bank analysis

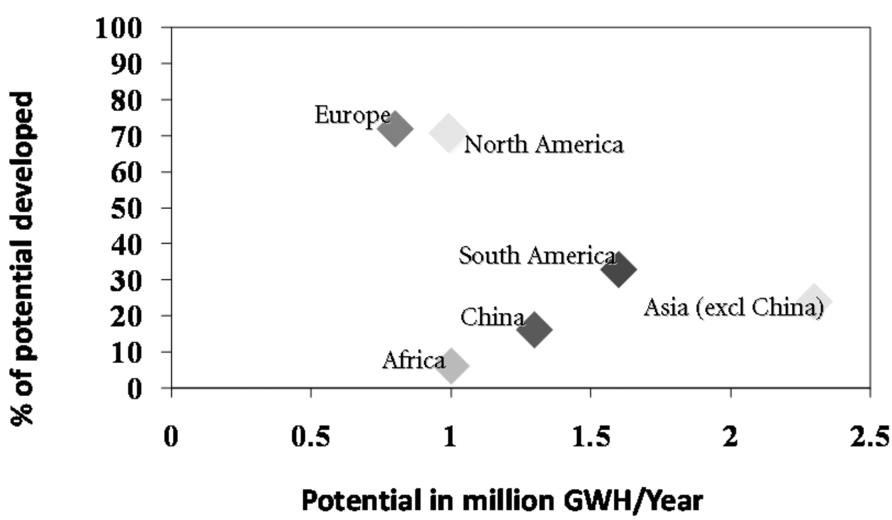

Figure 6. Development of Economically feasible Hydropower Potential in Different Regions
Source: World Bank analysis

important for the poor and are almost always accorded high priority by poor communities. Examples of innovative approaches abound, ranging from the provision of low-cost sewers in Orangi in northwestern Pakistan and in Brazil to behavior-modifying approaches such as Total Sanitation in Bangladesh, where village signs warn that "we do not marry our daughters to boys from villages that still practice open defecation!" Similarly, giving smallholders access to improved and appropriate irrigation technology, such as treadle and diesel pumps, has an important impact on the lives of poor people.

An appropriate strategy for countries to adopt is a blend of the four types of intervention described above: managing both resources and services, in each case intervening in a broad, systemic manner that directly targets the poor. For example, well-conceived water infrastructure should:

- Provide the basis for overall regional development and associated economic opportunities for poor people (Type 1 benefit)
- Have components that aim at improving watershed management, with associated benefits for the poor people who usually constitute the majority of those living in such degraded environments, and at developing operating rules that specify ecological flows for the benefit of downstream riparians.(Type 2 benefit)
- Be associated with reform of the irrigation, power-supply, and water-supply sectors, with broad benefits for poor people (Type 3 benefit)
- Provide targeted benefits to poor people who are resettled or otherwise affected by the project or who live in the vicinity of the project, and generate revenues that are dedicated in part to specific pro-poor activities (Type 4 benefit).

Who is Helping?

Recent decades have seen a bifurcation in the developing world. Some countries—including China, India, Brazil, and Mexico—have made striking progress and now have little difficulty raising domestic and international capital to meet their development needs. These countries have all pursued variants of the tried-and-tested "commonsense" development path followed by now-rich countries. They have invested in infrastructure, in agriculture, and in education. Growth has been strong and persistent, with spectacular reductions in the number of poor people.

On the other hand, there are many poor countries whose economies have not grown and where deep poverty persists. These countries remain heavily dependent on a foreign-assistance model that follows a quite different development philosophy, in which the social cart comes before the economic horse. Two examples from the water sector illustrate this. First, consider the issue of major water infrastructure. Figures 5 and 6 (page 9, above) show the massive gap between now-rich and poor countries. As the "red-green" coalitions led by single-issue NGOs in rich countries have become prominent in the development community, the World Bank, the regional banks, and bilateral financing agencies have effectively withdrawn from this business (as illustrated in Figure 7). The better-off developing

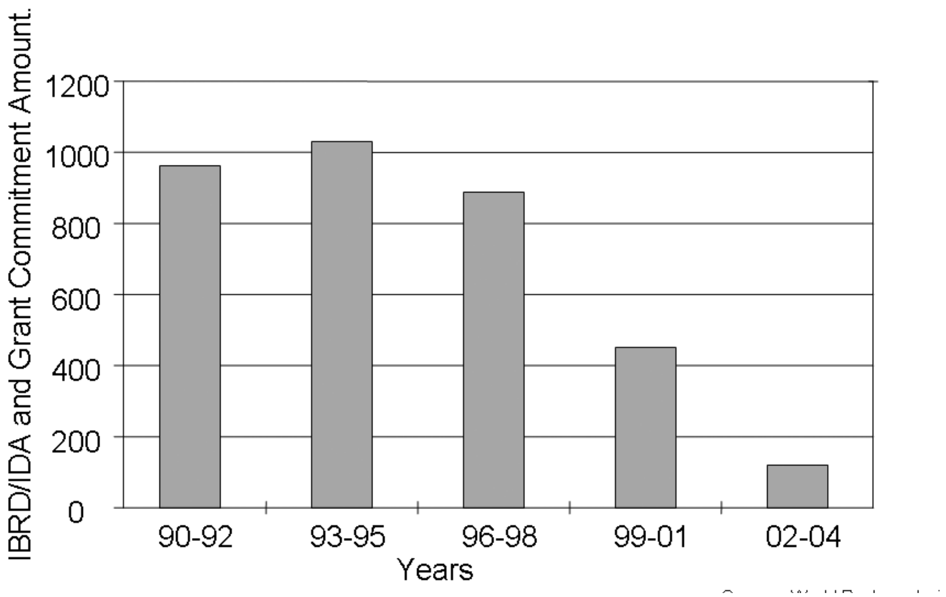

Figure 7. World Bank Lending for Hydropower
Source: World Bank analyses

countries "with choices" have gone ahead with their own resources; the poor developing countries "without choices" have been stranded and buffeted (as shown for Ethiopia in Figure 3) by their highly variable hydrology.

The story on agriculture is similar. Development assistance for agriculture has been reduced by about 75 percent over the past 30 years (Figure 8, next page), primarily because aid agencies have given priority to social needs over production, and because environmental NGOs do not like modern agriculture. Brazil provides a striking example of the different path taken by countries "with choices." Over the past 30 years, Brazil has become an "agricultural superpower,"[5] with the value of agricultural output increasing by 300 percent. Just 10 percent of this increase has come from increased inputs (land, machinery, seeds, fertilizers, pesticides, and labor), with 90 percent coming from increased efficiency. Underlying these increases is a large and consistent national investment in agricultural research—a striking contrast with the "flavor-of-the-month" approach favored by aid donors.

The current economic crisis has brought to the fore the changing global economic geography. "Who would have imagined," mused President Lula of Brazil, "that the IMF would be begging Brazil for a loan?" As the middle-income countries (MICs) have grown, they have become major sources of development financing. China has a trillion dollars of reserves, and Brazil's national development bank (the BNDES) now lends around $70 million a year, about twice the amount the World Bank Group lends globally. In the process, the MICs have started to fill the niches abandoned by the politically correct traditional development agencies. After decades of having to jump through endless hoops, African and Asian countries can now have major water infrastructure financed and built by China and Brazil—and

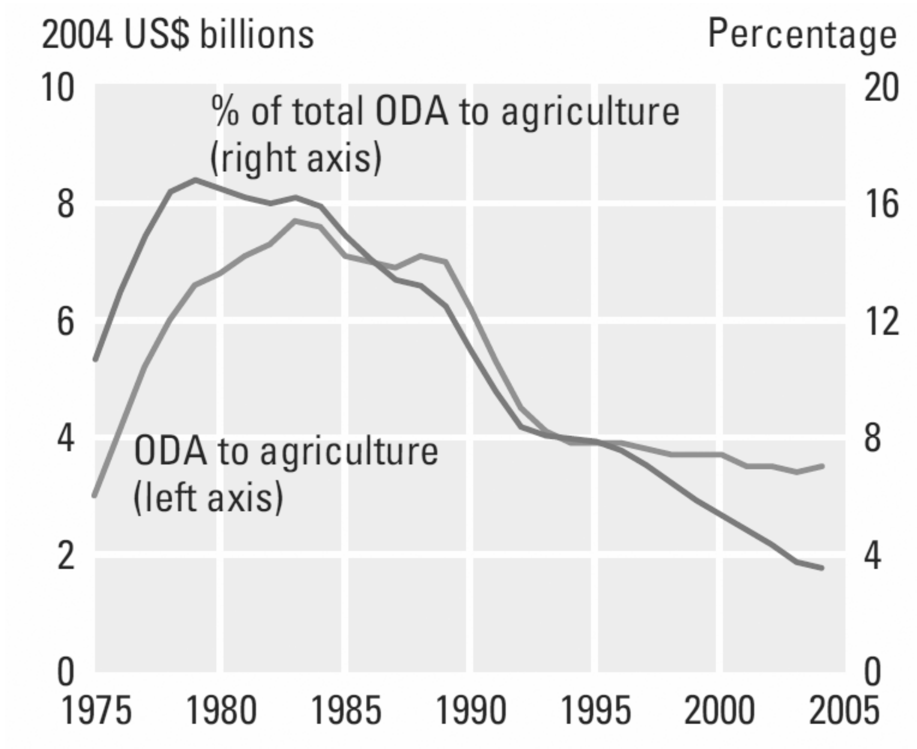

Figure 8. How Donors Reduced Support for Agriculture
Source: World Bank (2008)

built rapidly. China now participates in the building of about 200 major dams around the developing world, a number that is orders of magnitude greater than all of the dams supported by traditional development agencies.

KNOWLEDGE NEEDED TO UNDERSTAND AND ENHANCE WATER SECURITY

Imagine the task facing the "water tsar" of a country facing water stress. How would this water tsar need to conceptualize the challenge and what information would he need? While water challenges are highly location specific, some general categories of knowledge are needed. Figure 9 shows that the tsar needs (1) a broad, integrated conceptual understanding of the water challenge, and (2) information on (a) the historical context of water in his country and how this conditions the way people conceive of water problems and potential solutions; (b) the exogenous factors that determine the quantity and quality of water available; (c) the endogenous instruments he has available to influence the supply of and demand for water and the balance of these; and (d) the consequences of different strategies for major outcomes, such as economic growth, human health, food security, and migration.

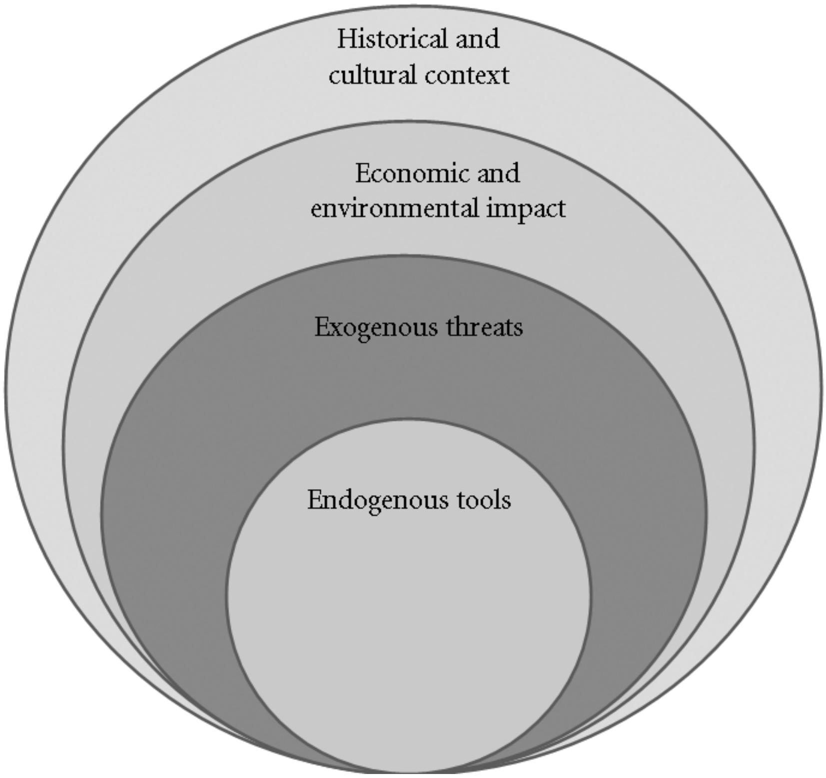

Figure 9. Addressing Water Security

Let us explore what is known about each of these and where innovation is needed to equip our water tsar.

Requirement 1: Understand the historical and cultural context. The interaction between hydrology and society is deep and ancient, and it profoundly conditions the ways that water management is envisioned. It thus conditions the policy options a government can exercise in its management of water. As one of a host of examples, consider the fact that the anagram for "water" is an integral element of the anagram for "*zhi,*" which means "political order in China."[6] Popular history has it that the emperor who failed to control the waters, especially floods in the Yangtze basin, was an emperor whose reign would soon end. This cultural understanding of the intertwined nature of water management and political legitimacy explains what the Three Gorges Project means in China and why building the project was an obsession for all modern Chinese leaders, including Sun Yat Sen, Mao Tse Tung, Deng Xiao Ping, and Li Peng. Seen in the West primarily as a massive hydropower project, power is a secondary benefit to the Chinese. The reservoir's operating rule is set primarily to increase the security of downstream populations against the ravages of floods, but the deeper, subliminal message is that a government that can tame the waters of the Yangtze is a government that can secure social order.

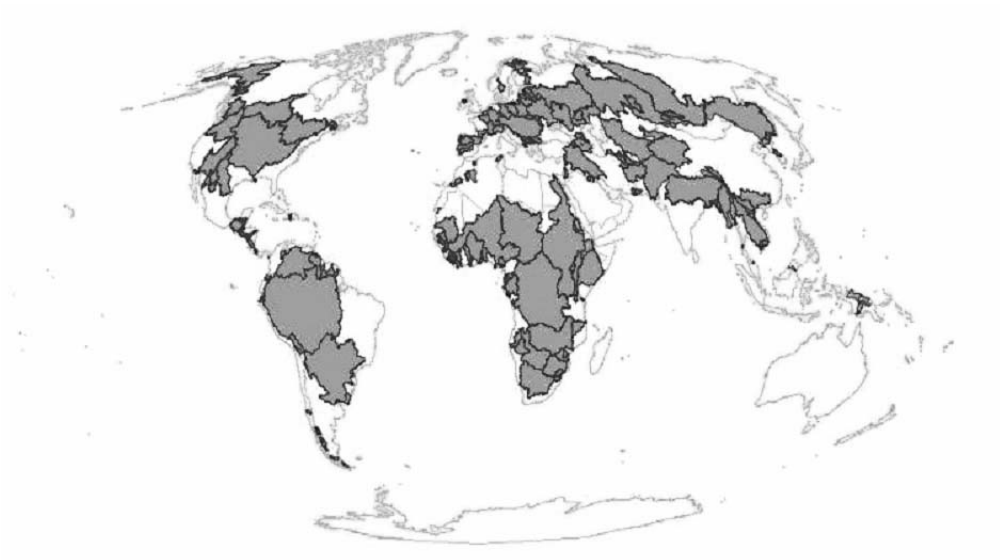

Figure 10. The 260 International River Basins of the World
Source: <www.transboundarywaters.orst.edu>

The management of water in India's Krishna Delta reveals similar deep cultural messages. This cyclone-ravaged area was historically one of India's poorest. In the mid-19th century, Arthur Cotton, a British military engineer, built a barrage at the top of the delta, providing secure irrigation services that transformed the area into one of the richest in the country. Ganesh, the elephant-headed god of prosperity, remains the most popular deity in the area, but he has competition from Arthur Cotton, who is worshiped for the security and prosperity he brought to the people of the delta. Cotton's story serves as an example for what a water tsar might do. When the water minister of the State of Andhra Pradesh was trying to convince me that the World Bank should fund an irrigation project, he took me to a statue of Arthur Cotton, noted his deification, and said, "This is what happens to people who build irrigation projects here!"

A study of society's relationship to water puts contemporary water fashions into context. Harvard historian David Blackbourn's (2006) book on the evolution of land and water in Germany shows that the natural landscape of Prussia, the preservation of which is so ardently defended by environmentally conscious Germans today, is in fact a man-made environment where drainage and flood-control projects executed by the Dutch converted an uninhabitable, malaria-ridden swamp into today's more palatable landscape. Blackbourn also shines light on the dialectic nature of water management, in which each successful response gives rise to new challenges. He suggests that every water manager should understand the natural and social history of water management in their environment: "The

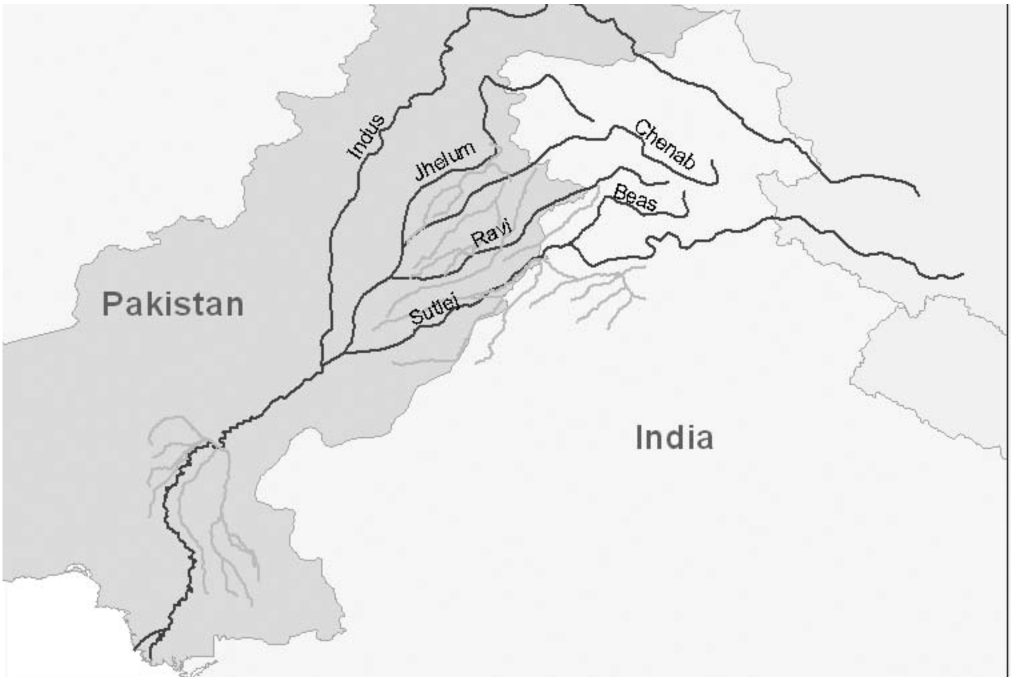

Figure 11. How Partition of India and Pakistan Cut Across River Basins
Source: Briscoe and Qamar, 2006

state of [the] art [of water management] is always provisional, . . . something that historians know well, but hydrological engineers [have] found hard to accept" (p. 68).

Requirement 2: Understand exogenous threats. Armed with an understanding of the historical and cultural context of water management in his country, the next task for our water tsar is to understand the exogenous threats to the quantity and quality of water available to manage.

Diplomacy and conflict management

The first reality is that many management jurisdictions (countries or states) depend on water that arises elsewhere. Figure 10 shows that a large percentage of the globe is covered by international river basins and that a much larger percentage is covered by equally difficult-to-manage interprovincial basins. This is the stuff of the projected "water wars" so beloved by journalists.[7] Consider Pakistan, a country whose very existence is a consequence of development of the waters of the Indus and its five main tributaries. As shown in Figure 11, the hastily drawn line on the map, which demarcated Pakistan from India in 1947, paid no attention to hydrological integrity. The main irrigated areas ended up in the Pakistan Punjab and the headwaters mainly in India and in the disputed province of Kashmir, as well as in China and Afghanistan. This hydrogeography posed a massive threat to Pakistan's very existence. For ten long years, Pakistani and Indian engineers worked with the World Bank to devise the Indus Waters Treaty, signed by Jawaharlal Nehru, Muhammad Ayub Khan, and the World Bank in Karachi in 1960. The treaty sanctified an ugly transformation, with the three eastern rivers given in their entirety to India and the three western rivers to Pakistan, and included the commitment of large amounts of resources from Pakistan, India, and the international community to build the required two large dams and massive link canals in Pakistan. Ugly it was, but practical it has turned out to be, with the treaty being one of the few examples of effective cooperation between India and Pakistan. But, as with all matters watery, every achievement is provisional, and the Indus Waters Treaty is now coming under unprecedented stress as a result of the heavy development of hydropower in Kashmir.[8]

The Himalayan glaciers are retreating and are expected to be only one-third of their present size by 2050. The Himalayas are the "water towers" for the Indus, Ganges, Brahmaputra, Irrawaddy, Mekong, Yangtze, and Yellow rivers. Since these river systems serve the vast populations of the Indian subcontinent, Southeast Asia, and China, the implications of glacial shrinking is of massive importance.

Similar challenges exist at all levels. In India, for example, the allocation of water among states—which, under India's constitution, have primary responsibility for water in their territories—is a mess. There is no clearly established process and there is a high degree of unpredictability, which leads to enormously costly "gaming" strategies and massive inefficiencies. At a 2005 discussion of a World Bank report titled "India's Water Economy: Facing a Turbulent Future,"[9] India's then–finance minister described how his country is "facing a growing set of little civil wars over water," and the then–minister of water resources bemoaned his fate "as minister of water conflicts."

While the details vary by place, the phenomenon of growing conflict over finite resources is a ubiquitous reality. There are two main lessons for our water tsar, which will be fleshed out, as always, taking local cultural, legal, and natural conditions into account. The first lesson is that there must be a stable, predictable assignment of water rights to the states involved. This is the hallmark of major international water treaties, such as the Indus Waters Treaty, and of interprovincial treaties, such as those that govern the Colorado River in the United States or the Murray-Darling River in Australia. The second lesson is that the principle that "water must be managed in an integrated manner in the river basin," which is beloved by contemporary hydrologists and environmentalists, is seldom practical. The primary requirement is that the responsibilities assigned in such agreements conform to the realities of the exercise of political and administrative power (typically countries and states or provinces). As with so much else, our water tsar must be practical and must be aware that the best can easily become the enemy of the good.

Climate change

Managing known hydrological variability has always been difficult and is seldom achieved. Now, however, our water tsar is faced with another overlay of uncertainty, as climate change brings shifts in the average quantities of water and greater variability. Consider two emblematic cases—the Himalayas and the Amazon.

The Himalayan glaciers are retreating and are expected to be only one-third of their present size by 2050. The Himalayas are the "water towers" for the Indus, Ganges, Brahmaputra, Irrawaddy, Mekong, Yangtze, and Yellow rivers. Since these river systems serve the vast populations of the Indian subcontinent, Southeast Asia, and China, the implications of glacial shrinking is of massive importance. Climate models show that rainfall is likely to increase substantially in large parts of the Himalayas, offsetting concerns about absolute shortfalls, although concerns about critical low flows and floods remain in many places. But what stands out as the most striking challenge is that of the Indus River, where snowmelt contributes almost half of the flow. Local drill-downs show an alarming situation for Pakistan, which already suffers from water scarcity and where glacial retreat will mean that flow is likely to fall by around 30 percent within 100 years. Our water tsar and his counterparts across this vast area certainly need to invest heavily in understanding what climate change will mean for the water they manage.

The Amazon presents a different but equally interesting case. Brazil's economic growth is heavily dependent on its benign hydrology—90 percent of its electricity is generated from hydropower, and moderate predictable rainfall is a major factor in its global leadership in agriculture and biofuels. An examination of cloud dynamics shows that the major source of rainfall to the plains of Brazil (and Argentina) is from the reevaporation of rain that falls on the Amazon forest, with the clouds then hitting the Andes and sweeping southward to the plains to deposit their moisture. A reduction in forest cover will change this balance, sending more water directly back to the Atlantic in the form of runoff and reducing reevaporation, and thus the moisture that makes its way to the plains. Brazil's water tsar will need to have good information on this, both to plan for the changed hydrological regime and to advocate for local and global actions that will limit deforestation.

Requirement 3: Deploying all tools in the water manager's tool box. Armed with good knowledge of the cultural context of water, equipped to deal with conflicts over transboundary waters, and understanding climate change, our water tsar now has to assess what is in his tool box to maximize water security in his country.

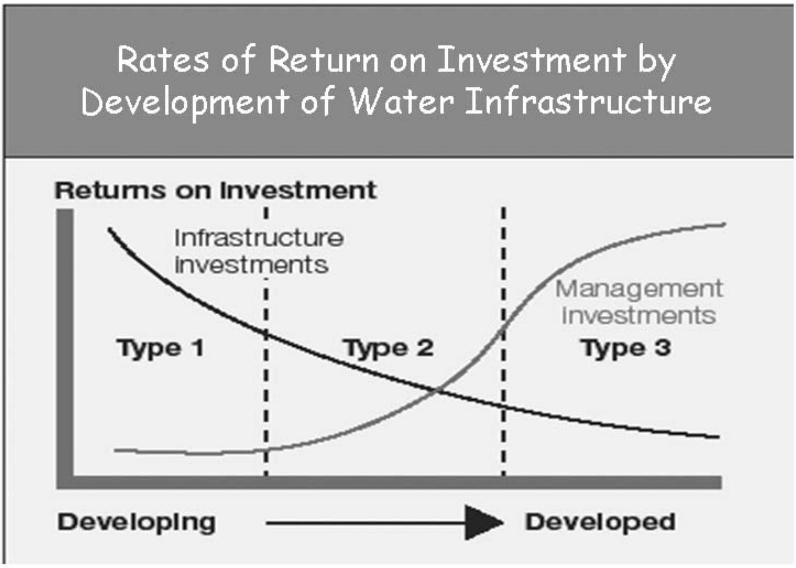

Figure 12. Sequencing of Infrastructure and Institutions
Source: World Bank (2003)

Broadly speaking, a water manager has two categories of tools—management instruments and infrastructure. In the context of a discussion on World Bank water policy, Chinese experts developed Figure 12 to make the point that physical infrastructure is a precondition for management of water and to highlight the dangers of rich countries (at the right end of the spectrum) prescribing priorities for poor countries (at the left end of the spectrum).

Tools to be deployed I: "Dumb" infrastructure

As suggested by Figure 12, a minimum platform of traditional ("dumb") physical infrastructure—dams, canals, hydropower plants, irrigation canals—is a precondition for management of hydrological variability and for reaping the economic benefits of water. Every currently rich country has made these investments; many developing countries have yet to do so. Figure 3 shows the consequences of infrastructure deficiency for economic security in Ethiopia, Figure 5 shows the vast differences in the capacity of rich and poor countries to store water, and Figure 6 shows similar differences in capacity to generate hydropower. Developing countries deeply (and correctly, in the view of this writer) resent rich countries, "at the right end of the spectrum" (Figure 12), who have invested massively in hydraulic infrastructure, telling poor countries "at the left end of the spectrum" that they should not make such investments.

Our water tsar necessarily and appropriately must try to construct a platform of water infrastructure in his poor country. Official development assistance agencies, pressured by the NGOs of rich countries, have instituted a suffocating set of rules that means that such agencies have become unreliable and costly forms of such investment financing.[11] Figure 7 shows the precipitous decline of World Bank lending for hydropower in the 1990s.

The rise of the middle-income countries and their increasing voice in institutions like the World Bank have started a process of reengaging such institutions with infrastructure. Much of this engagement, however, is either rhetorical or with low-risk projects. Until the regulatory spaghetti of so-called safeguards is modernized, however, such institutions will play a diminishing role. Fortunately, as described earlier, the MICs are becoming dominant sources of financing and expertise.

Economist Lawrence Summers has correctly discerned that the difference between developing countries that have progressed and those that have not is primarily in their respective capacities to implement. Here the Chinese excel, with their client countries getting high-quality infrastructure built and benefits delivered fast, which contrasts with the decades it takes to implement the few projects still financed by the World Bank and OECD donors. Our water tsar would certainly mobilize financing and expertise from China or one of the other MICs to build the infrastructure platform necessary to achieve water security in his poor county.

Tools to be deployed II: Institutions and management instruments

For countries that have a minimum platform of infrastructure, the key challenge is to develop institutions and instruments for enhancing water security. As is evident from Figure 1, insecurity from excess water due to floods is a profound cause of underdevelopment. Paradoxically, in a world dominated by concerns about water scarcity, excess water—floods—is a more accurate predictor of economic insecurity. As Deepak Lal (2005) has shown in his economic history of India, it was much easier and cheaper to move water to arid areas than it was to protect flood-prone areas. Thus agricultural growth in India has taken place in the dry northwest and west, while agriculture (and economic development) has foundered in flood-prone Bihar and West Bengal. In the same vein, a recent analysis of the flow of "virtual water" (water embodied in crops) in India shows that virtual water, paradoxically, flows from dry states to wet states. In dealing with the insecurity of excess water (a problem likely to increase in many places as a result of climate change), our water tsar can look to successful examples as varied as Japan, where reservoirs play a major role, to Bangladesh, where better land-use and settlement management has led to a huge reduction in deaths from flooding, and where floodwater stored in aquifers has fueled massive increases in agricultural output.

The flip side of the coin is the problem of scarcity and the associated challenges of creating instruments that signal to potential users the opportunity cost of water and providing incentives for rational allocation and efficient use. The professional and popular literature is full of exhortations to "fully price water." These exhortations are appropriate for situations where urban and industrial uses dominate, but they are largely irrelevant for the big problem, which is efficient use of water in agriculture, which accounts for about 70 percent of water use in developing countries. This is because the financial cost of providing agricultural water, which is the only thing that users will agree to pay, is, under conditions of scarcity, just a small fraction of the opportunity cost of water. In Australia's Murray Darling Basin, water charges to agriculture are about 1 U.S. cent per cubic meter, whereas the opportunity cost is over 30 U.S. cents per cubic meter.

The most effective way to induce efficient use of water in agriculture is to assign water rights to farmers and give them the right to trade these rights (subject to regulation that protects the rights of third parties and environmental uses). The Murray Darling Basin instituted such a rights-based system 30 years ago and now has the most sophisticated arid water management system in the world. Because rights are clearly assigned and tradable, water moves in voluntary transactions between sellers and buyers to higher-valued uses. This system has been severely tested by the unprecedented decade-long drought in South-East and Western Australia. Farmers in New South Wales, Victoria, and South Australia now receive about 70 percent less water than they did a decade ago, but the economic value of agricultural production has been almost unaffected. This is because the incentive system is clear and the market operates. As water has become scarce, the price at which water is traded (both seasonally and permanently) has risen, and water has moved out of low-value uses (such as growing rice) to high-value uses (such as growing fruits and vegetables). Other countries and parts of countries—the western states of the U.S., Chile, Mexico, Oman, and now Maharashtra State in India and Punjab State in Pakistan—are following the same model to varying degrees.

Countries moving toward such rights-based systems face critical design choices. Transactions costs matter a lot for the degree to which scarce water will move to its highest-value uses. In New Mexico, where the state water engineer approves water sales, transactions costs are much lower (and transactions much more frequent) than in Colorado, where such transfers are adjudicated by the courts.

As water becomes treated as an economic resource, an important complementary challenge arises from concerns about food security in large countries such as India and China. To free-market fundamentalists, this is a false problem. But in the real world, the fact is that domestic production of food grains is a must for large countries with huge populations, whose demands would overwhelm a shallow and often-politicized world grain market. The situation of China and India is quite different from that of "niche countries" like Australia and Chile, whose demands for grain are small and who can rely on pure market forces. Water scarcity is already a reality in the granaries of western India and northern China, with alarming declines in groundwater tables. As is happening in northern Maharashtra, these areas are moving toward high-value crops and away from grains. This is an important and appropriate change. However, it must be accompanied by accelerated agricultural development programs—including irrigation—in water-rich and previously neglected areas, such as northeastern India and southern China.

What our water tsar, contemplating greater use of market instruments, will hear is a chorus of "but there are still problems and the systems—even in

Australia—don't work perfectly." Armed with a deep understanding of the history of water management, he will remember that it is a dialectic process in which each solution is provisional and gives rise to the next generation of challenges. Like the Lord's work, a water tsar's work is never done!

Complementing this set of water-specific instruments is a set of financial instruments that focuses directly on the economic security of those subject to water insecurity. In India, for example, water-based actions must be complemented by mechanisms for insuring farmers against shortfalls in rainfall and crops and by food-for-work programs to maintain incomes in times of drought.

Finally, a central element of water insecurity in developing countries is health insecurity. Addressing this means building classic infrastructure of water and wastewater treatment plants in cities. But it also means finding much lower-cost methods for providing these services to poor people, such as the innovative approaches whereby communities and utilities "coproduce" sewers in Pakistan[12] and Brazil[13].And it means finding new ways, such as the social-marketing approach of "total sanitation" in Bangladesh, where, as mentioned earlier, villages advertise that they "do not marry our girls to villages who still practice open defecation." And it means doing fundamental research on the geochemistry of groundwater to determine how arsenic is being introduced into and mobilized by new patterns of groundwater use.[14] To address these public health sources of water insecurity, our water tsar needs new tools for understanding how old and new pathogens are spread, how behavior can be changed, and how to finance and maintain affordable infrastructure.

Tools to be deployed III: "Smart" infrastructure

Our water tsar, then, has a tool box that comprises both "dumb" infrastructure and instruments that have proven to have huge benefits in improving water security. He can go a very long way, as the Australian example illustrates, with the existing tools. But there is now emerging a promising new generation of "smart tools" that can leverage much better performance out of existing dumb infrastructure and institutions, and that can push the frontier in places where the capacity of existing tools has been used to the fullest.

"Smart" technology I: New generations of crops and agricultural technologies

Forty years ago, Malthusians, especially environmental Malthusians like Garret Hardin but also political Malthusians like Henry Kissinger, predicted that population was going to outstrip food supplies globally, especially in densely populated countries like India and Bangladesh. The Green Revolution, in which increased security of irrigation supplies played a central role, is one of the great human triumphs of the modern era.

The spike in food prices in 2008 made clear that, as with water, all victories are provisional and that there are dark clouds on the food-security horizon. First, there is clear evidence that returns from existing seed and agricultural technologies

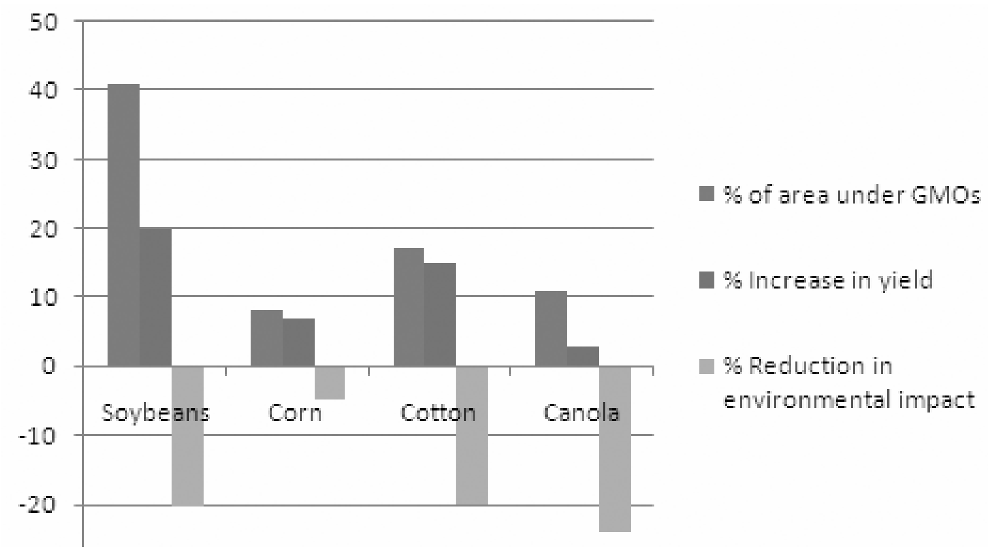

Figure 13. GMOs, Productivity and the Environment
Source: Brookes and Barfoot (2008)

are no longer keeping pace with demand. Second, the best land and water resources have already been used. Third, the green movement in rich countries has seriously impeded the development and adaptation of new seed and crop technologies (this is curious since, as shown in Figure 13, genetically modified organism [GMO] varieties produce more and require substantially less use of fertilizers and pesticides).

On the critical issue of modern agricultural technologies in general and the use of GMOs in particular, there is a deep gulf between the rich countries (especially Europe in this case) on the one hand and the poor (which are dependent on rich countries' "aid") and middle-income countries (and some major rich countries, including the U.S., Canada, and Australia) on the other. Green lobbies have played a major role in the precipitous declines in development assistance for agriculture (about 75 percent over the last 30 years) and in threatening poor countries (particularly in Africa) with retaliation if they use GMOs.[15] By bullying the pliant aid agencies, green lobbies dominate major global reports, such as the multimillion-dollar International Assessment of Agricultural Knowledge, Science, and Technology (IAASTD) report,[16] which tell countries that small is beautiful and to abandon modern technology in favor of organic farming. Economically independent MICs, which respond incredulously to this circus, have enthusiastically adopted technology-rich modern approaches and are flourishing. Brazil, for example, has invested massively and persistently in agricultural research and has seen output grow by 300 percent, with just 10 percent of this growth due to increased inputs and 90 percent due to increased productivity. Brazil is now an agricultural superpower, and MICs now account for eight of the top ten users of GMOs.

Our water tsar, then, would work closely with his counterparts in the agricultural establishment, and with companies that are producing new crop varieties that produce more with less. He would ensure that he is producing the water products demanded, and he would push for the production of crops that are more resistant to water and temperature stress.

"Smart" technology II: Measurement and reporting

"To manage is to measure." So goes an old adage. Nowhere is this more true than for water. It is also true that the technology used to measure water needs to evolve as its value increases and as technological possibilities expand. Two hundred years ago the British-built systems in South Asia relied on the only reliable measurement technology of the time: the clock. Each farmer in the famous warabandi system got and still gets a prescribed number of minutes of water on their fields. In adjacent areas, where tube well owners ran private markets,[17] water meters are ubiquitous. In the California drought of 1991, the state used aerial photography to ensure that farmers who had sold their water to the state water bank were not cheating.

A difficult challenge relates to the accounting of water that seeps from canals and fields into the groundwater. In many instances, one person's losses are another person's recharge. Ideally, water managers should be measuring not how much water a farmer diverted but how much water is actually lost from the system due to evapotranspiration. Experiments are now under way in Idaho and elsewhere using satellite images to determine not just how much water is applied to fields, but how much is being lost through evapotranspiration, opening the possibility that farmers will eventually be billed for the amount of water their activities remove from the system, rather than the amount of water applied to their fields.

Measurement without transparent reporting is a recipe for corruption. New technologies have made transparency much easier, automatic, and low cost. An interesting example is that of the Punjab in Pakistan. Five years ago, only officials of the irrigation department knew what the water entitlements were for different canals. Mistrust, theft, and corruption were rampant. For the past three years, entitlements and deliveries have been posted on www.irrigation.punjab.gov.pk and are updated weekly.

"Smart" technology III: Delivery technologies

Old-style irrigation techniques involved flooding more-or-less level fields and applying large amounts of fertilizers and pesticides. Only small fractions of the water and other inputs were effectively used by the plants. In recent decades, a suite of precision irrigation technologies has been developed. These include laser leveling of fields and drip irrigation, where water is dripped onto the root zones of plants, providing water just where needed. Water-transmission systems became the vehicles for the precision application of fertilizers and pesticides. Such technologies were originally applied in countries like Israel and Spain to high-value fruits and vegetables, but the technology has now spread widely, including into large markets like those of India and Pakistan, where there are now highly competitive markets for such delivery technologies. In some places, such as the Sao Francisco Valley in Brazil, farmers have gone a step further. Some grape producers now use sensometers in the soil to determine when crops need water and a variety of real-time measures of the chemical content of leaves to decide what nutrients need to be applied each day.

"Smart" Technology IV: Decision-support systems

Underlying all of these innovations is the need for better information and more sophisticated decision-support systems. These range from climate and weather models, which can give more precise short- and long-run forecasts; to systemwide models of the water and salt balances in whole basins, such as that of the Murray Darling Basin; to approaches for assessing supply-demand imbalances and cost-effective choices for closing these, such as the one being developed by McKinsey; to operational tools for industries, like those developed by the World Business Council for Sustainable Development (2006); to programs whereby farmers can take account of soil moisture, leaf content, and predicted rainfall and temperature in managing their crops.

"Smart" technology V: New technologies for treating water and wastewater

The cities of the developing world are growing fast and will continue to grow as modern, more productive agriculture needs fewer workers per unit of output. Most developing countries already are unable to keep up with this growth, and are unable to provide clean drinking water and adequate sanitation to most urban dwellers. Again the challenge is to walk on two legs—to develop accountable, efficient institutions, and to develop a new generation of lower-cost, more efficient technologies. On the institutional side, the recipe that has worked in rich countries—a clear legal and regulatory framework that stimulates competition among and between public and private providers—is working elsewhere. In Sao Paulo, Brazil, for example, the state utility (the world's fifth largest) used to be 100 percent owned and financed by government, and it performed poorly. Now the government owns just 51 percent, with private shareholders in the domestic and U.S. stock markets each accounting for a quarter. Financing is raised from both public and private sources, and the regulatory framework requires that all concessions are publicly bid. Output per worker has increased by 80 percent over the last 15 years.[18] In Brazil, too, there have been new, low-cost models where poor communities produce and manage feeder sewers and utilities manage the bulk infrastructure.[19]

There are promising new avenues for developing technologies that can purify water and wastewater at a lower cost. For example, engineered nanostructures and bioreactors that use high-flux, non-fouling membranes are likely to play key roles.[20] Improved membranes have been key to reducing the energy cost of desalination by about 60 percent, with the theoretical limit being about 25 percent of current levels. Since these technologies are relevant to rich countries, too, there is extensive basic and applied research ingenuity now being applied to their development.

CONSEQUENCES OF ENHANCED WATER SECURITY

Our water tsar is now equipped with knowledge of his country's exogenous threats to water security and with a full tool box of instruments for addressing these threats. However, he still needs to make his case—not to hydrologists but to cold-blooded finance and planning officials who say, "This is all well and good, but what does it mean for the well-being of our people?" He needs, in short, tools for translating outcomes in the water domain into outcomes in the social, economic, and environmental domains.

In the economic domain there has been, in many ways, a rediscovery of what was once taken as axiomatic, namely, that the development of a "platform of water infrastructure and institutions" has major direct and indirect benefits for people. A recent generation of World Bank–funded studies of major water projects in Brazil, India, and Egypt[21] confirms what an earlier generation of studies in the U.S., Australia, and Malaysia had shown, namely, (1) that it is not easy to predict precisely the benefits that will accrue to particular components of multipurpose projects, (2) that predictions of the aggregate benefits in these robust projects are historically quite accurate, (3) that the indirect benefits that come about because of the forward links (for example, to food-processing industries) and backward links (to the providers of fertilizers, for example) are about as large as the direct benefits, and (4) that while the rich are the primary beneficiaries of the direct benefits, the poor are often the greatest relative beneficiaries when indirect effects—especially generating employment—are taken into account. The implications for planners are clear: ex ante they need to dissect the set of forward and backward links emanating from such projects and to ensure that complementary investments are made so that society can reap the full benefits of the new opportunities created by such projects.

In the social domain, one of the greatest development challenges is migration. Regional development has always been a great attraction of major water projects, which implies the creation of permanent economic opportunities for both residents and migrants. Contemporary India provides vivid proof of the push and pull that water projects can have on migration. Every year, over a million people from Bihar migrate to the irrigated Punjab for seasonal work. And last year, when the Kosi River ("the sorrow of Bihar") once again flooded its banks, several million Biharis were pushed into the cities of India.

In the environmental domain, dams have proved to be major disrupters of ecosystems. Preserving rivers in their virgin condition is usually not an option in developing countries, but considerable progress has been made in recent decades to reduce the negative social and environmental footprints of water projects. For example, the area submerged per unit of energy generated in old-generation Amazon hydropower projects is 100 times the footprint of contemporary projects. Furthermore, the release of just-in-time flows into river deltas (as shown in the Manantali case described earlier in this paper) often can have a huge impact on environmental quality and on the livelihood of fishermen while having only a modest impact on the energy or irrigation produced by a dam.

All these cases call for the development of a new generation of knowledge, particularly knowledge that can guide practitioners, and for the training of a new generation of "integrating" scientists and practitioners.

EMERGING COALITIONS FOR CHANGE

In the water business, the glass is both half empty and half full. Half empty in that there is an increasing number of crises and conflicts over water, as visible in the newspapers of most countries of the world, which are exacerbated by the new overlay of variability and change emanating from climate change. But, the glass is also half full. As described in this paper, a growing number of countries and regions are starting to take substantial action to build the infrastructure and institutions necessary to improve their water security.

Environmental NGOs have long been active in water issues, mostly in saying no to almost any infrastructure or new technology. While NGOs "with no off switch"[22] still play a major role, there is also a growing number of NGOs that are scientific, knowledgeable, and searching for solutions with other players. Especially striking is the emergence of such NGOs in middle-income countries—the case of Brazil, for example, is well documented by London and Kelly (2007), where the luxury of advocating impractical solutions is less and less an option.

A new and promising phenomenon is the emergence of socially responsible corporations that are getting involved (1) because they see water conflicts constituting a "threat to their social license to operate," (2) because they see business opportunities and believe that the technologies they can produce can make a real difference, and (3) because they believe that the voice of business can make a difference in the all-important policy arena.

Finally, there is a veritable explosion of interest in the subject among young people and a corresponding response from many institutions of higher learning. It is a timid university that does not have, or is not contemplating, a global water institute these days! To cite one example, Harvard has initiated a "Water Security Initiative". Harvard and MIT faculty will partner with research institutions in other countries to develop a new generation of researchers and practitioners who have deep expertise in their own disciplines but also learn to integrate across disciplines as diverse as anthropology, biology, business, chemistry, climatology, economics, engineering, government, history, law, and public health.

There is, then, no question that water security constitutes one of the great challenges facing many countries and that there is a "gloomy arithmetic of water" at play. But it is also clear that there is an unprecedented opportunity to develop and apply new forms of knowledge and to turn this crisis into an opportunity for a better life for billions of people.

Endnotes

1. World Bank (2003).
2. Frater (2005).
3. World Bank (2003).
4. Pritchet (2001, p. 385).
5. Economist (2005).
6. There are at least three somewhat different etymological explanations. The Financial Times (1998) reports that "zhi" is a combination of the ideogram for water and that for a dyke or embankment. The Economist (2009 reports that the Chinese word for politics (zhengzhi) includes a character that looks like three drops of water next to a platform or dyke. The Harvard University Department of East Asian Languages believes that zhi means to control and is composed of two parts, water on the left and what is supposed to mean "joy" on the right. Thus, the full character is said to mean "water arranged to bring joy."
7. Barnaby (2009).
8. Wheeler (2009).
9. Briscoe and Malik (2006).
10. Briscoe and Qamar (2006).
11. Mallaby (2006).
12. Hasan (1992).
13. Melo (2009).
14. Harvey et al. (2006).
15. Collier (2008).
16. International Assessment of Agricultural Knowledge, Science, and Technology (2009)
17. Shah (1993).
18. Yepes and Dianderas (1996); Government of Brazil (2009).
19 Melo (2009).
20. Shannon et al. (2008).
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