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Future of Water for Food: Proceedings of the Future of Water for Food Conference Held at the University of Nebraska–Lincoln, May 3-5, 2009

University of Nebraska–Lincoln Office of Research and Economic Development

FUTURE OF WATER FOR FOOD

Proceedings of the Future of Water for Food Conference

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University of Nebraska

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Foreword

By 2050 the world population is expected to increase 40 percent and the demand for food will double.

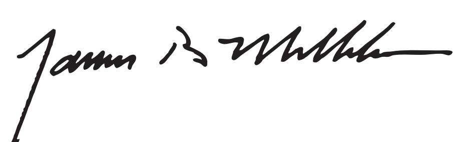
In a time when agriculture is being asked to produce more food for a growing population, our global water supplies face increasing demands and a changing climate holds unknown risks. Growing more food with limited water supplies is one of the greatest challenges facing the international community.

In May 2009 the University of Nebraska and the Bill & Melinda Gates Foundation hosted the Future of Water for Food conference to bring together experts from around the world to discuss this challenge and potential paths to solutions. This report documents the ideas and discussions that emerged.

The Future of Water for Food conference grew out of the University of Nebraska's recognition that there is a critical need for an organization with a global perspective and diverse expertise to address the challenges and issues surrounding the use of water for agriculture. To address that need, the university is committed to establishing the Global Water for Food Institute, a research institute dedicated to helping the world efficiently use its water resources to ensure the food supply for current and future generations. A key conference goal was to create a dialogue among experts from around the world about how the Global Water for Food Institute can develop the programs and partnerships to effectively address these issues.

The conference provided an invaluable opportunity to learn from experts throughout the world who bring decades of experience and perspectives from many disciplines and cultures. We can develop effective solutions only if we ask the right questions. The conference participants' ideas and perspectives will be invaluable in informing the development of the Global Water for Food Institute.

Jeff Raikes, CEO
Bill & Melinda Gates Foundation



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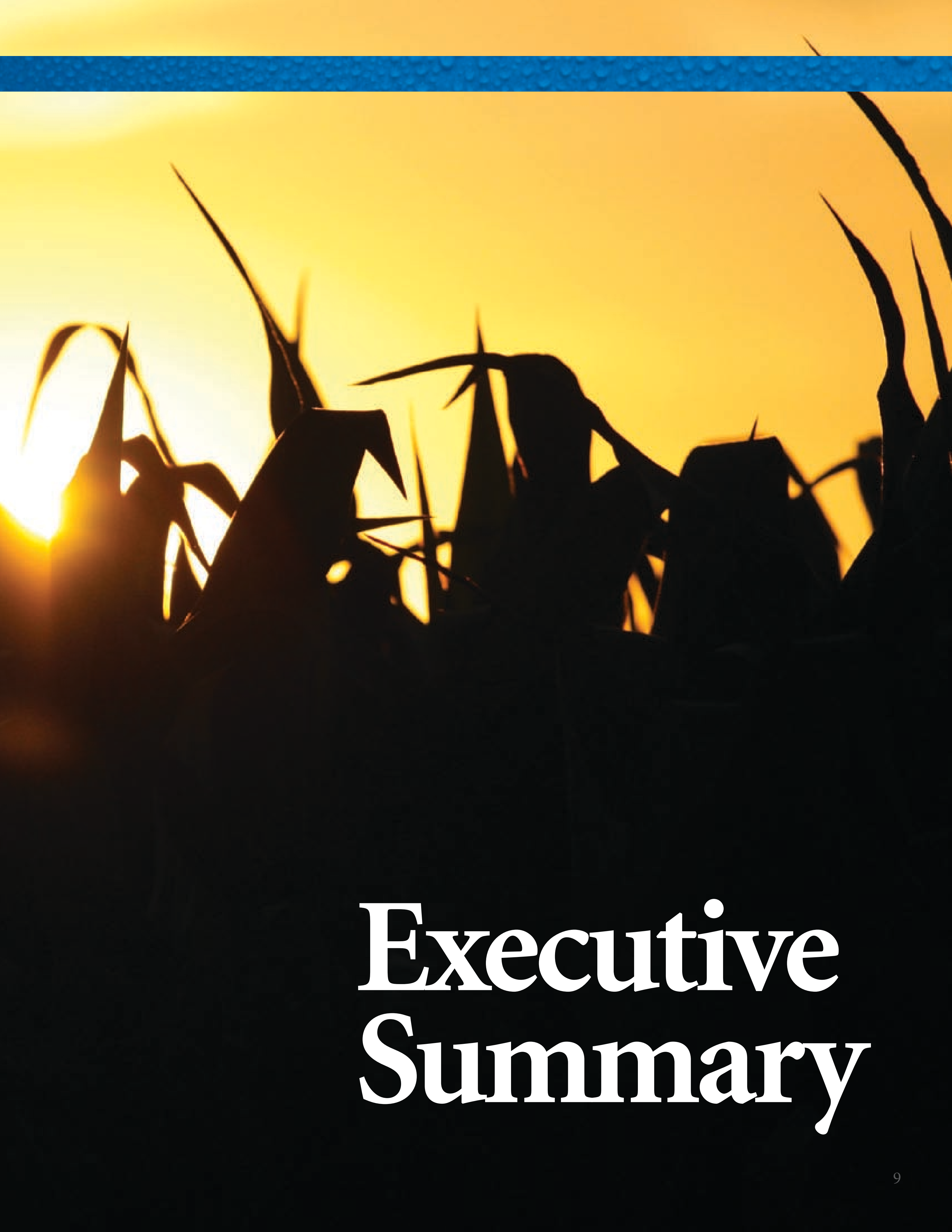


Executive Summary

Executive Summary

"Water is key. It's a critical issue. In many cases, it's a critical limitation. And we come together probably in some cases with different perspectives, but I think we can all agree that it's a critical challenge, one that we must take on," said Jeff Raikes, chief executive officer of the Bill & Melinda Gates Foundation in his keynote address at the Future of Water for Food conference.

Hosted by the University of Nebraska and the Bill & Melinda Gates Foundation, the conference was held at the University of Nebraska–Lincoln, May 3-5, 2009. The conference brought together more than 230 scientists and decision-makers representing universities, industry, government and nongovernmental organizations from the U.S. and five other nations to discuss the critical issues and challenges in providing sufficient water and agricultural development to feed the world's growing population.

"Water is key. It's a critical issue. In many cases, it's a critical limitation. And we come together probably in some cases with different perspectives, but I think we can all agree that it's a critical challenge, one that we must take on."

Conference participants addressed many aspects of the essential links between water and food and the most pressing issues – overuse, underuse and inefficient use of water, water quantity and quality, water scarcity, sustainability of the resource, distribution and demand conflicts, legal and institutional barriers to management and others – and offered recommendations for tackling the challenges.

A key goal of the conference was to create a dialogue among worldwide experts about how an institute to be established at the University of Nebraska can develop the programs and partnerships to effectively address these issues.

To frame the context for the Gates Foundation's interest in water for food, Raikes gave a brief overview of the foundation's priorities. The Gates Foundation was formed in 2000 with the guiding principle that all lives, no matter where they are lived, have equal value. Its initial emphasis on global health expanded in 2006 to include global development focused on agriculture, with the mission of becoming part of a catalytic effort to help the world's 2.5 billion people who live on less than $2 per day rise out of extreme poverty. The Gates Foundation's key goal is to help 150 million smallholder farmers triple their income by 2025. "If we can do that, we can help them lift themselves out of extreme poverty, and we can help them create new opportunities for their children," Raikes said.

Agriculture and water are inseparable, Raikes said. Many approaches to water management have not worked or have been inadequate. Innovative tools and technologies are needed to address five key challenges: overuse of the water resource; underuse of the water resource; inefficient use, in terms of not maximizing output per unit of water used; shifting water demands as economies grow; and changing water supplies in the face of climate change and other challenges.

James Goeke of UNL, who has surveyed Nebraska's groundwater resources for more than 40 years, emphasized that all humans are connected by their dependency on water. Quoting author Loren Eiseley's statement that "if there is magic on this planet, it is contained in water," Goeke said, "I assure you, there's a lot of magic in Nebraska." He described Nebraska's abundant water resources, including numerous rivers and streams and the High Plains aquifer, one of the largest in the western hemisphere, which contains 3.25 billion acre-feet of water, 66 percent of it in Nebraska. Groundwater and surface waters are inextricably connected, and the entire water budget must be considered in seeking solutions to water challenges. In the future, humans must balance water inflows from precipitation and outflows as evapotranspiration with how much water stays in storage, Goeke said.

How scarce is water? Water scarcity is based on physical availability and economic availability of the resource, said Peter Rogers of Harvard University. In economics, the price of a commodity is a good indication of scarcity. Yet society rarely pays for water, so its price is not a good economic indicator of scarcity. Economic scarcity occurs when water is available but is inaccessible because infrastructure has not been developed, a situation found in eastern India, Sub-Saharan Africa and western South America. Such areas provide a tangible opportunity to increase food production. Rogers spoke about technical, economic and regulatory actions to meet water challenges. One example is free trade to increase flows of "virtual water" – the water a country saves by importing agricultural products instead of growing them, freeing the saved water for other purposes. This offers one solution to the need for excessive amounts of local water for agriculture. Other actions Rogers suggested included water pricing; desalination, which increasingly is becoming more affordable for high value crops; improved irrigation efficiency; and ecosanitation, or reuse of wastewater.

Center pivot with low-pressure spray nozzles and hose drops

Simi Sadaf Kamal of the Hisaar Foundation spoke of the challenges of managing water for agriculture in Pakistan, a country that is 92 percent arid or semi-arid yet derives 25 percent of its gross domestic product from agriculture. An early emphasis in Pakistan on technological advances has changed to an increased focus on governance-based reforms. According to the World Bank, Pakistan is one of the world's most water-stressed countries. "Pakistan is already using 97 percent of its surface water resources and is mining its groundwater to support one of the lowest productivities in the world per unit of water and per unit of land, however you compare it," Kamal said. Key steps to move forward include dividing the Indus Basin into agro-climatic zones and developing long-term water strategies and crop combinations for each zone; improving agricultural practices and technologies to produce more crop per drop; rehabilitating and maintaining existing irrigation infrastructure; improving micro-irrigation techniques;

aggressively promoting water conservation; rehabilitating the freshwater-seawater interface on coasts; and adapting to climate change.

Better tools are the best means for managing the spatial and temporal distribution and redistribution of water to enhance food production, said Richard Allen of the University of Idaho. These tools include using micro drip systems and mini sprinklers and the highly successful treadle pump in developing countries. Better quantifying the available water supply and the amount of water consumed using improved groundwater surveys, water balance studies and models, and measuring evapotranspiration would help manage water. Improving food productivity per unit of water consumed must be a major research focus. One efficient way to achieve this is to increase transpiration and decrease evaporation. Methods such as no-till and minimum tillage reduce non-beneficial evaporation during the off-season and the growing season, making more water available for crop use. Allen also emphasized managing water consumption, rather than irrigation efficiency, and adopting a holistic approach to water accounting tailored to the hydrology of a water basin.

Sorghum, a drought tolerant crop

Photo courtesy of INTSORMIL

The U.S. faces a water crisis, said Robert Glennon, University of Arizona law professor and author of *Unquenchable: America's Water Crisis and What To Do About It.* The crisis is driven by water shortages due to drought, population growth, new demands from biofuels and other energy systems, sanitation and other uses. To encourage reallocation of water, government must stop allowing limitless access to a finite resource, Glennon said. Price signals and market forces are effective tools for reallocating water. Transferable water rights, which require developers to have sufficient water rights to support a project before starting construction, are an important reallocation tool.

How do we grow more food with less water?

The panelists on this topic focused on the use of science and technology to manage water and ensure an adequate food supply. Brian Larkins of the University of Arizona explained the science of developing crops with greater drought tolerance to sustain food production when water is limited and improving maize and sorghum to maintain nutritional values if crop yields decrease. Larkins is optimistic that genetic engineering can improve corn yields 15 to 20 percent in the next five years. Judith C.N. Lungu of the University of Zambia said that although water is available in Zambia and other countries, Sub-Saharan Africa still depends on low-productivity rainfed agriculture because it lacks essential infrastructure for irrigation. Africa's challenge is managing the available resources at local, national and inter-country levels when the precipitation is not dependable and where irrigation infrastructure is not developed, she said.

Scientists predict that by 2030, global food production must increase 50 percent to feed the population, said Ramesh Kanwar of Iowa State University. A 100 percent increase may be needed by 2050. Will Nebraska and other major agricultural producers be able to produce twice the amount of food produced today with the same amount of water?

To achieve that goal, the agriculture industry must develop plants that use less water and recycle nutrients more effectively, and create better irrigation systems. This is where science and technology must play a major role, Kanwar said.

Vincent Vadez of the International Crop Research Institute for the Semi-Arid Tropics emphasized finding the optimum combination of genetics and proper management to maximize returns in grains or dollars from a limited amount of water. To produce enough food to match the population growth by 2050, the productivity of dryland farming must improve, Vadez said. Eighty percent of the world's food is grown under rainfed conditions dependent on "green water," soil moisture generated from rainfall. "What ICRISAT can bring to a water institute is a more global dimension where we need to look very carefully at green water," Vadez said.

"The agriculture industry must develop plants that use less water and recycle nutrients more effectively, and create better irrigation systems."

Ron Yoder of UNL pointed out that although significant technological advances enable agriculture producers to squeeze the last bit of benefit out of a unit of water, the technology often goes unused. He cited several reasons: knowledge transfer does not reach those who need it most; technology costs more than the end users can afford; people don't fully understand hydrology and water budgets; and researchers do not pay close enough attention to the scale at which a technology is helpful. Most importantly, Yoder said, these factors must be integrated with the sociological, policy and educational issues in order to realize the true value of science and technology.

The cost of water

The policy and human dimensions panel discussion focused on the intertwined relationship among water, agriculture, energy, environment and poverty; the importance of developing sustainability; the need to integrate the scientific, economic, legal and social factors that affect water management and food production; and the importance of innovative, collaborative decision-making. Marc Andreini of the International Water Management Institute emphasized the need to make science-based decisions in Africa, focusing on three areas: the biophysical environment, especially hydrology and meteorology; choices about infrastructure needs, particularly water storage; and the processes of institutional and policy reform. "We need input from the social scientists. We need to know how the institutions and economic reforms that are to be made can be as meaningful as possible," Andreini said.

Sandra Postel of the Global Water Policy Project said a new mindset is needed in thinking about the nexus of water, poverty, environment, energy and agriculture. The sustainability of irrigated agriculture may not be tenable and has related technological, social, economic and policy components that must be considered, Postel said. These include the impact of climate change on water supplies; the need to integrate water use, water allocation and water management with the goal of preserving ecosystem health and ecosystem services; and development of appropriate technologies that are affordable and accessible to the poorest farmers. "Beginning to deal in a conscious way with the water footprint of our diets is going to be an important feature of achieving some kind of sustainability in water and food production," Postel said.

Sandra Zellmer of the University of Nebraska College of Law spoke about sustainable development and described three fundamental concepts of the United Nations Agenda

21 relating to water: providing adequate water supplies; maintaining the ecological services that provide goods and services for human communities and ecological communities; and recognizing capacity limits. Water law in the U.S. and internationally is on the brink of a new era, Zellmer said. Growing populations, growing energy demands and climate change will put increased pressures on water resources. The fundamental goal that all people have access to a clean, reliable water supply to satisfy fundamental human needs, including the need for food, has not changed. But as Agenda 21 recognizes, the new stresses will make innovative, collaborative and integrated approaches to water management all the more imperative.

"New stresses will make innovative, collaborative and integrated approaches to water management all the more imperative."

The appropriateness of large dams and large irrigation systems is now a global question, said Dan Tarlock of the Chicago Kent College of Law. Any effort to promote increased irrigation or greater use of water faces two challenges: the new legal requirements for integrated water management pushed by the nations that fund many of the projects in developing nations; and a host of new uncertainties, such as those posed by global climate change, which will call for greater flexibility in management institutions. The water resources development that takes place will be smarter and smaller, driven in part by the new legal environments.

The severe drought in Australia has accelerated changes in water management policy and use and attempts to allocate water in a more economically efficient and socially and environmentally acceptable manner, said irrigation consultant Otto Szolosi. Australia's 10-year, $12.9 billion Water for the Future Initiative has focused on adaptively managing water resources, securing water access entitlements for users, expanding water markets and introducing more effective prices and policies. Water trading is yielding significant economic and efficiency benefits. Australian farmers are adopting new management strategies, including reducing the total area irrigated, reducing water application rates, implementing irrigation scheduling, substituting crops that use less water and utilizing cover crops. Water trading, increased groundwater pumping and water recycling also are used.

Envisioning a Global Water for Food Institute

A core group of 65 experts attended a half-day working group session following the conference. This group included scientists and decision-makers representing U.S. and international universities, industries, government and nongovernmental organizations, and University of Nebraska administrators and faculty from a wide range of disciplines whose work focuses on water and food issues. Each working group included participants from diverse backgrounds – hydrologists, biologists, engineers, computer scientists, political scientists, lawyers, agronomists, economists, geoscientists, policymakers, university administrators, directors of nongovernmental organizations and foundations, farmers and industry executives.

Each working group had the same charge: A Global Water for Food Institute to be established at the University of Nebraska will be a research institute committed to helping the world efficiently use its limited freshwater resources to ensure the food supply for present and future generations. *Describe your vision for this institute.* Define the core components/priorities of the institute's mission, the metrics for success, the organizational structure and key partnering organizations.

Key recommendations from the working groups

- The area of water for food is growing in importance and no organization exists nationally or internationally that focuses exclusively on this issue. Nebraska is an ideal place for such an organization, and it is an opportune time to establish this institute.
- The institute's core mission should be to answer the question: *How can we produce more food per unit of water?* The answer to this question must be broadly construed and interdisciplinary – to develop, promote and disseminate the application of science, technology, education, policy and human behavior research to this problem.
- The right leader (executive director) is critical. The ideal director is someone with broad international experience and connectivity, who has drive and a sense of mission, and is able to raise funds. He or she can't be wedded to one group and must be able to bridge disciplines. The executive director's major role is establishing the institute and promoting it to the international water and food communities, establishing partnerships and pursuing opportunities.
- Partnerships are critical. The institute must partner with and can serve as a central link for many organizations – other universities, governmental agencies, nongovernmental organizations, foundations and private sector organizations nationally and internationally.
- The institute should have a global vision and a pragmatic international strategy, providing science-based approaches to state, regional, national and international challenges.
- The research should bridge basic and applied research, and action/practice, with an emphasis on developing practical applications based on the best science and engineering.
- Development of cooperative research programs with other universities and international organizations should be a core component.
- The institute should actively learn from others who have been working in the international water arena for decades.
- The research should focus both on rainfed and irrigated agriculture.
- The institute should not be a development organization but rather an institute to create and deliver knowledge (research, data, policy analysis, education) to *inform* development.
- A key focus should be knowledge transfer of the institute's products (data, research, technologies, tools, policy analysis, education) to the world.
- Agricultural production is a multi-dimensional, multi-scale system, the management of which requires research not only on water, seeds and fertilizers, but also the human dimensions. How people interact with and influence the system should be a focus.
- The institute should pursue a holistic approach that looks at river basin-wide hydrology, with an understanding that agriculture is an interacting component of a larger ecosystem.

Corn and wheat fields

1 Introduction

Introduction

Global agricultural productivity has increased dramatically over the past 50 years. Fueled by improved crop varieties, new irrigation technologies and improved agricultural practices, the global food supply has kept pace with a rapidly growing population. Yet today we face the possibility of global food scarcity. By 2050 the world population is expected to increase 40 percent, and the demand for food will double. Population growth is just one factor in this demand. Rising incomes in the developing world mean people are eating more meat and dairy products, which require more grain to produce. Corn, soybeans and other crops are being diverted to biofuel production in the developed nations. Worldwide, prime agricultural land is being lost to urban expansion. All of these factors are converging to create food scarcity.

This escalating demand on agriculture to produce food, feed, fiber and fuel will exert intense pressures on the quantity and quality of our water resources. Globally, most fresh water is used to produce food. Agriculture is responsible for 75 percent of all water withdrawals and 86 percent of total human consumptive use, the vast majority of which is used for irrigating crops.

In the 20th century growing demand for water was met by increasing the water supply with large-scale construction of dams and reservoirs, pipelines and extensive well drilling. Increasing the water supply is no longer a sustainable option because dam and reservoir building has reached a point of diminishing returns and water pumped from aquifers often is not replenished by rainfall. In the 21st century our focus must switch to developing advanced technologies and innovative management practices for efficiently and appropriately managing water resources, and finding solutions to overcoming the legal, cultural and institutional barriers to wisely and equitably manage our water and agricultural resources.

Already, water shortages are occurring in many of the world's major food production areas. In the future, burgeoning industrial and municipal demands will shift more water away from agriculture. In a time when agriculture is being asked to produce more food for a growing population, demand for water is growing and a changing global climate holds unknown risks. We must grow more food with less water.

The daunting issues surrounding water use – overuse, underuse and efficient use, sustainability of the resource, degradation of supplies, distribution and demand conflicts, balancing competing uses, and legal and institutional barriers to management – are globally important. Although many organizations in government, academia and the private sector are working to address global water issues and improve crop production systems, a need still exists for a focused global effort to bring together expertise from many disciplines, to conduct research focused on producing more food per unit of water.

> *"Many factors are converging to create food scarcity."*

For more than a century the University of Nebraska has been a leader in research on water, agriculture and the management of critical natural resources. This leadership grew naturally from Nebraska's position as a steward of vast natural resources. The native grasslands and farmlands of Nebraska comprise one of the most productive agricultural areas in the world – a level of production made possible by a wealth of water resources that includes numerous rivers and streams and the High Plains aquifer, one of the largest aquifers in the world, which contains 3.25 billion acre-feet of water, 66 percent of it in Nebraska. These resources enable the state's irrigated crop production, placing it first in the U.S. in irrigated crop acres and fourth in food production, giving Nebraska global significance as a food producer.

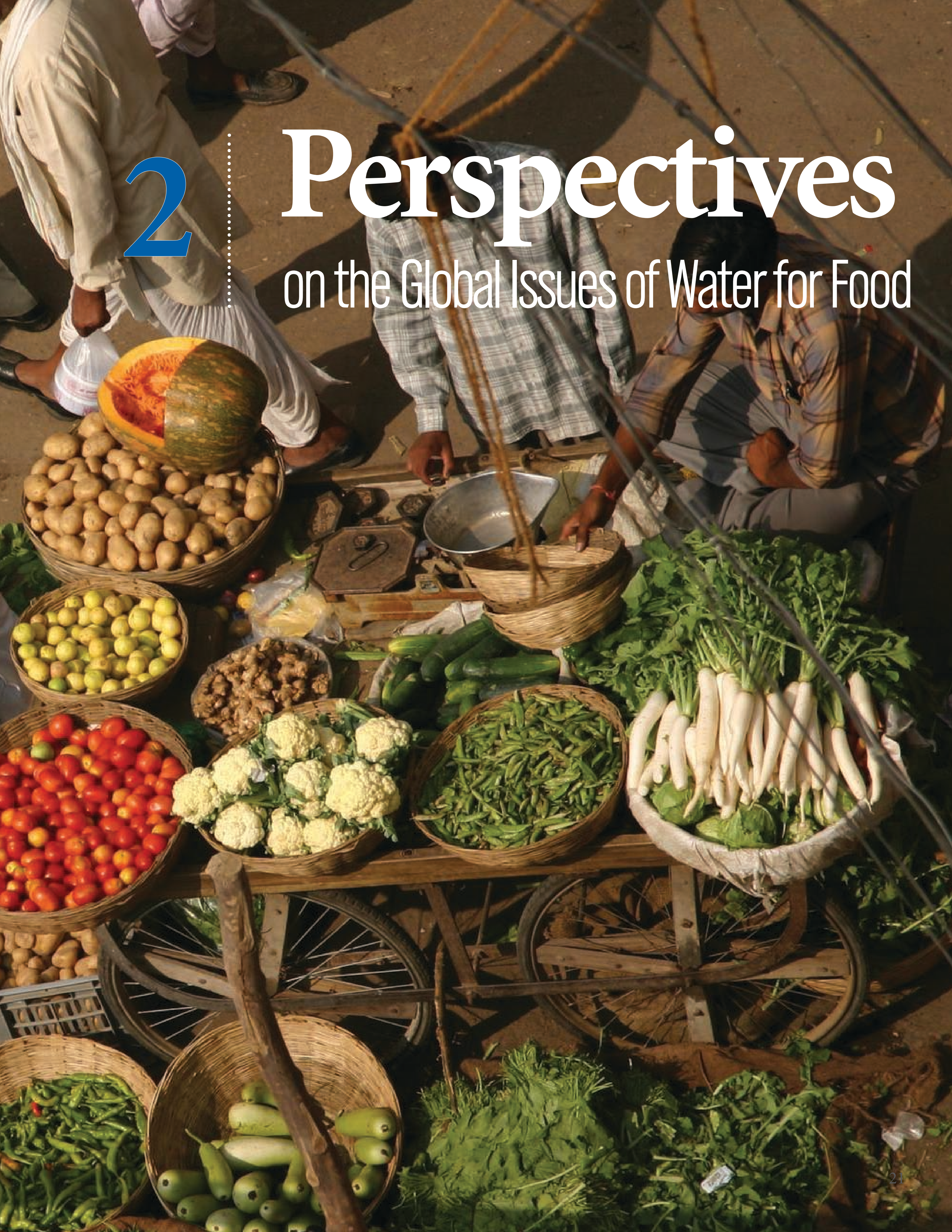
Center pivot irrigation systems were invented in Nebraska, and the state is home to the world's four largest pivot manufacturers. The state is a leader in innovative policies to manage and conserve surface and groundwater resources. This strong knowledge base developed by the public and private sectors, coupled with a long history of research, education and outreach focused on water and agriculture, positions the university and its partners to contribute innovative solutions to the global challenges of growing more food with less water and managing limited water resources in a thirsty world.

The University of Nebraska recognizes there is a critical need for an organization with a global perspective and diverse expertise to address the challenges and issues surrounding the use of water for agriculture. To meet that need, the university is establishing a Global Water for Food Institute, a research institute committed to helping the world efficiently use its limited fresh water resources to ensure the food supply for current and future generations. The Future of Water for Food conference, held May 3-5, 2009, and hosted by the University of Nebraska and the Bill & Melinda Gates Foundation, brought together experts from around the world to discuss the most pressing issues and essential linkages between water and food, and to explore how the Global Water for Food Institute can develop programs and partnerships to effectively address these challenges. This report documents those discussions.

Center pivot irrigation system

2 Perspectives

on the Global Issues of Water for Food



Keynote Address

Fighting Poverty with Water

Jeff Raikes
Chief Executive Officer, Bill & Melinda Gates Foundation

As CEO of the Bill & Melinda Gates Foundation and a native Nebraskan, Jeff Raikes shared information about the foundation and its role and approach to fighting poverty with water, as well as his personal interest in the subject. Raikes intended his address to be provocative and to challenge the attendees to consider the actions that must be taken to address what he believes is a significant crisis but also a significant opportunity – the future of water for food.

Jeff Raikes

Raikes' personal interest in water and agriculture is rooted in his family's history of farming in Nebraska since 1854. He described vivid memories of his father portraying the vast Ogallala aquifer as an incredible resource for agriculture, and his father's absolute belief and commitment to agriculture. "As a teenager I came away thinking, wow, we have this endless supply of water. Endless is what I thought," said Raikes, who grew up near Ashland, Neb.

During a recent conversation, Raikes learned that the water in his home area's river basin will likely be considered fully appropriated (having no additional irrigation capacity) within the next 12 months.

"Very stunning for me going from my discussion with my father as a teenager about this 'endless supply of water' to now recognizing what a challenge we have right here in my home state. So it's both with an institutional interest and a personal interest that I come here today to be a part of this very exciting session," Raikes said.

To frame the context for the Gates Foundation's interest in the area of water for food, Raikes gave a brief overview of the foundation's establishment and its work. The Gates Foundation was formed in 2000 with the guiding principle that all lives, no matter where they are lived, have equal value. The initial emphasis on global health was spurred by Bill Gates' learning of the huge number of children who die in developing countries each year from diarrhea caused by the rotavirus – deaths that could be prevented by treating the child with Pedialyte, as is done in the U.S. The idea that technologies in the developed world could save lives if made available in the developing world symbolized to Bill and his wife, Melinda, that the world does not treat all lives as equal. They believed the foundation could make a difference by bringing technology and science to the developing world.

Raikes said this mission expanded in 2006, when fellow Nebraskan Warren Buffett decided "to bet on Bill and Melinda … to invest back into society the wealth that he's created via Berkshire Hathaway. That was a big part of the impetus for the Bill & Melinda Gates Foundation to get into what we call global development." The foundation saw its role in global development as becoming part of a catalytic effort to help raise the 2.5 billion people in the world who live on less than $2 per day out of extreme poverty. In addition to global health and global agricultural development, the foundation also invests in U.S. education to help more children finish high school and go to college.

Agriculture: A compelling solution

The Gates Foundation believes, based on history and the work of the Green Revolution in the 1960s and 1970s and on its view of the future, that hunger and poverty are solvable. Almost 78 percent of the nearly 1 billion people who live on $1 or less per day live in South Asia and Sub-Saharan Africa. "This year, for the first time ever, more than a billion people will go hungry. If you look to the future, where we're now at 6.5 billion people, the world population is expected to exceed 9 billion by 2050. So that helps set some of the context of the crisis that I see as the opportunity," Raikes said.

Agriculture is a compelling solution to reducing hunger and poverty. Historically, almost no country has risen out of hunger and poverty without increasing its agricultural productivity. But while agriculture is key, it is a solution that has been ignored, Raikes said. In Sub-Saharan Africa agriculture comprises almost 30 percent of gross domestic product, yet agricultural spending is less than 5 percent of government budgets. This problem is exacerbated by disinvestment in foreign aid over the past 20 years, with the percentage of foreign aid directed to agriculture dropping from about 13 percent in 1985 to less than 4 percent in 2005. The result: hundreds of millions of farmers realize just a fraction of their potential.

> *"All lives, no matter where they are being led, have equal value. So when we look back at the Green Revolution, when we look back at what's happened in agricultural investment over the last 25 years, what lessons have we learned?"*

The Gates Foundation has set a key goal of helping 150 million smallholder farmers triple their income by 2025. "If we can do that, we can help them lift themselves out of extreme poverty, and we can help them create new opportunities for their children," Raikes said.

A few core principles drive the foundation's work in this area. The work focuses on Sub-Saharan Africa and South Asia because about 80 percent of the challenge exists in those regions. The foundation emphasizes smallholder farmers as the starting point for fighting poverty and reducing hunger. Women are at the center of these efforts because they comprise about 80 percent of the labor force in agriculture in these regions.

The Gates Foundation's approach involves significant investments in partnerships because the obstacles and the solutions to reducing hunger and poverty span so many sectors. One example is the Foundation's Alliance for a Green Revolution in Africa, a partnership with the Rockefeller Foundation. "That's a key part of why we wanted to participate in this conference, because of the partnerships that you will form in taking on the issues of water," Raikes said.

The foundation also believes it is important to support the full range of farmers' needs, which translates into four key initiatives in its agricultural development strategy. The first is science and technology, with a focus on research and development of crops using plant breeding techniques to produce hardier and more nutritious crops. The second is farmer productivity. Growth in the number of agricultural dealers is a way to provide quality seed, fertilizer and irrigation to farmers, and also a means of providing a support network for training and education. The third is market access. "We believe strongly in market access," Raikes said. "If farmers have access to markets, if they have a sense that they'll have the opportunity to sell their output, then they will have the ability to be able to make investments in the right kind of inputs, the right kind of practices that will improve their productivity."

Combining market access with farmer productivity and the right science and technology supports the range of farmers' needs. But the foundation also believes it is important to invest in policy and statistics, its fourth key initiative, so farmers and policymakers are informed. That also will be critical in the area of water management, Raikes said.

Water, the critical challenge

Agriculture and water are inseparable. "You know, in each of the areas I just mentioned, water is key," Raikes said. "It's a critical issue. In many cases it's a critical limitation. And we come together probably in some cases with different perspectives, but I think we can all agree that it's a critical challenge, one that we must take on, and I think that's why you're here."

Many approaches to water management have not worked or have been inadequate, Raikes said. "It's time for all of us to come together and demand of ourselves and of our colleagues new innovation, new approaches, because collectively you have the power to help hundreds of millions of people move from extreme poverty."

> *"It's time for all of us to come together and demand of ourselves and of our colleagues new innovation, new approaches, because collectively you have the power to help hundreds of millions of people move from extreme poverty."*

Raikes showed a slide of Lake McConaughy, Nebraska's largest reservoir on the Platte River. It was 22 miles long when he was born. Now it's 16 miles long and at 35 percent of capacity. "I put this picture in to illustrate that this is a challenge here in our country as well as a global challenge, and that's why we're excited about the idea of the Global Water for Food Institute," he said.

To give a sense of global contexts, Raikes compared maize or corn production practices in the U.S., India and Africa.

Irrigation. In the U.S. less than 20 percent of the corn crop is irrigated. In India, more than 40 percent is irrigated, and in Sub-Saharan Africa, less than 5 percent is irrigated.

Policy. U.S. policy is changing because of greater recognition that water resources are fully appropriated and must be better managed. Raikes suggested India still has an outdated policy developed 50 years ago to improve agriculture production and reduce hunger. Aggressive government policies encouraged use of fertilizer and heavy irrigation, and electricity was effectively free. Policymakers have since learned that the wrong economic incentives led to overuse of water. In the case of Africa, Raikes suggested the real challenge is a lack of policy, a lack of investment in the infrastructure that would make irrigation possible.

Productivity. Countries experience significant differences in terms of yields and water use. Average corn yields are about 9.5 tons per hectare in the U.S., about 2.4 tons per hectare in India and about 1.8 tons per hectare in Africa.

Jeff Raikes' keynote address

Raikes summarized and gave examples of the challenges arising from each context and said he hoped they would serve as a road map for the key challenges to address in the conference working groups.

Overuse. The water resources in extensive areas of northwestern and southern India are designated as overexploited, critical and semi-critical, a situation that has occurred in these areas in the last 20 years.

Underuse. In South Asia, the Middle East and North Africa, nearly 40 percent of cropland is irrigated. In Sub-Saharan Africa less than 5 percent of the cropland is irrigated, Raikes said, but the investment potential for irrigation is exciting. He cited figures recently released by Africa Infrastructure Country Diagnostic, showing profitable areas for irrigation of Sub-Saharan Africa totaling 32 million hectares. "If you could just imagine what could happen with 10 percent of that opportunity being converted into effective irrigation, it would be a significant improvement to the lives of those people and to the contribution to the food supply," Raikes said.

Inefficient use. Raikes showed a chart comparing water use per unit of maize or corn production in cubic meters per kilogram, with the U.S. at 0.57, India at 3.05 and Nigeria at 5.34. "When you overlay what you saw earlier in terms of productivity or yields with water use, you see that today we have great inefficiencies in how we use water," Raikes said, "and this is an area that we think there's a lot of opportunity for innovation, a lot of opportunity in science and technology."

Malawi is a good example, Raikes said. The rainfall in Malawi, if properly managed and made available in reservoirs with better soil management, could yield 8 tons of maize per hectare. Today, it yields just eight-tenths of a ton per hectare – 10 times less than its potential.

Hand watering crops in Senegal

Photo courtesy of United States Agency for International Development

Changing water demands. Water use changes as countries' economies develop. This is an important consideration for prioritizing policies and a place where innovation is needed, Raikes said. Comparing agriculture, domestic and industrial usage in the three regions, he showed that U.S. total water use is 7,000 liters per person per day, with 4,000 of those liters going to agriculture. In India total use is less than 3,000 liters per day, with about 2,500 liters for agricultural use. In Ethiopia, total use is less than 2,000 liters per day, with almost all used for agriculture. Human consumption of water is largely through agriculture throughout the world, but there are significant differences. More important is projecting what will happen as economies develop and how that will change water demands. This underscores the importance of innovative approaches that will improve water use efficiency and proper resource management, Raikes said.

Changing water supply. Showing a map of Africa from the Intergovernmental Panel on Climate Change Fourth Assessment Report, Raikes cited the large areas in northern and southern Africa predicted to have a 20 to 50 percent decrease in available precipitation by 2090. A large part of southern Africa that historically has been a significant breadbasket is predicted to have a 50 percent decrease. What does this mean for the institute's priorities? "It means that we have to have the agility to be able to respond. It means that we have to have the adaptability in terms of crops," Raikes said. "I'm showing this in Africa, but I know that this is something that's going to be an issue here in the state of Nebraska. I think we will need crop adaptability in terms of being able to handle higher temperatures and being able to handle less water."

The Gates Foundation's early approach to water

An example of the foundation's investment in research and development in this area is its work with CIMMYT, the International Maize and Wheat Improvement Group. A $40 million, five-year grant aims to produce water-efficient, drought-tolerant maize that is expected to help 30 to 40 million farmers and result in a 20 to 30 percent yield improvement. "Again, we like to think about the numbers, what's the impact going to be," Raikes said.

An investment in tools and technologies related to water and international development enterprises is a $13 million, four-year grant to develop micro-irrigation technologies with the goal of helping 100,000 farmers double their income, reduce their costs by 50 percent and increase their yields by 30 percent.

A four-year $10 million grant focused on 120,000 women in agriculture will create community workers who can help others develop market links and learn to use water sustainably. The goal is to have household income improvements of 75 to 100 percent through better support, training and education from the community itself.

In the public policy arena, the foundation is investing in a three-year, $10 million project with the International Water Management Institute to develop technology, policy and strategy recommendations for agricultural water management. The goal is to help 1 million farmers boost yields and income within five years. With the right in-country strategies, the program could potentially help 65 million farmers.

Key challenges for the conference

"Now I'd like to turn it around and talk a little bit about my challenge to you," Raikes said. "All lives, no matter where they are being led, have equal value. So when we look back at the Green Revolution, when we look back at what's happened in agricultural investment over the last 25 years, what lessons have we learned? What mistakes have been critical and what do we do to avoid them? What metrics and targets will galvanize innovation? What science and technology advances should be prioritized? What key information gaps can you fill, and how can you partner with other players, both public and private, to have the greatest impact?"

These are the challenges, Raikes said, and the questions he hoped would be considered in discussions throughout the conference. The Gates Foundation is conscious of the key role that water plays in agriculture, and also that the foundation is a small part of the ultimate solution.

"We're honored to be here and to be a part of this conference," Raikes said. "There is so much opportunity. We must seize it. We must fight poverty with water."

President's Welcome

The Right Time and the Right Place

James B. Milliken
President
University of Nebraska

"All of life and all ecological processes are conditioned on the circulation of water on the planet," said University of Nebraska President James B. Milliken, quoting from Jeffrey D. Sachs' book *Common Wealth: Economics for a Crowded Planet.* "Since civilization began," Milliken continued, "water has been central to life. We've established cities around it, fought wars over it, created myths about it and depended on it for food, power and transportation." Maintaining an adequate supply of usable water has always been a challenge, but today a tangle of interrelated issues — rapid population growth, climate change, the introduction of pollutants, new water-dependent sources of energy — has created a far greater sense of urgency," he said. "Today's speakers, some of the best minds on the subject of water in the world, will add to our understanding of these issues and perhaps, given the scope and the severity of the challenge that faces our world, frighten us a bit."

James B. Milliken

Nebraska is a fitting place to host the Water for Food conference, Milliken said. Nebraska is one of the world's leading agricultural centers and sits atop the High Plains aquifer, one of the largest in the world with more than 2 billion acre-feet of water in groundwater reserves; a state where the center pivot irrigation system was invented and changed the face of agriculture; a state that leads the nation in the number of irrigated acres and ranks fourth in food production. "We are a place that has been providing food for the world for a long time, and we're acutely aware of our need to continue to improve how well we do this and that the world depends on our ability to do it," Milliken said.

> *"We are a place that has been providing food for the world for a long time, and we're acutely aware of our need to continue to improve how well we do this."*

Forty-five years ago the university's Board of Regents established a Nebraska Water Resources Research Institute to serve as a center for research and policy, Milliken said. The Water Center has become a widely-respected resource for research on water quality, irrigation, drought, surface and groundwater management, crop productivity and economic and legal issues relating to water. More than 160 faculty members across the university, in disciplines ranging from engineering to law, natural resources, economics, agriculture, chemistry, biology and other disciplines, contribute to the center's work. "While we believe we've accomplished much of importance over the last 40 years, not only for farmers and ranchers, but for all of those who depend on their work, we believe we're in a position to do more," he said.

For these reasons the university believes this is the right time and the right place to create a Global Water for Food Institute, a world-class research, education and policy center that will provide a knowledge base for effective, practical solutions to the challenges of managing limited water resources worldwide and producing more food with less water. This conference is an important step in the process. It is exciting to bring together so many experts to engage in a conversation about how a Global Water for Food Institute could make the greatest contribution to resolving the water and food issues facing the world and to provide advice on the appropriate scope and the mission of this institute, Milliken said.

To eliminate any doubt about the link between water and prosperity, Milliken closed with a quote from Sachs' *Common Wealth*. "The variability of water availability is strongly and negatively related to per-capita income. It is not surprising that all 10 of the countries ranked as having the lowest human development are water-stressed countries with extensive dryland populations."

Chancellor's Welcome

Water, Food and the University

Harvey Perlman
Chancellor
University of Nebraska–Lincoln

In a state blessed with both significant surface and groundwater supplies and a dynamic system of food production, the interrelationship of water resources and food production has always been a central topic of inquiry for the University of Nebraska, Perlman said. For more than a century the university has been a leader in research and education in water, agriculture and natural resources management. This experience has helped make Nebraska a global food producer.

Harvey Perlman

It also has led the university to continually strive to find ways to maintain this high level of agricultural production while preserving water and soil resources for the benefit of future generations, he said. This work has led to technologies, management practices and public policies that are critical to the effort of growing more food with less water. University of Nebraska researchers have provided leadership in the development of no-till agriculture, drought tolerant crop varieties, efficient irrigation systems, policies governing water management and distribution, and other areas.

The University of Nebraska–Lincoln Water Center has been central to these efforts for 45 years, focusing on water issues affecting Nebraska and the critical focus on water for food. The Water Center will continue contributing to Nebraska and the university's broader efforts, Perlman said, providing experience to regions around the world struggling with similar issues. These issues are too important to Nebraska to ignore the insights and experiences of the global water community, and the University of Nebraska will be enriched by faculty interaction with experts around the world.

This university is well-positioned to assume a leadership role in addressing the interaction of food and water for Nebraska, and contributing to the global challenge of assuring an adequate food supply in the face of population growth and other claims on our water resources.

"We look forward to building partnerships with the many organizations and universities represented here today and learning how we can help catalyze the global exchange of expertise needed to address this challenge," Perlman said.

Speakers

The Significance of Water to Nebraska

James Goeke
Professor, School of Natural Resources
University of Nebraska–Lincoln

James Goeke has been a hydrogeologist in the School of Natural Resources at the University of Nebraska–Lincoln since 1970. His research focuses on the groundwater resources of central and southwestern Nebraska, groundwater management under conditions of scarcity, and the age of the Nebraska Sand Hills, research that has contributed to models of the unconfined aquifers in the central Platte region and stream-aquifer studies in the Republican River Valley. Goeke has worked closely with the Natural Resources Districts in west-central Nebraska to develop and implement state-mandated groundwater management plans.

James Goeke

James Goeke introduced his talk by reminding the audience that everyone is connected by a dependency on water. "The good life in Nebraska has its roots in our water supply. Author and scientist Loren Eiseley once said that if there's magic on this planet, it's contained in water," Goeke said. "I assure you, there's a lot of magic in Nebraska."

Groundwater in Nebraska

Goeke described the groundwater "magic" in Nebraska. Groundwater resources comprise less than 1 percent of the world's total water supply, and more people are competing for that resource. The High Plains aquifer is one of the primary aquifer systems in the U.S., covering more than 174,000 square miles in parts of eight states. Seventy-seven percent of this aquifer is contained in the Ogallala geological formation and is referred to as the Ogallala aquifer. In 1980 the High Plains aquifer stored 3.25 billion acre-feet of water. Sixty-six percent of that was in Nebraska, which covers the thickest portion of the aquifer, 12 percent was in Texas and 10 percent in Kansas.

In 1980 the total amount of depletion of groundwater since predevelopment in the High Plains aquifer was 166 million acre-feet. By 2007 depletion was 267 million acre-feet and 52 percent of these depletions were in Texas, where substantial groundwater pumping has occurred since the 1940s. Twenty-three percent of depletions were in Kansas. In Nebraska, areas of decline were offset by areas where groundwater levels rose, so Nebraska accounted for almost none of the total High Plains aquifer depletions. However, from predevelopment to 2007, Nebraska's groundwater storage capacity has declined 21.4 million acre-feet, a total of 1 percent of the predevelopment water in storage. That means 99 percent of Nebraska's original water supply is still available, which represents a tremendous opportunity, Goeke said.

Groundwater is one component of the total water supply budget that "is on a massive conveyor belt that is inexorably moving the groundwater to a point where it connects with the streams," Goeke said. It is important to consider the entire water budget: how much water flows into an aquifer from precipitation, how much water flows out as evapotranspiration and how much stays in storage. Balancing these components of the water budget is how water must be dealt with in the future.

Precipitation and surface water. Goeke described Nebraska as a transition state between the moist midcontinent and the semi-arid West. Rainfall in Nebraska varies from 32 inches in the sub-humid southeast corner to 16 inches in the semi-arid western region, with an average across the state of 22.74 inches. Eighty percent of that rainfall occurs during the growing season. "Many places aren't that lucky," Goeke said.

Nebraska has numerous streams and rivers, many originating in the Sand Hills and fed by groundwater. "Those are the arteries coming from the heart, the water heart of Nebraska," Goeke said. These rivers feed the Platte River, which supplies water for irrigation and for the well fields that provide water for Nebraska's population centers, Omaha and Lincoln.

A history of drought. Nebraska is the home of the Great American Desert. The drought of the 1930s was a significant event in Nebraska. Goeke showed a photo of a 1930s dust storm, with a farm family watching the dust cloud approach. "This was a significant hydrologic event," he said. "In this area we take these for granted, but these scar us socially, and they have impacted our future." The decade-long drought in the 1930s was nothing new. In reconstructions of droughts on the Great Plains dating back to the 1200s, there were 21 droughts that lasted on average 12.8 years. The longest drought lasted 38 years; the shortest lasted five years. The average period between droughts was 23.9 years.

> *"Loren Eiseley once said that if there's magic on this planet, it's contained in water. I assure you, there's a lot of magic in Nebraska."*

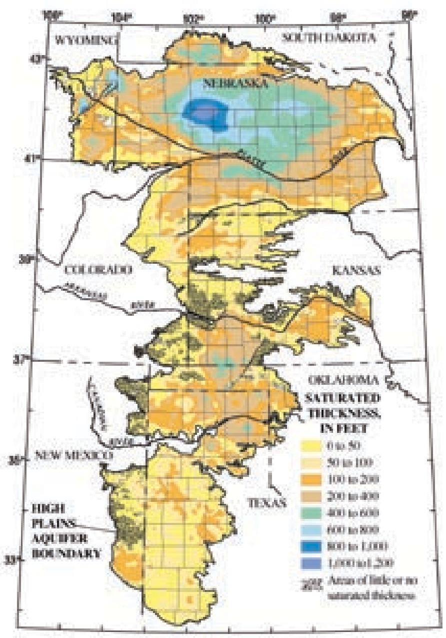
The Nebraska Sand Hills, the largest grass-stabilized sand dune area in the world, has experienced a number of periods during the last 18,000 years when unprecedented drought killed the grass cover on the dunes, and the dunes began to blow and move. The most recent, according to research by UNL geoscientist David Loope, was only 800 years ago. "I think we kid ourselves if we think it won't happen again," Goeke said.

"Nebraska can also be a water machine," Goeke said. Since the 1950s an average of 1.7 million acre-feet of surface water has flowed into Nebraska and an average of 8.9 million acre-feet of water flowed out of the state. Most of Nebraska's streams and rivers are fed by both groundwater and surface water. Ninety-seven percent of the flow of streams and rivers emanating from the Sand Hills – such as the Niobrara, Dismal, Calamus, Loup and Snake rivers – comes from groundwater. In other Nebraska streams, particularly in the eastern part of the state, surface water runoff contributes a bigger proportion of the streamflow.

The surface water-groundwater connection. Nebraskans had a great debate in the 1990s about whether surface water and groundwater were connected. Given the difficulties of thinking about how much water in a river like the Platte River is groundwater flow and how much is surface water flow, Goeke said he can understand why people might think that surface water and groundwater aren't connected. He believes they are connected and described many places in Nebraska where groundwater visibly spills onto the land surface to create streams. Many of these Sand Hills springs are under artesian pressure and are referred to as boiling springs, not because they are hot – they usually have a constant temperature of 56 to 57 degrees – but because the changes in barometric pressure make them appear to be boiling. The Blue Hole on the Dismal River is 24 feet across, Goeke said. A weight dropped into the Blue Hole sank to 120 feet, which is essentially the top of the Ogallala aquifer. This is the groundwater-surface water connection.

Nebraska's groundwater survey program. Nebraska has a long history of water research. *Irrigation in Nebraska* was the first bulletin produced by the Nebraska Agricultural Experiment Station in 1887, "and we have been working on water in Nebraska for well over a century," Goeke said. Since 1930 the University of Nebraska's Conservation and Survey Division has drilled more than 5,500 test holes in Nebraska. "When you drill back into Nebraska, it's like reading a book from the current day and reading back 35 to 65 million years. Every foot or so represents thousands and thousands of years of Nebraska history," Goeke said.

Groundwater irrigation in Nebraska. In 1960, Nebraska had 23,000 irrigation wells. The number of wells jumped to 36,000 in 1970 and to 68,000 in 1980. By 2007, Nebraska had more than 100,000 registered irrigation wells. "And when we look at what happened from 1972 to 1984, you can see the development of center pivots originated here in Nebraska and put to work in Nebraska," Goeke said. "When you think in terms of geologic time and you look at what we did in 12 years, it's absolutely amazing." However, well development came at a price. Water tables have declined as much as 45 to 55 feet in southwestern Nebraska. Yet water tables have risen in other areas of the state.



Graphic courtesy of U.S. Geological Survey

U.S. Geological Survey measurements of the Middle Loup River indicate that its discharge has actually increased, Goeke said. He encouraged the audience to visit http://groundwaterwatch.USGS.gov. Clicking on points in the map provides information about specific wells, including water levels, construction, saturated thickness and other data. "If water truly is the lifeblood of Nebraska, here is a good place to go. It empowers every citizen to actually see our resources and what's going on," Goeke said.

Groundwater laws in Nebraska. The Nebraska Department of Natural Resources regulates surface water use under the prior appropriation system. Groundwater is regulated by locally elected natural resources district boards under a correlative rights system. The Integrated Management Act, passed in 2004, formally recognized the need to integrate the management of surface water and groundwater. Under this law, if the state Department of Natural Resources determines that a river basin is fully or over appropriated, DNR and the local Natural Resources District must work together to develop a plan to integrate the management of surface water and groundwater. A temporary moratorium on issuing new surface water permits or groundwater well permits is imposed until the integrated management plan is implemented. As a result of these determinations, the western two-thirds of the state no longer has easy access to water.

Water budgets. People in Nebraska have been talking about water budgets since the 1960s. It is obvious, Goeke explained, that managing irrigation water use is the source of the problem and the source of the solution, but it is important to consider the total water budget, not just the water pumped for irrigation. Nebraska has 94.9 million acre-feet of water in the water budget. Since only 7 to 8 percent of this water is used by irrigation, simply placing limitations on irrigation cannot be the solution for the future. Many other things can be done; for example, practicing minimum tillage and better cropping practices, or using individual water budgets. Groundwater quality also must be addressed. The presence of nitrates and the herbicide Atrazine in Nebraska's groundwater poses potential health risks.

Water research in Nebraska. There is a tremendous future for applying the research that is being done in Nebraska to develop solutions to water challenges. "We have a tremendous amount of data in Nebraska, and with data come information, knowledge, intelligence and finally wisdom. And without data, I don't know that we individually or collectively can make wise decisions," Goeke said.

Research is being conducted across Nebraska. Water research facilities include the Gudmundsen Sandhills Research Lab, on 12,000 acres in the heart of the Sand Hills that overlays the greatest saturated thickness of the High Plains aquifer, and the 5,500-acre Barta Brothers Ranch. A new water science lab is being established on about 1,200 acres in the South Platte Valley in Lincoln County. Research and experiment stations also are located across the state. Nebraska has a tremendous opportunity to contact and educate people through research and extension around the state and has a long heritage in such education.

"In the end we conserve only what we love, we love only what we understand and we understand only what we are taught. The complex water systems, these intricate water systems, none of us know full well. We need to understand more about them if we're going to have a safe and sound, profitable, environmentally correct future."

The Role of Irrigation in Meeting the Global Water Challenge

Peter Rogers
Gordon McKay Professor of Environmental Engineering
Harvard University

Peter Rogers has a wide range of research experience in the consequences of population on natural resources development and in improving methods for managing the world's natural resources and the environment for sustainable development. Rogers presented his views on the global water challenge we now face and the role irrigation technology might play to meet that challenge.

Peter Rogers

In addressing the role that irrigation might play in the global water challenge, Peter Rogers explained that precipitation falling on the earth's surface is the ultimate source of water. He described its eventual separation into "green" and "blue" water, a concept first introduced by the Stockholm International Water Institute and further illustrated in *Water for Food, Water, For Life: Comprehensive Assessment of Water Management in Agriculture* published by the International Water Management Institute in 2007. According to IWMI, blue water is water in rivers, groundwater aquifers, reservoirs and lakes and is the main water source for irrigated agriculture. Green water refers to the soil moisture generated from rainfall that infiltrates the soil and is available for uptake by plants. It constitutes the main water resource in rainfed agriculture.

On average, about 56 percent of the water falling on the surface evaporates or transpires from forests, grazing lands and other natural habitats. About 4.5 percent evaporates or transpires from rainfed agriculture and another 2 percent from irrigated agriculture. The percentage of rainfall consumed by cities and industry is only 0.1 percent of the total rainfall.

How scarce is water?

Given that irrigated agriculture uses such a low percentage of precipitation, how can the Earth run out of water? The total available blue water, which is available for use from streams and groundwater, is about 12,500 cubic kilometers. The rest of the blue water is unavailable because it is either in the wrong place, such as remote arctic streams, or comes at the wrong time, such as during a flood. Based on these estimates, humans use 50 percent of the available blue water supply, which is close to the edge of sustainability.

If blue and green water are considered, humans use only 23 percent of the available water supply. Most of that is used by rainfed food, fiber and forestry crops. "You can heave a sigh of relief and say, well, gee, 23 percent is a lot better than 50-something percent," Rogers said. "So part of my argument again is, we have a global water problem coming up and … how close to the edge are we?"

How scarce is water? Water scarcity is based upon physical resource availability and economic resource availability. In economics, the price of a commodity usually is a good indication of scarcity. If something has a price, it's scarce. Yet people rarely pay for water, so the price of water is not a good economic indicator of scarcity.

The IWMI Comprehensive Assessment examined four types of water scarcity, noting the difference between not having any water and having water but not being able to use it. If less than 25 percent of the blue water is used, there is little or no physical scarcity; if more than 75 percent of blue water is used, there is a physical scarcity. Economic scarcity is caused by a lack of investment in water or the human capacity to access it, classified as less than 25 percent of the blue that water is being withdrawn.

According to the Comprehensive Assessment, key areas suffering from physical scarcity or near scarcity of water include northern and southern Africa, eastern Europe, southern India, southwestern U.S., and parts of China and Australia. Eastern India, large parts of Sub-Saharan Africa and western parts of South America are suffering from an economic scarcity of water. A tremendous amount of water is available in these areas, but proper infrastructure access has not been developed. These areas provide an excellent opportunity to increase food production.

The impact of climate change and socioeconomic changes on water demand

According to Rogers, the potential impacts of climate change are unclear. The Earth's temperature is rising and scientists suspect various areas will experience precipitation changes, but the impact is difficult to quantify. The Intergovernmental Panel on Climate Change says predictions about precipitation beyond 2050 are uncertain. Combining the output of 18 global climate change models shows a number of areas will have increased precipitation and runoff. Yet in other areas, including the southern U.S., Central America, regions around the Mediterranean, southern Australia and the southern tips of South America and Africa, mean surface water runoff will decrease 20 to 50 percent. "Certainly these areas are of concern," Rogers said.

> *"In economics, the price of a commodity usually is a good indication of scarcity. If something has a price, it's scarce. Yet people rarely pay for water, so the price of water is not a good economic indicator of scarcity."*

Rogers cited a study by Charles Vorosmarty (2000) that examined the forecasted changes in demand for blue water discharge for industry and agriculture compared to current uses under three scenarios: climate change only, population increase only and climate change with a population increase. The smallest increase in demand for blue water would occur under climate change only. With only population change, increases up to 20 percent could occur in many areas of the populated world, except the western U.S. and Australia. Given climate change *and* population increases, demand could rise more than 20 percent in most of the populated world. Rogers suggested that experts need to concentrate on how to handle the third scenario.

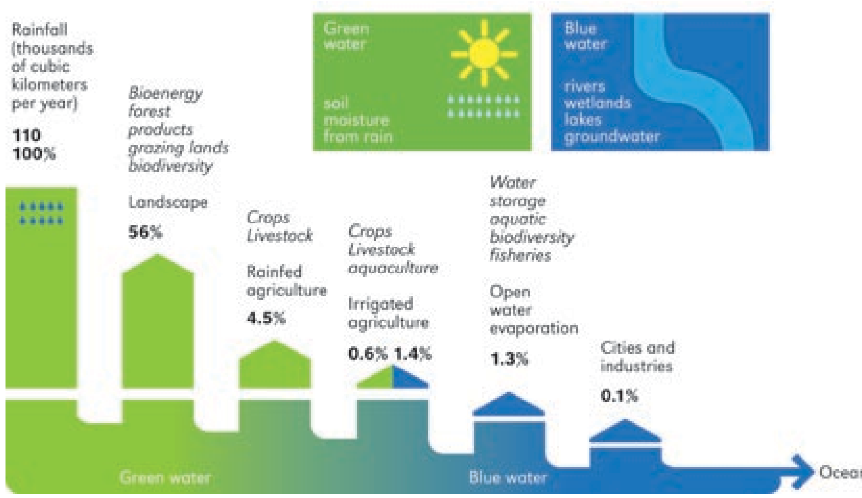
The IPCC fourth assessment report states that moderate global warming of only 3 degrees Celsius could benefit crops and pastures in the mid- to high latitudes but decrease yields in seasonably dry and low-latitude regions. Without major climate change, the number of undernourished people could decline from 820 million today to 100 to 380 million. With climate change, the number of undernourished could rise to 740 million to 1.3 billion. Changes in the frequency and severity of extreme events also could have significant consequences for food and forestry production and increase the risks of fires, pests and pathogen outbreaks. "We could do pretty well under climate change … or not," Rogers said.

Domestic water use by U.S. households is 333 liters per capita per day, almost the same amount used by the ancient Romans, Rogers said. He suggested that the conventional view that water use varies greatly among populations is true only when agricultural water use is not included. Household, service and industrial water use is 366 cubic meters per capita annually in the U.S., 232 in Europe and only 25 in Africa. But if water for agriculture is included, total usage is similar: 3,104 cubic meters per capita annually in the U.S., 2,970 in Europe and 1,393 in Africa. Additionally, people tend to eat more meat when a country's socioeconomic situation changes and their incomes rise. "This is part of the reason we're seeing in places like China and India a huge demand for animal products, and animal products use an awful lot more water than grain," Rogers said.

Can we meet the water demand for higher food production?

The 2007 IWMI Comprehensive Assessment stated that agricultural production must increase 80 percent by 2050 to feed greater numbers of people demanding more animal protein. To meet this target, rainfed cropland must increase by an additional 85 million hectares and irrigated land by an additional 60 million hectares. Governments will need to spend $304 billion to rehabilitate 222 million hectares of irrigated land and construct additional storage for 766 cubic kilometers of water. Based on these estimates, water scarcity will occur. Adding water for the production of biofuels means the system becomes considerably stressed.

Despite these predictions, Rogers was optimistic. The Comprehensive Assessment estimated crop evapotranspiration and irrigation withdrawals in 2050 under various scenarios: optimistic and pessimistic, rainfed, irrigation, trade and comprehensive management scenarios. Global water use today is about 7,500 cubic kilometers. Estimated water use in 2050 is 10,000 cubic kilometers, based on rainfed scenarios with productivity improvement. Without productivity improvement, global water use in 2050 will be 12,500 cubic kilometers. Rogers concluded these scenarios indicate that with production improvements and increased agricultural trade from water-rich to water-scarce nations, global food needs can be met.



Graphic adapted from the 2007 IWMI Comprehensive Assessment

Some technical fixes

Rogers proposed technical fixes to improve water availability. The first was virtual water – the water that a country saves by importing crops instead of growing them. The U.S. exports 100 cubic kilometers of water each year, the equivalent of a hundred billion tons, in the form of grain and other agricultural products. Australia and southern South America are the other major virtual water exporters, while large parts of the world are net importers. The total virtual water trade was 700 to 900 cubic kilometers per year in 2003 – a huge amount of water that receiving countries avoided using.

How would free trade affect virtual water flows? Rogers studied the effects of the North American Free Trade Agreement and found that relatively free trade sped up the process, with the U.S. importing more Canadian water and exporting more grain (virtual water) to Mexico and to Canada. "I think we need to look at these types of things," Rogers said, as they offer one solution to reduce the need for excessive amounts of local water for agriculture.

Desalination is another technical fix. In a World Bank study of the Middle East/North Africa region – one of the world's most arid – the return to water use in dollars per cubic meter was calculated at 50 cents for vegetables, 8 cents for wheat and 5 cents for beef. Water can be desalinated for about 50 cents per cubic meter, and some believe the cost could dip as low as 30 cents. This makes it economically realistic to use desalinated water for high-value crops, such as vegetables. "I wouldn't have believed this myself until I read this report that you could actually afford to use desalinated water for irrigation." Rogers said.

A third technical fix is economic and regulatory controls, which is the issue of freeing up trade. "What's wrong with more crop per drop?" Rogers asked. He cautioned although increasing crop per drop of water consumed is important, the real objectives must be clear. Is the goal to increase the kilograms of crop per cubic meter of water, the monetary return or the amount of protein or calories? All are important. Rogers stressed that the efficiency of all production inputs, including water, and the overall economic consequences must be assessed, otherwise "you can get silly conclusions."

"Water pricing is a very tough issue around the world."

Rogers closed with a list of six actions that could be used to manage water to meet future food challenges.

1. Water pricing. "Water pricing is a very tough issue around the world. It's tough in the United States. It's tough in every country I've visited," he said. However, some pricing is reasonable and makes people consider the cost of consuming water, using electricity to pump it and employing other inputs.

2. Conserve irrigation water, technical changes. "A 10 percent improvement of efficiency in irrigation applications would give you more water than you would need for all of the domestic and industrial water combined for a country," Rogers said. Improving the efficiency of irrigation and improving crop productivity and water use will reduce the amount of irrigation needed, "and irrigation water is the name of the game, obviously."

3. Invest in water infrastructure, maintenance issues. Improved maintenance of facilities would reduce water losses and non-beneficial evaporation.

4. Adopt ecosanitation. Recycling and reusing wastewater is already occurring in Orange County, Calif., and Singapore, where a reverse-osmosis water factory will start recycling 500 million gallons a day this year.

5. Ship virtual water, rationalize world food trade and exploit desalination.

6. Consider the conclusions of the IWMI Comprehensive Assessment:

- Sufficient land and water resources exist globally to produce food for a growing population over the next 50 years.
- It is probable that today's food production and environmental trends, if continued, will lead to crises in many parts of the world.
- The acute freshwater challenge facing humankind over the coming 50 years will be met only by improving water use in agriculture.

"I think it's a very sensible and a cautionary tale," Rogers said. "This is not going to be easy."

Use of Water for Agriculture in Pakistan: Experiences and Challenges

Simi Sadaf Kamal
Chairperson and Chief Executive
Hisaar Foundation

Simi Sadaf Kamal's 28 years of experience with water, environment and food security issues in Pakistan enable her to provide an in-depth look at the history of water and food production initiatives and institutional and legal frameworks and policies in her native land. As chairperson and chief executive of Hisaar Foundation, which promotes creative low-cost solutions and policies to address food, livelihood and climate change issues in Pakistan, Kamal speaks with authority on the benefits and costs of past initiatives and actions and the challenges involved in managing water to achieve food security.

Simi Sadaf Kamal

"If you look at Pakistan from space, you'll see this green kind of dragon moving down," Simi Sadaf Kamal said, "and that green would not have been possible if we did not have irrigation and irrigation-based agriculture." Ninety-two percent of Pakistan's land area is arid or semi-arid, yet about 25 percent of Pakistan's gross domestic product comes from agriculture. Most of Pakistan's irrigated agriculture is in the Indus Plain, which comprises about 25 percent of the country's total land area. The 85 percent of the cultivated area in the Indus Plain that is irrigated, indicated by the green area on the image from space, produces 90 percent of Pakistan's food and fiber requirements. (See page 41.)

History of water resources development in Pakistan

Kamal spoke about major events that shaped the recent history of water resources development in Pakistan. The early emphasis on technological advances in the 1960s changed to an increased focus on governance based-reforms, indicating changing trends in how Pakistan deals with water-related issues.

The Indus Waters Treaty. The Indus River Basin, which spans India and Pakistan, has often been the subject of disputes between the countries. In the 1960s India and Pakistan signed the Indus Waters Treaty. Although often criticized as unfair to Pakistan, the treaty has enabled water managers to meet and resolve water issues, even when the two countries were at war. The Indus Basin supports the largest contiguous irrigation system in the world. Started when Pakistan was under British rule, the system has expanded over the last 60 years to include three large dams, 16 barrages, check dams to raise the height of water in the canals, 56,000 kilometers of large inter-linked canals and 1.6 million kilometers of other canal systems that provide irrigation water to 36 million acres (14.56 million hectares). Water distribution in India and Pakistan is based on a system of water scheduling that takes into account the variability of supply each season.

The Green Revolution. The Green Revolution in Pakistan during the 1960s and 1970s introduced new high-yielding varieties of wheat, including the MexiPack cultivar, and 80 improved varieties of rice. Mechanization, water resources development and fertilizer and pesticide use also increased. As a result, wheat and rice production doubled and agricultural production as a whole grew at a rate of 6 percent. Western Pakistan became self sufficient in food grains and began to export rice, although eastern Pakistan, which became Bangladesh, still is not self-sufficient. Higher yields increased incomes. The implementation of price supports, favorable terms on trade, subsidies and credits also contributed to increased incomes.

From left: Roy Steiner, Jeff Raikes, Harvey Perlman, James B. Milliken

But the advantages brought by the Green Revolution were not sustained, Kamal said, in part due to the lack of change in other parts of the food production system. The use of inefficient flood irrigation methods continued, food storage capacity did not increase, farmers' ability to market their produce did not improve, agri-based industries did not develop, and the credits and subsidies benefited the landlords more than the landless sharecroppers who actually farmed the land.

In 1991 Pakistan signed the Water Accord, which divides water among Pakistan's provinces. Although India and Pakistan have been able to work together on water issues, within Pakistan much acrimony still exists over water management and allocation. For example, the Water Accord provides for a flow of 10 million acre-feet of water for downstream provinces, but this flow only materializes in flood years.

"The deficit in grain production in relation to population is predicted to reach 12 million tons by the year 2013."

Kamal said only 45 percent of the cultivable land can be under cultivation at any given time because of a lack of water to keep canals running simultaneously. Thirty-eight percent of Pakistan's irrigated lands are waterlogged. Salt accumulation also has grown at an unprecedented pace. Fourteen percent of the croplands, including land in the Indus Valley, have developed high salinity, and salt intrusion into mined aquifers has increased.

From the 1960s until 2000, Salinity Control and Reclamation Projects, which often are cited as a good practice, reclaimed 18.3 million acres (7.40 million hectares), decreased the number of salt-affected areas and controlled waterlogging. In the reclaimed areas the crop yields increased, the socioeconomic status of the farmers' communities improved and the gross value of production on SCARPs-treated land was enhanced substantially.

Groundwater wells and conjunctive use with surface water. Increased use of groundwater wells also has contributed to higher food production. The Indus Basin has almost 55 million acre-feet of fresh groundwater supplies. Although groundwater quality is highly variable, use of wells has grown since the 1960s to more than 600,000 wells. Well use increased in part because the government made electricity available at low or no cost, and groundwater now supplies water for half of all irrigation requirements. "Anybody who wants to can just go and start extracting water from aquifers because the electricity is so cheap, and this has contributed to the water problems in Pakistan," Kamal said.

The conjunctive use of surface water and groundwater has been hailed as a giant step forward in Pakistan, Kamal said, but there are indications of aquifer mining, which may become problematic because long-term use of groundwater may lead to secondary salinization. No one knows the extent of the problem because it's unclear how much salinity irrigated agriculture can tolerate in the long term.

Pakistan from space

Source: The World Bank Report, Pakistan's Water Economy: Running Dry, November 8, 2005, pg vii

Population growth. Pakistan's population of 165 million is growing fast. Rapid population growth coupled with a limited water supply is leading to increased poverty in Pakistan. Ninety-eight million people rely on agriculture for their income; 49 million earn below the poverty line; 54 million do not have access to safe drinking water; 76 million have no sanitation. "This is a very, very big challenge," Kamal said.

Water and food security for Pakistan in the 21st century

Providing sufficient water and food security in the 21st century are Pakistan's major issues. "The deficit in grain production in relation to population is predicted to reach 12 million tons by the year 2013," Kamal said. "That's not very far from now." According to the World Bank, Pakistan is one of world's most water-stressed countries. Irrigation canals work on rotation because there is not enough water to operate them simultaneously, and two-thirds of the water in canals is lost through seepage. The storage capacity of reservoirs is very low; Pakistan can store only a 30-day supply.

"Pakistan is already using 97 percent of its surface water resources and is mining its groundwater to support one of the lowest productivities in the world per unit of water and per unit of land, however you compare it," Kamal said.

Today the river bed of the Indus River downstream from the Kotri barrage, the last big infrastructure on the river before it reaches the sea, is dry 11 months of the year. "I have been there and I have shed tears because the River Indus is about a mile across at that place, and there is not a drop of water," Kamal said. Only one out of the 17 creeks of the Indus Delta is active. The seawater intrusion into the freshwater zone has extended far inland, the tidal zone is very heavily disturbed and the world's sixth-largest mangrove forest is being seriously impacted.

Lack of recognition of the value of water. Yet even under these conditions, people take the value of water for granted. Although there is some recognition that water has value, the common perception does not include an awareness that irrigation water and water for other uses is being provided far below its economic value. "The common perception says that you shouldn't have to pay for water. Water should be free. It is God's gift to mankind," Kamal said. She agreed with Peter Rogers that setting water prices at their full socioeconomic cost must be a top priority. This would be a real challenge for Pakistan, she added.

Lack of maintenance for water infrastructure. The financing of water services in Pakistan is dismal, Kamal said. The general taxpayer pays the interest on the investment made in water infrastructure; no one pays to replace dilapidated infrastructure. The actual users, the farmers, pay only a small fraction of the operation and maintenance costs. In addition, added Kamal, operation and maintenance is poor because the government manages irrigation services and many politicians award service jobs to their supporters. Therefore, the infrastructure is in very poor condition.

When new irrigation canals were built a century ago, they were designed to have parallel drainage canals to remove excess water from irrigated areas. The drainage canals were never built. Years later, a series of drainage projects designed to remove saline water from these irrigated lands were poorly built and increased the seawater intrusion. After an inspection of these projects, the World Bank concluded that poverty had actually increased in the coastal areas.

“A real paradigm shift is required to reframe the whole discourse on water for agriculture.”

Inequitable water distribution. Even in water-rich areas such as Punjab, an upstream province with an adequate water supply, not everyone gets water; and in the downstream province of Sindh, where water supplies are short, not everyone is deprived of water. Both provinces face the same challenge of providing an equitable distribution of water. “But if you pick up a Pakistani newspaper, most of the time the water reporting is about dams and about water sharing between the two provinces of Punjab and Sindh,” Kamal said. “Some of us are involved in very heavy advocacy to get people to think about water in different ways, to look at water more holistically and to grow out of only political discussions in terms of water sharing amongst the two bigger provinces.”

In Pakistan land ownership is a proxy for water rights; the amount of land someone owns determines how much water he or she gets. Landless people, including farmers who are responsible for managing irrigation water, have no water rights. Because few women own agricultural lands, they have very little voice in how water is distributed. Therefore, the benefits of irrigation infrastructure and rehabilitation have directly enriched the landowners. Land values have increased about 30 percent in the past decade, and these landowners are likely to continue receiving the lion’s share of the benefits of low water charges and infrastructure improvement, Kamal said.

Pakistan water policy. It is the landowners, with little incentive to adopt water conservation methods, who are sitting in parliament, Kamal said. This has resulted in a lack of a comprehensive set of water laws that define water rights and uses. The principles of water pricing are absent and the basis on which subsidies are given is unclear. Pakistan does not have policies to promote water conservation or assess polluter penalties.

Pakistan is attempting to develop a water policy, but the policy has had successive drafts from 2000 to 2006, and with each draft, the conservation policies have decreased. Other policy efforts include a Pakistan water resources strategy produced by the Ministry of Water and Power; a vision document by the powerful Water and Power Development Authority; a water strategy produced by the ministry; and a medium-term development framework that addresses water but has never been finalized because the two biggest provinces, Punjab and Sindh, cannot agree.

Provincial Irrigation and Drainage Authorities. In recent years, Pakistan has moved toward reform-based good practices. The irrigation drainage sector reform, supported by the World Bank, is still followed in parts of the irrigated areas in Punjab and Sindh. Reforms have combined irrigation and drainage functions into single Provincial Irrigation and Drainage Authorities (PIDA) supported by the Water Management Ordinances passed in 2002.

The PIDAs are supposed to operate and maintain the main canals, branch canals and drainage systems, and manage the flood protection infrastructure within the command areas. These authorities will eventually take over the rehabilitation and maintenance of 10 canal command areas. While this is encouraging, Kamal cautioned that operating and maintaining the barrages and outlets assigned to each PIDA is a big job. Under the PIDA are Area Water Boards, which divide the irrigation system into manageable chunks. Each Area Water Board has a number of Farmers Organizations and Water Course Associations – an effort to make management of the water system more transparent.

Rawal Dam, Pakistan

The PIDA is supposed to promote Farmers Organizations, which are the linchpin in this system. These organizations operate and maintain the irrigation system associated with their canal and are responsible for ensuring equitable and judicious distribution of water, including water for small and tail-end farmers, and non-agricultural and domestic water users. The Farmers Organizations also are supposed to guarantee a minimum drinking water supply and provide flood protection.

Kamal pointed out that the ordinance governing these organizations defines a farmer as someone who owns land. The farmers who actually work the land, handle the water and grow the crops usually do not own the land. They are not very committed to the system because they're left out.

Can Pakistan meet its water and food production challenges? Kamal says yes. "We can meet some of these challenges but not through business as usual. Not through what we have in place. A real paradigm shift is required to reframe the whole discourse on water for agriculture."

Kamal believes Pakistan must address the fundamental issues of land and water rights. Land reform is critical. Developing land holdings of more or less the same size and establishing a society that is more socially and economically homogeneous would increase productivity and equity and reduce poverty. There has been tremendous progress in areas of Pakistan dominated by medium-sized farms. This rapid rate of progress is partly because the farmers in the Farmers Organization are peers, providing a balance of power that is not possible in Farmers Organizations in which most of the farmers are landless. Kamal recognizes that achieving more inclusive land reform will be very difficult.

Kamal also sees the need to shift from focusing on the provincial distribution of water for agriculture, as in the Sindh-Punjab debate, to developing a comprehensive, better-managed water use program in irrigated and rainfed areas for all of Pakistan. There are large rainfed areas in Baluchistan and in the North-West Frontier Province, Kamal said, but they don't get needed support for agricultural development because this is the area where many of the so-called terrorist activities are happening.

Managing water demand. "We feel that there needs to be more of a focus on managing water demand. We have to stop people from asking for more and more water when there is no more water in the system to be mobilized," Kamal said. She explained that the argument for more irrigation infrastructure is based on an uncritical capitulation to the demand for more irrigation water for agriculture even though there is no more water in the system. Agriculture already absorbs 97 percent of the total mobilized surface water and almost all of the groundwater used in the country. "We need to unpack this demand and then go on a very strong advocacy trip to make people understand that we don't need to have more water to improve agriculture production, that better management is where we need to go," Kamal said.

> *"There needs to be more of a focus on managing water demand. We have to stop people from asking for more and more water when there is no more water in the system to be mobilized."*

Kamal listed the key steps for moving Pakistan forward.

- Divide the Indus Basin into agro-climatic zones and develop long-term water strategies and crop combinations for each zone.
- Improve agricultural practices and technologies to produce more crop per drop.
- Where feasible, rehabilitate and better maintain existing irrigation infrastructure.
- Improve micro-irrigation techniques. The Hisaar Foundation believes women are key to improving water management at the micro level and has developed the idea of establishing a women's water network. An existing program trains people, especially women and children in urban and rural areas, to grow crops on rooftops to achieve food security for their families, and then links them to a microcredit source after three to eight years. The program was so successful that about 25 percent of the women were already linked into microcredit after the first training.
- Aggressively promote water conservation.
- Rehabilitate the freshwater-seawater interface on coasts.
- Adapt to climate change.

"Now, these steps may seem to be hard, but they're really not that hard. It is a matter of changing mindsets," Kamal said. "If we can be strategic, if we can be innovative, then we can move forward."

Water Science and Research Issues Associated with the Future of Water for Food

Richard G. Allen
Professor of Water Resources Engineering
University of Idaho

Richard Allen's research focuses on evapotranspiration, irrigation water requirements and hydrologic systems. Allen was the lead author of the United Nations Food and Agriculture Organization publication "Crop Evapotranspiration," which serves as an international practice standard. He also was co-editor of the American Society of Civil Engineers Practice Manual 70, "Evapotranspiration and Irrigation Water Requirements." Allen has been a consultant to the United Nations, the World Meteorological Organization, the United States Agency for International Development and the governments of Portugal, Spain and Australia, with missions to India, Pakistan, Jordan, Yemen, Morocco, Egypt, South Africa and Turkey. He is a member of the NASA/U.S. Geological Survey Landsat Science Team.

Rick Allen

Richard Allen introduced his talk with this primary question: *How can we manage the spatial and temporal distribution and redistribution of water to enhance food production?* Better tools are the answer, Allen said.

Microsupplies versus macrosupplies

Allen made a distinction between developing countries and developed countries. In developing countries, research should concentrate primarily on the microsupply systems, such as micro drip and mini sprinklers and the widely successful treadle pump. The treadle pump is an inexpensive way to bring water supplies to farmers who can only afford a $20 to $100 investment. The pump only works with a shallow groundwater system, but this rarely is a problem, especially in areas (such as parts of India) where the pumps address waterlogging problems.

The treadle pump was developed by International Development Enterprises and has been supported by the Food and Agriculture Organization, World Bank and the Gates Foundation. These organizations are focusing on getting microsupply systems to farmers in the villages by creating local business systems to produce the equipment, avoiding the significant bureaucratic obstacles found in many countries. The greatest impact of these systems is that they move farmers from subsistence farming to reliably growing a high-value cash crop, putting money in their hands for educating their children, Allen said.

Macrosupplies, such as large reservoirs, must be considered in both developed and developing countries. Allen cited George Hargraves, a Utah State University researcher, who 10 years ago pointed out that while reservoirs have some large environmental problems, they also provide a major benefit by concentrating farming in river valleys. Concentrating the food production in a country like Brazil might actually reduce slash-and-burn agriculture, which is highly erosive and has other adverse ecological impacts. Allen concurred, stating that the environmental impacts of reservoirs must be weighed against the impacts of existing production systems. "You've got to kind of pick your poison in a way," Allen said. "If we're going to produce the food, if we're going to enable countries to be self-sufficient with food, sometimes the less toxic poison might be some surface reservoirs and more concentration of irrigation."

Allen added that groundwater aquifers must be better utilized. Unlike surface water reservoirs, aquifers have significantly less evaporation loss and don't inundate land. Supplementing supplies with water from groundwater reservoirs could be a major tool to help meet the challenges of climate change, including the kind of "gorilla" droughts described by James Goeke.

Improving food productivity per unit of water consumed

Allen questioned whether gains in biomass per kilogram of water consumed are hitting a natural plateau, especially when factoring in transpiration and evaporation. He cited a recent publication by Zwart and Bastiaanssen stating that over the last 25 years, the amount of biomass produced per unit of water consumed has not increased. Allen emphasized this is the amount of water consumed by plant transpiration, not the amount of water pumped to irrigate the plant. He firmly believes that genetic combinations exist that will make crops more productive, but production increases will be more difficult to achieve than in the 1970s and 1980s. Improving the harvest index will increase yields, Allen said, but he cautioned that some ecologists believe that big increases in the harvest index have passed. His conclusion: Improving management of water to increase food production will be one of the big issues in the next decade.

Nebraska Sand Hills lake

Reducing non-beneficial consumptive use of water

One efficient way to increase food production per unit of water consumed in developing countries is to increase transpiration and decrease evaporation losses, Allen said. He described a conversation with Eugene Glock, a Nebraska farmer, about no-till and minimum tillage practices actually reducing non-beneficial evaporation of water during both the off season and the growing season, making more water available for crop use.

"Can we just genetically and mechanically try to get full ground cover more quickly with our crops so that we get more transpiration and less evaporation?" Allen asked. He referred to a study in Idaho by Jim Wright of the U.S. Department of Agriculture, who measured the ratio of evaporation to precipitation during winter and found it to be quite high. Allen suggested that if this process can be inverted so that winter precipitation gets stored in the root zone instead of evaporating, this water could be used for transpiration in the growing season. It might be possible to harvest 50 to 100 millimeters of water per year and convert it to transpiration and increased food production. "That might be some of the more easy water to find," Allen said.

Manage water consumption, not irrigation efficiency

Allen also argued for better accounting of water, particularly in managing water consumption. He cited a paper by Frank Ward in the *Proceedings of the National Academy of Sciences* describing an effort to get more water into the Rio Grande River by subsidizing farmers to convert to more efficient irrigation systems, leaving more water in the river for downstream uses. But rather than conserving water, the efficient systems distributed water more evenly across the field, increasing transpiration and crop production. "Now, that's a good thing for crop production, and the crop went up, but the bottom line was that there's less water in the Rio Grande River downstream, which was part of the reason for this whole subsidy," Allen said.

It is important to define clear objectives for water management solutions, Allen said. If the objective is to simply increase crop productivity or relieve waterlogging problems, increasing water use efficiency is a good idea. But if the objective is to conserve water so it's available for new uses, increasing efficiency may be detrimental. In Allen's view, USDA Natural Resource Conservation Service programs that provide funds to farmers to use higher efficiency irrigation systems actually increase, not decrease, water consumption. He suggests these programs should be renamed as evapotranspiration sustaining programs.

Adopting a holistic basin approach

Allen also emphasized the importance of examining the big picture and adopting a more holistic, basin-based approach to water accounting. It is important to appreciate the close connection between surface water and groundwater and recognize that groundwater lies underneath 99 percent of the earth's terrain. In many cases, water "lost" in the field to deep percolation through the soil zone is not really lost because it recharges the groundwater. This groundwater then becomes available for another use. Water accounting also should recognize the reuse of water. Allen quoted Lyman Willerson of Utah State University, who said if people want to know how much they can increase a basin's total water consumption, go to where that water reaches the ocean. The water flowing into the ocean is the only excess water in the system.

Treadle pump

Allen believes the need for a more holistic approach to water accounting is becoming more apparent, citing the Web sites http://wateraccounting.com and http://winrockwater.org, which includes a forum to discuss water accounting, increasing water productivity and the need to adopt a river basin perspective.

The Idaho Legislature also is taking a more holistic approach to managing the Upper Snake River Basin aquifer to address conflicts over water use in the basin. The Snake River Plain aquifer holds as much water as Lake Erie and is a dynamic system with a close coupling between surface water and groundwater. Most of the water in the aquifer is from snow melt in the Teton Mountains and Yellowstone National Park area that is diverted from the Snake River into leaky canals that provide water to recharge the aquifer. In the first half of the 20th century, water levels in the aquifer increased because of inefficient irrigation systems. The higher water levels in the aquifer then increased discharge into the river.

"Improving management of water to increase food production will be one of the big issues in the next decade."

The spring discharge in the Thousand Springs, Idaho, area, which produces 80 percent of the trout found in American restaurants, relies on this spring discharge, which varies annually based largely on the amount of recharge from surface water irrigation. When irrigation from groundwater wells began around 1950, those irrigators depended on seepage and deep percolation from the canals for their groundwater supply. But as the number of wells increased, water in the aquifer and the Snake River decreased. According to Allen, because groundwater pumping is decreasing the water in the springs that supply the surface water users and aquaculture, there are several lawsuits between surface water users and groundwater users. One objective of the Legislature's plan is to maintain recharge to the aquifer by allowing seepage from canals to continue where it will benefit a groundwater or spring user.

Work with fractions, not efficiencies

To make water accounting more transparent and better understand how to make more water available for new uses, Allen advocates working with fractions instead of efficiencies. For example, describing an irrigation system as 40 percent efficient implies that 60 percent of the water diverted is wasted. In contrast, if considering the ratio of evapotranspiration to diversions (the amount of water consumed by evapotranspiration divided by the amount of water diverted), it's apparent that 40 percent of the water diverted was consumed and lost to the system, while 60 percent of the water was returned to the system for reuse and no water was wasted.

Quantifying water supplies and uses

Allen also believes scientists must better quantify the available water supply and the amount of water consumption through improved groundwater surveys, water balance studies and models, and quantifying evapotranspiration by various water uses. Allen described two processes that use Landsat satellite images to quantify evapotranspiration. The Surface Energy Balance Algorithm for Land (SEBAL), developed about 15 years ago by Bastiaanssen and Holland, is now used throughout the world. The Mapping Evapotranspiration at High Resolution with Internalized Calibration (METRIC) model, developed by Allen in collaboration with University of Nebraska–Lincoln researchers Ayse Irmak, Gary Hergert and Gary Stone, is a similar process used in the U.S.

SEBAL and METRIC use Landsat satellite images to take a snapshot of how much evapotranspiration occurs in an area at a given time. These images can be overlaid on maps of water rights to provide valuable information for lawsuits, mitigation efforts and water transfers. Allen has used aggregated METRIC evapotranspiration data to determine the performance ratio for a canal in the southwest part of the Snake River Plain aquifer. The performance ratio showed that the canal company was evaporating 40 to 50 percent of the water it diverted. That means that 50 to 60 percent of diversions return to the river as surface water returns or recharge the groundwater aquifer. Allen said he couldn't resist bragging about the Idaho Department of Water Resources, which is one of the 16 finalists out of a thousand applications for the Harvard University's American Government Awards this year for its use of METRIC for water rights and groundwater management programs.

Allen also described a study by Bastiaanssen using SEBAL to make a map that shows in millimeters the annual water consumption of rice in an area of Iran. Using estimates of the biomass of the harvestable rice, Bastiaanssen was able to develop a water productivity curve map. This information enables managers to determine where they should focus their efforts to decrease the non-beneficial consumption of water and make more water available for new uses.

Allen concluded this type of water measurement will be very important in adapting to the impacts of climate change on water supplies, which will include higher evapotranspiration, longer growing seasons, less snow and earlier snow melt, which affects reservoir supplies for irrigation.

America's Water Crisis and What to Do About It

Robert Glennon
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University of Arizona

Robert Glennon's expertise is in water law and policy. He serves as a water policy adviser to Pima County, Ariz., to the American Rivers' Science and Technical Advisory Committee and as a commentator and analyst on television and radio. He is the author of "Water Follies: Groundwater Pumping and the Fate of American Fresh Water" published in 2002, and "Unquenchable: America's Water Crisis and What To Do About It," published in 2009.

"We Americans are spoiled. Turn on the tap and out comes a limitless supply of high-quality water for less money than we pay for cell phone service or for cable television. We think of water as though it were like air, infinite and inexhaustible, when, in fact, water is very finite and very exhaustible. The United States is now facing a water crisis," Robert Glennon said.

"How can water be exhausted when water cannot be created or destroyed?" he asked. His answer: Some uses preclude the use of water by future generations. Every time a toilet is flushed in Los Angeles, as much as six gallons of water ends up in the Pacific Ocean. That water is not destroyed, but it is no longer where it's needed, when it's needed and in the form it's needed.

Robert Glennon

Components of the U.S. water crisis. A major component of the water crisis is that (in some areas), the demand for water is completely out of proportion with the supply. The city of Las Vegas personifies this situation. CityCenter is one of Las Vegas' latest developments. Costing $9.1 billion, it is the largest privately financed construction project in American history and includes six or seven towers from 37 to 61 stories tall.

The problem is that Las Vegas is running out of water. Patricia Mulroy, director of the Las Vegas Water Authority, has to scramble for water. To get water for the city she has offered to build a desalination plant on the Pacific Ocean for the cities of Tijuana, Mexico, and San Diego in exchange for some of their share of Colorado River water, which Las Vegas could access through Lake Mead. A $3 billion, 150- to 200-mile pipeline also will be built in central Nevada to pump groundwater and move it south to Las Vegas. Mulroy also is paying people in Las Vegas as much as $2 dollars per square foot to remove their lawns and has aired public service announcements encouraging water conservation. How can she justify the expense of these projects? Las Vegas' strip is the economic driver of the entire state but only consumes 3 percent of the total water used in the state. Agriculture is responsible for 80 percent of the water used in Nevada but produces only 6,000 jobs, the same number of jobs as an average-sized Las Vegas casino. Glennon said for Mulroy, it is a simple matter of dollars and cents.

Water shortages. Other places also face water shortages. Since 2007 farmers in Colorado have had their wells turned off in deference to senior appropriators. The small community of Orme, Tenn., ran out of water and had to truck in water. Scripps Institution scientists predict Lake Mead, the water supply for Phoenix, Las Vegas and Los Angeles, may go dry by 2021. A small paper company in South Carolina closed its doors, laying off several hundred workers because there was not enough water in the river to discharge the plant's waste flows. The Nuclear Regulatory Commission has denied two permits for power plants in Georgia, and three other states have denied permits for coal-fired power plants because there was not enough water to run them. The largest of the Great Lakes is too low to float fully-loaded cargo ships. The commercial fishing season off the coast of the Pacific states has been cancelled for two years in a row. In Riverside County, Calif., a score of commercial and residential projects were cancelled because of a shortage of water to support them. About two years ago, the city of Atlanta came within 90 days of having its principal water supply, Lake Lanier, dry up. These crises were not caused by concerns about endangered species or other environmental values. "It's about economics. Water lubricates the American economy just as oil does," Glennon said.

> *"We Americans are spoiled. Turn on the tap and out comes a limitless supply of high-quality water for less money than we pay for cell phone service or for cable television."*

Response to water shortages. "Ben Franklin said that 'when the well's dry, we will know the worth of water.' But he was wrong because we are running out, and we're paying no attention to it," Glennon said. How did Atlanta respond to the drought? The city imposed some modest water restrictions and conservation requirements – no water for swimming pools, car washing or watering the lawn. The governor called for a prayer vigil on the Capitol steps. The state legislature passed a resolution proclaiming that the border set in 1818 between Georgia and Tennessee was erroneously located and should be moved one mile to the north, allowing Georgia access to the water in the Tennessee River. What Georgia has not done is restrict new uses of water. Anyone in Georgia is free to make a diversion from a river or to drill a well, if no more than 100,000 gallons of water per day will be pumped.

The problem is not drought but population growth. Scientists tell us there is nothing special about the recent droughts in Georgia or California. The elephant in the room is population growth. California has 4.9 million more residents than during the drought of the late 1980s and the early 1990s. The U.S. population has grown to more than 300 million and is predicted to be 420 million by mid-century. Where will the water come from to serve this population?

Ethanol demand on water. Other demands for water also are increasing. According to Glennon, even a modern ethanol plant that recycles water requires four or more gallons of water to refine one gallon of ethanol. A modest-sized plant producing 50 million gallons of ethanol annually needs 200 million gallons of water. To grow enough corn to refine one gallon of ethanol may take an additional 1,700 to 2,500 gallons of water, Glennon said. Yet the California Legislature still decided the state should produce a billion gallons of ethanol a year by 2022. Meeting that goal would require every drop of water that now passes through the San Joaquin Sacramento Delta and provides water to 7 million acres of the nation's most productive farmland and water for southern California cities. While it takes a lot of water to produce energy, it also takes a lot of energy to move, treat, transport and pump water. In California, 19 percent of all energy use is for the movement and treatment of water. There is a very close connection between water and energy use.

Technology requires water. Another rather surprising increase in the demand for water, Glennon said, comes from high tech industries. One and a half percent of all the electricity in the U.S. is now used for the servers powering the Internet, and that figure is expected to double within the next 18 months. Water often is used to dissipate the heat generated by electricity use. An example is Google's giant server farm, a windowless concrete building that houses thousands of linked computers, all generating heat and cooled by water.

> *"The burden of development is being put on those who want to place new demands on the resource. This is a new way of thinking about our water supply."*

Engineering solutions are no longer viable. In the U.S., engineering solutions are the common answers to water shortages: divert more water from rivers, build more dams and drill more groundwater wells. But according to Glennon, those options are no longer viable, with very few exceptions. The consequences of groundwater pumping can be dramatic, causing land subsidence and rivers to run dry. Glennon described an area in his home state of Massachusetts that gets more rain than Seattle, yet the Ipswich River has been completely dry for the last five of eight years due to groundwater pumping.

Desalination is an option, according to Glennon, but not for low-value purposes. Desalination is expensive, consumes a lot of energy, and the brine removed from the water must be disposed of safely. Reusing municipal effluent is another possibility. In Tucson, Ariz., recycled water is used on golf courses, highway medians, turf facilities and cemeteries. Water conservation and water harvesting also show promise.

The American toilet. Glennon said his pet peeve is the use of the American toilet to dispose of human waste. In the American system, water comes out of the treatment plant and is sent to homes for drinking, cooking, landscaping and flushing the toilet. Only 10 percent is used for drinking and cooking, but Americans spend $50 billion a year treating all water to a drinking water standard. One-third of all indoor use of this water is for toilets. He stressed the need to consider alternatives such as waterless composing toilets.

Valuing water as a commodity

Glennon said making use of price signals and market forces to drive water reallocation is a tool that should be used in the U.S., but hasn't. "We don't pay anything for water. I mean that literally. What we're paying for is the cost of the service," he said. As an example, Glennon described the reaction of irrigators in Nebraska in 2003 when the Nebraska Public Power District decided to increase the rates it charges farmers to $3 per acre-foot. There was a storm of protest. Three dollars an acre-foot is equivalent to paying one penny for 1,080 gallons of water. That is how little we value water, Glennon said.

How can we use market signals to reallocate water? Before using market signals to reallocate water, society first needs to recognize humans' right to water, Glennon said. Sandra Postel and Peter Glick have estimated that people use between seven to 15 gallons per person each day. For the 300 million people in the U.S., this is 1 percent of the total water used in the country. That amount should be taken off the table and reserved for domestic uses. For the remaining water consumption, Glennon advocated promoting water conservation by establishing increasing block rates that are seasonably adjusted.

Glennon provided the example of a steel plant built by the U.S. government during World War II as another way to assess the value of water. According to Glennon, the government sold the plant to Geneva Steel after the war. By the end of the 20th century, Geneva needed to liquidate its assets and sold the land, which was prime developable land just outside of Provo, Utah, for $46 million. The plant itself was sold to a Chinese company for $40 million and the iron ore mine for $10 million. Because Geneva was no longer producing steel and polluting the air, the company had pollution reduction emission credits that sold for another $4 million. The total revenue from these sales was $101 million. Then Geneva sold the water rights. The water rights were worth more than the other assets combined.

"How did these water rights become so valuable?" Glennon asked. It happened because Jerry Olds, Utah's state engineer, said the state would not issue permits for groundwater wells for subdivisions unless developers have sufficient water rights to support the project. Olds is not halting development; he is saying that development must pay its own way. The burden of development is being put on those who want to place new demands on the resource. This is a new way of thinking about our water supply, Glennon said. Allowing unlimited numbers of permits epitomizes the tragedy of the commons because it incentivizes everyone to use as much of the resource as quickly as they can before someone else does, he said. In Utah, that cycle is being broken.

Dry irrigation canal

Water transfers. Glennon described a study of water transfers in the western U.S. that he and two economists had recently completed. According to the study, water transfers are not going from industry to industry, but are going from farm to non-farm uses. Because 80 percent of water use is by agriculture, most water transfers come from agriculture. Remarkably, although 31 million acre-feet of water have been transferred out of agriculture, agricultural income has been constant. The absence of decrease in farm income, according to Glennon, is because farmers are savvy business people. Faced with an opportunity to make money by selling water rights, they will make adjustments to maintain production. They may use sprinklers rather than flood irrigation systems; they may take the 40 acres with clay soil and low productivity out of production; or they may change their crop mix.

An example is lettuce farming in Arizona, Glennon said. It takes about 20 workers most of a day to harvest a field of iceberg lettuce with traditional methods. In Yuma, Ariz., a farmer decided to grow baby lettuce. The baby lettuce is harvested with a vehicle comparable to a giant electric razor. When the truck is finished harvesting, the farmer drives a tractor down the field and applies some fertilizer. There is no need for pesticides because the plants are so close together. The roots are already there and the crop comes back and the cycle is repeated. Farmers are finding value-added ways to make as much or more money with less water.

To encourage reallocation of water, Glennon said, people cannot have limitless access to a finite resource. Government must consider using price signals and market forces to encourage the reallocation of water, he said.

"In the end I am optimistic because this is a crisis, not a catastrophe," Glennon said. "We have options to avoid a catastrophe, but we need both the understanding that there is a crisis out there and the will and the moral courage to act upon it."

3 How Do We Grow More Food with Less Water?

Science and Technology Panel

Panelists
Ramesh Kanwar, *Charles F. Curtiss Distinguished Professor and Chair, Agricultural and Biosystems Engineering, Iowa State University*
Brian A. Larkins, *Porterfield Professor of Plant Sciences, University of Arizona; John F. Davidson, Ph.D., and Marian J. Fuller, Ph.D., Chair in Life Sciences, University of Nebraska–Lincoln*
Judith C.N. Lungu, *Dean, School of Agricultural Sciences, University of Zambia*
Vincent Vadez, *Principal Scientist, Head of Crop Physiology Laboratory, International Crops Research Institute for the Semi-Arid Tropics*
Ron Yoder, *Department Head, Biological Systems Engineering, and Associate Director, Agricultural Research Division and Extension, University of Nebraska–Lincoln*

Moderator
Sheri Fritz, *Willa Cather Professor of Geosciences and School of Biological Sciences, University of Nebraska–Lincoln*

The panel explored key issues and challenges in the science and technology of water management to ensure an adequate food supply for the world. Panelists brought many years of experience and perspectives from different areas of expertise. The panelists gave brief overviews of their subject areas and then responded to questions from the audience.

Brian A. Larkins: Drought Tolerant Crops

Brian Larkins is a plant physiologist whose research focuses on regulating seed development in cereal crops and the synthesis of seed storage proteins. Seed storage proteins are the principal determinants of grains protein quality. Larkins' remarks focused on two topics: creating more drought tolerant crops to sustain food production when water is limited, and improving the nutritional value of maize and sorghum to maintain nutritional values if crop yields decrease.

Plant mechanisms for dealing with drought. A drought tolerant crop, Larkins explained, is one with traits that make the plant more *tolerant* to water loss. Wheat, barley and rye *escape* drought by maturing before the summer droughts arrive. Other plants increase their tolerance to drought by producing high concentrations of amino acids or alcohol sugars, which enable cells to retain water. Plants also produce groups of proteins called dehydrins that stabilize the cytoplasm so it is not damaged by water loss. They also create heat shock proteins, key players in the stress response in plants. *Avoidance mechanisms*, such as the leaf rolling exhibited by corn and sorghum during dry periods, are perhaps the most important plant mechanisms to deal with drought. Avoidance mechanisms often involve the cuticle on the leaf; the presence or absence of hairs on the leaf; the length of time the leaf stomata stays open, allowing water to escape by transpiration; and the type of photosynthesis the plant uses.

Current focus of crop research. Don Dubick of Pioneer Hybrids did an experiment in which he took the highest-yielding hybrids Pioneer had produced over a 50-year period and planted them one foot apart. The yield for each hybrid was the same. However, when he planted the hybrids three inches apart, the newest hybrids outperformed the older hybrids. That result, Larkins said, indicates that plant breeders thought they'd been breeding for increased yields but instead produced plants with an increased tolerance for drought stress caused by crowding.

Much of this research is focused on corn. Corn is worth about $5 billion per year in the U.S. and $13 billion per year worldwide, and drought can cause a 40 to 50 percent reduction in corn yield resulting in major economic impacts. Seed and agricultural biotechnology companies also are focusing on approaches to increasing yield that go beyond traditional plant breeding techniques. They are actively trying to identify key genes and regulatory pathways that activate drought tolerance. In order to do map-based cloning, researchers have completed a very fine mapping of the corn genome to determine what genes and molecular factors have changed as a result of breeding programs. To date, research has shown differences in the expression of hundreds of genes in response to drought conditions, which illustrates the complexity of the genetic regulation of drought response.

However, yield increases have been achieved in corn by using a transgenic approach – taking a single regulatory gene that controls a number of processes that make the plant more drought-tolerant from one species and putting it in another. Researchers also have encoded a protein that increases the plant's protein synthesis capacity. In both of these examples, a change in a single gene increased yields 10 to 15 percent. These experiments indicate that improving drought tolerance does not need to be complex; engineering only a few specific genes can make great improvements. Pioneer Hybrids and Monsanto expect that within the next five years they will release new genetically engineered corn hybrids that increase yields under drought conditions by 15 to 20 percent.

Brian Larkins (foreground) and Sheri Fritz

Another approach Larkins described is engineering drought tolerant crops, such as sorghum and millet, to produce grain with the protein quality and other beneficial properties of corn. Although their flowers are quite different, corn and sorghum are sister crops with a number of similar characteristics. Over many years, CIMMYT, the International Maize and Wheat Improvement Center, has developed a quality-protein maize, which is a high lysine corn that solves the problems present in corn. Pioneer Hybrids is conducting the same type of research on sorghum, with funding from the Bill & Melinda Gates Foundation. "I will simply tell you that it's now possible to produce sorghum that is also high in protein quality and digestibility," Larkins said.

Larkins also expressed excitement about research being conducted by Bruce Hamaker of Purdue University. Hamaker is a food scientist who has been working on finding ways to use corn and sorghum flour to make bread. Bread dough made with wheat flour is viscoelastic so at room temperate it rises as the yeast ferments, producing a typical loaf. Corn flour is not viscoelastic at room temperature. However, adding 1 percent wheat glutenin, or corn starch and corn protein plus 1 percent milk protein, to the corn flour causes the loaves to rise at room temperature and look like bread. This process has great potential for people who suffer from celiac disease, an allergy to wheat proteins, and for places like Sub-Saharan Africa, where the cost of importing wheat is almost prohibitive, but sorghum is a common crop. "In theory you could accomplish the same thing with genetic engineering by putting in a gene that would add protein to the flour," Larkins said. These are the kinds of advances that can be made by engineering a single gene.

Judith C.N. Lungu: Food and Water Challenges in Africa

Judith C.N. Lungu, an animal physiologist, has specialized in livestock development at the University of Zambia for more than 20 years. She also has worked extensively with the rural farming communities of Zambia and serves on the boards of directors of Women for Change, the Zambian National Bank and the Livestock Development Trust. In her role as dean of the School of Agricultural Sciences at the University of Zambia, she is a leader in the development, coordination and implementation of programs to foster sustainable land and water management.

Lungu's presentation focused on the food and water challenges in Africa. The weather in Africa, Lungu explained, varies a great deal, with the north and south being quite cool. Rainfall distribution also varies greatly from place to place and season to season. The average precipitation in Zambia varies from 700 millimeters to 1,200 millimeters per year. Rainfall also is unreliable. Droughts and floods, which are increasing, affect more than 135 million people each year.

Judith C.N. Lungu

Agriculture and plentiful water, but little irrigation. Although agriculture contributes only 17 to 30 percent of Africa's gross domestic product and about 18 percent of Zambia's gross domestic product, the majority of the population of Sub-Saharan Africa depends on agriculture for its livelihood. This agriculture has very low productivity, less than 1 metric ton per hectare, so at least 60 percent of the growers, the majority of whom are women, are subsistence farmers. "They depend on rainfed agriculture, and in Zambia it comes in four months and the rest of the year it's dry, so some people in the rural areas … are the poorest of the poor. They are in extreme poverty," Lungu said.

The challenge for Africa is how to manage the available resources at local, national and inter-country levels when the precipitation is not dependable and there is little irrigation because the infrastructure is undeveloped. Lungu observed that some of the largest dams in the world, including the Kariba Dam in Zambia and Zimbabwe, and the Aswan Dams, are in Africa. It is said that one-third of the water in southern Africa is found in Zambia, yet only 5 percent of the cultivated land is under irrigation. Although Zambia sits on top of a large aquifer, only 12 percent of the farmers who irrigate rely on groundwater. Unlike some areas of Africa, where the problem is water scarcity, Zambia's problem is lack of infrastructure to use the water. Among those who irrigate are some large-scale farmers with center pivots, many of which were brought from Nebraska. However, most farmers use ditch irrigation. Some small farmers use treadle pumps, which women and children can operate. Close to one hectare of land can be irrigated with a treadle pump.

Adding to the problem is that the population is growing quickly in dryland farming areas, where agricultural productivity is very low. Because of the low productivity in Sub-Saharan Africa, 2.9 million people per year suffer hunger-related deaths.

Africa has a crisis, Lungu said. The water is there, but it's not being utilized. In Zambia more than 500,000 hectares could be irrigated and highly productive. Currently, only about 50,000 hectares are irrigated, and most are planted with perennial crops like sugar cane and coffee, which are not key food staples. Zambia and the rest of Sub-Saharan Africa has a great need for enhanced water use technologies to improve food security.

Environmental problems hinder food production. Other challenges to improving food production in Zambia are unrelated to water. They include soil degradation, decline in the quality of vegetation, and loss of wildlife and biodiversity. People in Zambia traditionally have relied on burning to clear land and cutting to obtain fire wood. These practices degrade the soil.

Addressing Sub-Saharan Africa's issues. Lungu outlined a number of steps needed to address the issues in Sub-Saharan Africa. Researchers need to understand the characteristics of the African climate; inventory water resources; invest in the development of surface and groundwater; and improve the water storage, water harvesting and water production efficiency for both rainfed and irrigated agriculture. Africa needs to provide affordable drinking water supplies so towns do not have to go without water for a week. Stakeholder information systems and participation also must improve so people can make good decisions.

Lungu described a number of programs that the country of Zambia and the University of Zambia are administering to improve food productivity. Zambia has been leading the effort to adopt conservation farming, in which microbasins are dug using a hand hoe and seeds are placed so they get water when it collects in the basins. These microbasins double or triple corn yields. The university is involved in breeding and mutagenesis efforts to produce stress tolerant crops and corn and sweet sorghum for biofuels and legumes. The university also is doing research on irrigating with river water polluted by mines. In general Zambia's water is extremely polluted, so controls need to be developed to prevent industrial and agriculture pollution.

At a continental level, Lungu continued, Africa is trying to promote regional integration. African countries have developed the New Partnership for Development, which includes the Comprehensive Agriculture Development Program. One of the key pillars of this effort is to develop a framework for sustainable land and water management. The University of Zambia is the lead institution for this pillar. The Country Round Table also was established to diagnose problems and design programs to address them.

"You (developed nations) have exploited your water. You have utilized it for development, but Africa has not developed, and we are hungry," Lungu said. "There are a lot of problems and people are living on less than a dollar a day, and yet the water is there." Zambia needs to exploit the water available to provide food security and reduce poverty but also avoid the mistakes developed nations have made, she said.

Ramesh Kanwar: The Role of Science and Technology in Water for Food

Ramesh Kanwar, an agricultural and biosystems engineer, has applied his expertise in sustainable irrigation and drainage systems, natural resources and water quality engineering extensively around the world as a consultant for the Food and Agriculture Organization of the United Nations, the World Bank, NATO and other international organizations.

Ramesh Kanwar

Kanwar began by stating how impressed he was to see University of Nebraska President James B. Milliken, Chancellor Harvey Perlman, several vice chancellors, other administrators and faculty in the audience throughout the forum. "I have been in academe for 32 years, and I have never seen a president and chancellor sitting all morning in the same session. It shows your commitment; it shows you are very serious."

Can we double food production? Kanwar launched his talk with the forecasts that indicate by the year 2030 humans must produce 50 percent more food to feed the world's population. By 2050, humans must produce 100 percent more food. The big question for Nebraska remains: By 2050, can Nebraska produce twice the amount of food it produces today with half as much water? Assuming the amount of water used for agriculture stays the same as today, Nebraska's productivity per drop of water consumed will have to double. To achieve that goal, scientists will have to develop more efficient plants that use less water and recycle nutrients more effectively, and develop better irrigation systems. This is where science and technology must play a major role, he said.

Water availability and quality. Food production has multiplied many times in areas where intensive agriculture has been developed. As a result, in countries such as India, groundwater tables have dropped 800 feet in the past 30 years. Water tables also are declining in Nebraska. "Are we going to develop the landscape so the land can absorb more water and, by increasing water infiltration, start recharging our depleted groundwater systems?" Kanwar asked. He believes increasing recharge would address some of the ecological issues the planet faces.

Kanwar also addressed the need to address water quality issues. Daily actions affect water quality. If this isn't addressed soon, by 2050 more people will die because of poor water quality than lack of food.

Global warming. Another major challenge is global warming. Some forecasts predict that all glaciers will melt away in the next 30 to 50 years. If that holds true, the rivers fed by these glaciers also will disappear. Sea water could rise 20 to 30 feet, forcing the 2 billion people whose livelihoods depend on rivers such as the Ganges in India, the Hingol in Pakistan, the Yellow in China, and similar river basins in south China and central and southeast Asia to flee. With these tremendous landscape changes, the people living along these rivers would not be able to support themselves.

Integrated training at universities. Kanwar ended by arguing that universities must change curricula to fit the water science and water engineering needs of the future. Courses in water policy, water marketing or water law must be offered to engineers and scientists so they can become an integral part of the dialogue. For these reasons, Kanwar said, he hopes the proposed Global Water for Food Institute will provide a knowledge base for global water issues and become a leading voice for the U.S.

Vincent Vadez: Increasing Rainfed Agricultural Production

Vincent Vadez is a crop physiologist at the International Crop Research Institute for the Semi-arid Tropics. His specialty is the impact of abiotic stresses such as drought and salinity on plants.

ICRISAT is one of the 15 centers of the Consultative Group on International Agricultural Research, which works to improve crops and commodities in the developing world. ICRISAT approaches the issue of water limitation with an Integrated Genetic and Natural Resource Management paradigm, looking at the optimum combination of genetics and management to maximize the return in grains or dollars from a limited amount of water. "We don't just look at the crop itself, but in partnership with other CGIAR centers, we look at the entire crop-livestock system," Vadez said.

ICRISAT's mission is to improve the livelihood of people living in the semi-arid tropics, where many people live on far less than one or two dollars a day. The mandate of ICRISAT is to improve five dryland crops that are well adapted to limited water conditions: sorghum, pearl millet, great northern beans, chickpeas and black-eyed peas.

Vincent Vadez

Blue water and green water. ICRISAT works with blue water, which is water from streams and groundwater used for irrigation, and green water, the water in the soil profile. With regard to blue water, ICRISAT has an active community watershed program to maximize water capture and to improve the small proportion (only 35 to 45 percent) of rainwater eventually used by crops. ICRISAT promotes water harvesting technologies and the use of percolation tanks to promote groundwater recharge. ICRISAT also collaborates with institutions that specialize in groundwater resources by advising on water-efficient crop rotations and finding the best crop options to optimize the use of groundwater resources.

"What ICRISAT can bring in a water institute is a more global dimension where we need to look very carefully at green water," Vadez said. Eighty percent of crop production worldwide is rainfed – it depends on green water. ICRISAT provides advice on the most preferable crop rotations, such as promoting dryland crops like sorghum and pearl millet, which are well adapted to water-limited conditions, as opposed to water-intensive crops such as rice, which continues to be favored.

ICRISAT also works on magnifying the recharge of the soil profile, reducing the volume of water evaporated from the soil and increasing the volume of water in the soil that crops can access. Among the techniques promoted by ICRISAT are land form treatments such as broad bed furrow, landscape management using half-moons, and in-situ soil conservation through no-till and crop residue mulching.

Ron Yoder

ICRISAT's major work is drought avoidance. One program uses biotechnology to identify and harness superior rooting traits to capture water. ICRISAT has a large facility that allows precise in-vivo assessment of root-related traits and the development of new approaches to assessing the capacity of plants to exploit the water in the soil profile. It also tests transgenics and has large germplasm collections with a wealth of variations that can be exploited for genetic improvement. ICRISAT has combined these approaches to find crops that are better able to capture moisture from the soil profile and produce more yields per unit of water consumed. Vadez said he agreed with Richard Allen's comment that researchers shouldn't be talking about water efficiency but about increasing the amount of crop produced per unit of water consumed.

Because soil fertility also affects yield, ICRISAT is working on optimizing soil fertility using micro-dosing techniques, seed priming and seed pelleting, which allow the delivery of an affordable amount of nutrient to the seedling. Vadez emphasized a key issue is ensuring that farmers have access to affordable fertilizers.

The real issue is resilience. Resilience – learning how to produce food while accounting for crop failures – is the real issue, Vadez said. In other words, a certain amount of yield potential is sacrificed to ensure there is some yield every year.

In summary, Vadez said promoting dryland farming is one way to increase productivity. Eighty percent of the world's food production is grown under rainfed conditions. To produce enough food to match the growth in population by 2050, researchers will need to increase the productivity of dryland farming.

Ron Yoder: Business as Usual is No Longer Enough

Ron Yoder has worked in agricultural water management for more than 30 years and has extensive international research experience, including stints in Brazil, Zambia and China.

Yoder began his presentation by reiterating Simi Sadaf Kamal's statement: "If we want to get to where we need to be – producing more food with less water – we cannot continue with business as usual."

Yoder noted that technology has advanced significantly to squeeze the last bit of benefit out of a unit of water. However, in most cases the technology is not being used because (1) the knowledge transfer does not reach those people who need it most; (2) the cost of technology is not aligned with what the end users can afford; and (3) as Richard Allen pointed out, many don't understand the baseline hydrology and water budgets. When examining the amount of production per unit of water used, whether a scientist considers just the plant, field, irrigation district, watershed, river basin or continent makes a difference, Yoder said.

Science and technology panel discussion

Science and technology provide many answers for making better use of scarce water resources, Yoder said, but to realize their true value, solutions must be integrated with sociological, policy and educational issues. If any one of these three factors is left out, it is not possible to maximize the benefit of each unit of water.

Questions and Answers

Moderator Sheri Fritz: *Given all the challenges, what do you see as the key scientific and technological issues that need to be addressed, and which of these issues do you think the Global Water for Food Institute at the University of Nebraska would be, if not uniquely equipped to address, at least in a good position to address?*

Vincent Vadez emphasized the need to focus on green water and on dryland or rainfed farming because there is no other option in many parts of the world. Ron Yoder said to maximize water usage, researchers need real-time decision support systems that provide inexpensive real-time information and data to help them make decisions. Ramesh Kanwar described a project he is working on in India that is providing a wireless technology network so farmers in villages can access accurate weather forecasting so they don't over-irrigate and waste water. Judith C.N. Lungu thought the institute should encourage research on the impacts of stress factors on crops to spur development of new crop varieties that optimize the use of available water and better meet the challenges of increased drought. Brian Larkins reiterated that the institute needs to bring together all information about agricultural and municipal issues, and new crop improvement technologies that is scattered across many organizations. A single, easily accessible Web site that contains all water-related information would be a major contribution, he said.

Fritz: *Can you identify any technology gaps, areas where we do not have the information we need to make progress on producing more food with less water?*

Kanwar said he believes there is still much room for improving irrigation systems. When he has visitors from other countries who want to learn about irrigation, he always brings them to Nebraska. He added that scientists should continue developing new varieties of crops that are more drought tolerant and require less water, fewer nutrients and less soil concentration. Corn doesn't have to be six to eight feet tall, he said.

Vadez emphasized the importance of developing genetic labeling, the need for more testing of new varieties to understand the impacts of using these plants, and the importance of being honest with the public. More research on dryland crops is needed, he said, and experts should encourage the use of existing drought-adapted dryland crops.

Yoder said it would be useful to know at the beginning of the season how much water will be available for crops and when to irrigate to maximize the benefit from the water available.

Larkins said the potential for learning how plants deal with drought has never been better. Researchers have learned more about the physiology of plants in the last 10 years than in the previous hundred years. The tools are there and interest in this area is great, he said. However, he cautioned, a major challenge for the U.S. is the shortage of plant breeders. It is difficult to find students who are not only knowledgeable in basic plant breeding techniques but also have enough understanding of molecular genetics and genetic markers to integrate these skills in a breeding program, Larkins said.

Mark Gustafson, Coordinator of Rural Economic Development, University of Nebraska Rural Initiative: *Given all the issues that need to be addressed, both social and technological, should the institute focus on culture, laws and policies, or would it be better to form partnerships with people who already have capacity to do those things?*

“Resilience – learning how to produce food while accounting for crop failures – is the real issue.”

Judith C.N. Lungu said a global institute must engage the Third World countries and bring them to a higher level of food production so citizens can feed themselves. “Instead of choosing only those countries that already have the capacity to partner with you, I believe you need to partner with developing countries, allow developing countries to have input into the direction you adopt so they can benefit from your efforts,” she said.

Kanwar had a different viewpoint. If Nebraska is making the investment, he said, the institute must think globally but act locally to solve the problems that the state of Nebraska faces. The question of what new knowledge needs to be created must be decided within the university system. However, a global perspective also is key because the U.S. is no longer the only leader in this field. The Global Water for Food Institute could provide a new level of leadership by creating partnerships with industry and foundations that can fund its work. The core mission of educational institutions like the University of Nebraska also includes training the future workforce. Hopefully, there will be endowed fellowships to train people to help the countries that cannot provide such training themselves, he said.

Prem Paul, Vice Chancellor for Research and Economic Development, University of Nebraska–Lincoln: *We understand this is one of our biggest challenges, but if we look at the investments we’re making in research, they are not sufficient. My understanding is that there is more dialogue in Washington, D.C., to invest more resources. The National Science Foundation has made this one of the major topics as its funding increases. The question is, from a science perspective, what is missing? What are the major gaps in science that need to be addressed through research?*

Vadez answered that the integration of knowledge from different disciplines is lacking. He believes the question of whether to focus on Nebraska issues or global issues is not relevant as long as the institute links the pieces together in a partnership mode, bridges the gaps between disciplines and harnesses the wider framework of genetic and natural resource management to deal with drought situations. The pieces are there; it is a matter of tying them together, he said.

In contrast, Larkins said researchers know very little about how crop drought tolerance works. It is a very complex trait that varies from one plant to the next. "Maize and sorghum are very closely related, and you would think we had some idea of why sorghum is drought tolerant and maize is not, but we don't," Larkins said. He added there also is a limit to how far breeders can push these crops to make them drought tolerant. Cactus plants in Arizona are wonderfully adapted to grow with hardly any water at all. The problem is they don't grow very fast, so people would starve if they had to eat only cactus. "Considering the time frame we have to solve this problem, which is the next 20 years, and considering how long it takes to develop a new crop variety, especially if it's a transgenic variety, which is going to require six or seven years of testing before we can make it available, we're really behind the eight-ball," Larkins said. Improving the food value of existing drought resistant crops, such as sorghum, so they could become primary food sources would be ideal, but there is much to learn about how to do this.

From left: Ramesh Kanwar, Judith C.N. Lungu, Brian Larkins, Vincent Vadez, Ron Yoder

Kanwar responded that identifying the knowledge gaps is key, which vary greatly depending on local factors such as the cost of energy and water, water policies and subsidies. However, Kanwar continued, the overall focus should remain on solving bigger societal issues. Food scarcity is going to be a challenge by 2050. Some populations will not have enough to eat; others will have plenty. How will societies share? The population is not going to double by 2050, but food production will. Why? The simple reason is that in countries with rapidly growing economies like China, which now consumes only 20 to 30 percent of the amount of food Americans consume, people want the same quality and amount of food available in the U.S. This is a major contributor to the imbalance of food among countries.

In closing, Fritz said that some fundamental scientific knowledge gaps need to be addressed in an integrated fashion. To date, this integration of knowledge across multiple disciplines has been missing. Finally, the institute needs to look at the big picture and decide which global issues and challenges Nebraska has the expertise and talent to address. Efforts should focus on these areas.

4 The Cost of Water

Policy and Human Dimensions Panel

Panelists
Marc Andreini, *Senior Researcher, International Water Management Institute*
Sandra L. Postel, *Director, Global Water Policy Project*
Otto Szolosi, *Irrigation Consultant and Former Lecturer, Charles Sturt University, Australia*
A. Dan Tarlock, *Distinguished Professor of Law, Chicago-Kent College of Law*
Sandra Zellmer, *Professor, University of Nebraska College of Law*

Moderator
John Owens, *Harlan Vice Chancellor for the Institute of Agriculture and Natural Resources, University of Nebraska–Lincoln, and Vice President for Agriculture and Natural Resources, University of Nebraska*

The panel discussion focused on the effects of water and agricultural policies on freshwater supplies, food production and security, the environment and the socioeconomic well-being of people at global, regional and local scales. Among the panelists were two lawyers, a civil engineer and an agricultural engineer, all of whom brought extensive experience in the field of global water management. The panelists gave brief overviews of their subject areas and then responded to questions from the audience.

Marc Andreini: The Biophysical Environment, Infrastructure and the Process of Policy Reform

Marc Andreini is a civil engineer and senior researcher at the International Water Management Institute with extensive experience in management and water supply projects in California and many African countries, including Ghana, Zimbabwe, Morocco, Tanzania and Botswana.

"Africa is a very heterogeneous place and it has enormous potential," Andreini said. "So what are we going to do? Water is clearly central, and Africans should make good use of the water that they have. We need to make science-based decisions." He highlighted three areas of focus: the biophysical environment, particularly the meteorology and hydrology of Africa; the infrastructure choices to be made; and the process of institutional and policy reform.

Biophysical environment. Although the colonial regimes did some environmental monitoring, these efforts mostly have a sketchy past, so the infrastructure to collect meteorological and hydrological data needs to be re-established. Africa needs an established monitoring network and groundwater research. To date, the information on groundwater in Africa is unreliable, fragmented and only available in certain European archives. In parallel, assessments using remote sensing techniques and geographic information systems also need to be established to understand current developments. Models to answer water allocation questions must be developed at international, national, regional and local scales. Andreini emphasized that to address conflicts, it is important to establish policies that provide equitable access to water at the local level.

Infrastructure: Water storage facilities. The lack of water storage facilities in Africa is critical. The U.S. has 6,000 cubic meters of storage per capita; South Africa has 750; and Ethiopia has only seven. Climate change is making the rainfall season shorter and the onset of the rainy season more erratic, further increasing the need for storage. Although dams are controversial, Andreini believes there is increasing interest in building medium and large dams. If Africa does this, it must be careful to develop well-designed projects that avoid the mistakes of the past. Andreini also advocated for increasing small reservoirs managed as a common property resource at a community scale. Finally, Andreini said, the sustainable and equitable use of groundwater reservoirs needs to be actively explored.

Marc Andreini

Institutional and policy reform. "We need input from the social scientists. We need to know how the institutions and economic reforms that are to be made can be as meaningful as possible," Andreini said. Greater regional integration must enable producers and sellers to buy and sell from one another across regions, provide greater access to markets and allow producers to buy inputs, such as pumping technology, fertilizer and seeds. This effort also involves making smart choices about transportation infrastructure, such as where to build roads.

Sandra L. Postel: A New Mindset for the Agricultural Water Economy

Sandra Postel is director of the Global Water Policy project, dedicated to the preservation and sustainable use of Earth's freshwater ecosystems. Postel is a respected scholar and author on science and policy related to water and the environment, including the books "Pillar of Sand: Can the Irrigation Miracle Last?" and "Last Oasis: Facing Water Scarcity," which appears in eight different languages and was the basis of a 1997 PBS documentary.

Postel said as she listened to the previous speakers, she was reminded of Albert Einstein saying a problem can't be solved with the same mindset that created the problem. "We really are talking about a new mindset if we're thinking about water and food and the whole nexus of water and poverty and environment and energy and agriculture that's come up time and again," Postel said. She then identified five themes to guide the discussion on developing a Global Water for Food Institute.

Sustainability of irrigated agriculture. Eighteen percent of the total acreage of arable land and tree crops on the world's continents is irrigated and produces 40 percent of the world's food. However, perhaps as much as half of this irrigation is not sustainable, Postel said. Groundwater is being over-pumped, rivers are running dry and soils are becoming salinized. Experts estimate that as much as 10 percent of the current food supply depends on groundwater, and in India, this number may be as high as 20 to 25 percent. Postel said it seems fairly certain that China, India and Pakistan – countries that were self-sufficient until recently – soon may need to import grain. Pakistan alone may need as much as 12 billion tons of grain by 2013. This will significantly impact the international grain trade and international food prices. Some of those changes will be positive for farmers, but they will burden the hungry people in Sub-Saharan Africa. Policymakers need to understand and prepare to deal with these impacts. The sustainability of irrigated agriculture has related technological, social, economic and policy components that must be considered. "We've heard that technologies can be developed, but if they're not going to be adopted, they're not going to do any good, so I think embedding these together is critically important if we take on that challenge," Postel said.

From left: Dan Tarlock, Sandra Postel, Marc Andreini

Climate change. "If we're going to be talking about food production and sustainability 20, 30, 40 years out, we've got to start getting our heads … wrapped around the magnitude of these changes," Postel said. Two billion people in south Asia depend on rivers fed by glaciers that are shrinking, and those water supplies will largely be gone within our planning period. At the same time, mountain snow packs are diminishing and changing river flow patterns, already evident in California. There will be more flooding in the spring and more dry spells that increase the competition for water during the summer when water is needed for crops.

Protecting ecosystem services. Postel discussed the need to value and protect ecosystem services. Agriculture, she said, happens in a landscape that provides important, intrinsic ecological goods and services. These ecosystem services consist of moving nutrients and sediments downstream to deltas, restoring productivity to flood plains, maintaining biodiversity and improving fish production. Though not largely valued in the marketplace, these measures are extremely valuable, particularly, but not exclusively, to subsistence dwellers in developing countries. According to Postel, a significant policy trend is underway to protect ecosystem health and ecosystem services. She said South Africa blazed this trail with its 1998 water act, which established the progressive concept of a water reserve. It has two components: the basic human needs reserve, which provides essential water for drinking, food preparation and personal hygiene, and the ecological reserve, which protects aquatic ecosystems. The European Union now has a water directive requiring all rivers to achieve at least a good status by 2015, and the recent Great Lakes contract in the U.S. basically prohibits big diversions from the lakes. These are concrete ways in which this concept of protecting ecosystem health and ecosystem services is being adopted. Water use, water allocation and water management must be integrated with this new goal of preserving ecosystem health and ecosystem services, Postel said.

"Water use, water allocation and water management must be integrated with this new goal of preserving ecosystem health and ecosystem services."

Developing and using appropriate technologies. "All of these things suggest to me we need to be moving toward a fairly tangible goal of at least doubling water productivity in agriculture over the next 15, 20 years, and I say that 'doubling' in a fairly broad sense," Postel said. That includes not just more crop per drop but also more nutritional value per drop. Designing technology that is affordable and accessible to the poorest farmers is key. One example is the treadle pump, a $35 investment that returns a hundred dollars in the first season for poor farmers living on a dollar or two a day. This technology has tremendous potential to lift large numbers of people out of poverty. Expansion of drip irrigation is another way to move toward this goal. Drip irrigation could be used with most crops, but only 1 percent of the world's irrigated land is under drip.

Changing diets and increased food demand. Postel spoke about the need to consider the increased water demands caused by the world's changing dietary demands. In China, 300 million people have moved into the middle class and are adopting diets more like those in the U.S., a trend that will increase. "Beginning to deal in a conscious way with the water footprint of our diets is going to be an important feature of achieving some kind of sustainability in water and food production," Postel said.

Sandra Zellmer: A New Era in Water Law

Sandra Zellmer's expertise is in water law, environmental law and ethics, and natural resources law. She recently served on the National Academy of Sciences National Research Council Committee on Missouri River Recovery, examining the impact of flood control measures and habitat restoration efforts from the river's headwaters to the Gulf of Mexico.

Sandra Zellmer

Zellmer quoted poet Thomas Hornsby Ferrell: "Here's a land where life is written in water," saying those words are as true today as when they were written in 1940, following the Dust Bowl years in the Great Plains. She also quoted Mark Twain, who said, "Hunger is the handmaid of genius." Likewise, Zellmer added, thirst is the handmaid, or perhaps the mother, of invention and innovation in water management. People have figured out how to store water behind massive dams, move water over hundreds of miles and over the Rocky Mountains, to purify and reuse polluted waters and even reverse the flow of some waters. Yet states continue to fight over who gets the water, how much they get and how it should be used. "This tells us – and this is what Ron Yoder and others have noted today – that we've done pretty darn well on the technology side of water management. … But I have to say we've done relatively poorly on the institutional side, governance, law and policy," Zellmer said.

How natural resources are allocated. Essentially, Zellmer explained, there are four basic ways to allocate natural resources:

- Eligibility criteria, such as geographic location on the headwaters of the stream, or preferences for various types of use, like domestic use;
- First come, first served, the rule of capture – the first one to use the water in an economically productive way develops a legally recognized right to the water;
- A more random access approach, such as government-sponsored lotteries, like those used to allocate sulfur dioxide emissions and other emissions credits; and
- Economic tools such as auctions and cap-and-trade.

Some basic concepts of water law. In the 19th century in arid areas of the western U.S., people developed the concept that someone can use water on non-riparian lands away from the stream. This was a departure from the rules used to manage water in many other areas of the world. Another concept adopted in the West is the law of prior appropriation: first in time, first in right. As long as the use is beneficial and non-wasteful, senior users can take their full allocation of water even if more economically viable or environmentally valuable junior users have to go without. This system provides certainty, which protects investments and reasonable expectations. Seniority is important because in most of the West, and certainly in Nebraska, agricultural users hold the most senior water rights.

In contrast, when water bodies cross state or international boundaries, water allocation is governed by the principle of equitable apportionment, reflecting the two bedrock principles of modern international environmental law. The first is that no nation has the right to use its territory in a manner that causes injury to the territory of another. The second is that trans-boundary waters should be shared equitably among riparians, so each may enjoy a fair share. In international law the determination of fair share is guided by factors including the natural physical factors; the geographic, hydrological, climatic and ecological features; the social and economic needs; the effects of water use by one nation or state on another; and the conservation and protection of the water resources.

"The fundamental goal to ensure everyone has access to a clean, reliable water supply to satisfy fundamental human needs, including the need for food, has not changed."

Sustainable development. Equitable apportionment, in turn, is becoming an important part of sustainable development. Using the definition from the United Nations Agenda 21, Zellmer said sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Zellmer described three fundamental concepts from Agenda 21 relating to water: (1) providing adequate water supplies; (2) maintaining the ecological services that provide goods and services for human communities and ecological communities; and (3) recognizing capacity limits, or carrying capacity.

Points of distinctions and convergence. Zellmer also described how the myriad systems of water law throughout the world reflect deep distinctions as well as points of convergence. The convergence points are greater reliance on science and integrated management, such as the conjunctive management of surface and groundwater resources, and drawing on the physical and social sciences to learn how to most efficiently and equitably engage in conjunctive management. Another point of convergence is a greater reliance on expert administrative agencies, such as the U.S. Environmental Protection Agency or, in Nebraska, the state Department of Natural Resources. This means less reliance on courts, the judiciary or legislatures because of the recognition that people with technological expertise are needed to resolve some of these scientifically driven questions.

One distinction is a conflict and continuing tension in international water laws between centralizing policies at the higher levels of government and a movement for greater grassroots initiatives and local watershed governance with transparency, accountability and implementation of legal principles. Zellmer said there also is a struggle between privatization and the use of market-based tools to allocate water resources and the vision of water as a common heritage, a public trust resource or even a human right.

A new era in water law. Water law in the U.S. and throughout the world is on the brink of a new era, Zellmer said. Growing populations, growing energy demands and climate change will put increased pressures on water resources. The fundamental goal to ensure everyone has access to a clean, reliable water supply to satisfy fundamental human needs, including the need for food, has not changed. But as Agenda 21 recognizes, new stresses will make innovative, collaborative and integrated approaches to water management all the more imperative. "You might say, make whiskey, not war, or more drinking, less fighting," Zellmer said.

A. Dan Tarlock: From Dams to Integrated Water Management

Dan Tarlock's interests focus on aquatic ecosystem conservation, water transfers, climate change and drought management. He has served on several National Research Council/ National Academy of Sciences committees studying the protection and recovery of stressed aquatic ecosystems.

Tarlock expressed his enthusiasm for the University of Nebraska establishing a Global Water for Food Institute, saying that although the U.S. has accumulated great expertise in water over the last two decades, it hasn't been as aggressive as it should be, or as many northern European nations have been, in applying this knowledge overseas.

Dan Tarlock

The question of large dams. Tarlock focused on the evolving international law of water use and management as it relates to dams. As a young lawyer in the 1960s, Tarlock thought his career would be guided by two bedrock assumptions. First, the construction of large multiple purpose dam projects would continue; and second, irrigated agriculture in the U.S. would continue to expand. The environmental movement ended the big dam era, and today there is almost no expansion of irrigated agriculture in the U.S.. Globally, the appropriateness of the large dams and irrigation systems is often debated, although philosophies are generally more lenient in developing countries.

Integrated water resources management. Traditionally, Tarlock said, international water law had one primary objective: to support the construction of big dams. It did so because the law was so incoherent it encouraged unilateral action. Over time the international community has tried to develop a system to constrain unilateral dam construction and to encourage more cooperative, integrated river management to balance a wider range of uses. Tarlock presented two examples of emerging river regimes where integrated water resources management and a richer management system have been taken seriously.

The Okavango River in southwest Africa has the classic conflicts. The river arises in Angola, but its development potential is unrealized because of the civil war and the Portuguese colonial legacy. The river flows through the top of Namibia, which is largely a desert except for the greener north. There is pressure to bring Okavango River water down into the drier center of Namibia. Downstream from Namibia in Botswana, the river forms the Okavango Delta, which supports a variety of ecosystem services and a well-funded, premier world wildlife area. Finally, the Okavango flows into a swamp in the Kalahari Desert known as the Okavango alluvial fan. The three countries along the Okavango River have developed a cooperative management institution that focuses on collecting data to understand the river. The institution is a work in progress, but, in Tarlock's view, has put the brakes on unilateral development; any development along the river must balance the interests of the three countries.

The Komati River arises in South Africa, flows through Swaziland and empties into the sea in Mozambique. Although the river has a very erratic flow, with periods of drought and high floods, it supports agriculture in all three countries. Sub-catchment flow targets have been established, but the consensus is that if irrigated agriculture is going to expand, or even be maintained, the countries must find a way to maintain the flow regime.

Two major problems will have to be addressed. The bottom line, Tarlock said, is that any effort to promote increased irrigation or even greater water use will face two problems. First, the new legal constraints, if only because the Dutch, Germans, Swedes, Danes and the British, who fund many of these efforts in developing nations, are going to require integrated water management. New laws will have to be adopted. "And, of course, there is going to be a whole host of new uncertainties. Global climate change is only one, so what you're going to have to see is a greater flexibility in management institutions," Tarlock said. Water resources development is going to be a lot smarter, and the scale of development will be smaller, partly driven by the new legal environment.

Otto Szolosi: Australian Water Issues and Policies

Otto Szolosi is a water management, irrigation, drainage and erosion control consultant who has participated in large-scale water reuse, wastewater and irrigation projects.

"Coming from Australia, I can assure you that water is a limited resource and that the whole country across the six states is facing major challenges in assuring a sustainable water supply," Szolosi said. "Seeing the water levels dropping in our storages … is scary, really scary."

Otto Szolosi

No water to waste. Today and in the future, Szolosi said, the combination of climate change and a growing world demand for water means there simply isn't any water to waste. The water in storage for Melbourne, a city with 3.8 million residents, is at 27.6 percent of storage capacity. All the major cities in Australia are under water restrictions. New houses must have three pipes, for fresh water, domestic waste and reuse of the shower and laundry water. In 2002, the average water usage was around 330 liters per person per day. Today the target is 155 liters per person per day, and in April Melbourne achieved 135 gallons per person per day. Most households also have a four-minute shower timer. The more water a household uses, the more it pays.

Many speakers have described a variety of technologies that will allow increased crop production with less water, but the implementation of these tools and the management of water resources, including the legal and the institutional issues, require much more attention around the world, Szolosi said. Ten years ago, Australians didn't comprehend the extent of the country's water shortage; many said it was a water management issue and an institutional and legal problem. With the continuing drought due to climate change, most Australians now agree that the water shortage is one of the country's biggest challenges.

Australia's water issues. Szolosi cited the following water issues:

- Over-allocation by state and territorial governments wastes water.
- Water is used by the private sector, but water administration is predominantly in public hands.
- The need for adaptive management of a highly variable resource contrasts with the need for entitlement security for those invested in production.
- There is disparity of water management practices and the emerging competition between the urban and rural sectors.
- The need for skill in planning for catchment water management conflicts with centralized policy setting regulations.
- The country has problems with water supply and aging infrastructure systems.
- The government limits current water allocations.

Australia's Water for the Future Initiative. In 2004, in response to the above issues, the Australian government launched the Water for the Future Initiative, a 10-year, $12.9 billion plan that provided national leadership in water reform to secure supplies for Australian households, businesses and farmers, and to allocate water to restore the health of Australia's stressed river systems. The initiative has four priorities: taking action on climate change, using water wisely, securing water supplies and supporting healthy rivers. Its programs have accelerated on the ground actions in these areas.

> *"Water trading ... is creating open and competitive markets where water use is managed rather than administrated by governments."*

Policymakers have had to acknowledge the impracticability of continuing to supply water at a low cost and the urgent need to address policy issues in water resource management. The country has begun to focus on water resource management through legislative and institutional change, attempting to allocate water in a more economically efficient and socially and environmentally acceptable manner.

Water trading, a major achievement of the initiative, is creating open and competitive markets where water use is managed rather than administrated by governments. It is yielding significant economic and efficiency benefits. The price of a temporary water right ranges from $200 to $1,200 per megaliter (1,000 cubic meters). When water trading began, the price was between $60 and $150 per megaliter; in the 2008 irrigation season, the average price for a temporary water permit was $1,066 per megaliter, and permanent water permits were trading at $976 per megaliter.

What has this initiative achieved after nearly five years? According to Szolosi, Australia has an increased focus on adaptively managing water resources for economic and environmental purposes, securing water access entitlements for users, expanding water markets and introducing more effective prices and policies. Australia's users across the board are improving their practices.

Will the changes meet the reform objectives? An expanded market that facilitates permanent and temporary trade in water entitlements, annual allocations and an improved delivery capacity represents great opportunities for irrigators to diversify, streamline and strengthen their businesses in the future. Water markets based on voluntary exchange have allowed buyers to reduce the impact of drought on farms either by selling their water to earn income during times of low allocations or to increase the water they can use for irrigation. Changes to water balances over time will result from changes in land use, climate, demography, and industry and water policies.

From left: Otto Szolosi, John Owens, Dan Tarlock, Sandra Zellmer, Sandra Postel, Marc Andreini

Governments have a responsibility to ensure that water is allocated to achieve socially and economically beneficial outcomes in an environmentally sustainable manner. Policy alone will not resolve Australia's water problems. Major spending is required to expand the infrastructure to improve water management.

The water shortage has caused even Australia's farmers to find new solutions and adapt. Their key management strategies include reducing the total area irrigated, reducing water application rates, implementing irrigation scheduling, substituting crops that use less water and planting cover crops. Water trading, increased groundwater pumping and water recycling also are effective tools.

"Past experience and ongoing projects prove that, yes, we can and we must make better use of our water resources," Szolosi said. "We just have to open up, put our heads together, and make sure that all the information across the countries will get into one basket like this Global Water for Food Institute and use this resource in the right way."

Questions and Answers

Vicky Weisz, Research Professor, UNL Center for Children, Families and the Law: *What are some strategies to speed up getting the appropriate institutions in place to address the problems described, and how might the prospective institute provide an understanding of how we can reduce the lag time between seeing a problem and getting the necessary institutions in place to address it?*

Sandra Postel answered that change comes from evolution in leadership and from grassroots pressure. How this happens depends on the local culture, geographic location and government system. She described how South Africa's change in the political regime, including naming a human rights lawyer as the head of the cabinet that governed water and forestry, brought a sense of ethics and human rights into water law that otherwise might not have happened. There are many examples of citizens mobilizing for change, she said, describing a case in Massachusetts where there was renewed interest in building a diversion dam to supply water to Boston. A mobilized group of residents forced people to think about conservation as a serious alternative. As a result, the state implemented incentives for a conservation strategy and did not build a dam.

Dan Tarlock had a shorter answer: Development takes money. Money is needed to fund the institutions, especially in the developing world. Tarlock also stated that an organization like the Global Water for Food Institute could provide cross-training to help water professionals established in one discipline become more fluent in other areas.

> *Change comes from evolution in leadership and from grassroots pressure.*

Mohamed Bazza, senior water resources officer for the Food and Agricultural Organization of the United Nations, said experience has taught him that the dimensions of policies, institutions and legal issues are more important than the scientific and technical aspects in addressing the world's food and water issues. The institute's approach to changing the culture on water and promoting the right policies and governance is crucial to addressing the issues that are being discussed. The recently released Third World Water Development report confirmed its previous conclusion and the conclusion of other reports, including the International Water Management Institute's, that people should not be alarmed that the world will not have enough water for food production in 2050. The crucial problem is how to use the water, which is what the new institute should concentrate on, Bazza said.

Sandra Zellmer pointed out that discussion is needed about education and how to prepare students to develop water management solutions to sustain and better use the water supply. She described the University of Nebraska's new Integrated Graduate Education and Research Training (IGERT) program funded by the National Science Foundation, which focuses on issues related to resiliency and sustainability in watershed management. The program brings students together in interdisciplinary teams to break down disciplinary divides.

Postel said there are examples of effective policies that can achieve the level of food productivity needed in the future. In her opinion, the solution involves a combination of subsidies dealing with pricing and rate structures and preservation of ecosystems, which effectively boosts water productivity. These things work in tandem and as individual efforts but haven't been mobilized on a large scale. It is clear that water policies need a complete reform, Postel said.

Conference Summary

Prem S. Paul
Vice Chancellor for Research and Economic Development
University of Nebraska–Lincoln

Prem Paul, vice chancellor for research and economic development at the University of Nebraska–Lincoln, began his conference summary by expressing his gratitude to the many experts who had come from around the nation and the world to participate in the dialogue and provide insights on how to provide sufficient water and food for the world's growing population. He also thanked Robert Meaney from the Robert B. Daugherty Foundation and the University of Nebraska Foundation for supporting the Future of Water for Food conference.

The day's discussions illustrated that a significant water crisis is looming, Paul said. Jeff Raikes made a strong case that agriculture is a key to reducing hunger and poverty, especially for the people that live on a dollar a day in south Asia and Sub-Saharan Africa. The conference discussions also made it evident that a global institute focusing on water for agriculture is needed. "The question is how do we manage our water resources and continue to support a vibrant agricultural economy?" asked Paul.

> *"The question is how do we manage our water resources and continue to support a vibrant agricultural economy?"*

Paul also provided comments from Gene Whitney, research manager of the energy section of the Library of Congress' Congressional Research Service. Whitney could not attend the conference but graciously provided the conference planning committee with his thoughts on forming a Global Water for Food Institute. He listed three factors that need to be kept in mind in planning for the institute: the scientific context, the institutional context and the informational context. Whitney said a framework and focus areas should be developed based on available expertise, and that it is important to "know what we don't know." Climate change must be considered because it is the 800-pound gorilla in the room. However, Whitney cautioned against becoming a climate-change institute; the focus must remain on water.

Paul closed with a summary of key points from the conference speakers and discussions.

- Agriculture is the key to reducing hunger and poverty for the billion people that live on a dollar a day in south Asia and Sub-Saharan Africa.
- The institute must be global in scope with a focus on producing more food per unit of water.
- There is a critical need for better science and technology, and there must be a balance between basic and applied research. "We cannot have enough science," Paul said.
- We need integrated water management approaches. Addressing these problems requires multiple disciplines – engineers, scientists, humanists and business people – for an effective, informed solution.
- We need water for food and energy, but we must balance those with the need to maintain functional ecosystems that are resilient and adaptable to change.
- The institute should identify the key research needs and carefully determine what initiatives should be pursued. Needs identified during the conference include:
  - Data and models to inform decision-making;

- – Better conjunctive management of surface water and ground water and of blue water and green water;
- – New biotechnologies and seed technologies to improve crop productivity;
- – Improvement in irrigation technology;
- – More low-cost, low-tech irrigation approaches, like the treadle pump; and
- – Improved information-gathering technologies, such as satellite monitoring of water use.

Prem Paul

- We need to assemble the vast amount of information generated worldwide and avoid duplicating efforts.
- People throughout the world need access to this knowledge. "There is information right now on the shelf that could be used to help our friends in other parts of the world," Paul said. Scientific information must be accessible to decision-makers to inform policy.
- It is important to identify and develop relationships and partnerships worldwide with agricultural and water experts. We need to have a global exchange of expertise, bringing scientists, scholars and students to Nebraska to participate in the institute and sending institute faculty and students abroad. "Yes, we're great in Nebraska, but we can learn from others," Paul said.
- Alluding to his childhood in India and his understanding of the conflict between India and Pakistan, Paul said the institute can learn from the agreement between the two countries over how to manage fights over the allocation of water.
- Water management needs diverse approaches, such as price signals and water markets, in dealing with allocation issues.
- Drought is an age-old, recurring problem, but global warming may change the drought scenarios that need to be considered.
- Women are the key to making progress in many regions, but they often don't have access to decision-makers or the tools to make an impact. This must be addressed.
- There is not enough investment in water research. As a global community we must raise awareness of the need for additional investment in water science, policy and education.

5 Envisioning
the Global Water for Food Institute

Envisioning the Global Water for Food Institute

A core group of 65 experts attended a half-day working group session following the conference. The group included scientists and decision-makers representing U.S. and international universities, industries, and government and nongovernmental organizations, and University of Nebraska administrators and faculty from a wide range of disciplines whose work focuses on water and food issues. Each working group included participants with diverse backgrounds – hydrologists, biologists, engineers, computer scientists, political scientists, lawyers, agronomists, economists, geoscientists, policymakers, university administrators, directors of NGOs and foundations, farmers and industry executives.

Group 1

The working groups all were given the same charge: A Global Water for Food Institute to be established at the University of Nebraska will be a research institute committed to helping the world efficiently use its limited freshwater resources to ensure the food supply for present and future generations. *Describe your vision for this institute.* Define the core components/priorities of the institute's mission, the metrics for success, the organizational structure and key partnering organizations.

Key recommendations from the working groups

- The area of water for food is growing in importance and no organization exists nationally or internationally to focus exclusively on this issue. Nebraska is an ideal place for such an organization, and it is an opportune time to establish this institute.
- The institute's core mission should be to address the question: *How can we produce more food per unit of water?* The answer must be broadly construed and interdisciplinary – to develop, promote and disseminate the application of science, technology, education, policy and human behavior research to this problem.
- The institute's name must reflect the core mission, water for food.
- The right leader (executive director) is critical. The ideal director is someone with broad international experience and connectivity, who has drive and a sense of mission, and is able to raise funds. He or she can't be wedded to one group and must be able to bridge disciplines. The executive director's major role will be establishing the institute and promoting it to the international water and food communities, establishing partnerships and pursuing opportunities.
- Partnerships are critical. The institute must partner with and can serve as a central link for many organizations – other universities, governmental agencies, nongovernmental organizations, foundations and private sector organizations nationally and internationally.
- The institute should have a global vision and pragmatic international strategy,

providing science-based approaches to state, regional, national and international challenges.
- The research should bridge basic and applied research, and action/practice, with an emphasis on developing practical applications based on the best science and engineering.
- Development of cooperative research programs with other universities and international organizations should be a core component.
- The institute should actively learn from others who have been working in the international water arena for decades.
- The research should focus both on rainfed and irrigated agriculture.
- The institute should not be a development organization but rather an institute to develop and deliver knowledge (research, data, policy analysis, education) to *inform* development.
- A key focus should be knowledge transfer and delivery of the institute's products (data, research, technologies, tools, policy analysis, education) to the world and bringing in the knowledge of others.
- Agricultural production is a multi-dimensional, multi-scale system, the management of which requires research not only on water, seeds and fertilizers, but also the human dimensions. How people interact with and influence the system should be a focus.
- The institute should pursue a holistic approach that looks at river basin-wide hydrology, with an understanding that agriculture is an interacting component of a larger ecosystem.

Suggested research areas
- Define and maximize the productivity of water (quality, timing, place) for the purposes of producing food.
- Utilize molecular biology and plant breeding research to develop food crops that

Group 5

Group 2

produce greater yields and nutrition per unit of water.
- Conduct studies of the transportation, marketing and financial infrastructure for water (water economics).
- Promote improved cropping systems and production practices to respond to a highly variable water supply in both irrigated and rainfed agriculture.
- Adapt and improve irrigation systems for smallholder and medium-sized farms.
- Develop innovative decision-support systems that provide easily accessible, science-based information to managers, decision-makers, policymakers and the general public.

Suggested policy focus areas
- Develop and disseminate analyses of applicable water management policies, dealing with the challenges of complexity, lack of institutional capabilities and competing needs.
- Contribute research on the best ways to develop and evaluate policy.
- Develop a protocol for assessing sustainable food security economies; assess sustainability and help people determine food security needs within the context of water resources and constraints.
- Nebraska's experience with natural resources district management and integrated planning can serve as a model for managing water resources elsewhere.

Suggested emphases for knowledge delivery/education
- Create an Institute Fellows program that provides fellowships in the institute's focus areas. Fellows will broaden the institute's expertise and provide knowledge enrichment (seminars, presentations, etc.) at the University of Nebraska and to academic and conference settings globally, becoming ambassadors for the institute and its programs.
- The institute should provide higher education and training through faculty and student exchange programs, nationally and internationally.
- Develop a Water for Food Web portal that links globally to information on this area and establishes the institute as a major information source.

Group 1

Mogens C. Bay
Bert Clemmens
Marshall English
Terry A. Howell
Brian A. Larkins
Thomas Trout
Ron Yoder

Facilitator: Sandra Zellmer
Recorder: Noah Clayton

Group 2

Marc Andreini
Richard J. Hoffmann
Suat Irmak
Ramesh Kanwar
Peter G. McCornick
Sandra L. Postel
Anthony Schutz

Facilitator: Sheri Fritz
Recorder: Ashley Washburn

Group 3

Mohamed Dahab
James Goeke
Simi Sadaf Kamal
Derrel L. Martin
E. Robert Meaney
Monica Norby
Peter Rogers
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Facilitator: Kenneth G. Cassman
Recorder: Lorrie Benson

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Karina Schoengold
Barry I. Shapiro
Donald L. Suarez
Otto Szolosi
Alan J. Tomkins

Facilitator: Mark R. Gustafson
Recorder: Maureen Moseman

Group 4

Group 6

Group 5

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Christopher Lant
Judith C.N. Lungu
Mark F. Madison
Sarah Michaels
Robert B. Swanson
Vincent Vadez

Facilitator: Donald A. Wilhite
Recorder: Elizabeth Banset

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James E. Ayars
Mohamed Bazza
Eugene Glock
Daniel Gustafson
Sally Mackenzie
A. Dan Tarlock

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Recorder: Sara Trickie

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Karrie Weber
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Wayne Woldt
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Charles Wortmann
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Donna Woudenberg
UNL

Ron Yoder
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John Yohe
INTSORMIL

Randy Zach
Nebraska Public Power District

Michael J. Zeleny
UNL

Sandra Zellmer
UNL

Vitaly Zlotnik
UNL

Gary Zoubek
UNL

Sarah Zulkoski-Benson
UNL

From left:
Gary Cunningham,
Brian Larkins,
Deb Hamernik ▶

From left:
Donald Wilhite,
Kyle Hoagland,
Mohamed Bazza ▶

Welcome reception
and dinner
▼

◀ Donald Suarez, Richard Snyder

▲ Ann Bleed

▲ Science and technology panel

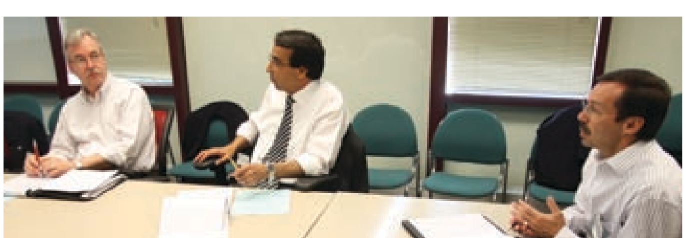
◀ Sheri Fritz, Jeff Raikes

First row: ▶
Robert Meaney,
Thomas Trout,
Mohamed Bazza

Second row:
David Manderscheid,
Barbara Couture,
Martin Massengale,
Bruce Dvorak

Marc Andreini,
Roy Steiner

From left:
Brian Larkins,
Harvey Perlman,
Tom Farrell



From left:
Daniel Gustafson,
Mohamed Bazza,
Steve Goddard

John Owens,
Prem Paul

Clockwise from left: Peter Rogers, Mohamed Dahab, Lorrie Benson, Kenneth Cassman

Marshall English, Derrel Martin

Mogens Bay, James B. Milliken