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Chapter 2- Global Perspectives on Water for Food

Prem S. Paul  
*University of Nebraska at Lincoln*, ppaul2@unl.edu

Monica Norby  
*University of Nebraska-Lincoln*, mnorby1@unl.edu

Gillian Klucas  
*University of Nebraska-Lincoln*

Ashley Washburn  
*University of Nebraska-Lincoln*

Elizabeth Banset  
*University of Nebraska-Lincoln*

*See next page for additional authors*

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Authors
Prem S. Paul, Monica Norby, Gillian Klucas, Ashley Washburn, Elizabeth Banset, and Vicki Miller
The water crisis will play a major role in the future of global poverty, yet little awareness of this critical issue exists and few discussions are taking place about securing water for food, Jeff Raikes said. In a call to action, Raikes advocated an integrated and interdisciplinary approach, one that pulls on all levers to solve the pending crisis.

The Crisis
Already about 75 to 80 percent of human water consumption is used to grow food, Raikes said. The projected doubling in food demand, coupled with climate change’s impact on geographic availability of water, will significantly increase the demand for water, precipitating a water crisis.

To illustrate the crisis, Raikes, who grew up on a family farm near Ashland, Neb., remembers his father describing the state’s wonderful agricultural resources – the rich soils and nearly infinite supply of water. But a photograph of Lake McConaughy in western Nebraska that shows a boat dock left high and dry far from the lake due to plunging water levels tells a different story. Similarly, a photograph of a dry Jialing River in the shadow of Chongqing, a Chinese city of more than 30 million people, illustrates how urbanization stresses water resources. Industrial water consumption is expected to more than double by 2050. And in a third photograph, a crowd surrounds a large well during a 2003 drought in Natwargadh in India’s Gujarat state. “Think about the regional context,” Raikes said. “In India, it may be low groundwater levels as the largest problem. In China … it can be rivers that don’t reach the sea.”

Raikes compared projections for 2050 to today’s food and water needs. Agriculture currently uses about 7 million cubic kilometers of water annually through evapotranspiration to produce the nearly 20 calories consumed daily. By 2050, based on projected food demand from population increases and dietary changes, water requirements will reach 13 million cubic kilometers under a business-as-usual scenario. That figure does not include demands from biofuels.

In addition, water is not where it is needed most, a problem likely to worsen. Raikes said the Bill & Melinda Gates Foundation is particularly concerned about areas of water scarcity, both physical and economic, because the places where water is scarce are the same places where hunger is worst.
Global weather trends are particularly threatening in Sub-Saharan Africa, which is likely to get drier. The way in which climate change will expose itself to the world, the way in which it will become tangible to people, is through a crisis, Raikes said. “My conclusion is that if we don’t change, if we don’t innovate across the spectrum of all the levers that we can pull, if we don’t take an integrated, interdisciplinary approach to this challenge, we are not going to be able to feed the world.”

Solutions
Given this crisis, what solutions are available? Raikes asked. Some options include:

- Using more land, an unsustainable worldwide solution in the long term.
- Using more water, an option in some areas of Sub-Saharan Africa, but sufficient water may be unavailable or inaccessible.
- Reusing wastewater, an important option for urban farming, but inappropriate for some crops and unable to alleviate much of the water pressure in rural areas.
- Wasting less food, an important but ill-understood option. An estimated 30 to 40 percent of all food produced fails to reach consumers because of post-harvest losses in developing countries and food disposal in developed countries. Less waste, however, can alleviate only some of the water pressure.

Despite these limitations, Raikes expressed optimism. His years spent in the technology world – seeing the power of both innovation in technology and inspired, passionate leaders working together to change the world – has proven to Raikes that great things can happen.

“Today, I endorse the vision of more ‘crop per drop,’” he said. “We have to get more food on the same land with the same or less amount of water.” Examples proving it is possible exist.

“The key question is how can we take what we learn, how can we build new innovations, and how can we bring them together into scalable and sustainable change?”

The gaps between actual and potential yields of rainfed agriculture in Sub-Saharan Africa, in Organisation for Economic Co-operation and Development nations and throughout the world, are large and provide reasons for optimism. According to the International Water Management Institute (IWMI) Comprehensive Assessment overseen by David Molden, investment costs per hectare to upgrade rainfed areas can be relatively low, particularly in Sub-Saharan Africa where...
most rural people live in rainfed areas and where more people can be lifted out of poverty. An optimistic outlook on yield growth demonstrates that achieving 80 percent of potential yield would meet 85 percent of food demand in 2050, particularly in the low-yielding farming systems where poor people tend to live. The IWMI Comprehensive Assessment suggests the world’s growing food demand can be met by rainfed agriculture, through yield gains combined with a modest 7 percent increase in agricultural land.

But that scenario is optimistic, and irrigation must be part of the solution, Raikes said. The gap between actual and potential yields in irrigated agriculture also is large. Looking at South Asia, primarily India where 50 percent of agriculture is irrigated, under an optimistic scenario in which 80 percent of the gap between actual and obtainable irrigated yield is bridged, more than half of the additional food demand can be met by improving output per unit of water on existing irrigated land.

“It will be your understanding of this crisis and your vision that leads to greater awareness and inspiring the necessary public and political will to support these investments.”

That approach includes combining the best practices of today and those yet to be discovered. Today’s best practices include: the right underlying seed technology, effective distribution and market access; great soil management, including appropriate fertilizer and practices like intercropping and conservation tillage; efficient irrigation; watershed management that brings communities together to think holistically about their shared watershed; and education and training so that information reaches farmers.

Best Practices of Tomorrow

The Gates Foundation supports agricultural research and development, from the most basic to the advanced, that will lead to tomorrow’s best practices, including efforts to help smallholder farmers develop and distribute more productive crop varieties that thrive in different soil types and are resistant to disease, pests and drought. Another major priority is the development of affordable water storage, pumps and micro-irrigation technologies. More effective and inexpensive technologies that let smallholder farmers capture and use water efficiently without creating unsustainable demands on natural resources remain critical.

Policies also must be devised to encourage more crop per drop, Raikes said. He outlined three characteristics of effective policies. First, policies must target the livelihood gains of smallholder farmers by securing water access through water
rights and investments in storage and delivery infrastructure where needed, and by investing in roads and markets. Second, policies must be integrated. Instead of focusing narrowly on rivers and groundwater, rain must be viewed as the ultimate source of water that can be managed. Instead of isolating agriculture as a production system, it must be viewed as an integrated, multiple-use system and as an agroecosystem, providing services and interacting with other agroecosystems. And finally, policies must provide the right incentives to support adequate water availability for producers. For example, rather than charging farmers for more water use, the parts of societies benefiting from reallocations may need to compensate farmers for less water use in agriculture.

**Water for Food: A Call to Action**

Raikes proposed an agenda for the Water for Food Institute to achieve “more crop per drop.” It includes: pushing everyone in the value chain toward more efficient use and toward greater awareness that water is a precious resource; employing innovations, such as using trade to promote the most efficient use of water; tapping science and technology to develop crops that more effectively use water; engineering ways to better capture and store rainfall; and encouraging better farm management practices so that available water is effectively and efficiently used.

“I feel that we must invest in and pull on all the key levers,” Raikes concluded. “We must take an interdisciplinary and integrated approach. It will be your understanding of this crisis and your vision that leads to greater awareness and inspiring the necessary public and political will to support these investments. It’s going to require, through leadership and innovations, your collaboration and teamwork across disciplines and across geographies. It can be this global Water For Food Institute that brings leadership together to set and drive this integrated agenda for more crop per drop.”
The Robert B. Daugherty Charitable Foundation’s $50 million gift to the University of Nebraska to develop the Water for Food Institute is a visionary gift that began with a visionary man, James B. Milliken said. Robert Daugherty returned to his home state of Nebraska after World War II to found the world’s most successful irrigation company. In his ongoing commitment to water use efficiency, he was a leader in the critical challenges facing agriculture.

Nebraska may seem an unlikely place to tackle those challenges with a new Water for Food Institute, Milliken said, but the state has a long history of serious, bold people who have helped change the world. Warren Buffett, one of the world’s wealthiest and most philanthropic people, has created enormous wealth for many, which has benefited not only the University of Nebraska, Buffett’s alma mater, but many other institutions. The Omahan has not had to stray far from home to be an important financial figure.

Other Nebraskans have revolutionized agriculture, saving millions of lives and improving millions more. George Beadle, born in Wahoo, Neb., and a University of Nebraska–Lincoln graduate, made significant contributions in molecular, cellular and developmental biology, earning a 1958 Nobel Prize with Edward Tatum for the “one-gene, one-enzyme” theory. Beadle’s contemporary, Henry Beachell, also a Nebraska native and UNL alumnus, worked in the U.S. Department of Agriculture’s rice breeding program. Later, at the International Rice Research Institute, he developed rice strains that dramatically increased yields, saving millions of lives. He won the 1996 World Food Prize and, working into his 90s, established a genetic seed bank for rice.

Norman Borlaug, an Iowan who attended the University of Minnesota, worked in Mexico in the 1940s and 1950s, breeding new disease-resistant wheat varieties. His work led to a sixfold increase in yields. In the 1960s, he convinced Pakistan and India of the value of wheat and is credited with saving millions from famine. Borlaug’s work played a leading role in the Green Revolution, for which he won the 1970 Nobel Peace Prize.

The next Green Revolution must be greener than the first, Milliken said, citing Bill Gates, who has called for considering small farmers’ needs, exploring a wide range of techniques, adopting solutions to local circumstances and ensuring sustainability.
“Doubling food production in a way that supports all human life and protects our environment is a challenge that will help define the work of the new Water for Food Institute,” Milliken said. “We envision it as a distributed global entity, with Nebraska as its home and the site of what we hope will be the most significant conference in the world on water for agriculture, but with research fellows, partners and collaboration centers located throughout the world.”

The global Water for Food Institute is a research, education and policy institute committed to helping the world efficiently use its limited fresh water resources to ensure the food supply for current and future generations.

The institute hopes to attract outstanding leadership from top research and teaching talent, and to build on the University of Nebraska’s more than 100 faculty members from disciplines related to water and agriculture, who include internationally respected leaders in surface water and groundwater interactions, drought mitigation, and water law and policy. Eventually, the institute will be located on Nebraska Innovation Campus, a 249-acre private-public development focused on food, fuel and water.

“In making his gift to the university, Bob Daugherty said that we have the right people and the right place at the right time to be successful,” Milliken said. “I’m grateful for his confidence, and I share his belief that Nebraska, with its richly varied water resources, its national leadership in agricultural production and irrigation and its public university that has a rich history of research and education and outreach on water, is indeed the right place.”

Beadle, Beachell and Borlaug accomplished tremendous agricultural advances using the best science available at the time. Today’s technologies and global communication provide great optimism that much more can be achieved in the 21st century, Milliken said.
The Robert B. Daugherty Foundation’s gift of $50 million to establish the Water for Food Institute, one of the largest gifts in University of Nebraska history, could not be more timely or important, Harvey Perlman said. The institute will allow the university to leverage its strengths and long-time expertise in research, policy analysis and education in water and agriculture to solve a critical world problem.

Efforts to advance food production are not always universally acclaimed, Perlman said. Floyd E. Dominy, who was born on a Nebraska farm 100 years ago and recently passed away, provides one example. While working as an extension agent in Wyoming, Dominy realized that building small dams to store water would help farmers in his region. He built more than 300 dams, more than previously built in the entire West. Later, as commissioner for the U.S. Bureau of Reclamation, he presided over the construction of many prominent dams, including Glen Canyon and Flaming Gorge. Dams were applauded for generating power, creating lakes, providing water for growing crops and expanding urban areas. But they also were denounced for destroying Native American historical sites, ecosystems and fish habitats. “Dominy’s activities on behalf of water for food remain clearly controversial, and illustrate the inevitable tradeoffs and competing demands made of our water resources,” Perlman said.

The University of Nebraska, a longtime leader in research, education and outreach in water, agriculture and natural resources management, offers the expertise and knowledge base to assume a leadership position. Its expertise extends beyond producing technologies and innovative management practices to sociology, economics, computer science, law and engineering – all important to addressing these complex issues.

The university has doubled its research funding in the past decade, enabling the leadership to begin developing Nebraska Innovation Campus, a premier private-public sector sustainable research campus on 249 acres adjacent to the university. The campus will provide exciting opportunities for collaborative research and product commercialization. Building on the university’s strengths, the campus will focus on water, food and fuel. The Water for Food Institute will play an important role, sharing many goals of developing sustainable solutions.
through partnerships with private enterprise and with researchers and educators throughout the world.

“The Water for Food Institute strengthens our university in ways we have yet to imagine and to build networks with partners we have yet to meet,” Perlman concluded. “Your attendance at this conference is just the beginning and gives us great optimism that we have focused our vision on the right strategies to create a preferred future. We are open and look forward to engaging in partnerships with many of you in this room to address the critical issues that bring us together.”
Breeding programs in Africa and Asia that screen for drought tolerance are effective and important components in improving food security, but few breeding programs do it, Gary Atlin said. He described the successful drought-tolerant breeding programs of the International Maize and Wheat Improvement Center (CIMMYT) and the International Rice Research Institute (IRRI).

Extreme rural poverty persists in rainfed systems and is concentrated in two major areas: maize areas of eastern and southern Africa and rice-based systems in South Asia. However, inexpensive grain from rainfed systems also keeps prices low, helping the urban poor survive, Atlin said.

Unlike commercial farmers, subsistence farmers must worry about yield in drought years because their food security and capital stock depend on what may be the difference between a half-ton yield and a quarter-ton yield.

Managed-stress Breeding
Atlin first looked at the origin of yield gains in rainfed agriculture in North America. In Iowa, rainfed corn yields in the 1920s were comparable to today’s yields in Africa. A substantial jump occurred mid-century with continued gains since then because plant breeding increased biomass and tolerance to high plant densities, improved drought tolerance and nutrient recovery, and faster recovery from cold stress.

These gains were achieved almost entirely from wide-scale, multiple-location testing under rainfed conditions in the targeted population of environments. Is that model applicable to rainfed systems in Africa and Asia? Atlin asked.

The approach is prohibitively expensive because of the need to test at hundreds of locations and so cannot be precisely reproduced, but expanding rainfed testing in Africa and Asia is greatly needed. Breeding programs and private companies, however, are investing more in yield testing under managed stress for tolerance to low fertility and drought conditions. CIMMYT was an early pioneer in breeding for drought tolerance in maize.
A managed-stress screen must be integrated into the breeding program, as opposed to using it only as a genetic analysis or research tool. CIMMYT screens for both low fertility and drought tolerance under severe stress conditions to identify materials with drought tolerance, a significant difference from commercial corn breeding in the U.S. CIMMYT aims to reduce yield 60 to 80 percent in its screening process and looks for high genetic correlation with what’s happening in farmers’ fields under the worst conditions. Working in the rain-free season, irrigation is stopped about 30 days before flowering with the hope of detecting severe stress symptoms. “It’s actually a tough target to hit precisely,” Atlin said.

“It’s an art, not a science, generating these screening environments.” The results can be dramatic-looking differences in plant water status and sometimes in yield, even when plant water status differences are invisible because of differing sensitivities of the flowering process.

30 Years of Recurrent Selection
Using this protocol, CIMMYT has conducted recurrent selection programs for 30 years, making gains of about 100 kilograms per hectare per selection cycle every couple of years. Grain yield increases appear to be associated with reduced ear and kernel abortion, shorter anthesis-silking interval and a faster growth rate at the ear shoot around flowering. Although additional harvest index improvement is often viewed as unable to further increase water productivity, that is not the case in drought-prone environments, Atlin said. Stress also severely affects harvest index in rice and maize and is a major area of gain when managed-stress screens are incorporated into the product development pipeline.

Atlin described CIMMYT’s Stage I testcross evaluation of four to six environments, including optimal rainfed management, severely nitrogen-depleted conditions, and managed stress in the dry season. CIMMYT has just begun experiments to examine gain from selection in its modern Africa-based programs. IRRI also incorporated drought screening into its rice breeding program in India and found, surprisingly, that the workhorse Green Revolution-irrigated varieties were much more sensitive to drought and were failing regularly under severe stress conditions. IRRI identified materials that are yielding about a ton more under stress conditions, and several varieties have been released.

“We’re very concerned that the new tools that are becoming available be applied in breeding programs targeted at the poorest farmers in rainfed situations.”

“Gains from rice and maize breeding programs have been quite large once we actually started to incorporate directed stress treatments,” Atlin concluded of CIMMYT and IRRI’s experiences. This first step resulted in a 20 percent yield increase relative to the commercial materials in southern and eastern Africa; one breeding cycle in rice delivered 50 percent gains under severe stress. Although this rate of gain won’t continue,
Atlin said, it is unlikely that transgenes or quantitative trait loci would have delivered similar gains without breeding advancements. The new biotechnology tools are adding onto a solid foundation of cultivar development.

“We’re very concerned that the new tools that are becoming available be applied in breeding programs targeted at the poorest farmers in rainfed situations,” Atlin said. CIMMYT is sourcing and applying tools, such as improved screening approaches and phenotyping protocols, double-haploid inducers, molecular-marker technologies and breeding informatics management.

**Transgenic Future**

CIMMYT also is involved in public-private partnerships to develop transgenes for improving drought tolerance and nitrogen-use efficiency for African smallholders through the Water-Efficient Maize for Africa project with Monsanto Company and the Improved Maize for African Soils project with Pioneer. The products of these collaborations will be drought-tolerant and improved nitrogen-use transgenic varieties available to African smallholders under humanitarian licensing and market segmentation arrangements.

Deployment of transgenics in developing countries requires $25 million to $100 million and at least 12 years to make it to a farmer’s field, Atlin said. Few African countries have a regulatory framework allowing them to accept transgenic technology, and those that do rely on data from the U.S. regulatory system. “At the moment, and I believe for the foreseeable future, only transgenes that can be commercialized by a company for farmers in a developed country will be made available in developing countries.” A transgene beneficial in Africa, but detrimental to U.S. yields, most likely will not be developed for marketing.

Drought tolerance in maize appears to be affected by many genetic factors, for which marker-index selection approaches are more suited. Fortunately, reduced costs for genotyping technologies are starting to allow CIMMYT and small breeding programs to apply these technologies. Next-generation sequencing of genome representations will make the haplotype, rather than the line, the selection unit, which will allow programs to share information but not germplasm. That ability, along with other advances Atlin described, will encourage the development of “open-source” breeding, which could reduce breeding cycle times by fivefold and potentially double genetic gains.

Making breeding informatics accessible to smaller breeding programs will be critical to the success of the new breeding system. “There’s a wave of genotypic data that’s going to break over us in the next year or so,” Atlin said. “This is not the distant future. This is happening. We will have thousands of polymorphisms available to use in making selections within the next year to 18 months. We need to put the systems in place to allow us to surf this wave of information.”

**Constraints**

Logistical constraints remain. Seed is expensive and difficult to produce, and many small companies in Africa cannot produce needed quantities, creating a serious logistical problem getting hybrid seeds to farmers. CIMMYT
works with 14 African countries and has released more than 40 varieties. Since 2003, collaborating seed companies have produced seed for more than 3 million hectares, but 30 million to 40 million more African farmers, as well as farmers in Asia and Latin America, need these seed gains.

“Breeding for drought tolerance is both urgent and effective, but relatively few breeding programs in the developing world actually do it,” Atlin said. Delivering drought tolerance requires an integrated pipeline with clearly defined target environments, expensive and intensive new phenotyping tools and extensive multi-location rainfed testing systems in the target environment.

Accomplishing it will take public consortia, public-private partnerships and open-source breeding models.

“There is going to be a revolution in breeding methods based on low-cost, high-density genotyping in the next three years,” Atlin concluded. “It’s already happened in the private sector. It’s going to happen now in the public sector. We need to make sure that farmers in drought-prone environments, the poorest farmers in rainfed regions of the world, are among the first to benefit.”
According to *Charting our Water Future*, a McKinsey & Company report, the world faces a significant water challenge and business-as-usual practices will not suffice, Giulio Boccaletti said. Cost-effective, sustainable solutions are possible but will require engaging economic activities across entire societies. The report, commissioned by concerned private-sector enterprises potentially affected by water scarcity, provides a useful decision-making tool for tackling water issues.

**The Water Challenge**
Currently, the world uses 4,500 billion cubic meters of water annually to meet agricultural, industrial and municipal demands. By 2030, under a business-as-usual scenario, the world would require nearly 7,000 billion cubic meters. However, according to estimates in the report, only 4,200 billion cubic meters of water will be available in 2030 for human uses, a measure not just of physical scarcity, but of the ability to sustainably supply water when and where it is needed. The figure is calculated by subtracting environmental needs, transfer loss and other loss variables from total renewable water resources for important global water basins.

Those figures represent a global projected water gap of 40 percent between future demands and capacity, with some areas facing gaps of up to 75 percent, Boccaletti said. The growth in demand stems largely from agriculture but also from industry and municipal systems.

How can this gap be closed? Boccaletti asked. Will countries be able to increase supply, or will they need to reduce demand either by increasing efficiency or by curbing economic activity? The problem is global, but ultimately solutions must occur at a local level. China’s water gap, for example, will be driven primarily by agriculture but also by significant growth from industrial and municipal uses, particularly thermal power production. “Power production is a significant fraction of the water demand in China,” Boccaletti said.

In South Africa, roughly 60 percent of water use goes to irrigated agriculture (20 percent of the country’s agriculture is irrigated), but a growing
demand comes from mining and other industrial uses. “The reality is that the competition between water for food and water for energy and water for other industrial activities is one of the fundamental issues that South Africa is facing,” Boccaletti said. India faces an even larger water gap across most sectors, driven by water demands from rice, wheat and sugar production.

**Need for Action**
Some have questioned whether a crisis is looming. In the past, increases in supply and improvements in water productivity have averted predicted imminent crises. Can the gap be closed by adding supply, such as building a new reservoir, to deliver more water where and when it is needed? Adjusting for historic rates of increasing supply and decreasing demand reveals that 60 percent of the 40 percent projected gap remains.

India illustrates why supply may be constrained. Reviewing costs of various supply measures used today, such as small-scale irrigation infrastructure and rainwater harvesting, the average cost of supply is about 2 cents to 3 cents per cubic meter. The average cost of adding new supply is higher, about 7 cents per cubic meter, and the cost of marginal units of water that can be delivered is closer to a dollar per cubic meter. China, too, illustrates another supply constraint. The relative fraction of non usable water is increasing because of pollution, so water quality is becoming intertwined with quantity.

**Solutions**
If past solutions cannot close the 40 percent water gap, then what can be done? To answer that question, the report includes an introduction to the water-availability cost curve, which takes into account all water uses, from drip irrigation to improved crops and efficient shower heads, and determines their specific costs and potential to close the gap between supply and demand in a particular basin. Overlaying the cost curve onto the gap helps determine which measures can close the gap and how far up the cost curve it is necessary to go. “It offers a menu of options, essentially, and a quantification of their potential and their cost,” Boccaletti said.

Using this method, can India or China, for example, close its water gap? What will it cost, and what would it take? No silver bullet exists; each country requires different solutions. India, for example, will need 755,800 million cubic meters of water by 2030. The cost-curve analysis shows that India has ample opportunity, in theory, to solve its water crisis. The cost to close the gap would equal $6 billion per annum, a small figure compared to India’s $50 billion, five-year agricultural program. About 80 percent of the ability to accomplish this involves increasing agricultural efficiency, including no-till farming and increased fertilizer use. “In the case of India, the most cost-effective measures have to do primarily with the rehabilitation of the existing infrastructure,” Boccaletti said.

“The cost-curve analysis actually starts framing the choices that policymakers have in thinking about the issue.”
China, in contrast, uses agricultural water more efficiently, but many opportunities exist to increase industrial and municipal efficiency. So China, too, can close its water gap, while, surprisingly, also saving $30 billion per year. Measures include industrial efficiency, such as reusing water in steel production.

The tool can be used to compare costs and savings using combinations of solutions and scenarios, such as increasing climate change effects and accelerated economic growth. This analysis demonstrates that closing the water gap is possible. In fact, the problem is not a lack of technology or money; it’s a policy, incentive and institutional question, Boccaletti said. “This actually starts framing the choices that policymakers have in thinking about the issue.”

**Transformation Pathway**

Boccaletti outlined six elements to drive water sector transformation: accepted, fact-based vision to drive change, not anecdotal evidence; leadership and institutional alignment; correct regulatory schemes and incentive design; private-sector investment because many countries are still fiscally constrained; the role of large-user efficiency; and technology development.

If the issue is not technology or money, then why are changes not happening? Boccaletti asked. Numerous financial, political, structural and social barriers exist, from insufficient access to capital and pricing distortions due to subsidies to limited management capacity and lack of information.
Strong public leadership partnered with the private sector is providing innovative water resource management models in the financial, institutional and technological sectors, John Briscoe said.

Understanding the historical, social and cultural contexts in which water exists is essential to conducting the practical work of watering the world. The Mandarin symbol for political order, for example, is a combination of the anagrams for river and embankment or dike, illustrating the ancient importance of water in China. To control water is to impose social order. China’s Three Gorges Dam, then, is as much about political symbolism as flood protection and hydropower.

Historical context also suggests the provisional nature of water management. Solutions appropriate at one time often lead to new realities. “The first point I’d like to make,” Briscoe cautioned, “is the great danger of looking back and saying how stupid we were in what we did, when things that were done at that time might have been entirely appropriate for that particular context, but then gave rise to a new set of challenges.”

Briscoe looked to Pakistan to illustrate the importance of history and evolving context when dealing with practical concerns.

Nearly all of Pakistan’s water comes from neighboring countries. When Britain drew the boundary between Pakistan and India in 1947, 85 percent of the irrigated area of the Indus Basin was in Pakistan, while the headwaters feeding it remained in India.

After 10 years of negotiations, a solution was devised giving Pakistan and India each three rivers feeding the Indus Basin. Both countries built an infrastructure of dams and canals to link their designated water to irrigated land within their boundaries. “This has been, I think, one of the great achievements in the world in the last 50 years,” Briscoe said. “Something worked between two countries that have often had a variety of great pressures between them for almost 60 years.”
Everything is provisional, however, he reminded. India is undertaking—rightfully, Briscoe believes—a large hydroelectric development program that puts stress on the Indus Waters Treaty. Will the treaty’s past success evolve to face new realities? Such water tensions are not unique. Worldwide, 260 river basins are shared by two or more nations, and tensions are growing between and within countries.

**Endogenous Tools**

In many areas, old tools are still important to solving current water problems. The U.S. has 6,000 cubic meters of water storage capacity for each resident, compared to Pakistan and India with 150 cubic meters, and, at the extreme end, Ethiopia with just 40 cubic meters per resident. In Ethiopia, rainfall and the gross domestic product are nearly perfectly correlated. “If nature fails, the country fails,” Briscoe said. “This is the simple reality of living without any hydraulic infrastructure.”

Countries have small endowments to invest in infrastructure. India, for example, developed the Bhakra-Beas complex, a project now widely criticized as primarily benefiting large landowners. However, Briscoe countered, “creation of agricultural wealth is not something which stops with the farmers. It then requires a whole set of forward and backward linkages to process the food, to produce the inputs for this.” An analysis found that indirect benefits equaled direct benefits. The biggest beneficiaries were people without land because of the increased demand for labor and higher wages. “This sort of investment really provides a foundation for a very broad amount of social and economic development,” Briscoe said.

Financial investments have changed considerably in the past decade. The World Bank and regional development banks once financed infrastructure projects, such as dams. In the 1990s, controversy...
from nongovernmental organization (NGO) protests against water projects persuaded international financial institutions to largely stop financing dam projects. As a result, middle-income countries like Brazil opted to continue building infrastructure on their own, while poorer countries that needed financial support were left in desperate situations.

In the last decade, China has moved into the developing world, financing 215 dams outside of China, compared to the World Bank’s five. This shift is viewed unfavorably in the West, but developing countries welcome Chinese dams and construction, Briscoe said.

Innovative Models

New ways of structuring institutions offer innovative models in water resource management. The Manila Water Concession, which provides water to about 50 million people through a locally led concessionaire, is a successful example. The project, led by former Philippines President Fidel Ramos, now provides water to Manila residents, 30 percent of whom previously had no formal water supply. Briscoe also described as institutional models SABESP, a Brazilian water utility; a Chilean “water stamp” program; and a Brazilian “condominial sewage” system.

Model public-private partnerships also are occurring in irrigation and drainage. For example, in Brazil most irrigation is private, provided by individual farmers. In the semi-arid northeast, however, Brazil is trying to increase output of the São Francisco River through public-private irrigation projects in which private “anchor enterprises” provide technology, marketing and credit, while the state provides millions of dollars in equity. The concessionaires must make 30 percent of the area available to small farmers.

“I think this sort of innovation is what’s needed if small farmers are going to be able to reap the benefits of this increasingly complex and information-rich area,” Briscoe said.

Water for energy also is integrally related. Rich countries have developed around 80 percent of their hydroelectric potential, while Africa has developed just 3 percent, suggesting huge potential. New hydroelectric projects that use bulb turbine technology, such as those in Brazil’s Amazon, submerge 100 times less area per megawatt generated than previous technology.

Historically, these projects were financed publicly. In Brazil, a regulator now arbitrates among developers, users and the government, providing a framework for competition that has resulted in a 30 percent reduction in project costs.

Exciting things are happening in managing these water resource sectors, Briscoe said. The Australians have established a sophisticated system of tradable water rights, where sellers make more from selling water when the price is high and water is scarce than from growing low-value crops, resulting in water moving from low-value to high-value uses. The Australian Treasury found that intra- and interstate water trading lowers by two-thirds the economic cost of reduced water availability on gross regional product.
Investment in Agricultural Innovation
Technologies offer a third area of innovation. Agricultural technical assistance has suffered the same fate as infrastructure investment, down to 3 percent in 2005 from 18 percent in 1980. Brazil, in contrast, continued to invest in agricultural research, resulting in enormous returns. Agricultural output is now three times higher than 25 years ago, not from cutting down the Amazon Forest, but due to innovation and better use of resources. “If you … contrast a Brazil with an Africa, which depends on the whims of donors, the contrast, in my view, couldn’t be more striking,” Briscoe said.

Nevertheless, the development community, as articulated in the World Bank’s International Assessment of Agricultural Knowledge, Science and Technology for Development, eulogized small-scale and organic farming and denounced the Brazilian model of technology-intensive and large-scale agriculture that relies on genetically modified organisms (GMOs), Briscoe said.

Yet middle-income countries understand that GMOs are essential to increasing agricultural production, Briscoe said, adding, “We then have, in my view, a really tragic situation. Because when you look at development, the middle-income countries have gone their own way very successfully. And Africa stays out of GMOs, as I understand, largely because of pressure of European donors. … This is, to me, a sin.”

Briscoe described other technological innovations in water and wastewater treatment technologies, nanotechnologies, desalination and information technology.

Private Sector Engagement
New forms of partnerships also offer exciting new processes. Companies that see water scarcity and pollution as threats respond in one of three ways: by partnering with an NGO largely for appearances, by reducing their footprint to acceptable levels, or by adopting a philosophy of creating shared value. Nestlé, for example, believes that to improve business, it benefits the company to view itself as part of the long supply chain and to get involved in demanding that government better manage water resources.

A growing group of global companies is beginning to understand the world’s water challenge, to question what it will mean to their businesses and to engage with public policy, Briscoe said. He added that this positive participation must be populated by not only multinational corporations but also domestic companies of high moral standing that understand the local context.

“We’re going to need public leadership and private innovation,” Briscoe concluded. He believes universities serve an important role in training, in generating and convening knowledge, and in creating a new sense of partnerships in which mutual learning occurs. “The world has changed. The world doesn’t begin and end in the United States anymore. … The world is out there in China, India, Africa, Brazil. These are places with enormous intellectual capability, where they’re able to actually innovate often much faster than we are.”
Comparing the potential for an agricultural revolution in Africa with the 1960s Green Revolutions in Asia and Nebraska, Ken Cassman concluded that Africa could achieve its own by following those examples in which irrigation played a pivotal role.

**History of Irrigation**

Human urban civilization began with irrigated agriculture. About 8,000 years ago, the fertile crescent of Mesopotamia and the Nile Valley underwent agricultural transitions. In Egypt, for example, the Nile River flooded yearly, covering the valley floor. When the water receded, farmers sowed their crops. They irrigated the arid land by lifting water from the water table, using tools such as the shadoof. Today, because of irrigated agriculture, Egypt has some of the world’s highest yields. In Asia, rice could be grown in areas that flooded naturally; dikes and lifting water kept the soils flooded. Around the world, irrigated agriculture transformed civilizations, supporting cultural diversity and productivity.

Yet by the mid-20th century, projections showed food production would not meet the growing population’s needs. Per-capita grain production peaked in the 1980s and has been declining steadily since. Today, 1 billion people do not get enough nourishment.

**Irrigation Benefits**

The need to improve food production propelled the Asian Green Revolution in the 1960s, underpinned by a massive expansion in irrigated area, which jumped from about 10 percent to about 18 percent of total crop-producing land. That 18 percent of irrigated land now produces 40 percent of the human food supply.

The high productivity of irrigated agriculture reduces the pressure to expand agriculture into environmentally sensitive areas. People already produce food in areas that should not be farmed, using unsustainable practices that degrade the land. In addition, urban expansion has reduced land area for grain crop production by about 1.8 million hectares annually since the mid-1980s. “If you want to accelerate climate change, if you want to threaten the existence of orangutans and Sumatran tigers, just start reducing the productivity of irrigated agriculture,” Cassman said.
A stable human population will be achieved when the world average per capita income equals $4,000, the point at which female fertility falls to replacement levels, he said. Will “business as usual” produce enough food at that point? Cassman asked.

To answer that question, Cassman compared the rate of gain for the world’s three major cereal crops of corn, rice and wheat, which comprise nearly 60 percent of human calories, either eaten directly or through livestock products.

“With all the investment in science and technology in agriculture, with all of the increase in irrigation that’s occurred in the last 40 years,” he said, “it has allowed us to maintain only a constant rate of increase. The relative rate of gain is decreasing all the time.” Projections show the rate of yield gain required to meet future food demand is not even close, Cassman said.

### Asia’s Green Revolution

Asia’s Green Revolution began with new science and technology, most notably high-yield rice varieties that allowed farmers to grow two crops per year instead of one. That second crop required irrigation during the dry season, effectively doubling the amount of irrigated land. “The Green Revolution wouldn’t have happened in Asia without an expansion of irrigated area,” Cassman said.

Irrigated farming practices kept food production ahead of population growth, benefiting society beyond fulfilling nutritional needs. Because irrigated agriculture is predictable, farmers could purchase improvements, fueling small-scale entrepreneurial industries in inputs, equipment and foods. Higher production lowered the cost of food for both rural and urban poor, freeing income for other sectors of the economy.
In addition, the higher value of irrigated agriculture justified government investment in education, research and infrastructure to support agriculture – benefits that also extended to rainfed agriculture.

**Nebraska’s Green Revolution**

Nebraska sits in an incredible location, Cassman said. Its western edge forms part of what was once known as the Great American Desert. The state’s eastern half belongs to the Corn Belt, the world’s most productive agroecological zone. The Rocky Mountains and the monsoonal moisture from the Gulf of Mexico create a moisture gradient across Nebraska from 14 inches of annual rainfall in the semi-arid west to about 31 inches in the eastern third. A greater climate gradient exists within Nebraska, Cassman said, than from the Atlantic Ocean to the state’s eastern border.

The state’s semi-arid central and western areas rely on irrigation, which accelerated during the 1960s, much as it did in Asia. Nebraska is now equal parts rainfed and irrigated agriculture and has more irrigated acres than any other state. Over time, Nebraska corn and soybean yields rose due to improved technologies. Because irrigated agriculture yields are consistent, deviations around the norm from year to year are small, even in the dry west. In eastern Nebraska, rainfed agriculture still does relatively well because of generally sufficient rainfall, but in the harsher west, rainfed agriculture experiences lower yields and greater variability year to year.

As in Asia, the stable supply of grain from irrigated agriculture has allowed other industries to invest. Nebraska slaughters more cattle than any other state – 7.6 million head – most of them coming from surrounding states without irrigation. Irrigation also has allowed Nebraska to increase its rate of gain in ethanol production compared to other states. Today, the biofuel industry, which didn’t exist 12 years ago, produces 1.8 billion gallons of fuel annually, worth $3 billion a year, $1.5 billion in capital investment and 1,000 jobs. Nebraska also is home to the world’s largest pivot irrigation manufacturers.

Nebraska’s population has increased 26 percent since 1960, to 1.78 million in 2008. However, the agricultural product per capita has increased fifteenfold during that period because of investment in irrigation and the value-added industries that irrigation enabled. Nebraska derives $10,000 per capita from agriculture, more than any other state.

As in Asia, Nebraska’s Green Revolution began with new science and technology, based largely on irrigated agriculture and integration with value-added industries. These advances also benefited rainfed agriculture. The rapid increase in yields and farm income lowered food prices for rural and urban poor. And the higher value of agriculture in Nebraska justified public sector investment in education, research, extension and infrastructure, as well as private sector investment in seed, equipment, processing and banks. The model for development in Nebraska was very similar to the model in Asia, Cassman said.

**Africa’s Green Revolution**

“What’s the vision for irrigated agriculture in a Green Revolution for Africa?” he asked. “I’ve heard about irrigation, but I haven’t heard if it has a significant role in ensuring the success of a Green Revolution in Africa.”
Much of Sub-Saharan Africa has the water conditions and the ability to support crop yields similar to semi-arid western Nebraska. Although areas of Africa receive higher rainfall and are well watered, proximity to the equator and higher temperatures create much higher evaporation rates.

Although not as well watered as Asia nor as amenable to physical infrastructure such as flooded rice, Sub-Saharan Africa has significant water resources. In fact, Cassman declared, Africa has enough water to provide stable yields and income to support investment in associated industries and infrastructure, which would benefit rainfed agriculture as well.

“If their agriculture is much more like the harsher rainfed environments of the western Corn Belt, can rainfed agriculture do it alone?” he asked. Africans have to perceive agriculture as profitable and worth the investment. If in one in four years, there’s no profit, as happens in rainfed systems, the return on investment is reduced. Although Cassman agrees that massive investment in rainfed agriculture is needed, he believes irrigated agriculture must play a critical role in Africa’s Green Revolution – a role that is not yet well defined.

A vision for irrigated agriculture in Africa must include an understanding of the location, quantity and quality of the renewable water supply to achieve a sustainable balance with environmental services and biodiversity.

Policies, infrastructure and markets also must enable irrigated agriculture. Nebraska’s Natural Resources Districts (NRDs), a unique system in which boundaries are based on a watershed unit of management, offers a model. Each of Nebraska’s 23 districts is autonomous and governed by a locally elected board of directors that has authority to tax land, implement policies, conserve resources and invest in enhancing resources. Each sets its own priorities and develops programs to serve local needs.

Many questions about irrigated agriculture in Sub-Saharan Africa must be answered before a sustainable agricultural industry will be possible, Cassman concluded. Water depletion, for example, will be a major challenge. Because Nebraska has dealt with similar issues in a similar environment, the state and a new institute can be valuable partners in the future water for food challenge.
Science Challenges at the Water/Food Nexus: An NSF Perspective

Richard Cuenca
Program Director for Hydrologic Sciences, National Science Foundation

Richard Cuenca discussed the predicted effects of climate change on food production, the need to offer farmers incentives to irrigate less to maximize profits, and water and food production research supported by the National Science Foundation (NSF).

Climate Change
Climate change will undoubtedly affect future water resources, but discrepancies among current climate change models make predictions difficult. In a review of climate change models, fewer than two-thirds agreed about whether climate change in a region would increase or decrease precipitation, with disagreement across much of the globe in parts of North America, South America, Sub-Saharan Africa, the Indian sub-basin and Australia.

In comparing two models – those of Australia’s Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the National Center for Atmospheric Research (NCAR) – the NCAR model predicts wetter conditions in Sub-Saharan Africa, Australia, India and parts of South America, places where the CSIRO model predicts drier conditions.

“These models simply do not agree,” Cuenca said. “Obviously we still have a ways to go in trying to get the correct forecast for climate change predictions.” Using NCAR’s climate change model, along with hydrology and crop production models, the International Food Policy Research Institute predicted the climate-induced change in production of various crops in 2050. Although some regions made gains, the predicted global production declined for all crops.

The analysis predicts that irrigated and rainfed wheat would suffer the most significant losses at 42 percent and 28 percent, respectively, particularly in the Indian sub-continent; irrigated rice also would decline 27 percent; and rainfed rice and rainfed and irrigated maize would decline more modestly, but still lose 13 to 16 percent of global production.

By 2050, predicted climate change would not only lower available calories below levels that would have been achieved in a world without climate change, but also would drive them below...
2000 levels worldwide. Additionally, climate change would decrease any gains made in child malnutrition rates relative to no climate change. In Sub-Saharan Africa, child malnutrition rates would be predicted to increase even further by 2050.

Deficit Irrigation Benefits
Deficit irrigation experiments demonstrate the need to irrigate less to maximize profit. Field experiments have shown that evapotranspiration rates, the combined water lost to soil evaporation and through plant leaf surfaces, are linearly related to applied water levels. Yield, however, is curvilinearly related to the amount of water applied. So while applying water at lower yields increases water productivity, at higher yields, much more water is needed to increase yields.

Cuenca cited a study demonstrating that, although maximum yield occurred at about 600 millimeters of water, after subtracting the cost of adding more water, the maximum net income occurred at about 500 millimeters of water.

“Why would a grower aim for maximum production when that last increment of water is going to have such a small effect on yield?” Cuenca asked. “There must be some other, more beneficial use of these higher increments of applied water,” such as for habitat, urban areas or irrigating other fields. Though additional time and money should deter growers from irrigating to maximize yields, they do so to minimize risk, Cuenca said. He emphasized the need not just to improve irrigation, but also to consider socioeconomic factors.

In irrigated systems, he said, “there’s always a cost of water. What this shows is that to maximize the net income in this case, we should be operating at some point below the maximum yield.” What incentives could encourage growers to consider other objectives besides maximum production? Cuenca asked.

NSF Investments
Cuenca described several national and international projects supported by NSF.

- The Long-Term Ecological Research (LTER) network, a cross-directorate research effort, addresses primary production, biodiversity, organic matter processing, disturbance regimes, and nutrient cycling and availability. The program began in 1980 and now spans 26 sites. LTER has become increasingly diverse and includes urban and international sites.

The program enables researchers to examine effects of climate variability and change, biogeochemical cycles, and biotic structure and dynamics. The data integrate ecology, geosciences and the social sciences and are available online. An educational component engages K-12, undergraduate and graduate students.
• A new $40 million investment in climate modeling aims to elucidate the differences in climate simulation models. Some projects should address how to downscale general circulation models to regional and decadal scales to provide more practical information for irrigation managers and water resource managers.

• Water Sustainability and Climate, another new solicitation supported with $25 million, requires an interdisciplinary approach incorporating biological sciences, earth sciences, social, behavioral and economic sciences, and engineering.

• The Office of International Science and Engineering supported an African Long-Term Research Network 2008 workshop in Mali to develop collaborative projects between U.S. and African scientists and to focus on nitrogen and phosphorus dynamics in different environments. Scientists will be working in eight villages of the Millennium Villages project to determine the nitrogen cycle and look for ways to find more nitrogen.

• The Mpala Research Centre ecohydrology project in northern Kenya evaluates the spatial and temporal patterns of plant water use efficiency from the individual plant level to landscapes. The site is part of the worldwide network of evaporative flux measurements and will provide information on evaporation, transpiration and carbon fluxes. The project also investigates dryland ecosystem land degradation, which lowers the carrying capacity for cattle, reducing the nutrition available to the population. NSF supports the project because the global evaporative flux network contains few sites in Africa (and none in east Africa).

“Theres always a cost of water. What this shows is that to maximize the net income in this case, we should be operating at some point below the maximum yield.”

• The Basic Research to Enable Agricultural Development (BREAD) program, a partnership between NSF and the Bill & Melinda Gates Foundation, provides $24 million from each foundation over five years to address constraints faced by smallholder farmers in the developing world. The program aims to identify the major constraints in plant production and to find innovative ways to overcome them. “This is an exciting project for NSF,” Cuenca said. “Only through this project do we have the capability of supporting some of our foreign counterparts. We have lots of projects all over the world, worth millions of dollars, but we cannot support foreign investigators directly except through this BREAD program.”

Cuenca concluded by emphasizing the human dimensions of research. “Ultimately the reason we are here is because we want to make things better for these kids, and we want to see them not be in a position of malnutrition.”
Although many people still have a pastoral view of agriculture, unprecedented modern technologies will meet the growing demand for food, Robert T. Fraley said. He described important advances in agronomic practices, breeding and biotechnology research occurring today in U.S. corn production.

Monsanto Company has committed itself to achieving sustainable agriculture and serving growers. Part of that commitment includes helping farmers double yields in corn, cotton, soybeans and spring-planted canola by 2030 – and do so with one-third fewer inputs per unit of output.

For U.S. corn, Monsanto’s goal is to raise yields from today’s 137 bushels per acre to 300 bushels per acre by 2030. Such gains won’t be accomplished with a simple technique or method but through advances in biotechnology and breeding, as well as systemic improvements in agronomic techniques.

“It’s important that this technology benefits all farmers,” Fraley said, from large-scale U.S. growers to smallholder farmers across Africa and Asia. “We can see these tools improve their lives, their profitability and their cultures and societies.”

In 1970, the year Fraley left his family’s farm, his father was thrilled that corn yield averages hit 75 bushels per acre. Today, technology powers record yields – more than 160 bushels per acre. “In 2030, we’ll look back at how we’re growing corn today the same way we kind of laugh when we look at how we did it in the 1970s. We’re going to experience the greatest explosion in the advancement of agricultural technology that the world’s ever seen,” Fraley said.

If productivity gains continue along the historical trend line, average U.S. corn yields will reach 200 bushels by 2030. However, improvements in agronomic practices, such as fertilizer technologies and seed treatments, as well as advances in breeding using new genetic tools, will increase yearly baseline gains slightly. New biotechnology traits will drive gains even further to the goal of 300 bushels per acre.

Inputs are an important part of the equation. Since 1970, new technologies have resulted in the steady use of nitrogen and a dramatic reduction in pesticide use. Going forward, rainfall and chemicals will remain steady, and fertilizer use will rise slightly with increased yields. It’s
important, however, to consider increasing yields. The same bushel of corn in 2030 will be produced with one-third less water, fertilizer and pesticide than it is today.

Although Fraley centered his discussion on U.S. corn production, he added, “We will more than double yields in almost all the other world areas as a result of the advances of this technology.”

**Agronomic Practices**
Advances in tillage techniques, planting, seed treatments and crop chemicals have changed agriculture dramatically, Fraley said. Conservation tillage, in particular, has been critical, helping to preserve soil quality and reduce water use and erosion. Conservation tillage has allowed crop production in parts of the world where tillage would release too much moisture to allow crops to grow. As additional reduced-tillage methods develop, planting and harvest technology and equipment improve, and genetics and traits advance, conservation tillage practices will continue to be adopted.

Monsanto’s Roundup Ready® technology has significantly improved in-crop weed control, facilitating the adoption of no-till and reduced tillage practices, Fraley said.

Planting technology also has advanced. In 1970, the average planting density in the U.S. was 17,000 plants per acre. Today, growers average 28,000. By 2030, Monsanto estimates that number will reach 35,000 to 40,000 plants per acre, driven by improved genetics and trait packages. Opportunities exist to greatly improve yield productivity. Breeding programs routinely plant 50,000 plants per acre, and some reach as high as 70,000 plants per acre.

As plants are grown more compactly, the need for disease control becomes more crucial. Monsanto has done much work on multiple seed treatment coatings in which molecules interact effectively and synergistically, minimizing seed damage and maximizing yield. Fraley anticipates dramatic changes in seed treatment and crop disease management as new active ingredients become available. Monsanto’s Acceleron® seed treatment has seen dramatic results in early growth advantages, and its Headline® fungicide typically provides a 7- to 9-bushel increase in corn yield.

“Clearly, where this is going is bringing it together in an integrated fashion,” Fraley said. “And that is having exactly the right hybrid, targeted at the right population, with the right row configuration, with the healthy start, the optimal fertilization to drive yield. … That’s where we’ll see a big opportunity for economic yield for farmers going forward.”

**Plant Breeding**
Breeding advances in the last five years have been remarkable, Fraley said. New tools and the ability to breed and mine germplasm globally make it possible to insert only those genes that enhance U.S. corn performance. Advances in sequencing technology will allow hybrids to be constructed literally gene by gene to determine ideal combinations.

New sequencing technology requires advances in automation to speed the breeding process. Monsanto developed an automated seed chipper,
 Speakers

a robot that precisely shaves off the endosperm, allowing DNA sampling. “That gives us the possibility of finding one rare recombination or trait event within millions and millions and sometimes trillions and trillions of events,” Fraley said.

The gains have been prolific. For example, Monsanto found that its DEKALB® brand hybrids improve gains in both drought and normal conditions. The fundamental seed genetics have changed dramatically in the past decade. “We’re taking the knowledge of the genetics and, increasingly, with our understanding of the structure and performance of individual genes, we will be able to target that performance under a given soil type, under a given weather condition and again maximize yield and productivity,” Fraley said.

Biotechnology

Fraley started Monsanto’s biotechnology program in 1980 when sequencing a gene was a six-month, multibillion-dollar investment. Today, the entire corn genome can be sequenced within a few weeks for a few thousand dollars.

Biotechnology has been adopted in 25 countries, with China and India leading the way. “That shows you how important, I think, the technology is, because in the end … once that advantage is incorporated in the seed, every farmer in the world knows what to do with that seed and can capture that advantage with very, very minimal barriers to adoption, other than policy, for all practical purposes,” Fraley said.

The advent of Roundup Ready® technology for weed control and YieldGard® technology for corn borer and rootworm resulted in tremendous benefits for drought mitigation. Protecting roots and stems is the first step toward building a drought-protected platform. Therefore, even a basic drought product must be packaged with the best agronomics in insect and weed controls.

Several years ago, Monsanto had a tremendous breakthrough when a single transgene introduced into a plant showed dramatic drought tolerance. Monsanto is now testing that gene – from a bacterium – in corn and has found that it increases yield under drought conditions by about 11 to 20 percent compared to non-transgenic hybrids. The company expects to launch the first biotech drought-tolerant corn, Csp Drought 1, in the U.S. within a few years.

After that, Monsanto plans to launch the second-generation drought corn product, which will provide an advantage in areas where drought occurs intermittently. An independently acting drought gene that can weather the occasional drought adds insurance value. Fraley predicted by 2030, corn seeds with multiple drought and nitrogen-use genes will be available, each driving for incremental performance and yield.

Global Expansion

The technology has quickly spread globally. The first biotech crop was launched in the U.S. in 1996 and today is grown in 25 countries. It should reach 50 countries by 2030, Fraley said.

“We’re going to experience the greatest explosion in the advancement of agricultural technology that the world’s ever seen.”
“Clearly, the area that needs this technology the most is Africa,” he said. “I believe that there’s both the opportunity and the need to bring technology that can have tremendous benefit there.” The challenges are more complex than agriculture and technology can solve; it will require policy and infrastructure. “But I also believe at the very core, if we can bring in technology that increases yield, that increases profitability, that increases base food security, that it can improve lives.”

Monsanto has partnered with the International Maize and Wheat Improvement Center (CIMMYT) and several African institutions to bring biotechnology to Africa in an effort funded by the Bill & Melinda Gates Foundation.

The goal of the full-systems approach is to bring targeted genetics and hybrids to Africa, including drought- and insect-control traits. To date, results of drought-protected corn have been comparable to results in the U.S., Fraley said. “Our goal is literally within five or six years of the launch of this technology in the U.S. that we will be able to bring this technology into Africa,” he concluded.
The International Center for Integrated Water Resources Management (ICIWaRM) recently became the first United Nations Educational, Scientific and Cultural Organization (UNESCO) Category 2 Water Center in the U.S. William S. (Will) Logan said about 20 Category 2 Centers in various stages of approval are scattered in major regions worldwide, except Sub-Saharan Africa. The centers are committed to supporting UNESCO’s strategic objectives to render technical assistance, build research capacity and exchange information. They are designed to form networks and increase UNESCO’s impact and visibility.

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An international agreement between the U.S. government and UNESCO preserved the semi-autonomous nature of ICIWaRM, which was the first such center in any field. “We are the guinea pigs who went through this system for the United States,” Logan said, adding that the unique agreement may smooth the way for similar centers. Conceived about five years ago, ICIWaRM began as a UNESCO operation in 2009.

ICIWaRM’s focus lies at the confluence of UNESCO’s International Hydrological Programme (IHP), the U.S. National Commission for UNESCO and the U.S. government’s objectives for water resource management, remaining consistent with the objectives of the three arenas.

Headquartered at the U.S. Army Corps of Engineers Institute for Water Resources, ICIWaRM is not strictly a Corps activity but a mix of U.S. government, academia, nongovernmental organizations and other international organizations that work on integrated water resources management. Partners include several universities, the American Society of Civil Engineers, the Nature Conservancy and many others. Key partners also include other Category 2 Centers, such as the International Centre for Water Hazard (ICHARM) in Japan and the Centre for Arid and Semi-arid Zones of Latin America and the Caribbean (CAZALAC) in Chile, which works on arid zone hydrology. These projects may offer connections for Nebraska.
ICIWaRM focuses on practical science and technology, including engineering and policy. Instead of drilling wells in villages or engaging purely in university-style research, the center works in the middle zone. “We’re definitely trying to partner with these other institutions and definitely, as always, seeking collaborations,” Logan said.

He described several examples of ICIWaRM’s work. A project in conjunction with the World Bank and the Inter-American Development Bank in Peru is strengthening the capacity for participatory, integrated and basin-scale water resources management in several river basins. ICIWaRM is integrating structured participation, systems modeling and planning.

A second project involves working with CAZALAC, the Chilean center, to create a drought atlas for several pilot regions in Latin America and the Caribbean. Another project offers short courses in hydrologic modeling and related fields to build capacity by emphasizing customized learning. Instead of using the Colorado River as a model, for example, participants study their own systems, coming away with practical information.

The Water for Food Institute may benefit from joining as a Category 2 Center. As such, the institute could take advantage of an existing network of other UNESCO programs and centers, including participating on each other’s boards and attending regional meetings. “It provides a great network to plug into,” Logan said.

Logan described Florida International University’s partnership with ICIWaRM to develop a joint program with the UNESCO-IHE Institute for Water Education to combine academic experience in the U.S. with an IHE degree. An exchange program between UNESCO-IHE and the University of Nebraska–Lincoln could be a valuable learning experience for students, he said.

“There are lots of good possibilities,” Logan concluded. “ICIWaRM would love to talk to you more about that.”

Harvesting rainwater in India
The solutions of the past won’t solve the world’s future water scarcity, David Molden said. He encouraged a holistic approach that fits each region’s circumstances, from the rainfed fields of Sub-Saharan Africa to industrial society’s own consumption and waste. Molden identified areas of opportunity, cautioned against old assumptions and proposed a new water agenda that could raise more food while also reducing poverty.

One-third of the world’s population lives with water scarcity, but it manifests in two distinct ways: physical water scarcity, in which no additional water is available for further development; and economic water scarcity, in which water is available but access is challenged by policies, finances or lack of infrastructure. It is in areas of economic water scarcity, such as many parts of Sub-Saharan Africa, that solutions can be found, Molden said.

Enough food is produced today to feed the world’s current population, but some people receive too much food, while a billion people receive too few calories. Raising the nutritional status of undernourished people, in addition to feeding an increasing population and meeting the growing demands for more meat, fish and milk, will require raising grain production by an estimated 70 to 100 percent. Calculations show one liter of water is required to produce one calorie of food, an astounding figure when considering the water needed to double food production. That requirement cannot be met using current production practices.

The Water Agenda
Molden described four major pathways to meet future food and water demands:

- Improve water productivity by growing more food with less water in irrigated and rainfed systems.
- Expand irrigated and rainfed agriculture, a path followed in the past that Molden believes is limited today because of insufficient water and land.
- Promote trade from highly productive to less productive countries, a “virtual water” trade promoted by Tony Allen, winner of the 2008 Stockholm Water Prize. While calculations show that trade would save much water, countries tend to shift to greater self-sufficiency rather than more open trade during food crises, limiting the value of this option. “If you’re a core rural person, can you really rely on a trade system?” Molden asked. “I doubt it. And that’s why I think it’s extremely important for people to be able to produce their own food.”
• Manage the demand for water and food by consuming and wasting less.

“I think what it is, is not pointing the finger at farmers,” Molden said. “But this water and food equation is about all of us, right? It’s about our role in solving this big equation.”

Rethinking Irrigation
Opportunities exist to improve water productivity, the amount of food that can be produced per volume of water. One opportunity can be found in the tremendous productivity variations in the world’s irrigated systems; some systems use water 10 times more productively than others. Improving under-productive irrigated systems is an important avenue for reducing the food gap while using less water. Another opportunity exists in the water productivity variations found within commodities, due in part to evaporation in low-yield areas. Beef and fish production operations also see large variations in water productivity, providing huge opportunities to improve livestock and fishery practices.

Despite these reasons for optimism, Molden also urged caution. The water and food community must rethink its view of irrigation. Irrigated systems may use water unproductively, thereby lowering yields, but they are not necessarily inefficient, the prevailing view. For example, in Chishtian, Pakistan, an irrigated agricultural area, 90 percent of the available water is used for irrigated crops and cities, a highly efficient use of the available water with little left for the environment. That is a much different picture than the commonly held view that 60 percent of irrigated water is wasted. Chishtian uses the available water efficiently, but yields are low relative to the amount of water used.

“We think about water and immediately most people start thinking about water and rivers and irrigation. Somehow we have to expand our minds about what water is, starting with rainfall.”

“Efficiency, in a lot of cases, is not the real problem,” Molden said. “It’s overuse of water by irrigation. The real problem is the extremely low values of water productivity in these areas. With that same amount of water, it is possible to double water productivity, grow twice as much food with this amount of water.”

Water Productivity and Yield
Crop breeding is another source of optimism and caution. In the past, crop breeding greatly improved water productivity, but those gains have leveled off, Molden said. Some understudied crops, such as the wheat alternative teff in Ethiopia, may still see water productivity benefits from improved crop breeding. But it’s important to consider that across many crops, water productivity rises faster at lower yields, leveling off at higher yields. In high-yield regions, when only slight gains in water productivity are achieved, even greater use of irrigation is encouraged. Yet increasing yields from 1 ton to 2 tons per cubic meter of water increases water productivity 74 percent.
“What does that mean for us?” Molden asked. “That’s the hot spot. … This is the area for the biggest potential for water productivity gains. This is also the area where there’s high poverty. If we can narrow in on that focus, we get two big wins at the same time.”

Tremendous opportunities to increase water productivity exist in rainfed agriculture, Molden said. The formula is simple: a little water, improved nutrients, drought-resistant varieties and field conservation practices to reduce nonproductive evaporation. “We think about water and immediately most people start thinking about water and rivers and irrigation. Somehow we have to expand our minds about what water is, starting with rainfall.” Growing more food using rainfed agriculture also would take pressure off river systems, improving resources in water-scarce areas.

Africa’s farming uses little irrigation. Rather than trying to expand irrigation, Molden believes the answer is to use other, smaller ways of getting water to people. Even in the Nile Basin, where conflicts over irrigation and hydropower continue, few opportunities exist to expand irrigation. Little attention is paid to the enormous opportunities for upgrading rainfed and pastoral lands in that region.

Holistic Solutions
Molden suggested de-emphasizing the distinction between rainfed and irrigated agriculture and focusing instead on a range of agricultural water management solutions, such as soil moisture. Of the available solutions in a given location, such as water harvesting, drainage and irrigation, which is the most appropriate?

The formula for success is there, but it isn’t being implemented fast enough. How, Molden asked, can we act faster? The answer lies partly with developing appropriate technologies. He cited a successful example in India where 70 percent of production comes from water obtained through small, portable pumps. Despite their popularity, the pumps are inefficient, expensive and contribute significantly to greenhouse gases. A need exists to develop affordable pumps using alternative energy sources, which also could be used in Africa.

But the answer requires more than technological solutions, Molden urged. Supportive policies, social structure, land and ecological sustainability, and infrastructure are key components as well. Molden relayed a lesson from Matsepo

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Michael K. Doane, David Molden and Robert T. Fraley
Khumbane, a South African woman who discussed the importance of “mind mobilization” to get past the paralyzing nature of poverty. That concept, Molden said, must extend to policymakers as well.

The water, food and livelihood agenda, Molden said, is about enhancing access to water for the poor, increasing water productivity in a way that enhances ecosystems, and transforming water governance and management.

The water and food community must look beyond seeds, pumps and fertilizer to big solutions, Molden said. He offered six solutions for the future:

- Upgrade rainfed systems with better water and soil management.
- Revitalize under-performing irrigation systems.
- Learn to manage groundwater sustainably.
- Reuse wastewater safely as more urbanites use wastewater as water sources.
- Transform water governance and management.
- Support these actions with better information systems.

Proceeding as before threatens Earth’s ecosystems and misses an opportunity to improve livelihoods and nutrition. Moving forward won’t solve water scarcity, but by working with farmers, the food and water community can raise people out of poverty and provide food to those who need it most. “I think we have to imagine working together,” Molden concluded. “And in that equation, it’s working with the farmers, the pastoralists, the governments and the managers of water resources. I think that’s the key: It’s partnership and moving forward.”
U.N. Panjiar described India’s success reforming its irrigation management into a participatory system, which has resulted in increased water use efficiency, distribution equity and improved conditions for farmers.

India has 16 percent of the world’s population but only 4 percent of its water resources and less than 3 percent of its land area. More than three-quarters of its usable rainfall arrives during a few spells of intense rain throughout the four-month monsoon season. Rainfall also varies geographically, with as little as 100 millimeters falling in the west and more than 10,000 millimeters in the northeast. About half of the country’s area is cultivable, and more than 75 percent of that land is used for crops, divided almost equally between irrigated and rainfed agriculture.

If India continues with the productivity and efficiency levels prevailing today, projected demand in 2050 will far exceed water availability, Panjiar said. However, if India achieves its water efficiency and productivity goals by then, availability is expected to match demand. Because rainfall varies considerably temporally and geographically, water storage remains vital. Even taking current construction projects into account, per capita storage will remain low compared to the world average.

**India’s Water Challenges**
India is facing many challenges in agricultural water productivity, including:

- Water availability per capita continues to shrink, from a comfortable 5,000 cubic meters in 1951 to 1,700 today.
- Surface water efficiency in irrigation, which uses more than half of the country’s water resources, varies from 35 to 40 percent but could be improved to 60 percent.
- Water infrastructure is deteriorating from lack of maintenance.
- Inappropriate irrigation planning leads to environmental degradation, waterlogging, salinity and alkalinity problems, groundwater quality degradation, drying wells and increased energy consumption.

“Integrated and coordinated development of surface water, groundwater and use of
rainwater ... needs to be encouraged and incorporated at the planning stage itself so that the irregularities of fluctuating rainfall and the degrees of the fluctuating surface water can be mitigated,” Panjjar said.

Financial sustainability also is problematic. Often state governments, responsible for managing water resource projects, provide inadequate funds for maintaining irrigation infrastructure due to low water rates and the inability to collect fees caused by a disconnect between project authorities and water users.

The irrigation sector faces two major problems. First, poor use of irrigation facilities stems from incomplete canals and surface irrigation projects caused by contractual and legal issues. Project constraints and low water availability make it difficult to maintain systems. Farmers, the major stakeholders whose fortunes are most directly linked to system performance, have not been involved in management, Panjjar said. Although the governments are responsible for irrigation management, they have not attempted to train farmers in water management. Lacking a legal framework or empowering environment, farmers have had no incentive to learn or take over irrigation systems. Because water is provided based on irrigated areas, farmers have adopted inefficient irrigation practices and often grow water-intensive crops.

A second problem facing irrigation in India is inequity in water distribution. Lack of regulations and farmer participation has allowed farmers at the headlands to over-irrigate, leaving inadequate water supplies for farmers at the end of the canal system. The government’s inability to maintain the irrigation infrastructure and ensure equity has “rendered the old irrigation system unsustainable and inequitous,” Panjjar said. “Adequate emphasis needs to be given to community participation, thereby ensuring the financial and physical sustainability of the systems. There is a need to have an enabling environment for empowering the farmers to take over the management of the irrigation systems, and this is what has been tried in India.”

Empowering Farmers to Manage Irrigation
India has begun developing a participatory irrigation management system (PIM), creating 57,000 water-users associations to date. The associations’ objectives are to take responsibility for managing the infrastructure, distributing water equitably, using water efficiently for optimal agricultural production and settling disputes among farmers. The associations also ensure conjunctive use of rain, surface and groundwater, and develop community responsibility to collect water fees. The participatory approach ultimately develops a sense of ownership among the farmers and ensures sustainability of the entire system.
Panjiar described the system’s tiered layering and management as well as the associations’ functions, including an assessment of water availability before the crop season and a social audit of water use afterward. Farmers can be penalized for violating the water schedules.

India has noticed many benefits from this participatory approach, Panjiar said. Farmer attitudes have changed. They pay water charges regularly and follow efficient irrigation practices, including shifting to less water-intensive crops following awareness training. The results have been considerable water savings and increased irrigation area coverage, which has improved farmers’ incomes. Water once sufficient to irrigate for only eight months now irrigates year round. Farmers’ feelings of ownership have led to increased interest in maintenance and scheduled enforcement, which also has created local jobs. Because farmers are looking after water regulation, overdrawing of water is declining.

The government returns between 30 and 100 percent of water revenue to the associations, which also levy additional charges for system maintenance, ensuring sustainability.

The central government developed a model PIM act and advised states to enact regulations that empower the water-users associations. To date, 15 of the 28 states have done so.

A Success Story
Panjiar described the Waghad Project in Maharashtra state, where the PIM system has proven very successful. “The most important benefit that has occurred to the water-users associations is that it has created a sense of ownership among the farmers,” Panjiar said. “That’s a really big thing.”

Ownership has led to sustainable management practices, decreased operation maintenance costs, and resulted in a threefold increase in the average irrigated area. Water charges have increased sevenfold, but recovery of fees has gone from 60 percent to 100 percent. Participatory irrigation management in Waghad basin, and the consequent increase in water use efficiency, has resulted in water savings of 30 percent.

Farmers also have shifted from growing rice and wheat to cultivating grapes, a more productive crop. As their knowledge and confidence has grown, farmers have expanded their operations. “Earlier, they were supplying grapes to the wineries,” Panjiar said. “Now they have decided to set up their own winery also, and they have launched a website of their own.”

The result is an increase in year-round employment opportunities and in productivity, which has gone from 1 gram per liter of water to 5 grams per liter of water.

Panjiar concluded with a description of the Participatory Action Research Program, which aims to increase yields and income per drop of water. The technologies developed in the lab are being implemented on the farm. Field projects are demonstrating the efficacy of improved irrigation, conservation and agronomic practices, and are carried out in a participatory mode. The project has been welcomed by farmers and has led to water savings, improved crop production and increased farm community incomes.
Although China has much irrigated land, it also has limited water resources, Shiqi Peng said. In the 1990s, China developed a water-saving irrigation strategy that has achieved tremendous success, although many challenges remain.

Precipitation distribution also is uneven, with 60 to 70 percent of precipitation falling in summer and autumn. Annual precipitation can fluctuate 20 to 30 percent between wet and dry years. Drought may occur throughout the year in China, and extreme droughts occur frequently. Prior to the 1990s, China implemented flood irrigation throughout the country. Under that system, farmers are responsible for keeping more water in the soil and providing more water to their crops through flooding. The irrigation schedule follows the crop-growth period for irrigation to achieve a high yield. With soil scanners, more water is returned to the ground during delivery; only 35 percent of water is transferred to the field.

“China’s government has paid attention to developing water resources and irrigation systems for food security,” Peng said. Irrigated land reached 57.8 million hectares in 2007, which accounts for 47.5 percent of total cultivated land, concentrated in the east and south.

Aspects of Water-Saving Irrigation Strategy

However, inappropriate management has caused many problems. To resolve some of those problems, the government developed a water-saving irrigation strategy, which contained five aspects. The first addresses supportive policy. The government issued an outline of development planning and cost-saving technologies to make
strategic points clear. Then, special funding was budgeted to support key infrastructure construction, to establish demonstration projects and to give subsidies to farmers that allow them to improve water management and purchase agricultural machinery and irrigation equipment.

The second aspect deals with infrastructure construction. A special budget was used to rebuild soil canals with cemented liners or to replace them with pipes to reduce leakage during delivery. By 2007, 24 percent of the total irrigated land had received infrastructure upgrades.

The third aspect involves improved water management. Furrow irrigation, alternate furrow irrigation, rice shallow irrigation, rice shallow irrigation scheduling and land arrangement were privatized in China. The planting structure changed according to rainfall and water resources. For example, rice production decreased sharply in areas with insufficient water resources, while potato growing, which can delay the sowing period, replaced corn due to the spring droughts in the northwest. “Climate adaptability of planting is good for reducing irrigation water use,” Peng said.

The fourth aspect promotes increased use of modern irrigation equipment. Since 1996, through demonstration projects, the government has helped farmers purchase modern irrigation equipment, which has been used on many cash crops, such as vegetables and fruit trees. State farms and agricultural companies in the northeast try to use pivot irrigation because of large farm sizes. Small-scale farmers use drop systems and sprinklers.

The strategy’s fifth aspect introduces rainfed technology to irrigated land. More than 350 millimeters of precipitation falls in irrigated areas. Straw-covered soil, deep-loosening tillage and no tillage were introduced to combine with irrigation. These measures reduced evaporation and irrigation frequency and retained soil moisture. Some small ponds were built near fields to collect rainwater for supplementary irrigation.

The government’s water-saving irrigation strategy has greatly improved food production and water use efficiency. Irrigated land continues to expand with the same amount of water supply. Grain production also has increased. In 1996, gross grain amounts reached 500 million tons with the same irrigation water supply. Farmers’ incomes have increased threefold by using irrigation equipment.

The delivery rate of irrigation water increased from 35 percent to 48 percent, and the amount of water supplied decreased about 2,000 cubic meters per hectare from 1988 to 2007. Each increasing point indicates that about 3.4 billion cubic meters of water were saved during transmission. These results could feasibly increase new irrigated land by 520,000 hectares.

Water use efficiency also increased. Evaluations showed that about 70 percent of total grain came from irrigated fields. The relationship between consumption of irrigated water and grain output can be expressed as 1 to 1.1 on average in 10 years, a 27 percent increase compared to 1988. The national average of integrated water use efficiency reached 0.85 kilogram per cubic meter.
New Water Challenges
Like other countries, however, China is facing serious water problems and new challenges. Last year, the government announced its aim to increase grain production capacity by 15 million tons by 2020. That increase will require about 42 billion cubic meters of new water with current technology. Where will that water come from? Peng asked.

The water supply is not increasing. The proportion of agricultural water use has declined and irrigation water has remained between 340 billion and 360 billion cubic meters since 1978. In addition, cash crops are a new area for agriculture development. Vegetables and fruit trees have increased, accounting for about 20 percent of agricultural water use. If farmers maintain traditional irrigation methods, cash crops will consume more water compared to grain crops – a serious concern, Peng said. Other problems include yield loss due to a greater frequency of droughts and the changing structure of agricultural labor that makes it difficult to adopt new technologies. For example, if farmers receive equipment but do not know how to use it, it will quickly be discarded.

How can China increase its water supply, and how can water be used in agriculture? Peng asked. Research has shown that total water resource consumption for agriculture is about 716 billion cubic meters a year, with 43 percent from irrigation water and 57 percent from precipitation. Therefore, it is important to combine rainwater technology in irrigated areas.

Other solutions include increasing the application of modern irrigation technology where conditions permit, as well as continuing to strengthen the agricultural infrastructure and to boost high-standard farmland construction, which China has already begun. Integrated water use efficiency combined with agronomics should increase in the future. “It has great potential, especially in the northwest and the southwest,” Peng said.

China also must strengthen training for technicians and farmers. County-level technicians must improve their ability to provide technical guidance and service to local farmers.

Other areas of needed improvement include water allocation, information technology, new varieties and social services.

China pays great attention to agricultural water use, Peng concluded. The implementation of the water-saving irrigation strategy has achieved great results, but water-saving agriculture involves many departments and technologies. “We have a long way to go,” she said, adding that China hopes to work with other countries to improve the technical level of water use and management and to promote sustainable development of agriculture and food security.

“China’s government has paid attention to developing water resources and irrigation systems for food security.”
Krishna C. Prasad offered perspectives for increasing available water supply, the social consequences to rural farmers in developing countries, and approaches the UNESCO-IHE Institute for Water Education takes to meet these challenges.

The International Institute for Hydraulic and Environmental Engineering (IHE) was incorporated into the United Nations Educational, Scientific and Cultural Organization in 2001 to reflect UNESCO’s priority of addressing water issues.

About 80 to 90 percent of the world’s potential to double food production – such as obtaining higher yield per hectare through double- or triple-cropping and modernizing existing or installing new irrigation systems – can be found in existing cultivated areas. Land reclamation provides promising venues for another 10 to 20 percent of potential yield increases.

Prasad said research has demonstrated that 80 percent of future water stress will come from population and development, not from climate change. Given that, are current capacity-building activities appropriate? Prasad asked. For example, 85 percent of U.S. global change research funding is devoted to climate and carbon.

**Population Dynamics**

An additional problem stems from lumped estimation of population dynamics. Developing countries tend to be considered together, but they are not homogeneous. There are profound differences between the least-developed countries and emerging countries. “It may be more useful to see the difference between those two categories and compare it across the whole spectrum,” Prasad said.

In emerging countries whose annual per capita income ranges from $1,000 to $12,000, growing economies are driving farmers into cities, resulting in substantial migration from rural to urban areas. The increasing urban demand for food pressures farmers to expand farm sizes and adopt mechanization. Producers grow higher-value crops to make a living on smaller plots, and many farm part-time, working jobs in industry or the service sector as well.

In contrast, low-producing farmers comprise most of the population in least-developed countries. They are extremely constrained by lack of inputs.
and resources to increase productivity. Prasad said weak institutional capacity inhibits their ability to adopt technological or economical interventions.

Developed countries are characterized by a low agricultural share of gross domestic product. Farmers represent only about 2 percent of the population, but their productivity is about 500 times that of small-scale farmers in less-developed countries.

Population levels have stabilized in developed countries, but continue to grow in the least-developed and emerging countries. In each country category, a large percentage of cultivated areas lack water management systems or have weak irrigation systems. Interventions are possible in all regions, but solutions will vary.

“The combinations of technological measures in the given settings, also institutional conditions of those regions or those countries, have to be matching,” Prasad said.

Urbanization poses an interesting dilemma, he said. Cities with more than 5 million people are increasing dramatically. The typical farmer must decide whether to switch to a bigger farm or move to the city. At the same time, pressure to provide food at an affordable price to urban people increases. Without a mechanism to help farmers expand, they must migrate to the city for alternative ways to make a living.

**Capacity Building through Education and Research**

One important challenge is more effectively turning scientific findings into practical technologies and improving economics and institutions, especially to support poor farmers in the least-developed and emerging countries.

Prasad highlighted approaches UNESCO-IHE is taking to address this challenge. With a mandate from the United Nations, the organization focuses on building capacity through education and research. It strives to be demand-driven and not just consider the supply perspective. Engaging in global partnerships is key, he said, particularly with the least-developed and Muslim countries, to help citizens implement solutions.

UNESCO-IHE focuses on impacts of global trends in population growth and increases in living standards; design, operation and maintenance aspects of water management systems; institutional aspects and stakeholder participation; and environmental, social and financial aspects of water management.

Pathways for achieving these foci include institutional reform through establishing mirror sites in partner countries; access through alumni and regional nodes in countries; and development of innovative educational activities to fill capacity gaps so countries can address problems internally through means such as distance education and double-degree programs.
Programs designed to help farmers increase agricultural production are much less costly ways of feeding hungry people than food aid programs, Pedro Sanchez said. He outlined recent successes in tripling Africa’s cereal crop production from 1 ton to 3 tons per hectare without increasing water needs.

African farmers average just 1 ton of cereal crops per hectare, the lowest output of any region in the world. By contrast, Latin America and South Asia produce 3 tons per hectare, China produces 5 tons, and North America and Europe produce about 10 tons per hectare. Africa’s low output stems from two overarching problems: unhealthy soils depleted of vital nutrients, such as nitrogen and phosphorus, and untamed waters, such as surface-sealed soils that prevent water from penetrating.

“I’d like to redefine the goal of the Green Revolution as going from 1 to 3 tons per hectare,” Sanchez said. “And I’m using corn mostly because it’s the most important crop in most of the areas in Sub-Saharan Africa. We think this is perfectly feasible.”

Sanchez cited evidence from two studies. The first comes from the Earth Institute’s Millennium Villages project, in which 80 villages clustered around 14 areas throughout Sub-Saharan Africa – all hunger hot spots – are empowered to accomplish the U.N.’s Millennium Development Goals, particularly those related to hunger. The project’s approach is science based but community led. When asked, villagers unanimously agreed they needed farming goods and a clinic. Farmers were given subsidized fertilizer and hybrid corn seed.

Corn yields doubled in the study’s seven Millennium Villages, each with about 1,000 smallholder farms. Prior to intervention, corn
yields averaged about 1.7 tons per hectare. After providing subsidized farming inputs, yields increased to an average of 4 tons per hectare.

In 2008, input costs and corn prices increased. At those rates, the input costs to produce an extra ton of corn averaged $135. By contrast, the same ton of food delivered through food aid cost $812—a 6-to-1 ratio. “If you want … to get people food so they can eat for a day, it will cost you six times as much as if you empower people to produce their food,” Sanchez said.

In addition, the percentage of households with maize yields greater than 3 tons per hectare or equivalent in other crops jumped from less than 10 percent to 78 percent; the percentage of households without food for at least one month per year dropped from 69 percent to 35 percent; and the percentage of stunted children (caused by chronic malnutrition) under two years of age decreased from 50 percent to 36 percent.

Sanchez cited improvements in other health indicators from increased use of malaria bed nets to improved sanitation and decreased child mortality, from 125 deaths per 1,000 live births to 50.

“The point I’m trying to make here: There’s a lot more than just increasing food,” Sanchez said. “All these things have to be together. What’s the point of having high production, if people are dying of malaria or the kids are dying of malnutrition? Or vice versa: What’s the point of having tremendous health services if people can’t produce food? The Millennium Villages have been working on the integrated approach, and I’m a strong believer in it.”

Africa’s First Green Revolution Country

Sanchez’s second source of evidence that tripling Africa’s yields is feasible comes from Malawi, Africa’s first Green Revolution country. In 2005, then new President Bingu wa Mutharika wanted to help the country’s farmers produce more corn. At the time, Malawi was importing 45 percent of its food to feed its 13 million people. The Millennium Project Task Force recommended subsidizing fertilizers and hybrid corn seed. Perplexingly, the world’s major donors—the World Bank, U.S. Agency for International Development and others—refused to subsidize African farmers. “You scratch your heads and say, ‘Aren’t we subsidizing American, European and Japanese farmers to the tune of a billion dollars a day? What’s wrong with this picture?’”

Malawi’s president decided to proceed anyway, and despite scarce resources and limited infrastructure, managed to get fertilizer and seed to 1 million of Malawi’s 2 million smallholder farms in time for the planting season. Production increased dramatically. In 2005, before the subsidy program, Malawi produced 1.3 million tons, averaging 0.81 tons per hectare, a 43 percent deficit in the country’s

“I’d like to redefine the goal of the Green Revolution as going from 1 to 3 tons per hectare. … We think this is perfectly feasible.”
food requirement. In the first year of the program, Malawi’s production nearly doubled, with an 18 percent food surplus. The following year, in 2007, Malawi reached 3.3 million tons, averaging 2.04 tons per hectare. With the 57 percent food surplus that year, Malawi became a maize exporter and food aid donor to neighboring countries. That year, subsidies cost $70 million but returned $688 million.

Much of Malawi’s soils suffer from lack of nitrogen, and some areas also experience dry spells at critical times in the growing season. Sanchez and his team are developing a digital soil map of the world to better manage local needs, by pinpointing areas requiring additional nutrients or erosion control and identifying regions that have a higher probability of drought stress. Malawi will be the first country with a detailed digital soil map.

Sanchez acknowledged that ridding Malawi and other African countries of poverty will require more than producing 3 tons per hectare of maize. Changes in farming practices, such as encouraging small farms to switch from maize to crops like vegetables and fruits, and improving business capacity, are needed. Some of this is already happening. Mobile banks, for example, allow villagers to secure their money and obtain loans.

Successes in Malawi spurred an effort to launch a global fund for smallholder agriculture, similar to The Global Fund to Fight AIDS, Tuberculosis and Malaria. On April 17, 2010, the Global Food Security Trust Fund was launched, with support from the World Bank, the Bill & Melinda Gates Foundation and several world governments, including the U.S., Canada, Japan and Spain. To date, 10 other African countries are following Malawi’s lead.

**The Green Revolution Bonus**
Increasing yields in tropical Africa from 1 ton to 3 tons per hectare can be achieved without increasing water, Sanchez said. He challenged the commonly held view that the proportion of plant transpiration to evapotranspiration is relatively constant. He cited a study by Johan
Rockström and his colleagues demonstrating that that constant is true from about 4 tons to 10 tons per hectare of grain yields. At 1 ton per hectare, however, the proportion of transpiration to evapotranspiration is about 15 percent because the space between plants leads to high evaporation. But at 3 tons per hectare, transpiration is more than one-third of the equation, and by 5 tons it’s about two-thirds.

“This is what I would like to call the Green Revolution bonus because as you go from 1 to 3 tons per hectare, you can get a lot more water,” Sanchez said.

Although studies have shown mixed results from fertilizer inputs in rainfed agriculture, inputs are still valuable additions in the long term, despite risks of crop failures. Inputs result in better root systems, and greater yields per hectare allow more water vapor to flow through transpiration than through evaporation.

“We’d love you to have a boarding pass on this plane and join us in this exciting adventure,” Sanchez concluded. “It’s happening. One to 3 tons per hectare can happen in the next 10 years.”