

WATER IN THE 21ST CENTURY: DEFINING THE ELEMENTS OF GLOBAL CRISES AND POTENTIAL SOLUTIONS

Upmanu Lall, Tanya Heikkila,
Casey Brown and Tobias Siegfried

Will we run out of fresh water in the 21st century? The media highlights the parched lands, dry riverbeds and springs and falling groundwater tables across the world daily. Over a billion people living in developing countries without access to safe drinking water are facing economic and water poverty.¹ Another real and troubling indicator is the rapid rate of aquatic habitat degradation and biodiversity loss in the last century.² Projected changes in climate due to greenhouse gases invariably portray a future world that is much drier in the tropics—where over half the world's population lives—and suggest a global increase in floods and droughts.

Is a global water crisis already upon us? The answer to this question seems to depend on who you ask. On the one hand, active voices such as Sandra Postel, Peter Gleick, Vandana Shiva, Lester Brown and Paul Elrich, as well as leaders of major global organizations with an interest in water, have been warning of an impending global water catastrophe. On the other hand, the mainstream academic community involved in hydrology and water has largely ignored the topic. For example, a Google search for “water crisis” leads to almost 1 million hits, but the same search on Google Scholar yields approximately 4,000 hits as compared to over 1 million Google Scholar hits for “climate change.” Many of these articles focus on policy solutions, but do not necessarily explore the nature of the problem in-depth. Furthermore, the literature is largely non-American and contains references to much of the same work. Introducing “global water crisis” into a Google search reduces the number of hits by a factor of ten. In fact, the handful of scientists who do study this problem have divergent opinions as to whether and when the world will run out of water.³ A handful of scholars—particularly economists—go so far as to claim that a global water crisis does not exist or is, at best, overstated.⁴ These scholars generally find that, on the whole, water access is improving worldwide and that with continued efficiency enhancements, the amount of water will continue to meet existing demands.

Perhaps the way the global water crisis has been defined—whether the world will run out of freshwater—is the wrong way to look at the problem. While there are many scholars looking at the range of localized and specific water challenges that are occurring around the globe, it seems that the academic community has yet to find success in accurately characterizing the sum of their parts. In this article, we argue that there are three distinct water crises—or challenges, depending on who you ask—that have yet to be systematically connected by scholars. It is by looking at how these three challenges are interrelated that we can better articulate the global characteristics of water resource dilemmas and, ultimately, identify the global factors that can help solve these dilemmas.

REORIENTING THE DEBATE: THREE CRISES ROLLED INTO ONE

Three types of water crises appear prominently in academic and professional discourse. First, there is the crisis of access to safe drinking water. This includes the inability to provide basic infrastructure to store, treat and deliver water supplies to a large part of the world's population. Second, there is the crisis of pollution that is analogous to climate change in that it relates to the impact of by-products of resource use. Third, there is the crisis of scarcity, or resource depletion, which is analogous to the fear of running out of oil. Now that we have defined three types of water crises, we can examine what we know about them, how they are linked, to what extent they are global problems and, finally, what are some possible solutions.

The Access Crisis

Many people equate the global component of a water crisis with the vast number of people worldwide whose economic productivity and social development is limited by access to safe drinking water. For instance, the World Health Organization, the World Bank Group Development Education Program, Global Water and the Global Water Challenge draw attention to the fact that over 1 billion people lack access to safe drinking water. As a result, the United Nations Millennium Development Goals, the World Water Forum and other groups have rallied around a common metric for this issue by measuring the number of people with access to safe drinking water. For example, one of the key targets under the Millennium Development Goals is to “reduce by half the proportion of people without sustainable access to safe drinking water.”⁵ Although these goals have been lauded as important policy directives, the international community has not yet made much progress in meeting them.⁶

Why is it so difficult to meet these goals? A vast body of literature points to the technical, institutional and financial challenges involved in developing the infrastructure and systems needed for water storage, supply and treatment.⁷ As this

Figure 1

body of literature has discussed, poor countries may not have access to sufficient capital to build large-scale infrastructure like reservoirs, water treatment plants or delivery systems. If they have donors to supply the initial capital, they often do not have the means to repay these loans. Some developing regions that acquire the resources to build new infrastructure later discover that they cannot afford to maintain it. Other times, donors build water supply projects that are grossly mismatched with the needs of local communities.⁸

Despite these challenges, research and practical experience have shown that the water access problem can be addressed—at least superficially—with existing knowledge and resources. For example, numerous low-cost technologies are now available to treat water quickly without large-scale infrastructure. Simple and cost-effective infrastructure, like rainwater harvesting systems, is readily available to many water-scarce communities.⁹ Additionally, creative financing mechanisms—like public-private partnerships—have been adopted by many local communities to pay for new water supply systems.¹⁰ These types of interventions—as well as successfully developed large-scale water supply infrastructure—have helped increase the number of people with nominal access to safe drinking water from 77 percent in 1990 to 83 percent in 2002.¹¹ It is because of these improvements in recent decades that some scholars have argued that a global water crisis does not exist.

The Pollution Crisis

Intertwined with the access crisis is the water pollution crisis. For those 1.1 billion individuals who lack access to safe drinking water, "safe" is often the key word. While the infrastructure for water storage and access is often available, sometimes the water is contaminated by chemicals, microbes or other pollutants that render it non-potable. Yet, just as we have the know-how to develop water supply technologies, we also have the know-how to treat contaminated water. In the last century, tremendous research efforts have translated into an ability to treat wastewater and remove many of the most well-known chemicals of concern, including the ability to reuse or release this treated water into the environment. Technological advancements and tighter environmental regulations have created major progress in controlling the pollution of water from point sources, such as industries and municipalities. Although exotic or emerging chemicals continue to be a concern, their control is an active area of research. Therefore, where there is political will and available funds, pollution emitted from point sources is now under control. However, the political will and funds available to control point sources are still limited in many regions of the world. Many poor countries face similar challenges in developing the infrastructure to treat water as well as in supplying water.

An even more difficult pollution problem to solve is that of non-point source pollution, which results from diffuse sources, such as farms, or is caused by atmospheric deposition from industrial polluters. This form of pollution can have wide-ranging impacts, both on human use and on ecology, particularly through the accumulation of contaminants in water bodies and through the biological food chain. Examples of large-scale and cumulative ecological effects include hypoxia in the Gulf of Mexico, *pfiesteria* in the Chesapeake Bay and the decimation of the Ganges River dolphins.¹² Historically, the effects of non-point source pollution have been easier to ignore than point sources because they affect humans less directly and visibly than sludge coming out of a pipe and directly polluting a drinking water source. Often, the cumulative impacts of non-point source pollution do not show up until they harm habitat and species living in downstream estuaries, bays and wetlands. These impacts cannot be ignored forever. As China has recently discovered, the extensive pollutants entering its waterways from factory waste, agricultural runoff and municipal sewage have had a tremendous impact on the quality of their aquaculture, causing decreased international confidence in their seafood markets.¹³

Although it is possible to reduce pollution from diffuse sources, it is typically challenging and costly. First, limiting non-point pollution requires substantial time and effort to figure out from whom and where the pollution is coming from, especially when the total amount of contaminants is high and when large volumes of water are moved during rainfall. In any given watershed, we may generally know that nitrogen

and phosphorous entering a river is coming from upstream farms or mercury is coming from deposition produced by regional power plants. However, it is often quite difficult—without direct and costly monitoring—to know how much each polluter contributes in a given location. Thus, this type of pollution is more difficult to regulate and control than point sources. The United States has struggled for decades to enforce the Total Maximum Daily Load (TMDL) requirements under the 1972 Clean Water Act. These requirements call for states and the federal government to identify sources of pollutants for each of the nation's waterways and to set acceptable limits for each pollutant.¹⁴

One approach to dealing with challenges of identifying non-point source polluters is to require all industries that produce diffuse pollution to adopt technologies or practices that reduce the flow of pollutants into waterways. Many of these technologies are known and relatively simple to adopt. For example, all farmers could plant riparian buffers to filter nutrients or cover crops to reduce leaching. Alternatively, ranchers could protect streams using fencing to keep livestock fecal matter from entering waterways. The problem with these solutions is often political.

If we examine the experiences of some of the wealthiest regions in the world, like the Chesapeake Bay watershed—which encompasses Washington, DC and six U.S. states—large industry polluters often vigorously oppose such regulatory actions because they affect their bottom line.¹⁵ Enforcement or consensual action is often hampered by the fact that there is very limited data on the effectiveness of these best management practices, and a cost-benefit analysis is therefore difficult.

Moreover, unlike point sources of pollution—where it is possible to estimate the quantities of pollutants in a watershed and the benefits of reducing those pollutants—predicting the effects of non-point source pollution is challenging. For example, stochastic extreme meteorological events can lead to sporadically large “loadings” of non-point source contaminants, which are difficult to predict. The cumulative impacts of a series of such events over a long period of time, and over large distances, can make it even more difficult to understand and estimate these pollutants. Mechanisms of non-point source pollution may also entail transport through multiple media. For example, this may include volatilization into the atmosphere, followed by deposition at a different location through rainfall, followed by the binding of pollutants into riverine or lake sediments. These mechanisms can operate from local to regional to global scales. Consequently, cause-effect analysis and monitoring for compliance or scientific analysis are made considerably more difficult.

Various incentives, such as low-cost loans or tax breaks to encourage voluntary pollution reduction measures among industries, can also fail. It is difficult to monitor and enforce non-point source pollution standards in large watersheds with multiple and diffuse polluters. Often, the opportunity looms for any one polluter to catch a

free ride off the efforts of others. Moreover, when non-point source pollution crosses political boundaries, upstream states have little incentive to control or treat pollution for the benefit of downstream states—unless downstream states have substantial political or economic bargaining power. Thus, non-point source pollution remains a significant challenge for technical, as well as socioeconomic and political, considerations.

The Scarcity Crisis

The third water crisis is one of scarcity. Scarcity refers to a situation when the water supply is inadequate in relation to the water demand for basic human and ecological necessities, including the production of food and other economic goods. Scarcity is arguably the principle component to the threefold water crisis because scarcity can drive—or at least exacerbate—both water access and water pollution. A community that has pumped all of its shallow groundwater dry will find it much more expensive to build deeper wells or to build trans-basin diversions to bring surface water in from another region. Additionally, when water supplies are depleted from a watercourse, the pollutants that may have accumulated there over time are likely to be more concentrated, thereby exacerbating the pollution crisis. This connection between water scarcity and pollution can then, in turn, lead to problems of water access. For example, municipal water supply systems can face increased treatment costs when reservoirs or instream flows are low because pollutant concentrations increase in the water they must treat.¹⁶ Water scarcity not only makes it more difficult to get adequate and clean water to meet human needs, but also harms aquatic habitats and species downstream.¹⁷

With regard to access, invariably the most economical sources are developed first. Therefore, as scarcity increases, the level and reliability of access to water suffers unless water system budgets are increased. As such, we implicitly recognize that price changes can regulate water demand but that such changes are, in turn, a measure of the scarcity of the resource. One-third of the developing world is expected to confront severe water shortages in this century due to increasing population size and changing climatic conditions.¹⁸ Subsequently, not only will the poor and the under-represented (e.g., non-human species surviving off ecosystems) have to struggle to find adequate water resources, they will have difficulty accessing safe drinking water free from the various forms of pollution previously mentioned.

Of course, similar to water access and pollution, there are mechanisms to mitigate water scarcity problems. In most parts of the world, temporal water scarcity is dealt with by building storage facilities, such as large dams and reservoirs that can be filled when natural flows are abundant and tapped when natural flows are scarce. When communities lack the space or political will to build new dams and reservoirs, some

have developed conjunctive water management programs that capture surface water and store it in groundwater basins through recharge basins or injection wells, which are then pumped for use during times of drought.¹⁹ Similarly, communities commonly address spatial scarcity by building aqueducts and canals to move water from a region that is water-rich to a region that is water-poor. However, even when communities have the financial and institutional resources to build and maintain such infrastructure, a long-term drought or increasing water demand can render the infrastructure insufficient. The recent problems in the Southwest of the United States—a region that relies on Colorado River water to supply most of its growing population—is an example of this challenge. The main reservoirs in this area—Lake Mead and Lake Powell—dropped from being nearly full in 1999 to half-full in 2007, leaving states bickering about what actions they will take if long-term drought and growth continue.²⁰ These states are now scrambling to find alternatives to make up for the likely losses in the basin they are so dependent upon. If structural solutions fail, migration can be the ultimate consequence of local water scarcity.

Some scholars and water managers argue that water markets or pricing schemes—especially in wealthy places like the U.S. Southwest—are an effective alternative for addressing water scarcity. In an economic system, the price of the commodity increases as scarcity increases, thereby regulating demand. However, pricing water is typically ineffective in modulating water supply and demand. First, there is political opposition to the creation of water markets because water is deemed a necessity. If water goes to the highest valued users, less wealthy individuals and species may be short-changed. Thus, even where markets exist, they are often regulated with pricing caps or only operate within limited sectors (e.g., between a small number of farmers).²¹ The legal and institutional frameworks that govern water allocation and rights can also create significant transaction costs that can hinder the effectiveness of even small-scale water markets. Such challenges indicate that although solutions to the scarcity are well-known, implementing those solutions is not easy when one considers the political, social and economic costs associated with alternative solutions.

CLARIFYING THE GLOBAL DIMENSIONS OF WATER SCARCITY

Given the difficulty of addressing water scarcity, access and pollution at even local scales, it is easy to understand why water crises are ubiquitous today. Yet, thus far, in characterizing the three water crises and their common solutions, we have not addressed any underlying *global* dimension of these three related problems. The global aspect of the climate issue is fairly obvious: Air pollution of individual countries translates into a pollution of the global commons that then impacts everyone in the future. However, we typically do not think of water as a global commons.

The possibility that North India may run out of groundwater in a decade leading to a collapse of agriculture in India is not viewed as a global problem.²² Likewise, the fact that the Yellow River no longer makes it to the sea, the fact that an aquifer in Long Island has been depleted and the three-hour daily walk for poor-quality drinking water in rural Ethiopia are all perceived and felt as local or regional problems.²³ The discussion of *global* water crises refers to the vast number of people around the globe facing these problems. In essence, the global crisis is viewed as a collection of local crises—whether they are related to access, pollution or scarcity—for which there is a global policy imperative. We rarely address the global elements of these individual problems. However, looking at the scarcity crisis more closely reveals a critical global issue.

Linking Local and Global Dimensions of Water Supply and Demand

It is apparent to anyone who has studied or thought about the global hydrological cycle that local water availability is intimately tied to the global and regional climatic processes that control the disposition and movement of atmospheric and oceanic water. Thus, the climate is a direct bridge between local rainfall or water availability, and global processes. In an era of climate change awareness, this connection is now well-documented and disseminated through popular and lay media.²⁴ However, the implications of this connection in terms of local and global water supply are not often obvious.

At the global scale, it is possible that the hydrologic cycle may accelerate as climate changes, implying that rainfall patterns, and hence water availability, may change both in space and time. Additionally, climate phenomena—such as the El Niño Southern Oscillation—lead to concurrent and persistent droughts in large areas of the world.²⁵ This implies that these areas are likely to experience water scarcity at the same time. With population growth, the ability of local storage infrastructure to buffer the population from the impacts of drought decreases. Further, noting that agriculture—and more specifically grain production—is a major water consumer, mega-droughts that span much of the globe limit the ability to address regional water scarcity through food imports from other regions. This emphasizes the dimensions of potential global water scarcity.

Many of our early population centers were built in areas with easy access to fresh water sources. Past civilizations that did not have continuous access to freshwater, or that existed in drought prone regions, sometimes perished (e.g., the Anasazi people of the U.S. Southwest). However, the development of local water storage and distribution infrastructure has since allowed societies to develop resilience to these climatic aberrations of supply. As a result, we still do not view water crises as stemming from a global hydrologic cycle that is akin to a global commons.

The ability to trade food is a primary factor that has allowed human populations to occupy certain geographical areas with much higher density than would be possible if all food had to be produced from locally available water. It is the virtual import/export of water through food that effectively connects the local dimensions of water scarcity to a global dimension. It is estimated that 30 percent of all water in global food today comes from a country other than the one in which the food is consumed.²⁶ This fraction is anticipated to grow, meaning that global market forces will play a role in both the supply and demand for local water resources. As globalization makes food trade an implicit mechanism for reducing the impacts of local food and water scarcity, the vulnerability to water scarcity will eventually extend to a global scale. One consequence of this extension could be global agricultural price shocks. Another consequence could be new or increased competition for water at the local level among differing sectors—municipal, industrial and agricultural—competition that can play out in political debates, court disputes and/or conflicts.

If climate change and the associated human migration projections pan out as indicated by current modeling efforts, water surplus, low population density and low-intensity land use areas—such as Canada and Siberia—may emerge as population centers and the agricultural production centers of the 21st century. There is some recognition of the possibility of this trend. Yet, to our knowledge, no formal analyses exist on the effects that such changes will have on resource use—water, food, land or energy—and ultimately what the socioeconomic implications of such changing patterns in resource use entail.

The Role of Agriculture

Agriculture is the dominant water user on the planet, accounting for 70 percent of global water use, on average, and greater than 90 percent in arid or semiarid regions.²⁷ Agricultural water use efficiency is typically very low. Although efficiency rates vary by crop type, for many crops only 10 to 20 percent of the water supplied in either irrigated (not drip) or rain-fed agriculture is transpired by the plant. The rest is lost either by direct evaporation from the soil or in the water distribution network. Furthermore, most of the agriculture on the planet is rain-fed, which has higher evaporation rates and lower crop yields than irrigated agriculture.²⁸ Thus, given that agriculture is the dominant water use and dramatic reductions in agricultural water use are technically possible without an impact on food production, it is an obvious target for meeting the challenge of water scarcity.

If an order of magnitude reduction in agricultural water use could be achieved, there would be no global water scarcity for the foreseeable future, at least not as a constraint on global carrying capacity for humans and other life. This has led to slogans like “more crop per drop” and work towards identifying technologies such as

drip irrigation or genetic modification of crops so they will consume less water or can be grown in salty water.²⁹ Efficient irrigation timing—through weather monitoring, appropriate use of nutrients and the use of weather or climate forecasts—combined with appropriate cultivars, can also reduce water usage.

However, practical progress towards significantly reducing agricultural water use has been made in very few places, like Israel, where agriculture has shifted to drip or recycled waste water use and to high cash value crops from subsistence agriculture or the production of cereals. For instance, drip irrigation accounts for only about 1 percent of all global irrigation, even though it can substantially reduce water use relative to flood irrigation, which is the most common practice.³⁰ Access to technology is only a small part of the solution. The economics, politics and sociology of agriculture—as well as education and cultural adaptation—play a significant role in limiting change.

Globally, food and agricultural product prices were steady or declined in real dollars over the last fifty years, and are only now starting to increase. Gains in productivity ushered in by technology—the Green Revolution—were responsible in part. Attempts to protect the rural sector—through water, energy and fertilizer subsidies—and support prices for agricultural products play a large and as yet, incompletely understood role in impacting local and global investment in reducing agricultural water use. For instance, an American cotton farmer who has access to advanced production technologies can achieve much higher yields than a cotton farmer in a developing country. Additionally, the American farmer, when given free or highly subsidized water, can then sell that cotton at a low price. Since the United States is a relatively large producer, it influences the global market price, thereby forcing other countries to politically provide similar support mechanisms to their farmers. This leads to profligate water use in both locations. The recent price increases reflect progressive limits on land and water productivity, the increasing population and the diversion of agricultural to non-food products like biofuels.³¹

Subsidies have a role in development and could be redirected toward incentives for water conservation. This transition requires some degree of international policy dialogue and concurrence to address the inherent collective-action problem of responding to signals of water scarcity. However, in practice, internal politics decrees a maintenance and proliferation of the status quo. Additional supports are added to protect the sector from losses due to a lack of water available either due to upstream abstractions or due to a climatic exigency. For instance, farmers in the Punjab in India are lobbying for state funds to dig wells deeper, since the regional groundwater table has declined in places by about 1 meter per year, to a depth of about 400 feet.³² Added to that, energy for pumping is provided to groundwater users for free or at a highly subsidized rate.³³ The result is that groundwater—which constitutes a fossil reserve—is being mined in many regions throughout India, and worldwide, where

farmers have access to cheap energy and the financial resources needed to pay for increasingly deeper wells.

Towards Agricultural Water Use Efficiency

In countries such as India and China where population densities are high, especially in rural areas, agricultural water use already poses a stress on urban consumption. Major urban areas do not have the ability to provide drinking water on a sustained basis, even though they constitute a higher value use compared to agriculture and are able to pay for such use. For example, many major Indian cities face severe water shortages, often limiting public access to water from a few hours per week to a few hours per day.³⁴ In theory, substantial volumes of water could be transferred from rural agricultural users to these urban sectors if greater efficiencies in agricultural use can be achieved. Much of the problem with such solutions in India is political. Providing highly subsidized rural water is a political norm that is difficult to challenge, even though the subsidies preferentially benefit a limited number of rich farmers and not the masses for whom these measures are intended.³⁵ Improvements in the rural economy that facilitate agricultural water use efficiency are key for benefiting urban users and ecosystems as well.

One approach to achieving improvement in water use efficiency is to create a situation that leads to more revenue per drop. Increased financial resilience could then justify individual or group investment in a technology that facilitates a more efficient production of goods, while still assuring a high reliability of the water supply. Such resilience can further diminish the internal political pressure to support agricultural subsidies, driven in part by the need to protect farmers from financial loss. For example, higher revenue crop production has become available to some small farmers in India and China through the introduction of contract farming by national and multinational corporations.³⁶

Under contract farming, farmers are provided with all inputs and technological training to grow high-cash value crops that are exported or processed into goods and paid at the time of harvesting. The approach removes credit risk, market risk and technology risk from the farmer and provides incentives for higher yields from the same inputs. However, it requires a much higher technological and information base to execute through all stages of the product supply chain. This may lead to a transition toward higher efficiency production and a reevaluation of the time horizon over which the future value of the fossil groundwater resource or investments in improved surface water irrigation infrastructure are assessed. The corporation may be better placed to buffer the financial risks from which the farmer has been freed, and innovations on managing and sharing the climate risk through insurance and other channels are emerging. Finally, the corporation can look at the global marketplace

for agricultural commodities and optimize what should be planted—where, when and how—considering market, labor and water constraints at local, regional or global levels.

For example, according to one study of global imports and exports of major crops between 1997 and 2001, those countries that have low water availability per capita imported about 20 percent of their water through food, whereas countries with high water availability imported over 68 percent of their water through food.³⁷ Arguably, substantial improvements in water use could be gained in the virtual water market. Such an approach requires considerably more robust access to water supply, withdrawal, quality information and prediction than is routinely available. This is an opportunity for scientific research and input into the process.

Clearly, such a market-driven process would require regulation to protect resources, as well as the interests of all groups, to facilitate a transition from subsistence farming to a competitive corporate supply chain for agricultural products. Labor force dynamics, environmental objectives, global regulation of commodity trading and local enforcement of water rights and environmental regulation would all need to be addressed. Climate risk, especially globally correlated climate risk—the possibility of simultaneous drought in multiple locations—would need to be addressed. Similarly, asymmetries in production choice—a mass migration to biofuels from food production—would also need to be monitored and addressed. How the global trajectory of agricultural product prices would evolve in the absence, reduction or redirection of subsidies and more efficient production is, at present, unclear. In other words, even knowing that it is possible to dramatically improve agricultural output per unit land of water, many questions remain about how the mix of products generated—as well as the utilization or transformation of the massive labor force currently engaged in agriculture—will affect the trajectory to more revenue per drop. Research questions, and a formal research agenda to address this emerging trajectory and its implications noted above, need to be formulated through a global scientific discussion.

CONCLUSIONS: GLOBAL AWARENESS AND GLOBAL SOLUTIONS

In summary, there is a water crisis in many regions of the world, and the problems will progressively become global. There are three crises, but the preeminent crisis is one of water scarcity. One of the dimensions of global water crises is already obvious to many; the problems of water access, water quality and scarcity are felt nearly everywhere, most prominently with the world's poor and under-represented. When we focus on the issue of scarcity—which can drive the other two crises—it is easier to identify the global nature of these crises as well as the connection between global and local forces. One of the key global elements relating to scarcity is the role of climate change.

While we are becoming more attuned to the impacts of climate change on local water supplies, to a large extent we have mitigated this global influence by developing infrastructure and other forms of adaptive water management tools. The biggest global force that currently drives water scarcity is agricultural water use. The global market for food contributes to the flows of water resources—at least virtual water—around the globe, intersecting with local economic forces that support inefficient water use within this sector. We argue that the solutions to the scarcity challenge—and ultimately to part of the access and pollution challenges—require both local and global action at the policy and economic level to improve agricultural water use.

The few solutions we have discussed in this article require significant policy changes at the local, national and international level. To remove the masks on water scarcity signals, nations have to find ways to either change or overcome the powerful interest groups in the agricultural sector. The incentives for any one country to shift policies are quite low without substantial international efforts to ensure that other major agricultural nations will also participate. If new agricultural supply-chain practices are part of the solution basket, industries need to be aware of these opportunities and national and local governments will need to find ways to incentivize and protect access rights for those farmers and industries willing to undertake new business practices. The precursor to such types of changes is, arguably, heightened awareness of the nature of the problem. Such awareness can occur if a professionalized forum is available to provide informed debate and opportunities for learning.³⁸ Such an analytical forum is largely a public goods problem, and one that requires collective action at the international level.

The benefit of international efforts to collectively investigate global water problems is evident from the impact of the International Panel on Climate Change (IPCC). One might ask, “Why is it that climate change has become a much greater scientific and social concern than water scarcity, access to safe drinking water, water pollution or resource depletion?” Arguably, this is because the climate change research community has come to agreement on the nature of the problem and on a metric with which to measure it. Global temperature increase over the last century is now well-documented, and in the last two decades a lot of scientific and political effort has been expended to connect this to greenhouse gas emissions, deforestation and other human-induced changes. Model-based scenarios and scientific intuition are used to project dire consequences for the future of the planet and its societies if greenhouse gas and temperature trends continue. A synergy between scientific inquiry and political action drives the climate change agenda further on both fronts as a global issue. Many significant uncertainties remain with climate change projections, even though the causative factors are agreed upon. A large number of these uncertainties pertain to the details of the hydrologic cycle—how water availability

will change and how the distribution of water through the atmosphere and through vegetation will modify climate. So far, we have only seen the beginnings of the conclusive impacts of climate change, and the action agenda is to find solutions before this crisis overwhelms us and causes irreversible damage. Our best guess is that these impacts may occur over decades.

Addressing climate change requires policy action, but also a search for technical solutions to quickly substitute fossil fuels, or effective carbon capture and sequestration. Energy conservation and use-efficiency improvements are important but will not be sufficient to meet the challenge. These observations emerge after nearly two decades of intense global debate—one that has been fueled and supported by information generated through extensive international research efforts—as well as the synthesis and scientific consensus coming out of the Intergovernmental Panel on Climate Change.³⁹ The debate continues, but at a relatively high level of maturity, and rapid technological evolution to address the anticipated problems is in the offing.

By contrast, the dimensions of the current and emerging water security challenge are not as well understood. Even when attention has been drawn toward water problems, it has been fragmented across the three types of crises we face today and targeted towards the local dimensions of the problems, which incidentally, are similar to the symptoms of global energy and climate change issues. This has prevented a focus on the preeminent scarcity crisis, which requires much more information generation and understanding. It is in many ways a more complex problem than CO₂-induced climate change, given that its global and local causes are more closely identified with social factors, local access and supply chains, and with many layers of common pool resource problems.

Developing a single technical solution that will address the problem is at first difficult to recognize. However, the agricultural use-efficiency issue emerges quickly as a dominant issue. Given that at least some technologies are readily available for use reductions, the solution in this case may very well be to first achieve conservation and efficiency improvements using these technologies. Innovations in corporate farming offer some promise to improve rural livelihoods, while providing access to global markets for agricultural products and facilitating the reduction of climate, market, credit and labor risks through efficient global pooling of financial resources. New technologies to reclaim contaminated or saline water may also be an important part of the equation. This could involve using solar or wind technology as energy sources or coupling them to efficient greenhouse-based agriculture. Greenhouse-based agriculture—which has been widely used in Israel—can produce high crop yields while recapturing much of the water transpired by the plants and evaporated from the soil. The reuse of water can lead to substantial reductions in overall water use from the agricultural sector. Current pessimism as to whether we will have sufficient

water to support life on Earth could be transformed into optimism, if we could formulate a path working toward these types of innovations.

The formation of a global roundtable as a focal point for analyzing the causes and anticipated future conditions of water scarcity could help achieve what the Intergovernmental Panel on Climate Change has done for climate change. An interesting difference in this regard is that the political dimensions and social importance of the water issues are much better recognized at the outset than they were for the climate change problem at the initiation of the IPCC. On the other hand, the causal structure and scientific bases for climate change and its impacts, as well as the supporting databases, were perhaps much clearer for climate change than for the water scarcity problem. Consequently, a global roundtable would need to focus, from the beginning, on the collection and analysis of the wide range of information sources that are relevant to understanding and predicting the causal structure of local and global water scarcity. It is through such a process that both the scientific and policy communities can begin to understand and respond effectively to the global drivers of water crises, fostering tools and choices that could help leverage the diverse and important local solutions that are already available. 

NOTES

¹ United Nations Development Program, *Human Development Report* (United Nations Development Program, 2006); A. Fenwick, "Waterborne Infectious Diseases—Could They Be Consigned to History?" *Science* 313, no. 25 (2006), 1077-1083; World Health Organization, *Water Sanitation and Health*, http://www.who.int/water_sanitation_health/mdg1/en/index.html.

² J.N. Abramowitz, "Imperiled Waters, Impoverished Future: The Decline of Freshwater Ecosystems" (Worldwatch Institute, 1996); M. Falkenmark, C.M. Finlayson and L.J. Gordon, "Agriculture, Water, and Ecosystems: Avoiding the Costs of Going Too Far" in *Water for Food, Water For Life: Comprehensive Assessment of Water Management in Agriculture*, ed. D. Molden (London: Earthscan and International Water Management Institute, 2007), 233-277.

³ Frank R. Rijsberman, "Water Scarcity: Fact or Fiction?" *Agricultural Water Management* 80 (2006), 5-22.

⁴ Bjørn Lomborg, *The Skeptical Environmentalist: Measuring The Real State of the World* (New York: Cambridge University Press, 2001), xxiii, 515.

⁵ See <http://www.un.org/millenniumgoals/#>.

⁶ Peter H. Gleick, "The Millennium Development Goals for Water: Crucial Objectives, Inadequate Commitments," in *The World's Water 2004-2005*, ed. P.H. Gleick (Washington, D.C.: Island Press, 2004), 1-15.

⁷ C. Va Dany, C. Visvanathan and N.C. Thanh, "Evaluation of Water Supply Systems in Phnom Penh City: A Review of the Present Status and Future Prospects," *International Journal of Water Resources Development* 16, no. 4 (2000), 13; Tushaar Shah, "Water Poverty and Economic Development: Cross-country Analysis and Implications for Policy Reform," in *IWMI-Tata Water Policy Program* (International Water Management Institute, 2005), 16; S. Tremolet and J. Neale, *Emerging Lessons in Private Provisions of Infrastructure Services in Rural Areas: Water and Electricity Services in Gabon* (World Bank, 2002), 1-77; A. Mody and M. Walton, "Building On East Asia's Infrastructure Foundations," *Finance and Development* 35, no. 2 (1998), 4; L. Mehta and O. Canal, *Financing Water for All: Behind the Border Policy Convergence in Water Management* (Institute of Development Studies, 2004), 1-37; M. Chang and H. Imura, "Development of Private Finance Initiatives (PFI)/Public-Private Partnerships (PPP) for Urban Environmental Infrastructure in Asia," in *Institute for Global Environmental Strategies* (Organisation for Economic Co-operation and Development, 2003); R. Maria Saleth and Ariel Dinar, *The Institutional Economics of Water* (Northampton, Mass.: Edward Elgar, 2004).

- ⁸ United Nations Development Program, *Human Development Report* (United Nations Development Program, 2006); World Commission on Dams, *Dams and Development: A New Framework for Decision-making: The Report of the World Commission on Dams* (London: Earthscan, 2000); P.H. Gleick, "Soft Path's Solution to 21st Century Water Needs," *Science* 320 (2003), 1524-1528.
- ⁹ S. Ngigi et al., "Hydro-economic Evaluation of Rainwater Harvesting and Management Technologies: Farmers' Investment Options and Risks in Semi-arid Laikipia District of Kenya," *Physics and Chemistry of the Earth* 30, no. 11-16 (2005), 772-782.
- ¹⁰ C. Brocklehurst and J. Janssens, "Innovative Contracts, Sound Relationships: Urban Water Sector Reform in Senegal," in *Water Supply and Sanitation Sector Board Discussion Paper 1* (World Bank, 2004); R. Kotze, "Government Facilitation of Public-Private Infrastructure Projects: Lessons from South Africa," *Journal of Project Finance* 61 (2000); G. Silva, N. Tynan and Y. Yilmaz, "Private Participation in the Water and Sewerage Sector-Recent Trends," *Public Policy for the Private Sector*, no. 147 (1998).
- ¹¹ World Health Organization, *Water Sanitation and Health*.
- ¹² David Malakoff, "Death by Suffocation in the Gulf of Mexico," *Science* 281, no. 5374 (1998), 190-192; Cavell Brownie et al., "Re-Evaluation of the Relationship between *Pfiesteria* and Estuarine Fish Kills," *Ecosystems* 6, no. 1 (2003), 1-10; David Dudgeon, "Large-Scale Hydrological Changes in Tropical Asia: Prospects for Riverine Biodiversity," *BioScience* 50, no. 9 (2000), 793-806.
- ¹³ David Barboza, "China Moves to Improve Quality of Its Seafood," *New York Times*, 28 December 2007.
- ¹⁴ Howard R. Ernst, *Chesapeake Bay Blues: Science, Politics, and the Struggle to Save the Bay* (New York: Rowman and Littlefield, 2003).
- ¹⁵ Ibid.
- ¹⁶ Casey Brown and Miguel Carriquiry, "Managing Hydroclimatological Risk to Water Supply with Option Contracts and Reservoir Index Insurance," *Water Resources Research* 43 (2007).
- ¹⁷ Sandra Postel, "Entering an Era of Water Scarcity: The Challenges Ahead," *Ecological Applications* 10, no. 4 (2000), 941-948; and M. Falkenmark, C.M. Finlayson and L.J. Gordon, 233-277.
- ¹⁸ David Seckler et al., *World Water Demand and Supply 1990 to 2025: Scenarios and Issues* (Colombo, Sri Lanka: International Water Management Institute, 1998); Andrew Keller, R. Sakthidavivel and David Seckler, *Water Scarcity and the Role of Storage in Development* (Colombo, Sri Lanka: International Water Management Institute, 2000); Peter H. Gleick, *Water: The Potential Consequences of Climate Variability and Change* (Oakland, Calif.: U.S. Geological Survey, Department of the Interior and Pacific Institute for Studies in Development, 2000); Sandra Postel, *Last Oasis: Facing Water Scarcity* (New York: W.W. Norton, 1997), xxxviii, 239; Mark W. Rosengrant, Ximing Cai and Sarah A. Cline, *Global Water Outlook to 2005: Averting An Impending Crisis* (Washington, D.C.: International Food Policy Research Institute, 2002).
- ¹⁹ William Blomquist, Edella Schlager and Tanya Heikkilä, *Common Waters, Diverging Streams: Linking Institutions and Water Management in Arizona, California, and Colorado* (Washington, D.C.: Resources for the Future Press, 2004).
- ²⁰ Randal C. Archibold, "Western States Agree To Water-Sharing Pact," *New York Times*, 10 December 2007.
- ²¹ Carl J. Bauer, "Bringing Water Markets Down to Earth: The Political Economy of Water Rights in Chile," *World Development* 25, no. 5 (1997), 639-656; Terry Lee Anderson and Pamela Snyder, *Water Markets: Priming The Invisible Pump* (Washington, D.C.: Cato Institute, 1997), vii, 228; David W. Yoskowitz, "Spot Markets for Water Along the Texas Rio Grande," *Natural Resources Journal* 39, no. 2 (1999), 345-355.
- ²² Sandra L. Postel, "Entering an Era of Water Scarcity: The Challenges Ahead," *Ecological Applications* 10, no. 4 (2000), 941-948.
- ²³ Corliss Karasov, "Water Pollution. Reviving China's Ruined Rivers," *Environmental Health Perspectives* 110, no. 9 (2002), A510-A511; Veronica I. Pye and Ruth Patrick, "Ground Water Contamination in the United States," *Science* 221, no. 4612 (1983), 713-718; Mhairi A. Gibson and Ruth Mace, "An Energy-Saving Development Initiative Increases Birth Rate and Childhood Malnutrition in Rural Ethiopia," *PLoS Medicine* 3, no. 4 (2006), 87.
- ²⁴ T. Flannery, *The Weather Makers: How Man Is Changing the Climate and What It Means for Life on Earth* (New York: Grove Press, 2005).
- ²⁵ C.F. Ropelewski and M.S. Halpert, "Global and Regional Scale Precipitation Patterns Associated with

the El Niño/Southern Oscillation," *Monthly Weather Review* 115, no. 8 (1987), 1606–1626.

²⁶ Daniel Zimmer and Daniel Renault, "Virtual Water in Food Production and Global Trade: Review of Methodological Issues and Preliminary Results" in *Virtual Water Trade: Proceedings of the International Expert Meeting on Virtual Water Trade*, ed. A.Y. Hoekstra (The Netherlands: IEH Delft Research Report Series No. 12, 2003).

²⁷ Gleick (2000); Food and Agricultural Organization of the United Nations (FAO), *AQUASTAT* (Rome: FAO, 2003); Peter H. Gleick, ed., *The World's Water: Biennial Report on Freshwater Resources* (Washington, D.C.: Island Press, 2004).

²⁸ David Molden et al., "Pathways for Increasing Agricultural Productivity," in *Water for Food, Water for Life: Comprehensive Assessment of Water Management in Agriculture*, ed. D. Molden (London: Earthscan and International Water Management Institute, 2007), 278–310.

²⁹ Mark W. Rosengrant, Ximing Cai and Sarah A. Cline, *Global Water Outlook to 2005: Averting An Impending Crisis* (Washington, D.C.: International Food Policy Research Institute, 2002); Peter H. Gleick, "Soft Path's Solution to 21st Century Water Needs," *Science* 320 (2003), 1524–1528; FAO, *FAO Newsroom Focus: More Crop Per Drop*, <http://www.fao.org/english/newsroom/focus/2003/water.htm>.

³⁰ Postel (1997), 239.

³¹ C. Ford Runge and B. Senauer, "How Biofuels Could Starve the Poor," *Foreign Affairs* 86, no. 3 (May/June 2007).

³² See <http://www.infochangeindia.org/WaterResourceIbp.jsp> and <http://www.lk.iwmi.org/pubs/-WWVisn/GrWater.pdf>.

³³ C. Scott and T. Shah, "Groundwater Overdraft Reduction through Agricultural Energy Policy: Insights from India and Mexico," *International Journal of Water Resources Development* 20, no. 2 (2004), 149–164.

³⁴ See Monica Chadha, "Water Supply Restored to Mumbai," *BBC News*, 27 December 2006; "3000 Villages Face Water Shortages," *Times of India*, 9 April 2007; Anita Raokashi, "Water Shortage Could Cause IT Bubble to Burst," *Asia Water Wire*, <http://www.asiawaterwire.net/node/324>.

³⁵ V. Jain, "Political Economy of the Electricity Subsidy: Evidence from Punjab," *Economic and Political Weekly* 38, no. 41 (2006), 4072–4080; N.K. Dubash, *Tubewell Capitalism: Groundwater Development and Agrarian Change in Gujarat* (Oxford: Oxford University Press, 2002).

³⁶ See Hongdong Guo, Robert W. Jolly and Jianhua Zhu, "Contract Farming in China: Supply Chain or Ball and Chain?" in *Minnesota International Economic Development Conference* (University of Minnesota, 2005); and SPICE report at: <http://www.manage.gov.in/pgpabm/spice/March2k3.pdf>.

³⁷ H. Yang et al., "Virtual Water Trade: An Assessment of Water Use Efficiency in the International Food Trade," *Hydrology and Earth System Sciences* 10 (2006), 443–454.

³⁸ Paul A. Sabatier and Christopher M. Weible, "The Advocacy Coalition Framework: Innovations and Clarifications," in *Theories of the Policy Process*, ed. P.A. Sabatier (Boulder: Westview Press, 2007), 189–220.

³⁹ C. A. Miller and P. N. Edwards, *Changing the Atmosphere: Expert Knowledge and Environmental Governance* (Cambridge, Mass.: MIT Press, 2002); also see the Intergovernmental Panel on Climate Change, Fourth Assessment Report, Working Group I Report, "The Physical Science Basis," <http://www.ipcc.ch/ipccreports/ar4-wg1.htm>.

Copyright of Journal of International Affairs is the property of Journal of International Affairs and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.