Conference Themes and Policy Responses

By Richard Howitt

The central theme that emerged in the conference papers was of the growing scarcity of water, both physical and economic, coupled with increasing uncertainty about how and where this water scarcity will affect society. The uncertainty of future water demands and supplies is nonstationary and ever-changing due to the effects of climate change, which will accelerate during the first half of the century.

Five main factors are driving increased water scarcity on both the demand and supply side: increased food demand driven by population growth, increased demand for animal protein in developing economies, reductions in water supply as some critical groundwater basins are forced into stabilization, changes in the intensity and location of precipitation due to climate change, and changes in the ability to store seasonal water due to increased ambient temperature.[1]

Adaptation mechanisms to respond to this increased scarcity include agricultural productivity growth, changes in irrigation technologies, changes in water allocation institutions such as markets, narrowing the yield gap on food crops, and providing cheap and improved information with which to manage water.

Section I summarizes conference papers that address alternative adaptation approaches to water scarcity. Section II discusses papers that

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reviewed the potential for technological and institutional solutions to water scarcity. Section III discusses three topics that were not deeply addressed in the conference—namely, the application of community-level endogenous institutions for water management, the importance of maintaining water quality for domestic use and agriculture, and the potential effect of emerging methods for remotely measuring resource information for water management in both developing and developed agricultural economies.

I. Adaptation to Water Scarcity

Susanne M. Scheierling and David O. Treguer's paper develops a global perspective of water scarcity which they measure as the difference between total withdrawals and total renewable flows. Their data show that in many basins, agricultural withdrawals alone are already larger than total renewables. Scheierling and Treguer show that when measuring water scarcity as withdrawals as a percent of total renewable water, resource scarcity varies from over 100 percent in the Middle East and North Africa to as low as 10 percent in several other regions. Kenneth G. Cassman also raises the problem of persistent overdraft in several major aquifers. He notes that much of the overdraft is due to poor governance institutions, but even with good governance, the overall extraction rate will have to be reduced. In contrast, in many parts of Africa and some parts of Latin America, there seem to be opportunities to expand irrigation well use and efficiency. Cassman concludes the current global irrigated area can be maintained but is unlikely to be increased.

Bonnie G. Colby's paper also addresses the difficulties of establishing efficient institutions on a national and international scale when there are significant linkages with other important sectors of the economy such as energy, municipal and industrial use, and environmental values. She shows how consumption by these different sectors differs significantly across regions of the United States. She cites some situations in which traditional community values are at odds with market signals, probably due to incomplete definition of the property rights to the resource. She concludes with a review of water trading that shows it to be a robust scarcity adaptation and shows how the quantities traded in Colorado River basin states changed from 1987 to 2010.

Several authors note a lack of consistent data on net water use and the value of water productivity. The data showing the dominance of India and China in irrigated water use and area implicitly draw attention to the importance of the sustainable groundwater extraction in both of these regions. In contrast, in her comments on the paper by Scheierling and Treguer, Quiqiong Huang stated that unsustainable groundwater use was concentrated in certain parts of northeast China, while other regions were essentially using groundwater in a sustainable manner.

Despite the concern from several conference participants (Rosegrant, Scheierling, Cassman, Gruere, Huang and others) about depleting aquifers in different parts of the world, we did not see a quantitative measure of groundwater overdraft in critical groundwater-using regions such as the Indo-Gangetic plain and northeast China. This information has to be calculated before truly comprehensive water balance for the future can be projected at a global scale. Attempts to do this using remote sensing by Richey and others are briefly reviewed later in this paper.

On the demand side is the slowing but ever-present growth in population. Mark W. Rosegrant's paper characterizes the complex relationship between agriculture, water, food, and population and diet using the comprehensive International Model for Policy Analysis for Agricultural Commodities and Trade (IMPACT) developed by the International Food Policy Research Institute (IFPRI). The results show an improving but not rosy future with reductions in the number of hungry world citizens and improvements in many diets. The extent to which current trends of income and meat consumption can be maintained is a pertinent question, as is the effect of biofuel production on food supplies. Rosegrant examines the effects of droughts and floods and the general linkage of water to economic growth using both the Impact modeling suite and results from a computable general equilibrium model. The results show a sharp increase in the price of cereals and potential decrease in the price of meat, with moderate increases in fruits, vegetables, and pulse crops. Using model projections out to 2050, the results show significant reductions in the world population at risk of hunger in Southeast Asia, South Asia and sub-Saharan Africa. The Middle East North and North Africa show small increases in the population at risk of hunger.

Rosegrant also surveys adaptation to increased water scarcity and new technology, plant breeding, farming systems, and institutional changes in water rights. The model shows there is still some potential for capital investment in irrigation water supplies. In particular, Central Africa has potential for 16 million additional hectares of large-scale irrigation and 50 million hectares for small-scale farms. These scenarios show a significant percentage change in cereal production and consumption and, consequently, a reduction in the risk of hunger. Like many of the speakers, Rosegrant projects a relatively slow growth in agricultural productivity and some progress in reduction of risk of hunger. Under a plausible scenario, the model shows a significant improvement in water and food security outcomes. However, Rosegrant notes that the model predictions fall short of the optimistic United Nations Sustainable Development Goals of eliminating hunger by 2030.

In contrast, Cassman's analysis of yield gaps in many major food crops and the potential to close these gaps through genetic improvements is more somber. He emphasizes the role of risk and decreasing returns on yield gaps in both developed and developing economies. He notes that growth in yield advances has been stable in recent years and finds no evidence that the exponential rate of gain in yields needed to close the production gap in many developing countries is forthcoming. the *Global Yield Gap and Water Productivity Atlas*, which includes both the mean crop yield and its coefficient of variation, show the distribution of crop yield gaps. Cassman also shows the effect of irrigation and rainfall on maize production in Nebraska and Iowa and draws parallels using the mean and coefficient of variation of maize yields in parts of Nebraska and rainfed maize-growing environments in sub-Saharan Africa. The effect of irrigation on simultaneously increasing mean yield and reducing the variation in yield is striking. Cassman proposes measures to evaluate the productivity of irrigation applied to maize in terms of water productivity measures. While he expects significant improvements in yields and productivity from innovations and agronomic and genetic practices, Cassman feels we have yet to use the true potential of big data on crop management, soils, and climates.

In his comments, Patrick Westhoff attributed much of the growth in grain demand to biofuel use and growth in per capita consumption in China. He argued that both of these trends will moderate. Rosegrant's paper presents a less optimistic view in a graph plotting per capita meat consumption against gross national income per capita. This is a reminder that food tastes as well as population numbers are shifting:

the trend of increased animal protein in the diet implies a strong upward shift in water demand despite a stable population.

II. Technical and Institutional Change

Technical change in irrigated agricultural production can be grouped into hydrologic technology changes, agronomic technology changes, and genetic technology changes. All three technologies can change the critical relationship between water use and agricultural production; however, the papers stress significant differences in how they influence fundamental water productivity between developed and developing countries. Hydrologic technology usually focuses on the field efficiency of irrigated production, defined as the ratio of applied water to the quantity of crop produced. Several speakers stressed that in developing countries, improvements in field efficiency often do not reduce net water use due to rational behavioral responses by farmers, who increase the area of irrigated production or shift crops to take advantage of the new efficiencies. This is an example of the Jevons paradox, which has changed the perception of the value of subsidizing field efficiency to induce water savings, a widely adopted water policy in developed and developing economies. In contrast, in her discussion of the paper by Scheierling and Treguer, Qiuqiong Huang stated that government-sponsored programs to improve field efficiency in China have been very effective in reducing net water use. She concluded that this is due to the small-scale and intensive nature of Chinese agriculture that prevents farmers from increasing water use in other crops or areas and undermining the gains in productivity from the improved field efficiency.

Cassman's paper emphasizes agronomic technology shortfalls expressed by the gap between potential yield and realized yield. He shows this yield gap is rarely less than 20 percent due to the increased risks and decreasing rates of return when farmers increase input use per acre much beyond this. One solution to this yield gap might be subsidized index insurance to shift some of the risk of closing the yield gap from farmers to national agencies. Another interesting finding is that much of the growth of yield realized in developed countries can be attributed to improved agronomic practices and mechanization rather than changes to the fundamental genetic stock.

The potential for substantial shifts in irrigated productivity due to genetic improvement was presented from two different perspectives. Cassman was not optimistic about the potential for genetically modified organisms (GMO) or clustered regularly interspaced short palindromic repeats (CRISPR) technologies based largely on data from developed countries' irrigation productivity. He was unable to find any dramatic gains in productivity resulting from these new approaches to plant breeding compared with advances due to new agronomic technology. In addition, many developing countries are reluctant to adopt GMO crops, as these crops may reduce their ability to export crops to some developed countries.

The paper's discussant, John Hamer, presented a contrasting view from the perspective of private industry. Hamer stated the current developments of both drought-resistant characteristics and significantly improved productivity from changes in genetic stock were proceeding rapidly and successfully. He cited examples where information from small start-up companies was leveraged by Monsanto and other companies. A critical factor for future crop adoption that came up in discussion was whether the new CRISPR gene technology will be characterized by the same stigma that currently impedes GMO technology. There was no consensus on this question.

Institutional changes to adapt to increased water scarcity also differ tremendously between developed and developing countries. In the context of developing countries, the conference papers on institutions focus almost exclusively on the optimal ways to implement water markets under different institutional circumstances. Mike Young's paper on the development of water markets in Australia presents a strong case for a wholesale modification of water property rights from the standard usufructuary water rights such as "prior appropriation" to those based on shares of the existing system. He stresses that there needs to be a clear demarcation between permanent rights as shares in a system and the annual allocations to those shares. His paper demonstrates dramatic changes in the net value of water in Australia over the last 10 years and emphasizes the importance of low transaction costs and a clear title to water. In addition, it is important to establish environmental water rights that can be traded on the same basis as other uses. In his comments on Young's paper, Nicholas Brozovic discussed the adoption of water markets in the United States and stressed the "path dependency" of institutional adoption. While he agreed with the principles that Young uses to define tradeable water rights, he was less sanguine about the difficulties of adopting a system similar to the Australians in the United States.

Despite these caveats, there is no question that the commoditization of both ground and surface water is a strong trend in many developed economies. Given the experience with other commodities, it seems that this trend toward pricing as an allocation mechanism for agricultural water and environmental uses will advance steadily and take the form of different institutional systems. Growing scarcity is driving the realization that despite significant environmental and social externalities associated with water use, water has all the fundamental characteristics of a commodity. The commodity properties are that it is highly substitutable across uses and locations, that a particular location of supply does not have unique characteristics despite the labels on bottled water, and that it can be stored without serious deterioration in quality.

One interesting exception to the market-based focus of the papers on water institutions in developed countries is the success of Natural Resource Districts (NRDs) mentioned by several conference participants. These districts have been established in Nebraska since 1972. There are 23 NRDs that control groundwater extraction by balancing artificial and natural recharge on a regional basis. The improved natural recharge of aquifers in Nebraska significantly helps the success of NRDs. Simple controls govern pumping within the districts, and most importantly, there is local control of pumping, monitoring, and enforcing simple control rules. Part of the success of Nebraska's NRDs may be that they are consistent with the principles of self-governing institutions proposed by Elinor Ostrom and discussed in the next section. Local control and enforcement is perhaps the most important principle of self-governance. Qiuqiong Huang's comments on Chinese irrigation institutions provided a counterpoint to the emphasis on markets in developed countries' economies. In China, the current emphasis is on subsidized technology in command-and-control systems for water allocation. Huang told us that water markets allocate groundwater in China, but there are mechanisms to restrict excessive pumping.

III. Some Omitted Topics in the Symposium

Despite the comprehensive topic coverage in the formal papers, I think that three topics important to understanding an agricultural water economy were underrepresented in the presented material. These topics are endogenous institutions, water quality degradation, and remote sensing methods for water and land use. A brief overview of these topics follows.

Endogenous local institutions

A significant omission from the discussion of institutions in conference papers is the work of Elinor Ostrom, the only person to receive the Nobel Prize in economics for work in resource economics. Ostrom's seminal work studied how small, self-governing, participatory institutional mechanisms arose from collective action in traditional societies. In particular, she focused on the management of common property resources which originated in the story of competitive water pumping from groundwater basins around Los Angeles area in the early 20th century and then was extended to analyze common property institutions in many other countries.

Ostrom developed eight principles for the collective choice management of resources under common property situations. She emphasized the need for consistency between appropriation and allocation rules, a point Mike Young makes in his paper on Australian water markets, and the benefits of locally based monitoring, measuring, and enforcement with graduated sanctions. Ostrom's work has made many contributions to both the design of optimal market mechanisms for water and, more importantly, the principles that will allow community-based management of common property resources. In developing countries, the clear and tradable property rights needed for water markets may be socially, physically, and economically impractical. By defining the community as the minimal management unit, the transaction costs of management can be greatly reduced. Rather than direct management of water allocations, the government can indirectly manage these water resources by providing information on village-level resource use and financial support for the village-level monitoring and enforcement of local rules. A potentially practical institution for water management in developing countries is one where control is decentralized to local units that may follow the process of community management based on Ostrom's principles. This combination of local control and centralized provision of information was raised by several speakers at the conference in the context of the system of Resource Management Districts in Nebraska. Resource Management Districts seem to have strong parallels with Ostrom's principles in that they rely on information on groundwater systems provided by state agencies but set and enforce their own management rules. Additional discussion of the implementation and principles behind Ostrom's work can be found in Cox and others.

Water quality for domestic consumption and agriculture

While the conference discussed managing water quantity extensively in a very wide range of aspects and levels of development, water *quality,* which is inextricably linked with water quantity use, was not discussed in any of the papers or questions from the audience. It may be no exaggeration to state that in several parts of the world, the degradation of groundwater quality by salinity, nitrate, and heavy metal accumulation is a greater threat to future use of that water resource than overdrafting. As we are often reminded, salinization has caused the collapse of many ancient traditional irrigation societies. Given the inevitability of saline concentration from the process of irrigation and evapotranspiration from external water supplies, agricultural irrigation systems cannot achieve a steady-state saline level without sources for external drainage and flushing of salts from the root zone. The need to flush excess salts from the root zone contradicts the fundamental nature of improving irrigation field efficiency. On the other hand, more efficient irrigation systems reduce the deep percolation and thus the transport salts into the online groundwater aquifer. For steady-state irrigation, one needs to strike the optimal balance between the minimal leaching fraction to maintain a salt-free root zone and that required for maximum efficient use of available water supplies.

Another source of degraded groundwater quality due to agricultural irrigation is excessive nitrate leaching. Given the high level of nitrate application in many irrigated crops, it is unusual for much more than 50 percent of the applied nitrates to be removed in the crop material, leaving the remaining nitrates to leach down through the root zone (although some of them are transferred to the air by volatilization).

The quantity of nitrates leaching into the groundwater is a function of the rate of nitrate applied to the crop and the time nitrate resides in the root zone, which is determined by the method of irrigation and the leaching fraction that results from it. More efficient irrigation methods, such as drip, reduce the nitrates leached into the groundwater, as they allow a greater residence time of the water and dissolved nitrates in the roots. Thus, a greater proportion of nitrates is taken up by the plant and removed as vegetative matter. The same relationship between application and water efficiency applies for the source of other groundwater contaminants, namely, heavy metals and pesticide residues.

While salinity is a major concern since it decreases crop yields, the level of nitrate pollution of groundwater has substantial public health costs, most particularly if young children are exposed to it through a supply of drinking water. Nitrate poisoning in young children is often known as blue baby syndrome. In many rural irrigated regions in both developed and developing countries, nitrate levels above safe drinking water levels persist. However, many rural water sources still have to rely on contaminated groundwater, which imposes costs and risks on a population sector that is least able to offset these risks with other sources of water or move to other locations. Clearly, nitrate and pesticide contamination leaching into groundwater is a major problem in many irrigated areas.

Emerging information systems for improved water management

Many of the water management institutions discussed and criticized in the conference papers are forced to manage using proxy variables due to the cost and difficulty of precisely measuring water use on a scale suited to management. This is one area in which substantial and recent breakthroughs due to better information technology systems may have a real chance of changing the precision with which water can be managed while simultaneously reducing transaction costs. Two different systems using remote sensing promise to measure surface water evapotranspiration and changes in groundwater volume with greater precision than currently available. The first system is the Metric (Sebal) method, which uses an energy balance measure from the Landsat satellites and climate data from local ground-based sources to calculate evapotranspiration (ET) for each 40 x 40 meter pixel every one to two weeks depending on cloud cover and satellite passes. The second system uses data from NASA's Gravity Recovery and Climate Experiment (GRACE) systems to estimate changes in groundwater stocks over large, basinwide geographic areas.

The Metric ET method has been extensively tested over the past 15 years and found under many conditions to have a high level of accuracy compared with standard field lysimeter-based ET measures. (Allen and others). In Idaho, where most of the pioneering work on this method has been done, Metric is accepted as reliable information on which to base the settlement of water rights in the Idaho courts. This ability to accurately measure net water use on a field, farm, or basin scale enables users and managers to calculate the net withdrawals from groundwater as long as surface water supplies are relatively accurately measured. In addition, using the Metric system to estimate water use shows considerable savings in transaction cost over conventional methods. A comparison in Idaho shows that conventional metering costs $119 per well per year, while comparable estimates using Metric cost $32 per field per year. When Metric is more widely used, additional economies of scale should be achievable. Estimations using Metric are now being used for water management in several other western states.

Groundwater stocks can also be measured by remote sensing. Richey and others use the GRACE satellite system to measure changes in groundwater stocks on a global basis. Currently, the GRACE system is normally aggregated at a scale that precludes its use for individual basin management but presents an invaluable method of assessing changes in groundwater stocks on a consistent and accurate basis worldwide. Richey and others measure groundwater stress in 37 of the world's major basins. They use a general measure of renewable groundwater stress (RGS), which, similar to Scheierling and Treguer's paper, is defined as the ratio of use to estimates of availability. Richey and others use the trend in subsurface storage anomalies over the study period to quantify the change in groundwater by accounting for withdrawals, capture, and changes due to natural factors such as drought. Their results show that eight aquifers are overstressed based on RGS_{GRACE}, and 13 of the study aquifers are variably stressed based on RGS_{GRACE}. Seven of these systems are in the low stress category including the Ganges, where there is a high rate of mean annual recharge. Thirteen aquifers are characterized as unstressed: these are mainly located in remote forested areas and rainfed regions with an absence of irrigated agriculture.

Famiglietti and others apply GRACE measurements to depletions to aquifers in California's Central Valley over a 78 month period. Their results show a greater rate of groundwater depletion (which may well be unsustainable) than other methods, with potentially dire consequences for economic and food security.

IV. Summary

The conference presented a series of provocative and challenging papers that ran the gamut of interactions between water and agriculture in developing and developed economies. The key consensus throughout the conference was the increasing scarcity of water due to both supply reductions (due to climate change and overdrafted aquifers) and a strong increase in demand (due to increasing populations and shifts in diet). While there is not clear agreement among the speakers, there was a consensus that continuous advances in both institutional and technological responses to increased water scarcity would be forthcoming in developed and developing agricultural economies. In developed countries, irrigated agriculture will continue to increase productivity. At the same time, developed countries will respond to ever-increasing environmental requirements by adopting more of a market orientation toward water allocation to redistribute scarce water resources over time, location, and economic sectors.

Developing countries face a more challenging situation due to the twin problems of a growing population and shifts in diet toward greater meat consumption. In addition, developing countries probably face similar constraints on future groundwater extraction due to the current level of unsustainable overdrafting. Some speakers noted that institutional change toward a market orientation may not work as well in developing countries due to problems of property rights, transaction costs, tradition, and enforcement. However, several speakers show that there is significant potential to improve irrigated agricultural production in developing countries.

Finally, I apologize to those speakers whose views I may have misrepresented and to those whose prescient insights I may have overlooked. Any omissions are entirely my fault, with my only excuse being the pace and intensity with which this successful conference evolved.

Endnote

[1]Basins that are currently severely overdrafted are in the Middle East, the Indo-Gangetic plain, the Ogalalla foundation under the U.S. High Plains, California's Central Valley, and parts of northeast China.

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