WATER SUPPLY CHALLENGES FOR THE 21ST CENTURY

HEARING

BEFORE THE

COMMITTEE ON SCIENCE AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

ONE HUNDRED TENTH CONGRESS

SECOND SESSION

MAY 14, 2008

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CONTENTS

May 14, 2008

Appendix: Answers to Post-Hearing Questions

WATER SUPPLY CHALLENGES FOR THE 21ST CENTURY

WEDNESDAY, MAY 14, 2008

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
Washington, DC.

The Committee met, pursuant to call, at 10:00 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Bart Gordon [Chairman of the Committee] presiding.

BART GORDON, TENNESSEE
CHAIRMAN

RALPH M. HALL, TEXAS
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Hearing on

Water Supply Challenges for the 21st Century

Wednesday, May 14, 2008
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

Witness List

Dr. Stephen Parker
Director, Water Science and Technology Board, National Research Council

Dr. Jonathan Overpeck
Director, Institute for the Study of Planet Earth, and Professor, Geosciences and Atmospheric Sciences, University of Arizona

Dr. Robert Wilkinson
Director, Water Policy Program, Bren School of Environmental Science and Management, University of California-Santa Barbara

Mr. Marc Levinson
Economist, US Corporate Research, JPMorgan Chase

Dr. Roger Pulwarty
Program Director, National Integrated Drought Information System (NIDIS) NOAA Climate Program Office

HEARING CHARTER

COMMITTEE ON SCIENCE AND TECHNOLOGY U.S. HOUSE OF REPRESENTATIVES

Water Supply Challenges for the 21st Century

WEDNESDAY, MAY 14, 2008
10:00 A.M.–12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

Purpose

On Wednesday, May 14, 2008, at 10:00 a.m. the House Committee on Science and Technology will hold a hearing entitled *"Water Supply Challenges for the 21st Century."* The purpose of the hearing is to examine the challenges of managing water supplies to meet social, economic and environmental needs in the United States. Population growth, changes in water use patterns, competing demands for water supply, degradation of water quality, and climatic variation are all factors influencing the availability and use of water. The hearing will also examine the role of the Federal Government in helping states and local communities adopt and implement sensible and cost-effective water resource management policies.

Background

Water is necessary to every aspect of life. Although some regions of the U.S. have limited water supplies, especially areas west of the Mississippi River, the U.S. is endowed with substantial supplies of fresh water. However, population growth, increased per capita water use, water quality degradation, and increased withdrawals to support agricultural, industrial, and energy production activities combined with climate variability have increased water shortages across the country.

In order to meet the challenge of providing safe, reliable water supplies for society we need improved information about the status of our water resources, policies to encourage water conservation, and technological improvements that will enable us to maintain and improve water quality and to improve our water-use efficiency to allow us to accomplish society's goals with less water. Through this hearing, the Committee hopes to ascertain how and to what extent water science and technology can ease the Nation's water resource challenges.

Assessment of U.S. Water Supply

In the 19th century, U.S. population stood at a little more than five million citizens. By 1959, the U.S. population had grown to almost 180 million people. Our population is now over 300 million with a one percent rate of growth. Available surface water supplies have not increased in the United States since the 1990s, and groundwater tables are continuing to decline.[1] It is clear that the U.S. water supply cannot support future populations and economic activity at its current rate of consumption.

In order to better manage water supplies, there is a critical need for good data about our water resources and how supplies vary over time. Currently, quantitative knowledge of water supply is inadequate in the United States.[2] The U.S. Water Resources Council completed the most recent, comprehensive, national water availability and use assessment in 1978.[3]

In response to increased concerns about future increased water shortages, the Bush Administration created the Subcommittee on Water Availability and Quality

[1] "Report to Congress on the Inter-dependency of Energy and Water," U.S. Department of Energy. December 2006.

[2] U.S. Government Accounting Office, 2003 Report: *Freshwater Supply States' Views of How Federal Agencies Could Help Them Meet the Challenges of Expected Water Shortages.* GAO–03–514; National Research Council, 2004. Assessing the National Streamflow Information Program. National Academies Press, Washington, D.C

[3] The Council, established by the *Water Resources Planning Act* in 1965 (P.L. 89–80), comprising the heads of several federal departments and agencies, such as Interior and the Environmental Protection Agency, has not been funded since 1983. U.S. Government Accounting Office, 2003 Report: *Freshwater Supply States' Views of How Federal Agencies Could Help Them Meet the Challenges of Expected Water Shortages.* GAO–03–514.

(SWAQ) of the National Science and Technology Council's Committee on Environment and Natural Resources to coordinate a multi-year plan to improve research on water availability and quality. The Subcommittee concluded in a 2007 report that a robust process for measuring water requires a systems approach to assess surface water, ground water, rainfall, and snowpack from the perspectives of quantity, quality, timing, and location.[4]

Initiatives to Address Water Supply Shortages

States have initiated a number of steps to address water shortages. These activities include: Development of drought preparedness plans to reduce their vulnerability to droughts and development of drought response plans to provide assistance to communities and businesses that are vulnerable to drought; monitoring water availability and water use of major water supplies; coordinating management of ground and surface water supplies; developing and implementing policies to encourage water conservation and allocate water among competing uses within their jurisdictions; exploring options for increasing water supply such as cloud seeding to increase rainfall or investment in desalinization plants.

At the federal level, there are numerous federal departments, independent agencies, and several bilateral organizations have some responsibility for water programs and projects within the United States. The federal agencies with primary responsibilities for water resources include: The Bureau of Reclamation which provides municipal and irrigation water and operates hydroelectric facilities in the western states; the Army Corps of Engineers which has responsibility for projects involving flood control and flood plain management, water supply, navigation, and hydroelectric power generation; the National Oceanic and Atmospheric Administration which is responsible for weather and climate prediction through the National Weather Service, including the operation of the National Drought Information System and maintains wildlife habitat and ecosystem protection through its coastal zone and fisheries management programs; the U.S. Geological Survey which assesses the quality, quantity, and use of U.S. water resources and maintains a national stream gauge network used for monitoring stream and river flows and flood forecasting; the Environmental Protection Agency which protects public health and the environment by ensuring safe drinking water, controlling water pollution, and protecting ground water.

The Federal Government has also established standards for toilets and the Environmental Protection Agency recently established a voluntary program, WaterSense, to encourage the marketing and adoption of water conserving technologies and practices.

Most of the authority for allocating water resides within State governments. When water disputes arise involving two or more states, the federal government has a role to play based upon Congress's power to regulated interstate commerce and through congressional approvals of binding agreements known as compacts. The seven Colorado Basin states have a long-established compact governing water allocation of the Colorado River. The extended drought in the Southeast has brought attention to an ongoing interstate conflict among Alabama, Florida, and Georgia over water allocation in the Apalachicola-Chattahoochee-Flint (ACF) river system. According to the Congressional Research Service, at least 47 states and the District of Columbia at some time have been involved in disputes over water that have resulted in litigation or initiated negotiations to establish an interstate compact.[5]

In a 2003 report of the Government Accountability Office (GAO) report, states identified five federal actions they believed could best support their efforts to improve water management. Better coordinated federal participation in water management agreements along with financial assistance to increase storage and distribution capacity, improved water data, flexibility in the administration of environmental laws, and increased consultation on federal or tribal use of water rights.[6]

Economic Impacts Associated with Water Shortages

In the United States, over 50,000 water utilities withdraw approximately 40 billion gallons per day of water from the Nation's resources, to supply water for domes-

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[4] The Subcommittee on Water Availability and Quality. *A Strategy for Federal Science and Technology to Support Water Availability and Quality in the United States.* September 2007. 35pp.

[5] Congressional Research Service, Memorandum to the House Committee on Science and Technology, "States involved in Interstate Water Disputes," May 9, 2008. 3pp.

[6] U.S. Government Accounting Office, 2003 Report: *Freshwater Supply States' Views of How Federal Agencies Could Help Them Meet the Challenges of Expected Water Shortages.* GAO–03–514

tic consumption, industry, and other uses.[7] When severe water shortages occur, the economic effect can be substantial. According to a 2000 report from the National Oceanic and Atmospheric Administration, eight water shortages from drought or heat waves each resulted in $1 billion or more in monetary losses over the past 20 years.[8]

An adequate supply of treated water is integral to many industries, including agriculture and food processing, beverages, power generation, paper production, manufacturing, and mineral extraction. Water shortages can negatively affect companies and entire industries and reduce job creation and retention. Current industry trajectories, population growth, and dwindling water supplies all point to increased water shortages. Increased water demand will come with increased costs to all businesses, industries, and municipalities which rely on the same water resources. The Association of California Water Agencies (ACWA) reported in April 2008 that California is now losing income and jobs due to the state's water supply crisis.[9]

Water Energy Nexus

Water is a vital component of our economy's energy sector. Water is used for resource extraction, refining and processing and transportation. Water also is essential for electricity generation. The expansion of biofuel supply is also going to require substantial water resources. The National Research Council predicts that the surge in ethanol production is likely to lead to adverse effects on local water sources and water quality.[10]

The use of water in the extraction and processing of petroleum-based transportation fuels is relatively small compared to the electric-generating industry. According to the Department of Energy's National Energy Technology Laboratory, the thermoelectric power sector accounts for 39 percent of total freshwater withdrawal in the United States, and 3.3 percent of total freshwater consumption. This consumption for electricity production accounts for over 20 percent of nonagricultural water consumption. Water is also used directly in hydroelectric generation, which constituted approximately 14 percent of energy produced in the United States in 2006 according to the Energy Information Administration (EIA).

Not only do we need vast quantities of water for energy production, but we also need energy to transport and treat water. DOE estimates that nationwide, about four percent of U.S. power generation is used for water supply and treatment. Across the country, the amount of energy used to provide water to meet agriculture needs represents the most significant regional difference. However, the supply and transport of water can be quite energy-intensive. For example, pumping water to consumers that live far away from the source can be energy intensive. California's State Water Project pumps water 444 miles of aqueducts from three recreational lakes in Plumas County in Northern California to Riverside County in Southern California and is the state's largest energy consumer using between two to three percent of California's energy (5,000 GWh per year).[11]

Witnesses

Dr. Stephen Parker, Director, Water Science and Technology Board, National Research Council. Dr. Parker will discuss the recent work undertaken by the Water Science and Technology Board of the National Academy of Sciences on water supply and water management. He will also discuss the major challenges facing states and local governments in providing adequate water supply to meet societies competing needs.

Dr. Jonathan Overpeck, Director, Institute for the Study of Planet Earth, and Professor, Geosciences and Atmospheric Sciences, University of Arizona. Dr. Overpeck will discuss the potential impacts of climate change on water supply, particularly in the Southwest.

Dr. Robert Wilkinson, Director, Water Policy Program, Bren School of Environmental Science and Management, University of California-Santa Barbara. Dr. Wilkinson will discuss the linkage between energy and water supplies both in terms

[7] "Water Loss Control," George Kunkel, Jr. *Water Efficiency.*

[8] U.S. Government Accounting Office, 2003 Report: *Freshwater Supply States' Views of How Federal Agencies Could Help Them Meet the Challenges of Expected Water Shortages.* GAO–03–514.

[9] "California Water Supply Crisis Affecting Economy," *Water and Wastewater News.* April 21, 2008

[10] "Fuel for Thought," National Academies in Focus. Volume 8 Number 1.

[11] "Water Energy Use in California," California Energy Commission.

of the water needed to provide energy and in terms of the energy needed to transport and treat water.

Mr. Marc Levinson, Economist, U.S. Corporate Research, JPMorgan Chase. Mr. Levinson will discuss the key findings of JP Morgan's recent report *"Watching Water: A Guide to Evaluating Corporate Risks in a Thirsty World,"* and the potential impacts of water supply shortage on businesses and the economy.

Dr. Roger Pulwarty, Program Director, National Integrated Drought Information System (NIDIS) NOAA Climate Program Office. Dr. Pulwarty will discuss what information is currently available through NIDIS to regional, State and local water decision-makers. He will also address what future information is required for better water policy planning.

Chairman GORDON. Good morning and welcome everyone, and to our witnesses, thank you for letting us conduct a little business here.

As was stated, this is a busy time. We have several Members in markups elsewhere. They will be coming back, but their staff is either here or in the anteroom watching. This will be televised, so we will have the opportunity for this to go out, and we appreciate you being here.

Water is an essential input to virtually everything we do, from growing and processing food to manufacturing the products we use to date, to producing the energy we need to power our economy. Water is essential to all life and to maintain public health and the diversity and beauty of our environment.

The recent droughts experienced in the West and the Southeast and increased competition for water supplies suggest that we must take a closer look at how we are managing our water resources. Thirty-six states expect to experience significant water shortage by 2013, population growth, increased per-capita water use, degraded water quality, and climate change have all impacted our availability, our available supplies of water.

In my district water sources have dried up, and wells have run dry. Towns have been forced to implement water restrictions to deal with a decreased supply. According to the Tennessee Valley Authority, the first eight months of 2007 were the driest in the last 118 years of Tennessee history. When severe water shortage occurs, the economic impact is substantial. In 2007, the Tennessee Valley Authority was forced to shut down a nuclear reactor due to a lack of acceptable cooling water in the Tennessee River.

According to a 2000 report from NOAA, each of the eight water shortages over the past 20 years from drought or heat wave resulted in $1 billion or more in monetary losses. A recent report by J. P. Morgan indicated that a single production interruption at a semiconductor plant could cost $200 million in lost revenue.

I believe with investment in research and development, public education, and better information on the status of our water supplies, we could avoid the high cost, social disruption, and environmental damage associated with water shortage.

Our committee has already begun to bring forward legislation to help us better utilize water resources. Last week the Subcommittee on Energy and Environment reported bills by Representative Hall and Mr. Matheson to authorize research at the Department of Energy and Environmental Protection Agency on water treatment and to increase the efficiencies of our water use.

We will be looking for more opportunities to address this important issue.

I would like to thank our panelists for appearing before us today to share with us their views on the problems we currently face in water supply and their suggestions for addressing these problems in the future, and I look forward to a lively discussion from this impressive panel.

[The prepared statement of Chairman Gordon follows:]

PREPARED STATEMENT OF CHAIRMAN BART GORDON

Good morning and welcome to today's hearing.

Water is the essential input to virtually everything we do—from growing and processing food to manufacturing the products we use everyday to producing the energy we need to power our economy. Water is essential to all life and to maintain public health and the diversity and beauty of our environment.

The recent droughts experienced in the West and the Southeast and increased competition for water supplies suggest that we must take a closer look at how we are managing our water resources.

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Chairman GORDON. At this time I would like to yield to my distinguished colleague from Texas, our Ranking Member, Mr. Hall, for an opening statement.

Mr. HALL. I thank you, Mr. Chairman, and I am, of course, pleased that we are having this hearing here today.

Water supply is, as you say, a very critical issue facing our country. Water is the lifeblood of our economy. Every sector requires it and would be crippled without it. Energy and agriculture are the two largest consumers of water, I understand, but it is also a vital part of manufacturing, fishing, and obviously, everyday living.

Water's importance to U.S. prosperity is one that has been discussed in various reports over the last decade, government sponsored and private sector alike. It has hit home for some of us where our districts have been subjected to periods of long drought or massive flooding. This Congress is well aware of the dangers of water shortages and over-abundance.

Two years ago we passed, and the President signed, the *National Integrated Drought Information System Act of 2006.* We did this in response to a need for a centralized location for drought information. I am very pleased that Dr. Pulwarty is here to talk about it. Although this law is not the only answer, it is part of the larger solution required for good water policy and good management.

What we need are the proper tools and resources for local, State, and regional decision-makers to adapt to changing conditions. I look forward to hearing from the panelists today on possible solutions to our nation's water challenges.

And I thank you, and I yield back the balance of my time.

[The prepared statement of Mr. Hall follows:]

PREPARED STATEMENT OF REPRESENTATIVE RALPH M. HALL

Thank you, Mr. Chairman. I am pleased we are having this hearing today. Water supply is a very critical issue facing our country. Water is the life-blood of our economy. Every sector requires it and would be crippled without it. Energy and agriculture are the two largest consumers of water, but it is also a vital part of manufacturing, fishing, and obviously, everyday living.

Water's importance to U.S. prosperity is one that has been discussed in various reports over the last decade, government-sponsored and private-sector alike. It has hit home for some of us, where our districts have been subjected to periods of long drought or massive flooding. This Congress is well aware of the dangers of water shortages and overabundance.

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What we need are the proper tools and resources for local, State and regional decision-makers to adapt to changing conditions. I look forward to hearing from the panelists today on possible solutions to our nation's water challenges. I yield back the balance of my time.

Chairman GORDON. Thank you, Mr. Hall, and thank you for your hospitality. We had a hearing down at Texarkana on the COMPETES Bill this Monday, and it was very interesting. It adds to our committee's institutional memory and knowledge in this very important area.

And I ask unanimous consent that all additional opening statements submitted by the Committee Members be included in the record. Without objection, so ordered.

[The prepared statement of Ms. Johnson follows:]

PREPARED STATEMENT OF REPRESENTATIVE EDDIE BERNICE JOHNSON

Thank you, Mr. Chairman. As Chair of the Subcommittee on Water Resources and Environment, this issue is very important to me.

Dallas, as does other cities, has a propensity to flood. Adequate infrastructure is important to properly manage water and avoid flooding problems.

On the other hand, the State of Texas has encountered years of tremendous drought. Our cattle ranchers and farmers have depended on disaster relief from the devastating lack of water.

The Science Committee has a role to play in water issues.

We can invest in research to examine infrastructure needs.

We can support efforts to improve water clarity and purity, to protect the health of our populace.

We can direct studies on climate change and its impact on our water resources.

We are tasked with the responsibility of ensuring a safe, reliable water supply for society.

We need improved information about the status of our water resources and policies to encourage water conservation,

We must discover technological improvements that will enable us to maintain and improve water quality and to improve our water-use efficiency to allow us to accomplish society's goals with less water.

Today's witness panel includes individuals representing federal advisory groups such as the National Research Council and National Oceanographic and Atmospheric Association (NOAA).

It also includes academic witnesses, such as Dr. Overpeck from the University of Arizona and the University of California–Santa Barbara.

The Committee will be interested to hear the panel's suggestions as to water research and development priorities at the federal level.

Again, welcome to today's witnesses. I thank the Chairman and Ranking Member for their leadership on this issue and yield back my time.

[The prepared statement of Mr. Carnahan follows:]

PREPARED STATEMENT OF REPRESENTATIVE RUSS CARNAHAN

Mr. Chairman, thank you for hosting this important hearing on managing the U.S. water supply. Population growth, variation in our climate and degradation of water quality all complicate current water supply management in our nation.

It is incumbent upon those of us in Congress to examine ways that we can improve water conservation efforts, and research both new technologies such as desalinization to increase water supply as well as avenues to improve water quality. I am particularly concerned about water quality in my own congressional district. One county within my district is changing from a rural to more suburban county, which has created pressure to supply more water to more people. Septic tanks are leaking into tributaries and streams with the potential for contaminating water supply. In another area, sewer overflows occur due to an aging infrastructure.

I am also interested in the link between energy and water, which I anticipate Dr. Wilkinson will address in his testimony today. I would appreciate hearing more about his views on hydroelectric power in this country, whether this untapped resource is worthy of additional federal investments and if he sees room for further research into more efficient power generation from hydroelectric dams.

I would like to thank today's witnesses, Dr. Parker, Dr. Overpeck, Dr. Wilkinson, Mr. Levinson and Dr. Pulwarty, for taking the time to appear before us. I look forward to hearing all of our witness's testimonies.

[The prepared statement of Mr. Mitchell follows:]

PREPARED STATEMENT OF REPRESENTATIVE HARRY E. MITCHELL

Thank you, Mr. Chairman.

The diminishing supply of water is an issue that truly hits home.

In Arizona, our habitability is closely tied to the availability of reliable safe water sources.

According to the Arizona Department of Water Resources, Arizona has experienced drought for over a decade. The Colorado River system as a whole is now in its eighth year of drought.

I believe that it is absolutely critical that we address the growing shortage of our nation's water supply and work to establish progressive and cost-effective water resource management policies.

I look forward to hearing from our witnesses about the challenges of managing water supplies.

I yield back.

[The prepared statement of Mr. Smith follows:]

PREPARED STATEMENT OF REPRESENTATIVE ADRIAN SMITH

Thank you, Mr. Chairman.

Water supply issues are a challenge in my home State of Nebraska. Water availability is a critical concern in much of my district where center pivot irrigation is the lifeblood of farmers. A nearly decade-long drought in Nebraska's Panhandle has put extreme stress on water resources and those who rely on them.

Water quality problems are potentially burdensome for small towns in my district, which face high costs for remediation of their drinking water supplies in order to comply with U.S. Environmental Protection Agency regulations pertaining to naturally-occurring contaminants, such as arsenic, in their wells.

Energy is a topic on everyone's mind and many energy generation methods require water to produce power. Hydropower, nuclear energy, petroleum refining, clean coal technologies, and biofuels production all require large amounts of water. I have long been an advocate of keeping all energy options on the table. I want to ensure the water needed is available for the energy choices of the marketplace.

Balancing the various uses of water is a constant challenge as various groups demand its use for drinking water; agriculture; energy generation; habitat, especially for endangered species; and recreation. As a Nebraskan and a Congressman, I want to ensure these demands are properly prioritized, and, as possible, they each are recognized for their contribution to Nebraska's economy and quality of life.

I look forward to hearing the testimony of our witnesses and hope they will be able to shed light on each of these problems and offer practical steps for their resolution.

Thank you, Mr. Chairman, and I look forward to working with you in the future.

Chairman GORDON. It is my pleasure now to introduce the witnesses this morning.

Dr. Stephen Parker is the Director of the Water Science and Technology Board at the National Research Council, and Ms. Giffords, I would like to yield to you. Somehow we always work Arizona into most hearings, so you are up.

Ms. GIFFORDS. Thank you, Mr. Chairman.

It is a privilege for me to introduce a tremendous colleague from Arizona, Dr. John Overpeck, who is one of the brightest stars of the University of Arizona. Dr. Overpeck is a Climate Systems Scientist at the UofA, where he is also the Director for the Institute for the Planet, for the Study of Planet Earth, Professor of Geosciences and a Professor of Atmospheric Sciences.

Dr. Overpeck has published over 120 papers on climate and the environmental sciences. He recently served as a Coordinating Lead Author for the Fourth Assessment Report of the UN Intergovernmental Panel on Climate Change, which shared the 2007 Nobel Peace Prize with former Vice President Al Gore.

And I want to thank you and your colleagues for coming to present before our committee the reports from that very important document.

For his interdisciplinary research Dr. Overpeck has also been awarded the U.S. Department of Commerce bronze and gold medals, as well as the Walter Orr Roberts Award of the American Meteorological Society. He has been a Guggenheim Fellow and serves on the Board of Reviewing Editors for Science Magazine.

Dr. Overpeck's research focuses on global change dynamics with a major component aimed at understanding how and why key climate systems vary on time scales longer than seasons and years. Through his research Dr. Overpeck is working to help foster a new paradigm of interdisciplinary knowledge creation between physical, biological, and social scientists, all with the goal of serving the environmental needs of society in a more effective manner.

I am very pleased to have Dr. Overpeck here. He is an authority in Arizona, and I am pleased to have such a distinguished panel, group of panelists to talk about an issue that is vitally important to the West and to our country.

Chairman GORDON. Thanks, Ms. Giffords.

Dr. Wilkinson, I won't be quite as generous with you, but nonetheless you are very distinguished. You are the Director of the Water Policy Program at the Bren School of Environmental Science and Management, at the University of California-Santa Barbara. Welcome.

And Mr. Marc Levinson is the Economist for the U.S. Corporate Research at J.P. Morgan Chase and author of J.P. Morgan's recent report, *"Watching Water, a Guide to Evaluating Corporate Risks in a Thirsty World."*

And finally, our last witness is Dr. Roger Pulwarty, Director, Program Director for the National Integrated Drought Information System at NOAA Climate Program Office.

We would like for you to try to keep your opening statement to about five minutes and your written testimony will be made a part of the record. When you have completed your testimony, we will have questions by our Members.

Dr. Parker, please begin.

STATEMENT OF DR. STEPHEN D. PARKER, DIRECTOR, WATER SCIENCE AND TECHNOLOGY BOARD, NATIONAL RESEARCH COUNCIL

Dr. PARKER. Good morning, Mr. Chairman, Members of the Committee, and others. I am Stephen Parker from the National Research Council, and I am pleased to participate in today's hearing.

I have been in my position at the Water Science and Technology Board for 26 years and have overseen about 200 studies relevant to today's topic. Thus my remarks are general and drawn from our body of work, not one particular recent study.

It is hard to overstate the importance of high-quality water supplies to our nation, yet in many areas supplies are essentially fixed, and the quality is deteriorating. At the same time, demands for water to support population and economic growth, the environment, and other purposes continue to increase. Examples of the mounting array of water-related problems exist in every region of the country, especially the West and Southwest.

Both of these regions have rapidly-growing populations and have been affected by climate variability, drought, and the tightening water supply picture as many new users vie for limited supplies and call for changes to traditional allocation rules.

Lasting solutions to these challenges of water supply and demand and water quality will require creative science-based strategies and innovative water technologies.

I have phrased my central concerns in the form of four questions. If the answers to some of these questions are no, I fear that we may be in for a national water crisis, something like that portrayed in the media.

Question one, will there be sufficient water to support both future economic and population growth while sustaining ecosystems? The fast-growing Southwest and Southeast face great challenges in meeting increasing water demands. Most of the sources and supplies of water for these regions are fully allocated among environmental, urban, and agricultural uses. Unfortunately, the Nation seems lacking in a long-term strategic vision of alternative means for accommodating growth with existing supplies. We believe the Nation has under-invested in research and development needed to help municipalities augment water supplies in this post-dam-building era. For example, through waste water reuse, desalination, and other approaches, including aquifer storage and recovery.

Question two. How effectively can our water management systems and institutions adapt to climate change? Existing data reveal some significant climate changes in the U.S. in recent years. Warmer temperatures in some regions and potential impacts on water supplies are of special concern. Although there are uncertainties regarding future climate projections, there is broad scientific agreement that rising temperatures are having a number of effects such as earlier melting of snowpack, which affects agricultural production, increases flood risks, and is forcing changes in reservoir operations. Two, higher sea levels, which will increase salinity in coastal water supply aquifers and alter marshes and wetlands. And three, in changing amounts of precipitation and extreme climatic events.

My question three. Will drinking water be safe? Over the past 100 years investments in water treatment and distribution infrastructure has made the quality of U.S. drinking water among the best in the world. Today we take safe water for granted. Nevertheless, new chemicals and biological agents continue to emerge and intentional or unintentional contamination of drinking water supplies represents a real and continuing threat. Additionally, much of our urban drinking water infrastructure is reaching the end of its expected lifetime and will need to be replaced in the next 25, 10 to 25 years.

Question four. Can existing water policies effectively respond to present and future challenges? Many of the Nation's water policies and practices were created and designed for yesterday's water resources challenges and are becoming obsolete. For example, the *National Environmental Policy Act,* the *Clean Water Act,* the *Safe Drinking Water Act,* and the *Endangered Species Act* were all passed in the early 1970s. Likewise, many dam operators and water allocation plans are designed for a set of users in an earlier era and are being challenged by increasing demands from users such as recreational, urban, and environmental interests.

It seems important that the Nation's water management institutions and body politics stay vigilant to assure and perhaps restore modern and appropriate management and legal instruments to meet the challenges. The case is compelling for governmental leadership and support for water resources research and maintenance of strong governmental scientific and technical capabilities.

My written statement discusses numerous examples of past federally-funded water research that have produced significant payoffs to the Nation. The advances in water science and technology that society is now requiring are likely to be inadequate if federal action is not taken as the states and non-governmental organizations have limited resources to invest in required research.

That concludes my statement. I commend the Committee for recognizing the importance of water resource and the role of the government in water resources to the Nation. I hope you act quickly and strategically, as I often worry that we are living on borrowed water capacity, created by conservative engineers in the past, and that our water supply cushion is disappearing.

I would be happy to answer your questions. Thank you.

[The prepared statement of Dr. Parker follows:]

PREPARED STATEMENT OF STEPHEN D. PARKER

Good morning, Mr. Chairman, Members of the Committee, and others. My name is Stephen D. Parker. I am Director of the Water Science and Technology Board (WSTB) of the National Research Council. As you may know, the National Research Council is the operating arm of the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine of the National Academies, and its goal is to provide elected leaders, policy-makers, and the public with independent, expert advice based on evaluations of scientific evidence.

I am delighted to have the opportunity to participate in today's hearing, which examines the challenges of managing water supplies to meet social, economic, and environmental needs of the United States. Population growth, changes in water use patterns, competing demands for water supply, degradation of water quality, and climatic variations all are factors that influence the availability and use of water. I have held my position with the WSTB for 26 years and have overseen approximately 200 studies relevant to the topic of today's hearing. Thus, my remarks are drawn from a whole body of work, rather than just one recent report. (Note that my written statement has attached to it a listing of some our most relevant reports from the past several years.) Given the nature of the WSTB mission—to help ensure and improve the scientific basis for water management—my statement tends to emphasize science and research.

High quality, reliable drinking water is fundamental to human existence and quality of life. Not only is water a basic human need, but adequate, safe water supplies are crucial to the Nation's health, economy, security, and ecosystems. A key strategic challenge is to ensure adequate quantity and quality of water to meet human and ecological needs, especially given the growing competition among domestic, industrial-commercial, agricultural, and environmental uses. To successfully address the Nation's water resources problems likely to emerge in the next 10–15 years, decision-makers at all levels of government will need to make informed choices among often conflicting and uncertain alternative actions.

There is abundant evidence that the conditions of water resources in many parts of the United States are deteriorating. Further, demands for water resources to support population and economic growth continue to increase, although water supplies generally are fixed in quantity and already are fully allocated in most areas. Examples of the mounting array of water-related problems exist in every region of the country. Today, these problems are especially pronounced in the West and in the Southeast. Both these areas are sites of rapidly-growing populations and have been affected by climate variability, drought, and a tightening water supply picture as multiple and new users vie for changes to more traditional allocation rules and patterns. Lasting solutions to these challenges of water supply and demand balances, as well as water quality, will require creative, science-based, and economically feasible strategies. The following questions highlight the central concerns; if answers to some of these questions are "no," it portends a future with complex water resource problems that will challenge the capacities of our scientific, engineering, and management organizations charged to address water resources issues. (Note that I do not attempt to separate water quantity from water quality considerations as the two are inextricably linked.)

- **Will there be sufficient water to both sustain ecosystems and support future economic and population growth?** The fast-growing states and cities of the Southwest face great challenges in meeting increasing water demands. Most of the sources and supplies of water for this arid region are fully allocated among environmental, urban, and agricultural uses. Mechanisms for reallocating water away from current uses, along with technological means for augmenting supplies, all have physical, economic, and social limits. Other rapidly growing areas of the Nation, like the Southeastern U.S., also are exhibiting increasing vulnerability to drought. The traditional means for coping with ever-increasing water demands was to augment supplies by constructing more dams. For a number of reasons, that strategy today is far less viable. Unfortunately, the Nation has limited precedent and seemingly a lack of long-term, strategic vision for alternative means for coping with increasing economic and population growth with existing, limited water supplies. Furthermore, we believe the Nation has under-invested in the research needed to help municipalities augment water supplies, for example through wastewater reuse, desalination, or aquifer storage and recovery.
- **How effectively can our water management systems and institutions adapt to climate change?** Existing data reveal some significant climate changes in the U.S. in recent years, with implications for water quality and quantity. Warmer temperatures in some regions, and potential impacts on water supplies, are a special concern. Although there are uncertainties regarding future climate projections, there is broad scientific agreement that rising temperatures are having a number of effects, such as (1) earlier melting of snowpack, which affects agricultural production, increases flood risks, and is forcing changes in reservoir operations; (2) higher sea levels, which will increase salinity in coastal aquifers and alter marshes and wetlands; and (3) changing patterns of precipitation, such that extreme climatic events may increase in magnitude and frequency.

- **Will drinking water be safe?** Over the past 100 years, investment in water treatment and distribution infrastructure has made the quality of U.S. drinking water among the best in the world. Enormous gains in public health were realized from the virtual elimination of typhoid and cholera, such that today, the provision of safe supplies of drinking water is taken for granted. Nonetheless, new chemical and biological agents continue to emerge and intentional or unintentional contamination of drinking water supplies represents a real and continuing threat. Further, much of our drinking water infrastructure is reaching the end of its usable lifetime and will need to be replaced in the next 10–25 years.
- **Will the quality of the Nation's waters be enhanced and maintained?** Passage of the *Clean Water Act* helped the Nation make great progress during the 1970s and 1980s in improving surface water quality, through financial support for municipal wastewater treatment plants and a permitting process for point sources of water pollution. Today, the more pressing surface water quality problem is non-point source pollution. Effective management of non-point source pollution problems requires good data on surface water quality. However, there are only limited water quality data for many of the Nation's rivers and streams, including some large and very important ones. For example, a 2008 report of ours noted the limited data and limited monitoring efforts in many stretches of the Mississippi River, and recommended a more extensive and integrated approach to the river's water quality monitoring and assessment. Better information on water quality, and better management of non-point source pollution problems, also will require stronger, more aggressive federal leadership.
- **Can existing water policies effectively respond to present and future challenges?** Many of the Nation's water policies and practices were created and designed for an earlier era of water resources challenges and problems. For example, the *National Environmental Policy Act,* the *Clean Water Act,* the *Safe Drinking Water Act,* and the *Endangered Species Act* all were passed in the early 1970s. Further, many dam operations and water allocation plans, designed for a set of users in an earlier era, are being challenged by increasing demands from users such as recreational, urban, and environmental interests. Moreover, many water professionals are concerned about declining engineering and scientific capacity in the Nation's key water resources organizations—which is occurring at a time when the Nation needs high-level, professional expertise in its primary water institutions more than ever.

Advances in the science and technology through research needed to address these problems are likely to be inadequate if no federal actions are taken, as the states and non-governmental organizations have limited resources to invest in required research. The Nation also will need stronger expertise in its leading water institutions in order to stay abreast of engineering and scientific developments, and to be able to interact productively with the scientific community at large. The increasing need to ensure clean and adequate water supplies, and to manage increasingly rapid human-induced modification of natural and social environments, make a compelling case for governmental support of water resources research and strong governmental scientific and technical capacity.

There are numerous examples of federal government-funded research on water resources that have led to significant payoffs for the Nation. The flood forecasting systems that help save lives and protect property, and the drought forecasting systems that help keep farmers and municipalities abreast of water availability conditions, both rest on federally supported data gathering and research. Research in the past has led to the development of innovative water and wastewater treatment technologies, such as membranes. Other examples include improved management of salts in irrigated agriculture, and better understanding of implications regarding voluntary transfers of water among different users. Studies of eutrophication in inland waters, mercury deposition, and nitrogen loading in the Chesapeake Bay watershed seem to provide examples of federally funded research that has improved the effectiveness of regulatory processes. Research has allowed the Nation to increase the productivity of its water resources, such that today the same amount of water yields, on average, more agricultural output than it did 50 or 100 years ago. Finally, the Nation today uses many aspects of its water resources base far more efficiently than in the past, due to advances in water-efficient plumbing fixtures, landscaping practices, and wastewater reuse techniques. Future scientific and technical advances will be required to meet the water resources needs of an expanding

U.S. population and to maintain the quality of the Nation's surface, groundwater, and aquatic systems.

That concludes my statement. I commend the Committee for recognizing the importance of water resources—and the role of the Federal Government in water resources—to the Nation. I'd be happy to answer your questions. Thank you!

Some Relevant Recent WSTB Reports of Interest to the Subcommittee

Desalination: A National Perspective 2008

Colorado River Basin Water Management: Evaluating and Adjusting to Hydroclimatic Variability 2007

Improving the Nation's Water Security: Opportunities for Research 2007

Integrating Multi-scale Observations of U.S. Waters 2007

Mississippi River Water Quality and the Clean Water Act: Progress, Challenges, and Opportunities 2007

Prospects for Managed Underground Storage of Recoverable Water 2007

Water Implications of Biofuels Production in the United States 2007

Drinking Water Distribution Systems: Assessing and Reducing Risks 2006

Progress Toward Restoring the Everglades: The First Biennial Review, 2006

River Science at the U.S. Geological Survey 2006

Toward a New Advanced Hydrologic Prediction Service (AHPS) 2006

Public Water Supply Distribution Systems:Assessing and Reducing Risks 2005

Regional Cooperation for Water Quality Improvement in Southwestern Pennsylvania 2005

Water Conservation, Reuse, and Recycling 2005

Assessing the National Streamflow Information Program 2004

Confronting the Nation's Water Problems: The Role of Research 2004

Estimating Water Use in the United States: A New Paradigm for the National Water-Use Information Program 2002

Missouri River Ecosystem: Exploring the Prospects of Recovery, The 2002

Privatization of Water Services in the United States: An Assessment of Issues and Experience 2002

Watershed Management for Potable Water Supply: Assessing the New York City Strategy 2000

BIOGRAPHY FOR STEPHEN D. PARKER

Stephen D. Parker was educated in hydrology and civil engineering at the University of New Hampshire. He is a senior staff member at the National Research Council of the National Academies. Currently he is Director of the Water Science and Technology Board (since 1982). With the WSTB, Mr. Parker is responsible for study programs in a broad range of water related and natural resources topics. Subject areas include water supply; aquatic ecology and restoration; ground water science, technology, and management; hydrologic science; water quality and water resources management; pollution control; and other related topics. His duties involve strategic planning, program development, policy analysis, report writing, interaction with federal agency program managers, supervision of a staff of approximately 10, and others. Parker's technical expertise lies principally in hydrologic engineering and water resources systems analysis. Prior to joining the NRC in 1982, he was in charge of river basin planning studies at the Federal Energy Regulatory Commission (1979–82). From 1972–79, he was with the New England Division of the Army Corps of Engineers, where he reached the level of chief of hydrologic engineering; the focus of his technical work included water quality, flood and drought, and hydropower system studies. From 1970–72, Parker was employed by Anderson-Nichols consulting engineers in Boston where he worked on water supply oriented projects. In 1969–70, Mr. Parker served in the U.S. Navy in Vietnam, where he commanded a river patrol boat He is a certified Professional Hydrologist, a member of the research advisory board of the National Water Research Institute, and active as a member of the American Institute of Hydrology and American Water Resources Association. In 1997, he was elected a fellow by the Association of Women in Science, and in 1998 he received the NRC Individual Achievement Award from the National Academy of Sciences/National Academy of Engineering.

Chairman GORDON. Thank you, Dr. Parker, and Dr. Overpeck, you are recognized.

STATEMENT OF DR. JONATHAN OVERPECK, DIRECTOR, INSTITUTE FOR THE STUDY OF PLANET EARTH; PROFESSOR, GEOSCIENCES AND ATMOSPHERIC SCIENCES, UNIVERSITY OF ARIZONA

Dr. OVERPECK. Chairman Gordon, Ranking Member Hall, Congresswoman Giffords, and other distinguished Members of the Committee, I thank you for allowing me to come and discuss these issues with you today.

One of our chief potential challenges to ensuring reliable water supply will be climate variability and also climate change. And it appears likely that both climate variability and climate change are already starting to challenge water supply in parts of our country.

Significant parts of our nation are currently in drought. Droughts in the West, central plains, Texas, and the Southeast all vie for title of the worst current drought. These droughts now occurring in the U.S. are, however, modest compared to the severe natural droughts that took place before the 20th century.

For example, western North America has seen 25-year and much longer megadroughts in just the last 1,000 years. It is safe to say that if the water supply infrastructure in many parts of our country, for example, the West, were to see such a drought, it would be overwhelmed today.

However, what is most disturbing about these natural megadroughts of the past is that we are not sure what caused them, nor are we confident that we can predict them. It is just a matter of time before we will get another megadrought, and this means that we should think seriously about making our society more resilient in the face of megadroughts.

Now, I would like to turn to the issue of climate change. The climate system is changing, very likely due to humans, and this change could also pose another major challenge to water supply in parts of our nation. Parts of our country have already warmed more than two degrees Fahrenheit in the last century and could warm another 15 or more degrees by the end of the century if we don't do something to curb emissions of greenhouse gases.

The warming has already led to substantial decreases in spring snowpack, which, in turn, has led to decreased flow in some major river systems of the United States, including the Colorado River. Current river flow estimates for some parts of the country, for example, the Colorado River, that serves seven states and over 30 million people, indicates that water supply could be greatly reduced by mid century or before.

In addition, the latest climate change science indicates that much of the conterminous U.S. could see an increase in the annual maximum number of consecutive dry days between rainfall events, a decrease in average soil moisture, and an increased likelihood of drought. Although the projected changes are less certain outside the West and Southwest, the current state of climate science suggests that they, these all should be considered real possibilities for the future.

What then can we do about this challenge? Fortunately, there are some no-regrets actions that can be taken regardless of cause, natural or human-caused climate change. We need an accelerated effort to understand climate-related water supply variabilities, both physical, biological, and social.

For example, we must incorporate realistic assessments of future climate change into water management models that are being used to assess future supply change. Also, ground water serves as a major buffer during times of drought. We must try and determine how much ground water really exists underground at local scales around our country and how quickly this ground water can be recharged in the future, both by precipitation and human mechanisms.

And lastly, we need to determine, for example, how much water can be diverted safely from agriculture, another important buffer in times of drought, to uses that support population growth in potentially water-limited regions.

Number two, we need an accelerated effort to understand climate change variability, climate variability and climate change processes, as well as how to predict them. Essential progress can be accelerated via greater funding of basic, for example, National Science Foundation and use-inspired, for example, NOAA, DOE, and NASA, climate research observation and modeling.

Number three, we need a national climate service that is designed to support local and regional decision-makers in dealing with climate-related reductions in water supply.

Finally, in addition to no-regrets options that I have just summarized, there is also the option of mitigating or reducing the likely impacts of climate change on U.S. water supply. If we wish to forestall for sure potential major climate change threats to water supply, large reductions in greenhouse gas emissions, namely 80 percent below 1990 levels by 2050, must be initiated soon.

Mr. Chairman, Members of the Committee, thank you.

[The prepared statement of Dr. Overpeck follows:]

PREPARED STATEMENT OF JONATHAN OVERPECK

Summary

One of the chief potential challenges to ensuring a reliable water supply will be climate variability and climate change. An analysis of recent climate patterns indicates that both are already starting to challenge water supplies in our nation, and that these on-going challenges provide an important lesson for the future. Climate variability, in the form of decades-long drought, is a major threat to ensuring sufficient water supplies. Human-caused climate change, including temperature increases, snowpack reductions, streamflow decreases, and increased probability of drought, will only make the situation more challenging. Options for meeting these climate challenges include much needed focused research, a new national climate service focused on local and regional decision-makers, and a policy that reduces global greenhouse gas emissions. The outlook for climate-related changes in U.S. water supply is not positive, particularly in the West, Southwest, Texas and into the Southeast. Even in other parts of the Nation, water supply could become more limiting. However, the good news is that there is time to prepare for increasing water supply challenge, and to also avoid water supply reduction threats deemed dangerous. Urgent attention is warranted.

Chairman Lampson, Ranking Member Inglis, and other Members of the Committee, thank you for the opportunity to speak with you today on *Water Supply Challenges for the 21st Century.*

My name is Jonathan Overpeck. I am the Director of the Institute for the Study of Planet Earth at the University of Arizona, where I am also a Professor of Geosciences and a Professor of Atmospheric Sciences. I have published more than 120 papers in climate and the environmental sciences, and recently served as a Coordinating Lead Author for the UN Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment (2007). I have been awarded the U.S. Department of Commerce Bronze and Gold Medals, the Walter Orr Roberts award of the American Meteorological Society and a Guggenheim Fellowship for my interdisciplinary research. I also serve as Principal Investigator of the Climate Assessment for the Southwest (CLIMAS), an interdisciplinary Regional Integrated Science and Assessment (RISA) project funded by NOAA. In this capacity, and others, I work not only on climate system research, but also on supporting use of this research by decision-makers in society.

One of the chief potential challenges to ensuring a reliable water supply will be climate variability and climate change. I would like to describe these challenges, and then discuss what our nation can do to meet them. A basic message is that it appears likely that both climate variability and climate change are already starting to challenge water supplies in our nation, and that these on-going challenges are an important lesson for the future.

Climate Variability, Drought and Water Supply

As Figure 1 shows, drought is currently affecting significant portions of our nation. Droughts in the West, Central Plains, Texas, and in the Southeast vie for the title of worst current drought. Most notably, the drought in the West, although recently softened by good winter snowfall, has persisted since about 1999, and could be far from over.

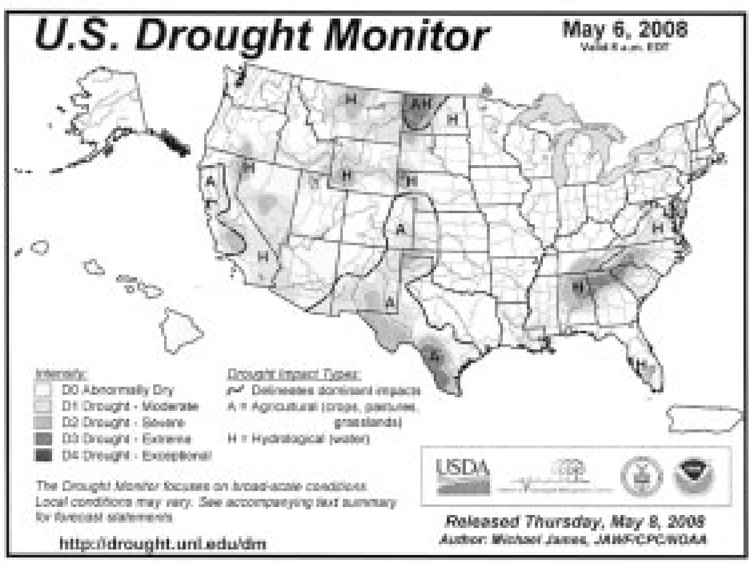

Figure 1. *Recent status of drought across the United States as of the first week of May, 2008. This map reflects recent drought relief in some areas due to above average winter snowfall in the West. The West has seen much more serious drought off and on since 1999, making the on-going western drought the worst that has occurred in the region since the nineteenth century. (From http://drought.unl.edu/dm)*

The causes of the current droughts across the U.S. are hotly debated in the climate science community, but it is safe to say that at least some of the current drought conditions are due to natural climate variability. Most likely, variability in the oceans is causing atmospheric circulation to drive drier-than-normal conditions in parts of our nation. For example, this seems to be the prime candidate for explaining the Southeast U.S. drought.

Drought of the type now occurring in the U.S. is modest compared to the more severe natural droughts that took place before the twentieth century. These earlier droughts can be reconstructed using tree-rings, lake sediments, cave formations, and other natural archives of past climate. For example, western North America, from deep into Mexico, through the western U.S. and into Canada, was gripped by a severe 20- to 25-year drought in the late sixteenth century. Droughts lasting many decades occurred during medieval times in the West, and likely had profound impacts. For example, we now know from hydrological modeling that these past "megadroughts," were they to occur in the future, would have dramatic negative impacts on the Colorado River and the water this river supplies to seven states.

It is safe to say that the water supply infrastructure in many parts of our country (e.g., the West) would be overwhelmed were a megadrought like those of the past to occur again in the future. I will return to this challenge later in my testimony.

What is most disturbing about the natural droughts of the past is that we are not sure what caused them, nor are we confident that we can predict them. Thus, it is difficult for climate scientists to say how long the current droughts will last, or whether they will intensify. What climate scientists can say, however, is that it would be foolish to assume that droughts much longer—and more severe—than those of the last 100 years won't happen again. It is just a matter of time, and this means that we should think seriously about making our society, particularly in those areas that are prone to drought (e.g., see Figure 1), more resilient in the face of future drought.

Climate Change and Water Supply

The climate system is changing, very likely due to humans, and this change could also pose another major challenge to water supply in parts of our nation. Although temperatures over most of our country have risen over the last 100 years, climate change is most notable in the U.S. West and Alaska. Across the West, temperatures have gone up by about 2°F, and more than the national average. This warming has led to significant decreases in spring snowpack, which in turn, have led to decreased flow in some major rivers, including the Colorado River. These temperature, snow, and river flow changes appear to be due, at least in part, to human-caused climate change. These changes are also quite similar to those projected by climate models for the future.

Furthermore, there are some indications—still hotly debated in the climate science community—that the current western drought itself may be related to human causes. In the Southwest, we have seen a northward shift in winter/spring storm systems that seems consistent with our understanding of human-caused climate change, and leaves the region with below-average precipitation. However, it is too early to know for sure if the current western drought, the worst in at least 100 years, is due to humans or not. What we do know is that human-caused warming is making the impacts of the drought more serious than the cooler droughts of the twentieth century.

Many of the climate changes we are currently seeing appear to be consistent with what climate models project for the future. Given the recent (since 2000) jump in global carbon dioxide emissions to the atmosphere, we are now on track, over the next 100 years, to warm parts of the coterminous U.S. by more than 15°F in summer. This change, when coupled with dramatic warming in other seasons as well, should drive a much greater atmospheric demand for moisture, reduced spring snowpack, and regional river flows in the western U.S.

Figure 2 shows only one recent estimate of how runoff, and hence river flow, could change in the next 50 years. Other estimates exist, but for the Colorado River Basin, almost all estimates are negative; some estimate suggest as much as a 40 percent reduction could occur by mid-century. Future warming and precipitation change, particularly in the spring season, appears to point only to one direction of water supply change - down.

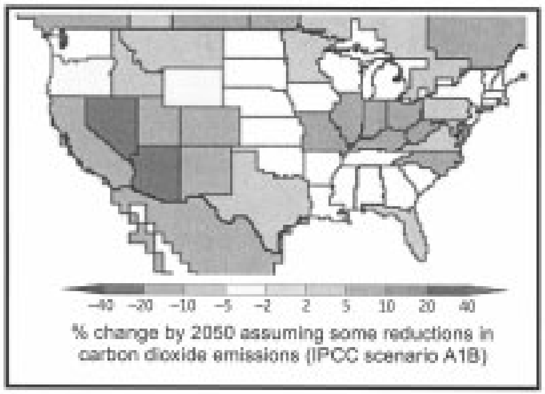

Figure 2. Changes in runoff volume projected by the middle of the twenty-first century (relative to the period 1900 to 1970 average). Color denotes percentage change (median value from 12 climate models). Where a state is colored, 8 or more of 12 models agree on the direction (increase versus decrease of runoff change under the IPCC's "SRES A1B" emission scenario. Current emissions are significantly higher than this emission scenario. (From Milly et al., 2008, Science 319, 573-574.).

Might Climate Change Spare Water Supply in all but the West and Southwest?

Figure 2, as well as most other projections of future climate-related water supply, paints a challenging picture for the West and Southwest regions of the country that have recently been experiencing some of the fastest growing populations in the Nation. Does this mean the rest of the country is safe from climate-related reductions in water supply? The answer is almost certainly "No."

In addition to the average change depicted in Figure 2, climate theory and projections also point to a human-caused increase in the frequency of drought. The recent IPCC (2007) assessment of climate model projections indicates much of the conterminous U.S. should see an increase in the annual maximum number of consecutive dry days between rainfall events, a decrease in average soil moisture, and an increased likelihood of drought. Although these projected changes are less certain outside the West and Southwest, the current state of climate science suggests they should be considered real possibilities for the future.

The Combined Challenge of Climate Variability and Climate Change.

Current scientific understanding of both climate variability (drought) and climate change indicates that there is a real future likelihood of both natural and human-caused reductions in climate-related water supply. We now know that decades-long droughts can occur naturally in parts of the U.S., just as climate change could lead to greater aridity and an enhanced probability of drought in many parts of the country, particularly the West, Southwest, Texas, and across to the Southeast. These are the same parts of the country that are now experiencing drought. Thus, the present could be a window on the future.

Meeting the Climate Challenge to U.S. Water Supply.

The future climate challenge confronting our nation's water supply is real, and will likely be due to both natural and human-caused threats. Fortunately, there are some "no-regrets" actions that can be taken regardless of cause:

(1) Call for, and support, an accelerated effort to understand climate-related water supply vulnerabilities, both physical, biological, and social. Much remains to be learned about our nation's water supply, and how it might be managed in the future. It is outside the scope of this testimony to go into great detail, but some key questions warrant greater understanding:

- How can we improve the current generation of *hydrologic models* used to project future river flow? For example, model-based estimates of future climate-change related reductions in Colorado River flow range from small (e.g., 10 percent) to large (e.g., 40 percent) by the middle of the century. Effective management of future water supply will require better hydrologic models.
- How best incorporate realistic assessments of future climate change into *river management models?* This process has begun, but needs to be accelerated given the importance of realistic projections not just of physical water supply, but also how well these supplies can be managed to meet projected use.
- How much *groundwater* exists locally around the country, and how quickly can groundwater be recharged in the future, both by precipitation, and/or human mechanisms? Many parts of the country, particularly in the West, consider groundwater to be a principal source of water, at least in times of surface-flow shortage. And yet, precise information about the volume of these underground water resources is often not available, nor is the full potential of underground water banking fully understood. This limits realistic planning.
- How much water can be diverted safely from *agricultural use* to uses that support population growth in potentially water limited regions? In many areas, agriculture accounts for 70 percent or more of total water usage. How much of this water should be diverted from agricultural use in order to support population growth, or is water left in agriculture best viewed as a resource that can buffer long droughts when other water resources become inadequate. Water left in agriculture can be sold to non-agricultural users in order to make up for water lost to drought. What is the true value of agricultural water use?

(2) Call for, and support, an accelerated effort to understand climate variability and climate change processes, as well as how to predict them. Climate change science has made tremendous advances in the last decade, but is still limited due to incomplete science infrastructure and knowledge. Essential progress can be accelerated via greater funding of basic (e.g., NSF) and "use-inspired" (e.g., NOAA, DOE and NASA) climate change research. Well-planned global climate observing systems—both *in situ* and space-based—must be completed, and special efforts are needed to extend these observing networks to include much denser climate-related observations at the local to regional scales so important for decision-making. Climate modeling capability must also be enhanced to improve the realism of state-of-the-art models, particularly with regard to simulating (and predicting) climate variability and change at the global to regional-scales needed for enhanced planning and decision-making.

Some regions with likely greater-than-average exposure to climate-related water challenges, require an extra effort to understand what is at stake and what we can do about it. For example, the Southwest U.S. is the fastest growing part of the country, but it is also the region that could be most at risk to water supply shortage. Despite this, we lack an adequate understanding of the summer monsoon system that brings substantial rainfall to some parts of the region. We can't say whether this summer rainfall will likely go up, or go down. We don't know the implications of how changes in this basic water resource could be managed. As with other key regional issues, urgent attention is needed to make sure that some parts of the country don't become big losers in the face of climate variability and change.

(3) Call for, and support, a national climate service that is designed to support local and regional decision-makers in dealing with climate-related reductions in water supply. At present, the climate-related decision-support needs of regional stakeholders (e.g., water managers) are not met adequately. A number of federal and State agencies have recognized this problem, and planning has begun at a number of levels for a more organized, interagency, national climate service. The key to success for such a service is that it be accountable to, and meet the needs of, regional decision-makers. This service should benefit from the national climate research, observations and modeling infrastructure (e.g., within NOAA), and it should also benefit from the experiences, and stakeholder-partnerships, of the NOAA-funded interdisciplinary Regional Integrated Science and Assessment (RISA) program. Any national climate service needs to have a strong accountability mechanism to ensure that the regional decision-making needs are met, first and foremost.

In addition to the above "no-regrets" options, there is the option of mitigating—or reducing—the likely impacts of climate change on U.S. water supply:

(4) Create policy that reduces global greenhouse gas emissions. Current state-of-the-art climate science indicates that a tighter water supply could occur in many parts of our nation due to climate change. Large temperature increases, greater atmospheric demand for moisture, increasing snow reductions, river flow declines, and a likely increase in the probability of drought, all appear to be already underway in some parts of the globe, including the U.S. Climate model projections indicate that these trends will likely create an increasing challenge to water supply into the future, to 2100 and beyond. A national climate service (see #3 above) would serve to quantify the levels of climate-related water reductions that can be met through technology, planning and adaptation. Beyond any "adaptable" level of climate change-related water supply reduction, however, exists potentially dangerous levels of climate change that can be avoided through an aggressive effort to reduce greenhouse gas emissions.

Summary

The outlook for climate-related changes in U.S. water supply is not positive, particularly in the West, Southwest, Texas and into the Southeast. Even in other parts of the Nation, water supply could become more limiting. However, the good news is that there is time to prepare for increasing water supply challenge, and to also avoid water supply reduction threats deemed dangerous. Urgent attention is warranted.

Thank you for the opportunity to address you today.

BIOGRAPHY FOR JONATHAN OVERPECK

Jonathan Overpeck is a climate system scientist at the University of Arizona, where he is also the Director of the Institute for the Study of Planet Earth, as well as a Professor of Geosciences and a Professor of Atmospheric Sciences. He received his BA from Hamilton College, followed by a M.Sc. and Ph.D. from Brown University. Jonathan has published over 120 papers in climate and the environmental sciences, and recently served as a Coordinating Lead Author for the Nobel prize winning UN Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment (2007). He has also been awarded the U.S. Department of Commerce Bronze and Gold Medals, as well as the Walter Orr Roberts award of the American Meteorological Society, for his interdisciplinary research. Overpeck has also been a Guggenheim Fellow, and was the 2005 American Geophysical Union Bjerknes Lecturer. He serves on the Board of Reviewing Editors for *Science* Magazine.

Chairman GORDON. Thank you, Dr. Overpeck, and Dr. Wilkinson, you are recognized.

STATEMENT OF DR. ROBERT C. WILKINSON, DIRECTOR, WATER POLICY PROGRAM, DONALD BREN SCHOOL OF ENVIRONMENTAL SCIENCE AND MANAGEMENT, UNIVERSITY OF CALIFORNIA–SANTA BARBARA

Dr. WILKINSON. Thank you, Mr. Chairman. Chairman Gordon, Members of the Committee, I appreciate the opportunity to share some thoughts with you today. I have got some Power Points, and I will try to click through them quickly.

Let me start with the four points I would like to make. Integrated policy and planning I am going to pitch, and I have in my written testimony that we couple the science and technology assets that we have with policy processes. Multiple benefit strategies, designs for flexibility, and put it all in a climate change context.

This is a map of total water withdrawals in the U.S., and I will draw your attention to the little mountains off on the right-hand side of the picture. Most of those are thermal power plants. I was asked to address the water energy nexus, and so there is a differentiation here between the east and the west to some extent as to what we are withdrawing water for in different areas.

Many water systems in the U.S. are already over-allocated and stressed. Every major supply system in California is already over-allocated.

Here is a population growth map and water resources, and you can see even in areas that are marked in blue in terms of water resources when we look at the drought monitor for the U.S. Jonathan has in his presentation the same map for two months later, almost exactly, drawn from the current map here in May, it looks almost identical, so you can see some of that tremendous drought in the Southeast is occurring in areas that until recently many thought were wet and somewhat immune to the same kind of droughts.

Nearly 20 years ago two of the stars in the field of climate science, Roger Evall and Paul Wagoner, made a very important observation. Governments at all levels should reevaluate legal, technical, and economic procedures for managing water resources in the light of climate changes that are highly likely.

Indeed, we are seeing those changes unfold, and we need to visit, again, our institutions and legal frameworks as well as our science and technical capacity.

Just a quick little bit of history of where we were only 50 years ago in our thinking about water resource management. This is a map of North America. You will see in the upper left the water collection region. Coming down through the water transfer region it was thought that Oregon and Washington didn't need much, and we will distribute it down in the Southwest and be very generous right on across the Mexican border. And you will see in the middle of the picture the optional water distribution region, maybe even share some there.

This was a serious plan. Here is the plumbing for that plan, and that was the way we were thinking about managing water through inter-basin transfers only 50 years ago. A lot of thinking has changed from the idea of building facilities in the West in particular with surface storage, with conveyance systems. We have some remarkable engineering and remarkable systems, but we are having difficulty with the match between hydrology and those systems providing for our needs.

What we need is integrated whole-system approaches to water and energy management in the context of science and technology, of climate change, economics, and environmental concerns. We need policy strategies that are designed to tap multiple benefits and are flexible in the face of changing circumstances.

So let me briefly go through then some energy observations here. About nineteen percent of California's electricity (I am going to focus here on California, if I may) and about a third of our natural gas goes to water. In fact, water is the top use of electricity in California. Now, our systems, as you can see ground water and local water projects, actually provide the majority of water, but we have major plumbing facilities as well.

I will run you through the State project very quickly. That is the red line on this map. Here is all the pumping plants for that system. Here is one of them, the largest pumping plant in the world. That is only half of it at the foot of the Tehachapi Mountains, and this is what it looks like as we plot out all of the energy inputs to those systems.

Putting that on a bar chart, the red bars are the inner-base and transfer points, including the Colorado River Aqueduct and the

State Water Project. You will note that they exceed ocean water desalination in terms of energy intensity already. Energy intensity is the total amount of energy embodied in water used in a particular place.

We run through a calculation, California has been doing quite a bit of this work now, to figure out every step in that water process and then to understand opportunities to manage it differently.

Here is one of the largest uses as you can see, single families for the U.S., not just California, and then going to the, half this residential, half of that is outdoors, half is indoors. Here is California's official State water plan, and here are the sources of water for the next quarter century. I will draw your attention to the bar on the right. Urban water use efficiency, doing something about that water use on the demand side is where we expect to get most of our water in the future, along with conjunctive management and recycled water. Those are the big ones.

I am going to skip through because my time is out, but here are some of those opportunities for water management that are going to provide the new water supplies, at least according to our State planning process in California. Coupled to that is capturing storm water in different techniques that are often simple but very effective, recycling water, going to hi-tech filtration, reverse osmosis for different sources.

And then going to the flip of that very quickly, the water intensity of energy, actually energy, thermal energy facilities are the largest use of water withdrawn in the United States along with agriculture over a third and about a three percent of total consumption.

The federal labs are doing a lot of work on this. Analysis is indicating that we have got lots of opportunities to produce energy with very little or no water, and we have other opportunities that use tremendous amounts of water. So we have choices to make.

Quick conclusions then. Water scarcity and quality will remain key issues. Vast opportunities do exist, though, for efficiency improvements. Science and technology are critically important in addressing water supply quality challenges but policy design and implementation is equally as important. So integrated whole-system planning and designing policies and infrastructure for flexibility and multiple benefits.

I pose two questions in my written testimony. How can we decouple water and energy systems where there are high costs, stresses, damages, or vulnerabilities to systems, and how can we maximize water and energy efficiency and productivity so as to maximize benefits to society?

Thank you very much.

[The prepared statement of Dr. Wilkinson follows:]

PREPARED STATEMENT OF ROBERT C. WILKINSON

The Committee on Science and Technology of the United States House of Representatives has chosen a critically important topic with this hearing on *Water Supply Challenges for the 21st Century*. Thank you for the opportunity to share some information and ideas with you today.

I will focus on the water/energy nexus as it relates to science and technology, and also as it relates to policy design and implementation. The selection and implementation of policy instruments to address water and energy management challenges is integrally linked to the foundation provided by science and technology. Policy frameworks are important in achieving positive outcomes based on our investments in science and technology.

The two main points I would like to convey today involve the need for:

1. *Integrated, whole-system approaches* to water and energy management in the context of science and technology, climate change, economics, and environmental concerns, and;
2. Policy strategies that are designed to tap *multiple benefits* and are flexible in the face of changing circumstances.

Due to the importance of the climate change context for both water and energy, I provide brief comments on water/energy/climate links and tie them specifically to science and technology policy developments, particularly at the State level.

This testimony presents both detailed California examples and U.S.-wide data and considerations. Because we have developed good data and analyses of some of the water/energy/climate challenges in California, I will focus in this testimony on specifics from the state. The methodology and many of the lessons may be extrapolated to other parts of the country.

The Water and Energy Context

Water use for urban and agricultural purposes around the world has been facilitated through diversions of surface water and extraction of groundwater delivered through conveyance systems. Both water and energy are often transported over long distances from their sources to the place where they are ultimately used. As technological capacity developed over the past century, surface water diversions, groundwater extraction, and conveyance systems increased in volume and geographic extent. Interbasin transfers supplemented water available within natural hydrological basins or watersheds. Agricultural and urban uses of arid lands were vastly extended by imported water. Similarly, energy systems have evolved from largely local sources a century ago to continent-wide electricity grids and pipeline networks, and to global supply-lines.

Rainfall patterns in the United States vary widely. In Las Vegas, the driest of America's major cities, precipitation averages barely four inches (102 mm) per year. Portland, Oregon has nine times the precipitation of Las Vegas. Miami, Florida is doused with over 55 inches (1,397 mm) per year, and the Northeast usually receives above 75 inches (1,778 mm) per year.

Generally, states east of the Mississippi have been assumed to have abundant water resources for water supply purposes. Recent droughts and shortages in Florida and the Southeast as well as other parts of the "wet" east are changing this perception. West of the Mississippi, and particularly west of the Rocky Mountains, federally subsidized engineered systems of large dams and aqueducts or pipelines provide water supplies to many users. These systems were constructed during the 1900s, motivated primarily by droughts that occurred periodically. Today, the sources of water for these facilities are over-allocated, and "new" future supplies are increasingly coming from improved water-use efficiency and recycling rather than from expensive new water supply development projects.

The focus of technology development and policy for much of the past century has been on the supply side of both the energy and water equations. That is, the emphasis was on extracting, storing, converting, and conveying water and energy from natural systems to users. Water and energy policy throughout the world has generally been designed to facilitate the development and use of these supply-side technologies. In the last quarter century, however, scientific developments and technological innovation has increasingly been applied to improvement of the *efficiency of use* of energy and water resources. (*"Efficiency"* as used here describes the useful work or service provided by a given amount of water or energy.) Significant potential economic as well as environmental benefits can be cost-effectively achieved through efficiency improvements in water and energy systems. Various technologies, from electric motors and lighting systems to pumps and plumbing fixtures have vastly improved end-use efficiencies.

Today, the main constraints on water *extractions* are not technology limitations. Indeed, there is significant spare capacity for pumping and conveyance in many areas. The limits are increasingly imposed by competing claims on scarce water resources (e.g., the various claims to the Colorado River), legal constraints, and environmental impacts.

Costs of building and maintaining infrastructure have also risen dramatically. The maintenance cost for existing water and wastewater systems is staggering. The American Society of Civil Engineers estimate an annual need for over $30 billion for safe drinking water ($11 billion) and properly functioning wastewater treatment systems (about $20 billion) in the United States.[1] They also indicate a need for about $1 billion per year to repair unsafe non-federal dams, the number of which has increased by a third in the past decade.[2]

The focus of technology development and implementation policy to meet water needs is therefore increasingly on more efficient use and on water treatment technologies. Innovation and development of technology in the areas of end-use water applications and water treatment has progressed rapidly. Techniques and technologies ranging from laser leveling of fields and drip irrigation systems to the improved design of plumbing fixtures, industrial processes, and treatment technology have changed the demand side of the water equation. End-uses of water now require much less volume to provide equivalent or superior services. Rainwater capture for groundwater recharge and other innovative water capture strategies are also enhancing water supply reliability. Water supply systems (e.g., treatment and distribution) are also becoming more efficient. For example, geographical information systems (GIS) and field technologies allow for improved capabilities to locate leaks in buried pipes.

The Climate Change Context for Water Policy

Climate change poses important water and energy management challenges. Science is indicating that the rate and magnitude of warming and related impacts are increasing. The Intergovernmental Panel on Climate Change's (IPCC's) Fourth Assessment Report in 2007 projected that the rate of warming over the 21st century—up to 11.5 degrees Fahrenheit—would be much greater than the observed changes during the 20th century. The report also confirmed that "11 of the last 12 years (1995 to 2006) rank among the twelve warmest years . . . since 1850."[3] (The year 2007 has now registered as the second hottest year, extending the trend.) The IPCC projects the following changes as a result of increased temperatures:[4]

- more frequent hot extremes, heat waves, and heavy precipitation events
- more intense hurricanes and typhoons
- decreases in snow cover, glaciers, ice caps, and sea ice
- rise in global mean sea level of seven to 23 inches, however this projection does not include accelerated ice sheet melting and other factors.

Climate models consistently indicate a warmer future for the U.S. West. Evidence of warming trends is already being seen in winter temperatures in the Sierra Nevada, which rose by almost two degrees Celsius (four degrees Fahrenheit) during the second half of the 20th century. Trends toward earlier snowmelt and runoff to the Sacramento–San Joaquin Delta over the same period have also been detected.[5] Water managers are particularly concerned with the mid-range elevation levels where snow shifts to rain under warmer conditions, thereby reducing snow-water storage. California's Department of Water Resources, along with the California Energy Commission, has been tracking the climate change science since the 1980s.[6]

California law states clearly that "Global warming poses a serious threat to the economic well-being, public health, natural resources, and the environment of California."[7] The potential impacts of climate change and variability to California are serious.[8] Integrated policy, planning, and management of water resources and en-

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[1] American Society of Civil Engineers, Report Card, *http://www.asce.org/reportcard/2005/page.cfm?id=23*

[2] American Society of Civil Engineers, Report Card, *http://www.asce.org/reportcard/2005/page.cfm?id=23*

[3] *Climate Change 2007: The Physical Science Basis: Summary for Policy-makers.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, p. 4. *http://www.ipcc.ch/index.htm*

[4] *Climate Change 2007: The Physical Science Basis: Summary for Policy-makers.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. *http://www.ipcc.ch/index.htm*

[5] Dettinger, MichaeLD., and Dan R. Cayan. 1994. Large-scale atmospheric forcing of recent trends toward early snowmelt runoff in California. *Journal of Climate* 8: 606–23.

[6] California Department of Water Resources, 2006. Progress on Incorporating Climate Change into Management of California's Water Resources, *http://www.climatechange.ca.gov/documents/2006-07_DWR_CLIMATE_CHANGE_F1NAL.PDF*

[7] *California Global Warming Solutions Act of 2006,* (AB32) Section 38501 (a).

[8] Intergovernmental Panel on Climate Change (IPCC) documents at: *http://www.ipcc.ch/index.htm*; Wilkinson, Robert C., 2002. *The Potential Consequences of Climate Variability and Change for California, The California Regional Assessment,* Report of the California Regional Assessment Group for the U.S. Global Change Research Program, National Center for Geo-

Continued

ergy systems can provide important opportunities to respond effectively to challenges posed by climate change. Both mitigation (i.e., reducing greenhouse gas emissions) and adaptation (dealing with impacts) strategies are being developed. While both energy and water managers have used integrated planning approaches for decades, the broader integration of water and energy management in the context of climate change is a relatively new and exciting policy area.

Integrating Water and Energy Policy

Government agencies at various levels are currently integrating water and energy policies to respond to climate change as well as to environmental challenges and economic imperatives. Water and energy systems are interconnected in important ways. Developed water systems provide energy (e.g., through hydropower), and they consume energy through pumping, thermal, and other processes. Government agencies are looking at water delivery system and end-use water efficiency improvements, source switching (e.g., using recycled water for industry and irrigation), improved rainwater capture and groundwater recharge, and other measures that save energy by reducing pumping and other energy inputs. Recent studies are indicating significant opportunities in each area.[9] Several California examples of coupled science/technology/policy approaches are presented here. While they are specific to the state, many of the basic features are similar in other states across the U.S.

New approaches to the integration of water, energy, and climate change policy and planning, including policy processes at the state's Energy Commission, Public Utilities Commission, Department of Water Resources, Water Resources Control Board, and Air Resources Board, are being developed. Methodologies to account for embedded energy in water systems—from initial extraction through treatment, distribution, end-use, wastewater treatment and discharge—and water use by energy systems, have been developed and are outlined below.[10] Institutional collaboration between energy, water, and other management authorities is also evolving.

Integrated Energy Policy Report, November 2005, CEC–100–2005–007–CMF: and Klein, Gary (2005). California Energy Commission, California's Water—Energy Relationship. Final Staff Report, Prepared in Support of the 2005 Integrated Energy Policy Report Proceeding, (04–IEPR–01E) November 2005, CEC–700–2005–011–SF.

Water is now recognized as the *largest electricity use* in California. Water systems account for approximately 19 percent of total electricity use and about 33 percent of the non-power plant natural gas use in the state.[11] The California Energy Commission (CEC) and the California Public Utilities Commission (CPUC) have both concluded that energy embedded in water presents large untapped opportunities for cost-effectively improving energy efficiency and reducing greenhouse gas (GHG) emissions. The CEC commented in its 2005 *Integrated Energy Policy Report* that: "The Energy Commission, the Department of Water Resources, the CPUC, local water agencies, and other stakeholders should explore and pursue cost-effective water efficiency opportunities that would save energy and decrease the energy intensity in the water sector."[12] Fortunately this corresponds with the state's 2005 Water Plan.[13]

The California Energy Commission's staff report, *California's Water—Energy Relationship,* notes that: "In many respects, the *2005 Water Plan Update* mirrors the state's adopted loading order for electricity resources described in the Energy Com-

graphic Information Analysis, and the National Center for Ecological Analysis and Synthesis, University of California, Santa Barbara. Available at: *http://www.ncgia.ucsb.edu/products.html*

[9] See for example: Park, Laurie, Bill Bennett, Stacy Tellinghuisen, Chris Smith, and Robert Wilkinson, 2008. *The Role of Recycled Water In Energy Efficiency and Greenhouse Gas Reduction,* California Sustainability Alliance, available at: *www.sustainca.org.* Also see: California Energy Commission (2005). *Integrated Energy Policy Report,* November 2005, CEC–100–2005–007–CMF: and Klein, Gary (2005). California Energy Commission, California's Water—Energy Relationship. Final Staff Report, Prepared in Support of the 2005 Integrated Energy Policy Report Proceeding, (04–IEPR–01E) November 2005, CEC–700–2005–011–SF.

[10] Wilkinson, Robert C. (2000). *Methodology For Analysis of The Energy Intensity of California's Water Systems, and an Assessment of Multiple Potential Benefits Through Integrated Water-Energy Efficiency Measures,* Exploratory Research Project, Ernest Orlando Lawrence Berkeley Laboratory, California Institute for Energy Efficiency; California Energy Commission (2005). *Integrated Energy Policy Report,* November 2005, CEC–100–2005–007–CMF: California Energy Commission (2005).

[11] California Energy Commission (2005). *Integrated Energy Policy Report,* November 2005, CEC–100–2005–007–CMF.

[12] California Energy Commission (2005). *Integrated Energy Policy Report,* November 2005, CEC–100–2005–007–CMF.

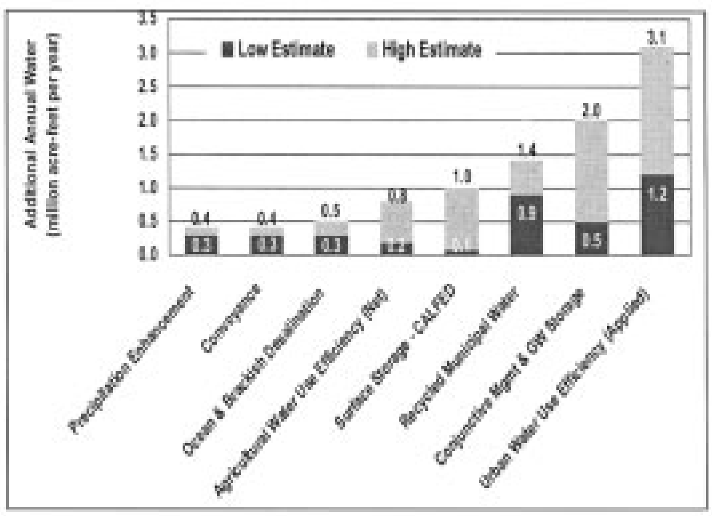
[13] California Department of Water Resources (2005). California Water Plan Update 2005. Bulletin 160–05, California Department of Water Resources, Sacramento, CA.

mission's *Integrated Energy Policy Report 2005* and the multi-agency *Energy Action Plan*." [14]

One of the top recommendations in the California Energy Commission's 2005 *Integrated Energy Policy Report* (IEPR) is as follows: "The Energy Commission strongly supports the following energy efficiency and demand response recommendations: The CPUC, Department of Water Resources, the Energy Commission, local water agencies and other stakeholders should assess efficiency improvements in hot and cold water use in homes and businesses, and include these improvements in 2006–2008 programs." It observes that "Reducing the demand for energy is the most effective way to reduce energy costs and bolster California's economy." [15]

Improvements in urban water use efficiency have been identified by the Department of Water Resources in its official State Water Plan as the *largest new water supply* for the next quarter century, followed by groundwater management and reuse. The following graph indicates the critical role water use efficiency, groundwater recharge and management, and reuse will play in California's water future.

Water Management and Supply Options for the Next 25 Years
California State Water Plan 2005



Source: California Department of Water Resources, 2005.

The CEC staff report notes that, "As California continues to struggle with its many critical energy supply and infrastructure challenges, the state must identify and address the points of highest stress. At the top of this list is California's water-energy relationship." [16] It continues with this interesting finding: "The state can meet energy and demand-reduction goals comparable to those already planned by the state's investor-owned energy utilities for the 2006–2008 program period by simply recognizing the value of the energy saved for each unit of water saved. If allowed to invest in these cold water energy savings, energy utilities could co-invest in water use efficiency programs, which would in turn supplement water utilities' efforts to meet as much load growth as possible through water efficiency. Remark-

[14] Klein, Gary (2005). California Energy Commission, California's Water—Energy Relationship. Final Staff Report, Prepared in Support of the 2005 Integrated Energy Policy Report Proceeding, (04–IEPR–01E) November 2005, CEC–700–2005–011–SF.

[15] California Department of Water Resources (2005). California Water Plan Update 2005. Bulletin 160–05, California Department of Water Resources, Sacramento, CA.

[16] Klein, Gary (2005). California Energy Commission, California's Water—Energy Relationship. Final Staff Report, Prepared in Support of the 2005 Integrated Energy Policy Report Proceeding, (04–IEPR–01E) November 2005, CEC–700–2005–011–SF.

ably, staff's initial assessment indicates that this benefit could be realized at less than half the cost to electric rate payers of traditional energy efficiency measures." [17]

This finding is consistent with an earlier analysis which found that energy use for conveyance, including interbasin water transfer systems (systems that move water from one watershed to another) in California, accounted for about 6.9 percent of the state's electricity consumption.[18] Estimates by CEC's Public Interest Energy Research—Industrial, Agriculture and Water (PIER–IAW) experts indicate that "total energy used to pump and treat this water exceeds 15,000 GWh per year, or *at least* 6.5 percent of the total electricity used in the state per year." They also note that the State Water Project (SWP)—the state-owned storage and conveyance system that transfers water from Northern California to various parts of the state including Southern California—is the largest single user of electricity in the state, accounting for two percent to three percent of all the electricity consumed in California and using an average of 5,000 GWh per year.[19]

The magnitude of these figures suggests that *failing* to include embedded energy in water and wastewater systems, and *failing* to tap energy saving derived from water efficiency improvements would be a policy opportunity lost.

Tapping Integrated Water/Energy Opportunities

Elements of typical water infrastructures are energy intensive. Moving large quantities of water long distances and over significant elevation gains, treating and distributing it within communities, using it for various purposes, and collecting and treating the resulting wastewater, accounts for one of the largest uses of electrical energy in many areas.[20]

> ***Energy intensity*** **of water is the total amount of energy, calculated on a whole-system basis, required for the use of a given amount of water in a specific location.**

Water systems include extraction of "raw" (untreated) water supplies from natural sources, conveyance, treatment, storage, distribution, end-uses, and wastewater treatment. The total energy embodied in a unit of water used in a particular place varies with location, source, and use.

There are four principle energy elements of water systems:

1. primary water extraction, conveyance, and storage
2. treatment and distribution within service areas
3. on-site water pumping, treatment, and thermal inputs (heating and cooling)
4. wastewater collection, treatment and discharge

Pumping water in each of these stages is energy-intensive. Other important energy inputs include thermal energy (heating and cooling) applications at the point of end-use, and aeration in wastewater treatment processes.

1. **Primary water extraction, conveyance, and storage.** Extracting and lifting water is highly energy intensive. Surface water and groundwater pumping requires significant amounts of energy depending on the depth of the source. Where water is stored in intermediate facilities, net energy is required to store and then recover the water.

[17] Klein, Gary (2005). California Energy Commission, California's Water—Energy Relationship. Final Staff Report, Prepared in Support of the 2005 Integrated Energy Policy Report Proceeding, (04–IEPR–01E) November 2005, CEC–700–2005–011–SF.

[18] Wilkinson, Robert C. (2000). *Methodology For Analysis of The Energy Intensity of California's Water Systems, and an Assessment of Multiple Potential Benefits Through Integrated Water-Energy Efficiency Measures,* Exploratory Research Project, Ernest Orlando Lawrence Berkeley Laboratory, California Institute for Energy Efficiency.

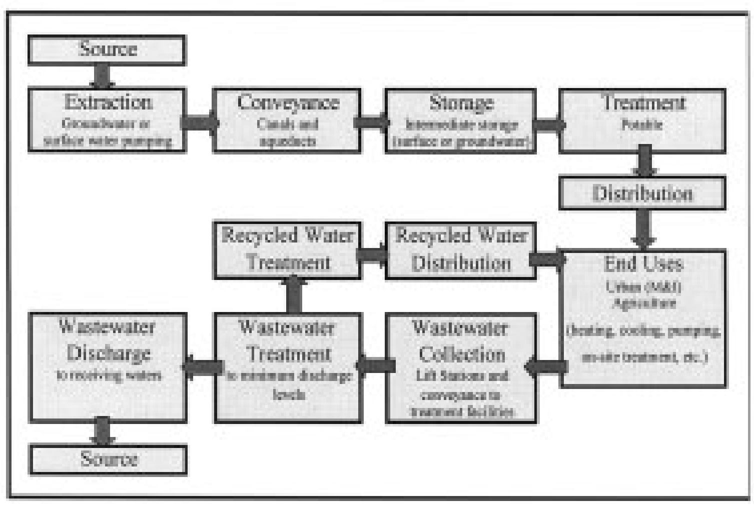
[19] California Energy Commission (2006). Public Interest Energy Research—Industrial, Agriculture and Water, *http://energy.ca.gov/pier/iaw/industry/water.html*

[20] For a methodology to examine water intensity, see: Wilkinson, Robert C., 2000. *Methodology For Analysis of The Energy Intensity of California's Water Systems, and an Assessment of Multiple Potential Benefits Through Integrated Water-Energy Efficiency Measures,* Exploratory Research Project, Ernest Orlando Lawrence Berkeley Laboratory, California Institute for Energy Efficiency.

2. **Treatment and distribution within service areas.** Within local service areas, water is treated, pumped, and pressurized for distribution. Local conditions and sources determine both the treatment requirements and the energy required for pumping and pressurization. Some distribution systems are gravity-driven, while others require pumping.
3. **On-site water pumping, treatment, and thermal inputs.** Individual water users require energy to further treat water supplies (e.g., softeners, filters, etc.), circulate and pressurize water supplies (e.g., building circulation pumps), and heat and cool water for various purposes.
4. **Wastewater collection, treatment, and discharge.** Finally, wastewater is collected and treated by a wastewater system (unless a septic system or other alternative is being used) and discharged. Wastewater is sometimes pumped to treatment facilities where gravity flow is not possible, and the standard treatment processes require energy for pumping, aeration, and other processes.

The simplified flow chart[21] below illustrates the steps in the water system process.

Flow Diagram of Energy Inputs to Water Systems



Source: Wilkinson

The energy intensity of water varies considerably by geographic location of both end-users and sources. Water use in certain places is highly energy-intensive due to the combined requirements of conveyance over long distances and elevation lifts, treatment and distribution, and wastewater collection and treatment processes. Important work already undertaken by various government agencies, professional associations, private sector users, and non-governmental organizations in the area of combined end-use efficiency strategies has demonstrated considerable potential for improvement. Significant and profitable energy efficiency gains are possible through implementation of cost-effective *water* efficiency improvements.

The Energy Intensity of Water in California: A Case Study

California's water systems are uniquely energy-intensive due in large part to the pumping requirements of major conveyance systems which move large volumes of water long distances and over thousands of feet in elevation. Some interbasin trans-

[21] This schematic and method is based on Wilkinson (2000) with refinements by Gary Klein, California Energy Commission, Gary Wolff, Pacific Institute, and others.

fer systems such as California's State Water Project (SWP) and the Colorado River Aqueduct (CRA) require large amounts of electrical energy to convey water.

Water use (based on embedded energy) is the second or third largest consumer of electricity in a typical Southern California home after refrigerators and air conditioners.[22] The electricity required to support water service in the typical home in Southern California is estimated to be between 14 percent to 19 percent of total residential energy demand.[23] The Metropolitan Water District of Southern California (MWD) reached similar findings, estimating that energy requirements to deliver water to residential customers equals as much as 33 percent of the total average household electricity use.[24] Nearly three quarters of this energy demand is for pumping imported water.

Water system operations pose a number of challenges for energy systems due to factors such as large loads for specific facilities, time and season of use, and geographic distribution of loads. Pumping plants are among the largest electrical loads in the state. For example, the SWP's Edmonston Pumping Plant, situated at the foot of the Tehachapi Mountains, pumps water 1,926 feet (the highest single lift of any pumping plant in the world) and is the largest *single user* of electricity in the state.[25] In total, the SWP *system* is the largest user of electricity in the state.[26] A study for the Electric Power Research Institute by Franklin Burton found that at a national level, water systems account for an estimated 75 billion kWh per year (about three percent of total electricity demand).[27]

The schematic below shows the cumulative net energy, and the incremental energy inputs or outputs, at each of the pumping and energy recovery facilities of the SWP. (Energy recovery is indicated with negative numbers, which reduce net energy at that point in the system.)

[22] Wilkinson, Robert C. (2000). *Methodology For Analysis of The Energy Intensity of California's Water Systems, and an Assessment of Multiple Potential Benefits Through Integrated Water-Energy Efficiency Measures,* Exploratory Research Project, Ernest Orlando Lawrence Berkeley Laboratory, California Institute for Energy Efficiency; QEI, Inc. (1992). *Electricity Efficiency Through Water Efficiency,* Report for the Southern California Edison Company.

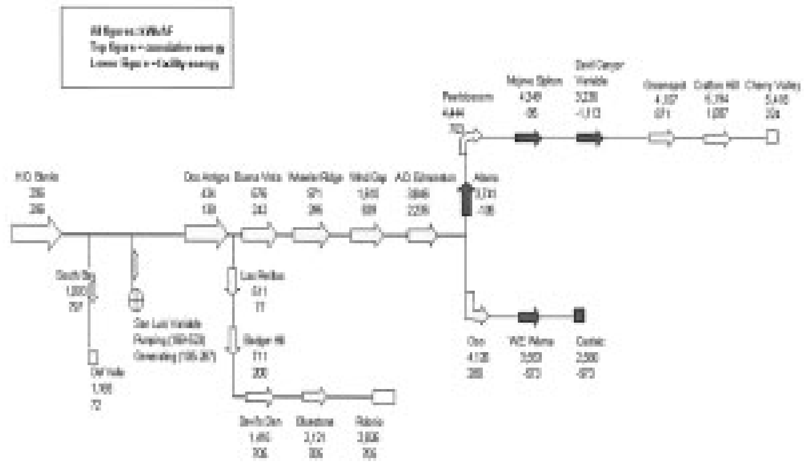
[23] QEI, Inc. (1992). *Electricity Efficiency Through Water Efficiency,* Report for the Southern California Edison Company.

[24] Metropolitan Water District of Southern California (1996). *Integrated Resource Plan for Metropolitan's Colorado River Aqueduct Power Operations.*

[25] California Department of Water Resources (1996). *Management of the California State Water Project.* Bulletin 132–96.

[26] Anderson, Carrie (1999). "Energy Use in the Supply, Use and Disposal of Water in California," Process Energy Group, Energy Efficiency Division, California Energy Commission.

[27] Burton, Franklin L. (1996). *Water and Wastewater Industries: Characteristics and Energy Management Opportunities.* (Burton Engineering) Los Altos, CA, Report CR–106941, Electric Power Research Institute Report.



State Water Project Energy Inputs and Recovery
(Kilowatt-Hours per Acre Foot Pumped - Includes Energy Recovery)

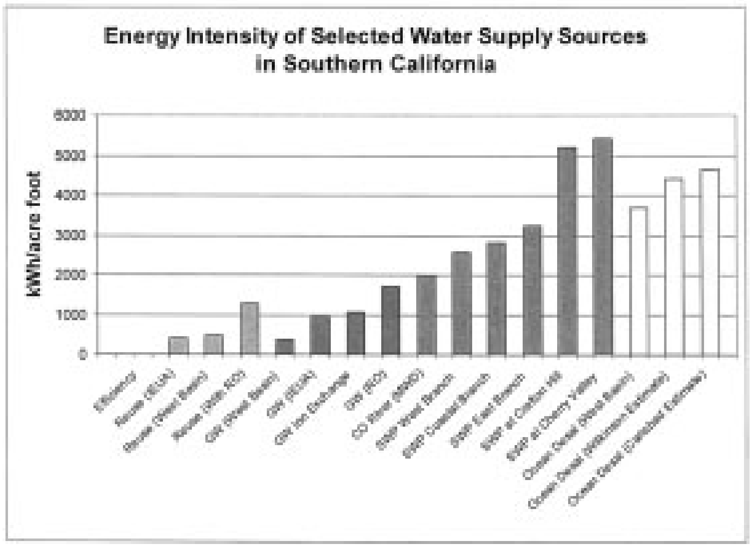
Source: Wilkinson, based on data from
California Department of Water Resources.

Approximately 5,418 kWh are required to pump one acre-foot of SWP water from the Sacramento-San Joaquin Delta to Cherry Valley on the East Branch, 2,580 kWh/af at Castaic on the West Branch, and 2,826 kWh/af to Polonio on the Coastal Branch. Approximately 2,000 kWh/af is required to pump Colorado River water to Southern California.[28] This is raw (untreated) water delivered to those points. From there conveyance continues by gravity or pumping to treatment and distribution within service areas.

Note that at certain points in the system the energy intensity is high because the service areas are located at higher elevations. At Pearblossom (4,444 kWh/af) *raw* water supplies are roughly equivalent to estimates for desalinated ocean water systems. (Ocean desalination is estimated at 4,400 kWh/af based on work by the author for the California Desalination Task Force.) At Crafton Hill and Cherry Valley, the energy intensity of imported water is well in excess of current estimates of ocean desalination.

The following graph shows the energy intensity of major water supply options for actual inland and coastal locations in Southern California.

[28] Metropolitan Water District of Southern California (1996). *Integrated Resource Plan for Metropolitan's Colorado River Aqueduct Power Operations.*



Source: Wilkinson based on data from IEUA, West Basin MWD, DWR, and desalination estimates.

Each bar represents the energy intensity of a specific water supply source at selected locations in Southern California. The data is presented in kWh/af. Water conservation—e.g., not using water in the first place—avoids additional energy inputs along all segments of the water use cycle. Consequently, water use efficiency is the superior water resource option from an energy perspective (and typically from a cost perspective as well). For all other water resources, there are ranges of actual energy inputs that depend on many factors, including the quality of source water, the energy intensity of the technologies used to treat the source water to standards needed by end-users, the distance water needs to be transported to reach end-users, and the efficiency of the conveyance, distribution, and treatment facilities and systems.[29]

Note that improved efficiency (e.g., fixing leaks, replacing inefficient plumbing fixtures and irrigation systems, and other cost-effective measures) requires no water system energy inputs. Next to water conservation, recycled water and groundwater are lower energy intensity options than most other water resources in many areas of California.[30] Even with advanced treatment to deal with salts and other contaminants (the blue and green bars), recycled water and groundwater usually require far less energy than the untreated imported water (red bars) and seawater desalination (yellow bars). The Chino desalter, a reverse osmosis (RO) treatment process providing high-quality potable water from contaminated groundwater (the energy figure above includes groundwater pumping and RO filtration) is far less energy intensive than any of the imported raw water. From an energy standpoint, greater reliance on water conservation, reuse and groundwater provides significant benefits. From a greenhouse gas emissions standpoint, these energy benefits provide significant potential emissions reduction benefits in direct relation to their energy savings.

Groundwater pumping energy requirements vary depending on the lift required. The California Energy Commission's Public Interest Energy Research—Industrial, Agriculture and Water program provides the following assessment of pumping in important parts of the Central Valley: "The amount of energy used in pumping

[29] Wilkinson, Robert C. (2000). *Methodology For Analysis of The Energy Intensity of California's Water Systems, and an Assessment of Multiple Potential Benefits Through Integrated Water-Energy Efficiency Measures,* Exploratory Research Project, Ernest Orlando Lawrence Berkeley Laboratory, California Institute for Energy Efficiency.

[30] Park, Laurie, Bill Bennett, Stacy Tellinghuisen, Chris Smith, and Robert Wilkinson, 2008. *The Role of Recycled Water In Energy Efficiency and Greenhouse Gas Reduction,* California Sustainability Alliance, available at: *www.sustainca.org*

groundwater is unknown due to the lack of complete information on well-depth and groundwater use. DWR has estimated groundwater use and average well depths in three areas responsible for almost two-thirds of the groundwater used in the state: the Tulare Lake basin, the San Joaquin River basin, and the Central Coast region. Based on these estimates, energy used for groundwater pumping in these areas would average 2,250 GWh per year at a 70 percent pumping efficiency (1.46 kWh/acre-foot/foot of lift). In the Tulare Lake area, with an average well depth of 120 feet, pumping would require 175 kWh per acre-foot of water. In the San Joaquin River and Central Coast areas, with average well depths of 200 feet, pumping would require 292 kWh per acre-foot of water."[31] Analysis of these different sources provides a reasonably consistent result: Local groundwater and recycled water are far less energy intensive than imported water or ocean desalination.

The energy intensity of most water supply sources may increase in the future due to increased concerns regarding water quality.[32] It is worth noting that advanced treatment systems such as RO facilities that are being used to treat groundwater, reclaimed supplies, and ocean water have already absorbed most of the energy impacts of higher levels of treatment. By contrast, some of the raw water supplies may require larger incremental energy inputs in the future for treatment. This may further advantage the local sources.

Policy Implications: Tapping Multiple Benefits Through Integrated Planning

When the costs and benefits of a proposed policy or action are analyzed, we typically focus on accounting for costs, and then we compare those costs with a specific, well-defined benefit such as an additional increment of water supply. We often fail to account for other important benefits that accrue from well-planned investments that solve for multiple objectives. With a focus on *multiple benefits,* we account for various goals achieved through a single investment. For example, improvements in water use efficiency—meeting the same end-use needs with less water—also typically provides related benefits such as reduced energy requirements for water pumping and treatment (with reduced pollution and greenhouse gas emissions related to energy production as a result), and reduced water and wastewater infrastructure capacity (capital costs) and processing (operating costs) requirements. Impacts caused by extraction of source water from surface or groundwater systems are also reduced. Water managers often do not receive credit for providing these multiple benefits when they implement water efficiency, recharge, and reuse strategies. From both an investment perspective, and from the standpoint of public policy, the multiple benefits of efficiency improvements and recharge and reuse should be fully included in cost/benefit analysis.

Policies that account for the full embedded energy of water use have the potential to provide significant additional public and private sector benefits. Economic and environmental benefits are potentially available through new policy approaches that properly account for the energy intensity of water.

Energy savings may be achieved both upstream and downstream of the point of use when the energy consumption of both water supply and wastewater treatment systems are taken into account. Methods, metrics, and data are available to provide a solid foundation for policy approaches to account for energy savings from water efficiency improvements, though can and should be improved. Policies can be based on methodologies and metrics that are already established.

Policy Precedents and the Role of Government

Water and energy are currently regulated by government because there is a compelling public interest in oversight and management of these critical resources. Encouraging and requiring the efficient use of both water and energy is a well-established part of the policy mandate under which government agencies operate. Inefficient use of water and energy leads to public and private costs to the economy and the environment. The public interest in resource-use efficiency relates directly to environmental impacts and public welfare. This is why we have efficiency standards for energy and water resources. *Water-using devices,* like energy-using devices, are often regulated through various policy measures including efficiency standards.

[31] California Energy Commission (2006). Public Interest Energy Research—Industrial, Agriculture and Water, *http://energy.ca.gov/pier/iaw/industry/water.html*

[32] Burton, Franklin L. (1996). *Water and Wastewater Industries: Characteristics and Energy Management Opportunities.* (Burton Engineering) Los Altos, CA, Report CR–106941, Electric Power Research Institute Report.

Policy regarding both energy and water already addresses water use and related embedded energy use. For example, the U.S. *Energy Policy Act of 1992* set standards for the maximum water use of toilets, urinals, showerheads, and faucets. (See Table below.) Why does the U.S. *Energy* Act include standards for water use? It is because the energy required to convey, treat, and deliver potable water supplies, and the energy required to collect, treat, and discharge the resulting wastewater, is significant. The energy savings resulting from water efficiency are also significant.

Plumbing Standards in the U.S. Energy Policy Act of 1992
(Standard measured at 80 psi or 552 kPA)

Fixture	U.S. Standard	Metric Equivalent
Water Closets (Toilets)	1.6 gallons per flush	6.0 liters per flush
Showerheads	2.5 gallons per minute	9.5 liters per minute
Faucets	2.2 gallons per minute	8.3 liters per minute
Urinals	1.0 gallon per flush	3.8 liters per flush

These standards became effective in 1994 for residential and commercial plumbing fixtures, although the commercial water closet standard was not required until 1997 because of uncertainties regarding performance of the fixtures. In this respect, the United States is well behind certain countries of Europe, where the six-liter water closet has been in use for many years and where horizontal axis washing machines are more common than in the United States.

In 1996, the U.S. Congress passed a reauthorization of the *Federal Safe Drinking Water Act.* For the first time, Congress formally recognized the need for water conservation planning by allowing individual states to mandate conservation planning and implementation as a condition of receiving federal grants for water supply treatment facilities.[33] This was a significant step for the federal government. At about the same time, the U.S. Bureau of Reclamation set conservation and efficiency requirements for those agricultural and urban water agencies that receive federally subsidized water from the Bureau facilities. This also was a significant step. Other federal statutes create incentives for farmers and landowners to participate in soil and water conservation programs, and to initiate voluntary water transfers of conserved water.

The significant water efficiency and conservation activity, however, takes place at the State and regional levels. Interest in water efficiency is primarily highest in those regions of the country where precipitation is lowest, or where wastewater treatment costs have skyrocketed. Seventeen states, representing over 60 percent of the Nation's population, had already adopted their own plumbing efficiency standards long before passage of the federal law in 1992. Fifteen states have also adopted specific conservation programs, which vary from mandating conservation planning by water utilities to requiring actual implementation of specific water efficiency programs. The states most active in conservation activities are: Arizona; California; Colorado; Connecticut; Florida; Kansas; New Jersey, Oregon; Texas; and Washington State.[34] Individual cities have also adopted water efficiency programs where necessary (New York City, Boston, and Las Vegas are examples).

In general, where water supply withdrawals are regulated by State agencies, water conservation is usually a prominent planning requirement for water utilities. A number of states not only require plans of their water utilities, but also require that progress be demonstrated in water efficiency programs before approvals for continued water supply withdrawals are given. Many states also condition State grants for new facility construction upon a satisfactory demonstration of conservation planning and implementation by the water utility.[35]

California adopted plumbing standards in 1978 for showerheads and faucets, and water closet standards in 1992. Comprehensive conservation planning was adopted

[33] U.S. Environmental Protection Agency (1998). *Water Conservation Plan Guidelines for Implementing the Safe Drinking Water Act.*

[34] Miri, Joseph, 1999. "Snapshot of Conservation Management: A Summary Report of the American Water Works Association Survey of State Water Conservation Programs." American Water Works Association.

[35] One of the best sources on water efficiency in the U.S. is Mary Ann Dickinson, Executive Director, Alliance for Water Efficiency, P.O. Box 804127, Chicago, IL 60680–4127. The Alliance web site is: *www.allianceforwaterefficiency.org*

in 1983 for all water agencies serving more than 3,000 connections or 3,000 people.[36] In a unique consensus partnership, a Memorandum of Understanding was signed in 1991 by major water utilities and environmental groups pledging to undertake water efficiency practices (the "Best Management Practices").[37]

Environmental Benefits of Integrated Water and Energy Efficiency Strategies

Water conservation is a powerful tool in the integrated resource management toolbox. By reducing the need for new water supply and additional wastewater treatment—particularly in areas of rapid population growth—conserved water allows more equitable allocation of water resources for other purposes. By way of illustration, one estimate indicates that the installation of 1.6 gallon per flush toilets in the U.S. will save over two billion gallons *per day* nationwide by the year 2010.[38] These saved water resources can be directed toward future water supply growth or other uses for the water. It "stretches" the available supply.

Perhaps most significantly, it has become clear in recent decades that the extraction and diversion of water supplies has had major impacts on the quality of the natural environment and on individual species. Facilities built to dam, divert, transport, pump, and treat water are massive projects that often cause serious and sometimes irreversible environmental impacts.

As a result, water conservation is playing an important role in helping meet the environmental goals of many communities. Efficiency programs have been required in numerous areas to help achieve some of the following results:

- Maintaining habitat along rivers and streams and restoring fisheries;
- Protecting groundwater supplies from excessive depletion and contamination;
- Improving the quality of wastewater discharges;
- Reducing excessive runoff of urban contaminants; and
- Restoring the natural values and functions of wetlands and estuaries.

The Role of Price Signals Coupled With Policy

Attention has turned to technologies that improve energy and water-use efficiency. From industrial processes to plumbing fixtures and irrigation systems, water is being used far more efficiently than in the past. One reason the focus of technological innovation has shifted from supply development to improving efficiency is economics. When water is cheap, there is little incentive to design and build water-efficient technologies. As the cost of water increases, technology options for reducing waste and providing greater end-use efficiency become more cost-effective and even profitable. Technologies for measuring, timing, and controlling water use, and new innovations in the treatment and re-use of water, are growing areas of technology development and application.

Impetus for scientific inquiry and technology innovation and development has been provided by both price signals (increasing costs) and public policy (e.g., requirements for internalization of external costs). Public policy is increasingly incorporating these costs, including those of climate change, into resource prices. As water and energy prices continue to reflect full costs, including environmental costs previously externalized, they increase.

At the same time, technology has provided a wide range of options for expanding the utility value through efficiencies (less water and energy required to perform a useful service). The ability to treat and reuse water, improve energy efficiency, and substituting ways to provide services previously performed by water and energy. Broader application of these technologies and techniques can yield significant additional energy, water, economic, and environmental benefits.

Public policy can be designed to encourage "best management practices" by both water and energy suppliers and users. Appliance efficiency standards (for both energy and water) and minimum waste requirements are examples. Policy measures have also been used to frame and guide market signals by implementing mechanisms such as increasing tiered pricing structures, meter requirements (some areas do not even measure use), and other means to utilize simple market principles and price signals more effectively.

[36] California Water Code, Sections 10620 et seq.

[37] California Urban Water Conservation Council (1991). "Memorandum of Understanding Regarding Urban Water Conservation in California," (First adopted September, 1991).

[38] Osann, Edward and John Young (1998). *Saving Water Saving Dollars: Efficient Plumbing Products and the Protection of American Water.*

In an economic and resource management sense, efficiency improvements are now considered as *supply* options, to the extent that permanent improvements in the demand-side infrastructure provide reliable water and/or energy savings. Most experts agree that coupling technology options such as efficient plumbing and energy-using devices to economic incentives (e.g., rebates) and disincentives (e.g., increasing tiered rate structures) is the best strategy. The coupling provides both the means to improve productive water and energy use and the incentive to do it.

Seawater Desalination's Role in Integrated Water Supply Portfolios

Seawater desalination has been viewed as the ultimate drought hedge, enabling water providers to augment water supplies with desalted ocean water, a virtually inexhaustible water source. Both the theory and practice of desalination date back to the ancient Greeks and perhaps earlier, but costs have held desalination to limited use.

The salinity of ocean water varies, with the average generally exceeding 30 grams per liter (g/l). The Pacific Ocean is 34–38 g/l, the Atlantic Ocean averages about 35 g/l, and the Persian Gulf is 45 g/l. Brackish water drops to 0.5 to 3.0 g/l. Potable water salt levels should be below 0.5 g/l.

Reducing salt levels from over 30 g/l to 0.5 g/l and lower (drinking water standards) using existing technologies requires considerable amounts of energy, either for thermal processes or for the pressure to drive water through extremely fine filters (RO), or for some combination of thermal and pressure processes. Recent improvements in energy efficiency have reduced the amount of thermal and pumping energy required for the various processes, but high energy intensity is still an issue. The energy required is in part a function of the degree of salinity and the temperature of the water.

Seawater desalination is a primary source of water in some countries in the Middle East. It is also becoming an important resource in other countries including Spain, Singapore, China, and Australia. A few recent examples include:

- In 2006, Singapore completed a 36 MGD seawater reverse osmosis (SWRO) plant capable of serving 10 percent of its national water demand.[39]
- As of 2006, more than 20 seawater desalination plants were operating in China.[40]
- In November 2006, Western Australia became the first state in the country to use desalination as a major public water source.[41]

A number of desalination plants are currently being planned or developed in the U.S. On January 25, 2008, Tampa Bay Water announced that it had commenced full operations of its 25 MGD desalination plant, presently the largest seawater desalination plant in North America. At full capacity, the plant will provide 10 percent of the drinking water supply for the Tampa Bay region.[42] In 2004, the Texas Water Development Board (TWDB) identified desalination as an important strategy for meeting growth in water demand.[43] In its 2006 update to the Governor and the Legislature, the TWDB stated that "Seawater desalination can no longer be considered a water supply option available only to communities along the Texas Gulf Coast.[44] It must also be considered as an increasingly viable water supply option for major

[39] "Tuas Seawater Desalination Plant, Seawater Reverse Osmosis (SWRO), Singapore," watertechnology. *http://www.water□technology.net/projects/tuas/*, viewed April 23, 2008.

[40] "Seawater desalination to relieve water shortage in China," China Economic Net, Feb. 28, 2006, *http://en.ce.cn/Insight/200602/28/t20060228_6217706.shtml*

[41] "Perth Seawater Desalination Plant, Seawater Reverse Osmosis (SWRO), Kwinana, Australia," watertechnology. *http://www.water□technology.net/projects/perth/*

[42] "Drought-Proof Water Supply Delivering Drinking Water, The Nation's first large-scale seawater desalination plant eases Tampa Bay region's drought worries." News release, January 25, 2008, *http://www.tampabaywater.org/whatshot/readnews.aspx?article=131,* viewed April 23, 2008.

[43] "According to the 2002 State Water Plan, four of the six regional water planning areas with the greatest volumetric water supply needs in 2050 will be regions that have large urban, suburban, and rural populations located on or near the Texas Gulf Coast. These populations could conceivably benefit from a new, significant, and sustainable source of high-quality drinking water." *The Future of Desalination in Texas, 2004 Biennial Report on Semvater Desalination,* Texas Water Development Board, p. ix.

[44] Section 16.060 of the Texas Water Code directs the Texas Water Development Board to ". . . undertake or participate in research, feasibility and facility planning studies, investigations, and surveys as it considers necessary to further the development of cost effective water supplies from seawater desalination in the state." The Code also requires a biennial progress report be submitted to the Governor, Lieutenant Governor, and Speaker of the House of Representatives.

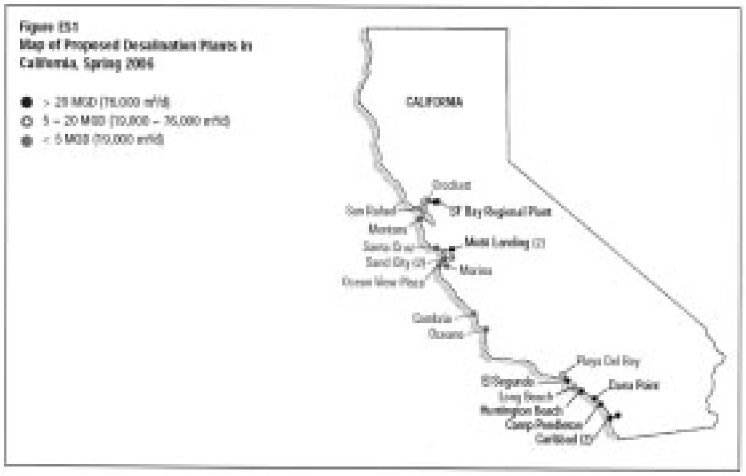
metropolitan areas throughout Texas."[45] The report encourages State investments for a full-scale seawater desalination demonstration project by the Brownsville Public Utilities Board ". . . as a reasonable investment in a technology that holds the promise of providing unlimited supplies of drinking water even during periods of extreme drought."

In California, interest in seawater desalination is also escalating. Heather Cooly and colleagues at the Pacific Institute found that as of 2006, about 266 to 379 MGD of new seawater desalination facilities were planned in California.[46]

[45] "The Future of Desalination in Texas, 2006 Biennial Report on Seawater Desalination," Texas Water Development Board, Executive Summary, pp. iv–v.

[46] Cooley, Heather, Peter H. Gleick, and Gary Wolff, 2006. *Desalination, With a Grain of Salt,* Pacific Institute for Studies in Development, Environment, and Security, 654 13th Street, Preservation Park, Oakland, California 94612, *http://www.pacinst.org/reports/desalination/index.htm*

Planned Seawater Desalination Plants as of 2006



Source: Cooley, Heather, Peter H. Gleick, and Gary Wolff, 2006. *Desalination, With a Grain of Salt*, Pacific Institute, http://www.pacinst.org/reports/desalination/index.htm

In November 2007, Poseidon Resources won conditional regulatory approval from the California Coastal Commission to build a $300 million plant north of San Diego. The Carlsbad Desalination Plant will be the largest in the western hemisphere if completed as planned. On its web site, Poseidon reported that most of the plant's capacity has already been committed to serve baseload water requirements for local water agencies.[47]

Water Inputs to U.S. Energy Systems

The other side of the water/energy nexus is the water intensity of energy. In this case, water inputs to energy systems are identified and quantified to understand where water is used, and how much is required for different types of energy sources and services.

Water inputs to energy systems are significant but highly variable. For example, primary fuels, such as oil, gas, and coal, often require water for production, and they sometimes "produce" water of various qualities as a by-product of extraction. Biofuels may require water not only for irrigation of crops but also for production processes. Electricity generation in thermoelectric plants typically uses water for cooling and other processes, although dry cooling technology exists and is improving. Some forms of electricity production such as wind and certain co-generation processes require no water at all.

The USGS estimates in its most recent analysis that 48 percent of all U.S. freshwater and saline-water withdrawals were used for thermoelectric power, with the majority of the fresh water extracted from surface sources (e.g., lakes and rivers) and used for once-through cooling at thermal power plants. USGS notes that "about 52 percent of fresh surface-water withdrawals and about 96 percent of saline-water withdrawals were for thermoelectric-power use."[48]

Water is increasingly viewed as a limiting factor for thermal power plant siting and operation. Large-scale thermoelectric plants in the U.S., Europe, and elsewhere have experienced serious problems in recent years due to the lack of available cooling water. Power production was reduced or curtailed in Europe during the heat

[47] Posidon Resources, *http://www.carlsbaddesal.com/partnerships.asp*

[48] Hutson, Susan S., Nancy L. Barber, Joan F. Kenny, Kristin S. Linsey, Deborah S. Lumia, and Molly A. Maupin, 2005. *Estimated Use of Water in the United States in 2000,* U.S. Geological Survey, Circular 1268, (released March 2004, revised April 2004, May 2004, February 2005) USGS, P. 1. *http://water.usgs.gov/pubs/circ/2004/circ1268/index.html*

wave in 2003, and power plants in the U.S. have been impacted by low water and by elevated temperatures, or both, during the past decade. As recently as this past winter power plant operators were concerned about the impact of the drought in the U.S. Southeast and the potential for adverse impacts to thermal power plants. Hydroelectric power production is also impacted by low water levels, including a continuing long-term dry period in the Colorado River basin.

Although cooling systems account for the majority of water used in power generation, water is also used in other parts of the process: water may be used to mine, process, or transport fuels (e.g., coal slurry lines). These processes may have important local impacts on water resources. Some energy sources such as oil shale, tar sands, and marginal gas and petroleum reserves may have additional water needs and/or significant local impacts on water quality and quantity.

The U.S. National Labs have been working for several years on an "Energy/Water Nexus" effort.[49] A report entitled *"Energy Demands on Water Resources Report to Congress on the Interdependency of Energy and Water"* was submitted to Congress in 2007.[50] As with other analyses of the issue, the report found that some energy systems are highly dependent on large volumes of water resources (and vulnerable to disruptions), while other energy sources are independent of water. Further analysis of the opportunities for improving resilience and of beneficial decoupling water and energy are in order.

The National Energy Technology Laboratory (NETL) has developed several studies and reports, including an updated report entitled *"Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements"* in 2007.[51] NETL has strong expertise on coal and thermal power production at coal-fired power plants. Its study indicates that water *consumption* is projected to increase over a range of scenarios, while *extraction* is expected to decline. This is due to an expected shift away from one-through cooling systems, which cycle more extracted water through the plants, but consume (e.g., evaporate) less than recycle cooling systems. The study also indicates that carbon capture and storage (CCS) as a strategy to reduce greenhouse gas emissions will add significant water consumptive demands to coal-based power production.

Other studies from federal labs and research institutions are exploring links between energy systems and water requirements. The National Renewable Energy Lab (NREL), for example, has been working on the role of renewables to reduce water demands from the energy sector.

A recent research project by graduate students at the University of California, Santa Barbara found that water use for renewable forms of energy varies substantially.[52] Solar photovoltaics, wind turbines, and landfill gas-to-energy projects require very little water, if any. Likewise, geothermal and concentrating solar power (CSP) systems that employ dry cooling technology also have minimal water requirements. In contrast, irrigated bio-energy crops could potentially consume exponentially more water per unit of electricity generated than thermoelectric plants. Geothermal plants may also have high water requirements, depending on the geothermal resource and the conversion technology employed. Many geothermal plants, however, rely on geothermal fluids (often high in salts or other minerals). Finally, although reservoirs often have multiple purposes (e.g., flood control, water storage, and recreation), evaporative (consumptive) losses from hydroelectric facilities per unit of electricity are higher than many other forms of generation. As the following graph indicates, water requirements vary substantially, depending on the primary fuel source and the technology employed.

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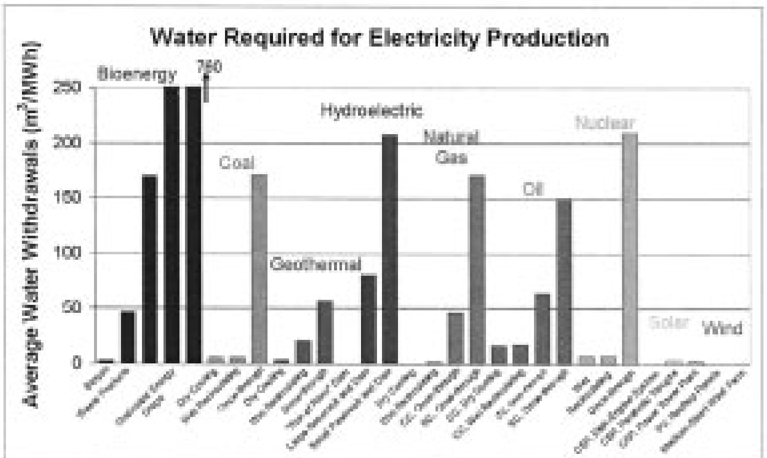
[49] See for example Sandia's web site at: *http://www.sandia.gov/energy-water/*

[50] See "Energy Demands on Water Resources Report to Congress on the Interdependency of Energy and Water," U.S. Department of Energy, December 2006, *http://www.sandia.gov/energy-water/congress_report.htm*

[51] National Energy Technology Laboratory, 2007. "Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements" 2007 Update, DOE/NETL–400/2007/1304, *www.netl.doe.gov*

[52] Information and graph are from Dennen, Bliss, Dana Larson, Cheryl Lee, James Lee, Stacy Tellinghuisen, 2007. "California's Energy-Water Nexus: Water Use in Electricity Generation," Group Project Report, Donald Bren School of Environmental Science & Management, University of California, Santa Barbara, available at: *http://fiesta.bren.ucsb.edu/~energywater/*



Water requirements for different forms of electricity generation. Source: Dennen, Bliss, Dana Larson, Cheryl Lee, James Lee, Stacy Tellinghuisen, 2007. "California's Energy-Water Nexus: Water Use in Electricity Generation", Group Project Report, Donald Bren School of Environmental Science and Management, University of California, Santa Barbara.

The various water inputs to energy systems are, as noted, highly variable. It is not at all clear that meeting our energy needs requires large amounts of water, as has been the case in the past. Indeed, the data above indicate that we have choices. An important step in addressing the water and energy challenge is to analyze the relationships between them and the technology and policy options.

Recommendations for Further Research and Development

There are of course various approaches to meeting the challenge of water and energy in the 21st century. I am pleased to have been asked by this committee to provide some thoughts on directions for research and development.

It is always useful to begin by examining the questions to be addressed. If one asks how to provide low-cost water for energy supplies and low-cost energy for water supplies, then the question leads to certain kinds of analysis. This indeed is how some are framing the question at present.

It seems clear that both water and energy are scarce in both the economic and physical sense, and that there are many competing demands for them. It also seems self-evident that environmental impacts (often externalized in the past), are real and growing. One of the most significant, but by no means the only one, is climate change.

These observations lead to a conclusion that we should ask a different set of questions. It is tempting to take this opportunity to deluge a Congressional Committee with a wish-list of research ideas. Instead, I will start with just two questions:

1. How can we decouple water and energy systems where there are high costs, stresses, damages, or vulnerabilities to systems?
2. How can we maximize water and energy efficiency and productivity so as to reduce demands on each and maximize benefits to society?

Of course these questions involve important data collection and analysis of sub-elements of each. To take my first example, we need to identify costs (full costs and an accounting for distortions—e.g., subsidies and externalities—at all levels), stresses (e.g., limits of systems and things like the causes of, probabilities of, and consequences of, exceeding those limits), potential economic, environmental, and social damages (including irreversible damages), and vulnerabilities of systems to perturbations caused by either natural events (dry spells) and/or of those with bad intensions (national security). These are critically important questions for the Nation, and they are not being properly asked and framed, let alone addressed.

The second question leads to a set of studies that is long overdue. We have focused so heavily on supplying energy and water in unlimited quantities at "low prices" that we have failed to ask the basic questions regarding opportunities to do more with less, let alone limits of the capacity of systems and the implications of inefficient and unproductive use (waste) of critical resources.

My recommendation to this committee is that you follow these important hearings with a process to formulate key questions and issues to be addressed by the unsurpassed research, business, and public policy capacity of the United States in addressing these critical challenges. The Committee should give careful consideration to designing, framing, and setting forth key questions to be addressed by the research and development community (which I would take to include research institutions, business, NGOs, and other interested stakeholders as well as key government agencies) to meet the challenges of water and energy for the country.

A good example of an effective collaborative along these lines that involves a number of federal agencies as well as the research community, local and State government, NGOs, business, and others is the Sustainable Water Resources Roundtable.[53]

By focusing on the key questions, the Committee can provide both the leadership and the guidance that is needed.

Conclusion: Opportunities for Integrated Water/Energy Policy Policy

Policy frameworks are critical to achieving success based on advances in science and technology. In considering alternative policy strategies, decision-makers should carefully analyze and consider the potential multiple benefits available from integrated strategies.

The United States, like other nations, faces formidable challenges in providing water and energy to its citizens in the face of scarcity, rising costs, security threats, climate change, and much else. We are fortunate to have the scientific and technological capacity, and the institutions of governance, to take on these difficult challenges. Policy formulation, starting with Congress asking penetrating and thoughtful questions, is a critical starting point. From this framework, research and development strategies can be developed to address society's challenges in effective ways.

For the past century, the focus of technological innovation in water systems was on the extraction, storage, and conveyance of water. Huge dams, aqueduct systems, and "appurtenant" facilities were designed, financed, and built to accomplish the task. Major rivers have been entirely de-watered. The costs—economic, environmental, and social—are evident.

Integrated water and energy management strategies, with a focus on vastly improved end-use and economic efficiency for both, and careful consideration of alternative technology opportunities provided by advances in science and technology, can provide significant *multiple benefits* to society. Costeffective improvements in energy and water productivity, with associated economic and environmental quality benefits, increased reliability and resilience of supply systems (all elements of the "multiple benefits"), are attainable.

It may be worth quoting the California Energy Commission from its *Integrated Energy Policy Report:* "Reducing the demand for energy is the most effective way to reduce energy costs and bolster California's economy."[54] Consistent with this approach, improvements in efficiency are identified by the California Department of Water Resources as the largest (and in fact the most certain) new water supply for the next quarter century, followed by groundwater recharge and water reuse. The state's Energy Commission noted: "The *2005 Water Plan Update* mirrors the state's adopted loading order for electricity resources."[55]

Methodologies and metrics exist to tap the multiple benefits of integrated water/energy strategies, though they can and need to be improved. The policies required to incentivize, enable, and mandate integrated water and energy policy exist and are being refined to tap ample opportunities to improve both the economic and environmental performance of water and energy systems.

With better information regarding energy implications of water use, and water implications of energy use, public policy combined with investment and management strategies can dramatically improve productivity and efficiency. Potential benefits include improved allocation of capital, avoided capital and operating costs, and reduced burdens on rate-payers and tax-payers. Other benefits, including restora-

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[53] Sustainable Water Resources Roundtable, *http://acwi.gov/swrr/*

[54] California Energy Commission (2005). *Integrated Energy Policy Report,* November 2005, CEC–100–2005–007–CMF.

[55] Klein, Gary (2005). California Energy Commission, California's Water—Energy Relationship. Final Staff Report, Prepared in Support of the 2005 Integrated Energy Policy Report Proceeding, (04–IEPR–01E) November 2005, CEC–700–2005–011–SF.

tion and maintenance of environmental quality, can also be realized more cost-effectively through policy coordination. Full benefits derived through water/energy strategies have not been adequately quantified or factored into policy.

Public concern regarding environmental costs of diverting and extracting water is another reason for the shift in technology focus from extraction to efficiency. Precipitous declines in populations of fish, and damage to ecosystems around the world, have driven this growing call for more sustainable water systems.

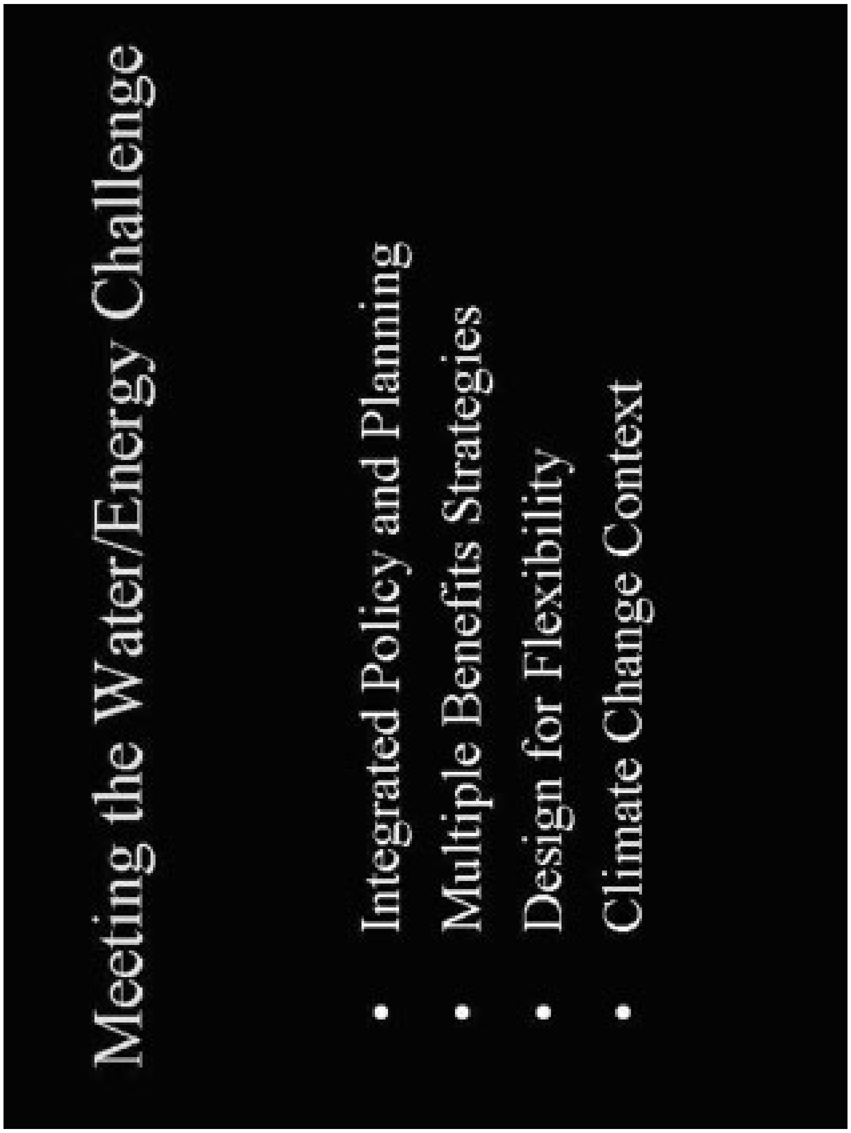
Current technology can provide water supplies through efficiency improvements at substantially *less cost* than the development of new supplies in most areas. As water prices increase to reflect full capital, operating, and environmental costs, it is likely that technology will play an even greater role in providing water efficiency improvements.

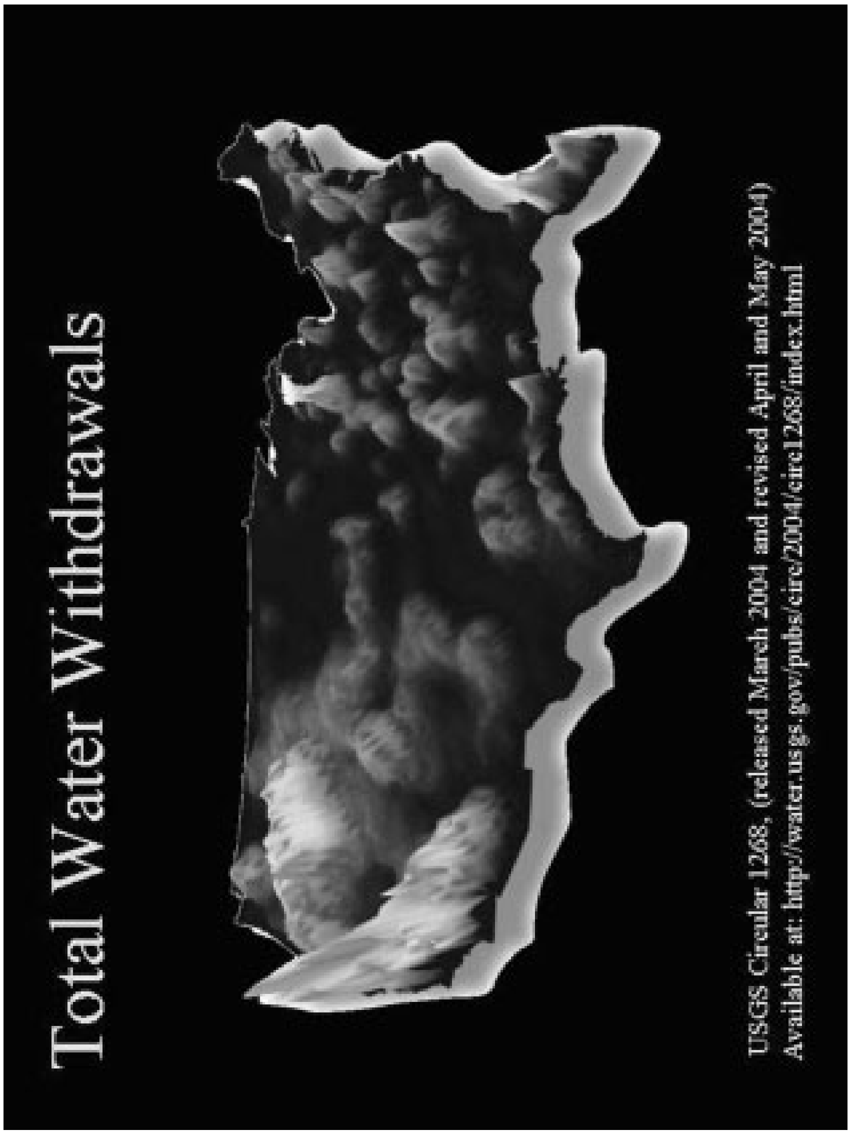

Water Supply Challenges
for the 21st Century
Committee on Science and Technology
United States House of Representatives
Washington D.C.
May 14, 2008

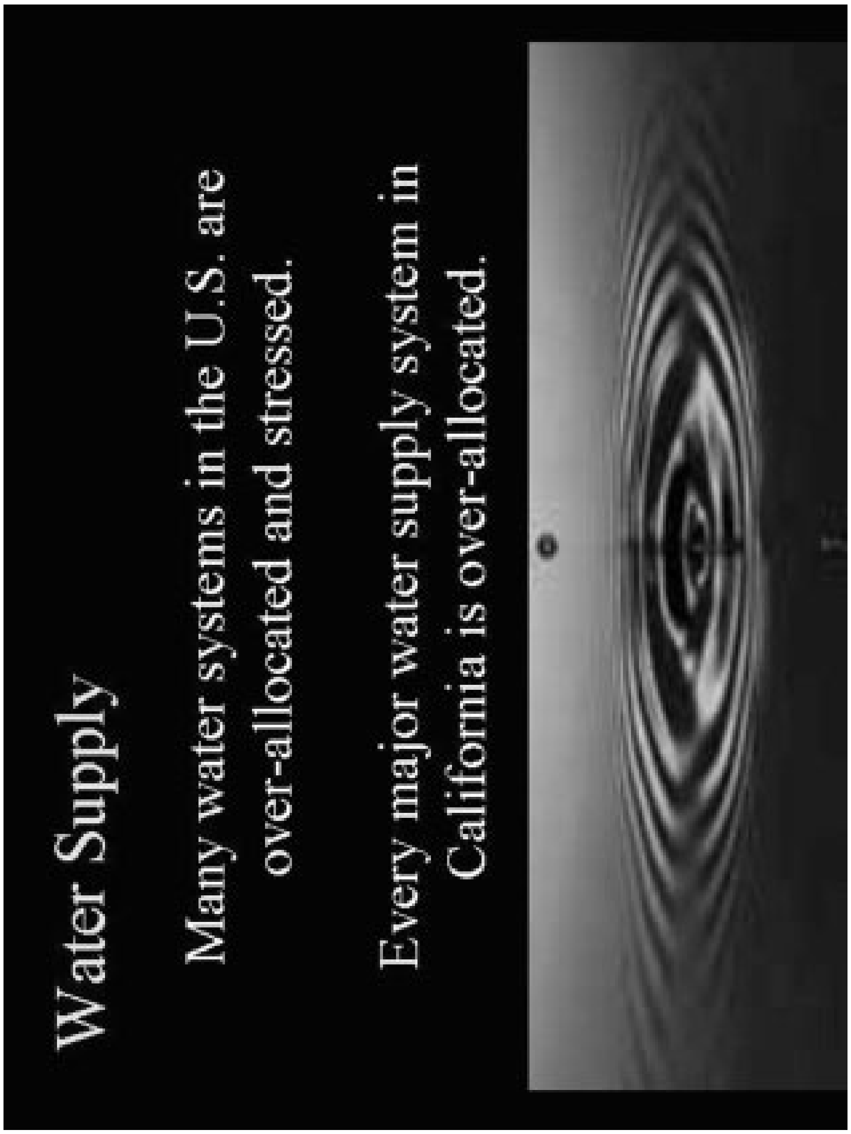
Robert Wilkinson, Ph.D.

Director, Water Policy Program
Bren School of Environmental Science and Management
University of California, Santa Barbara

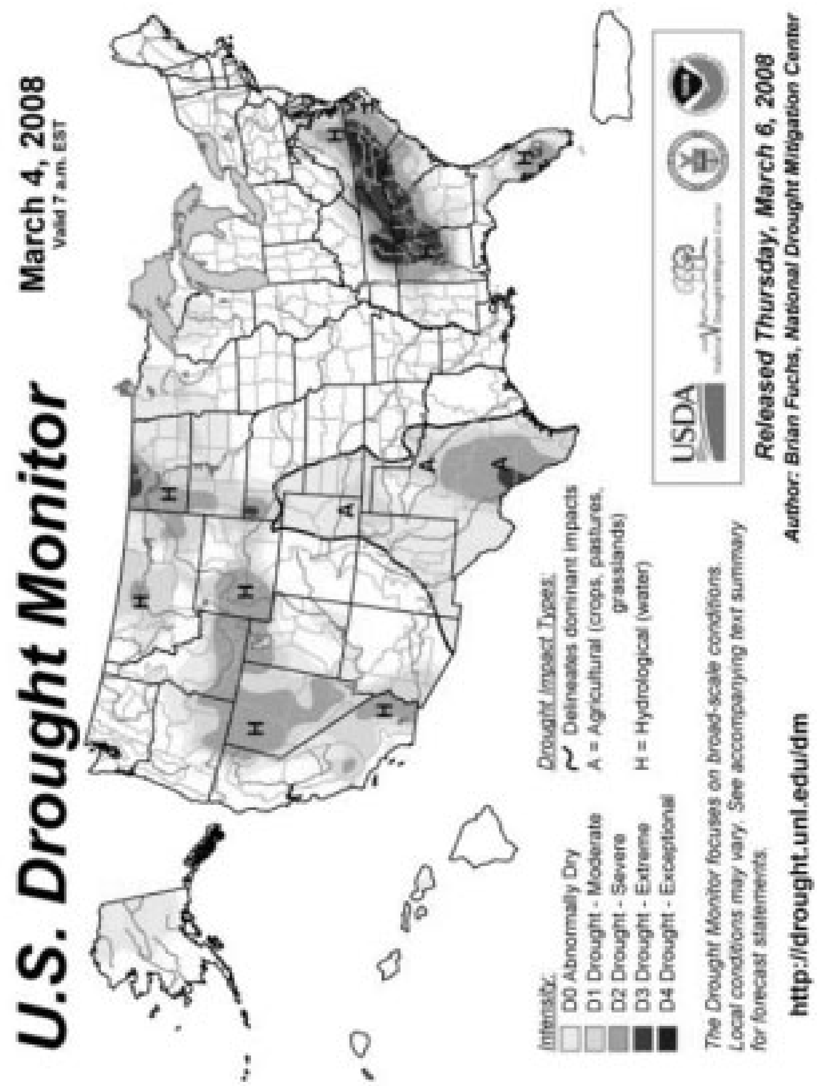
wilkinson@es.ucsb.edu

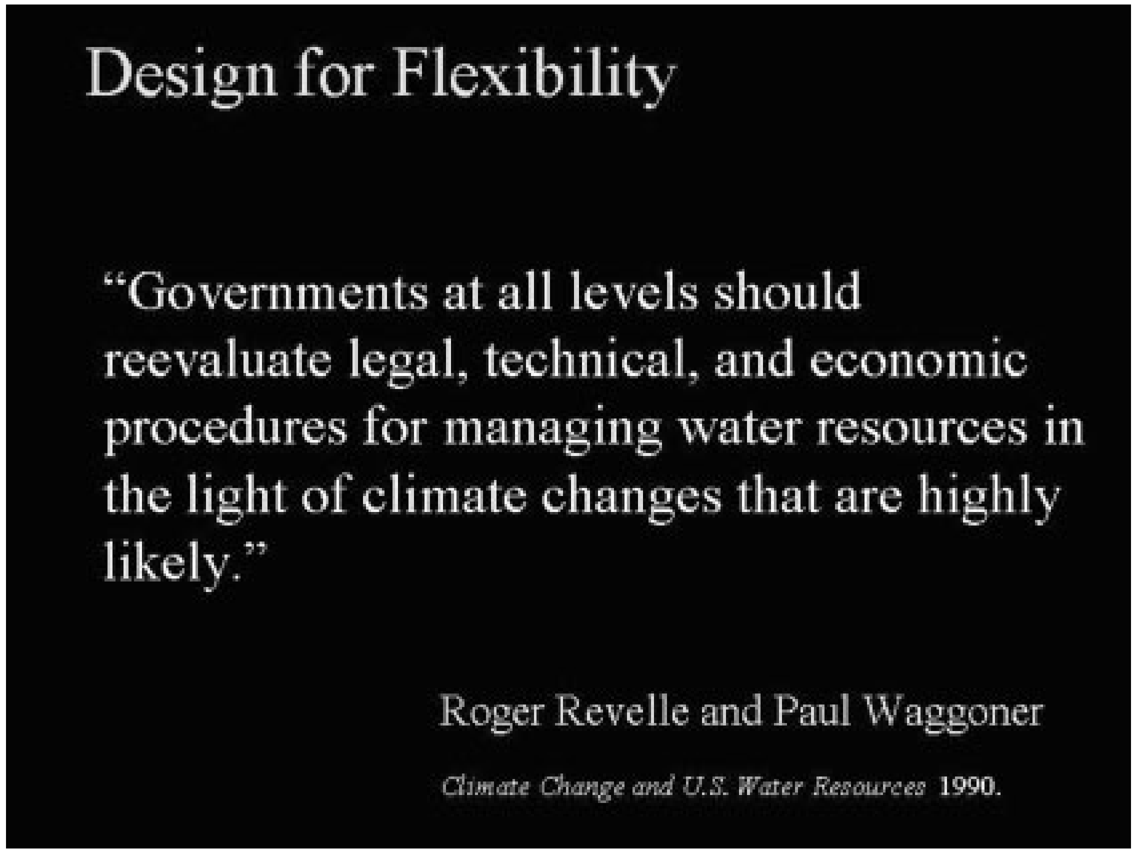

Meeting the Water/Energy Challenge
• Integrated Policy and Planning
• Multiple Benefits Strategies
• Design for Flexibility
• Climate Change Context

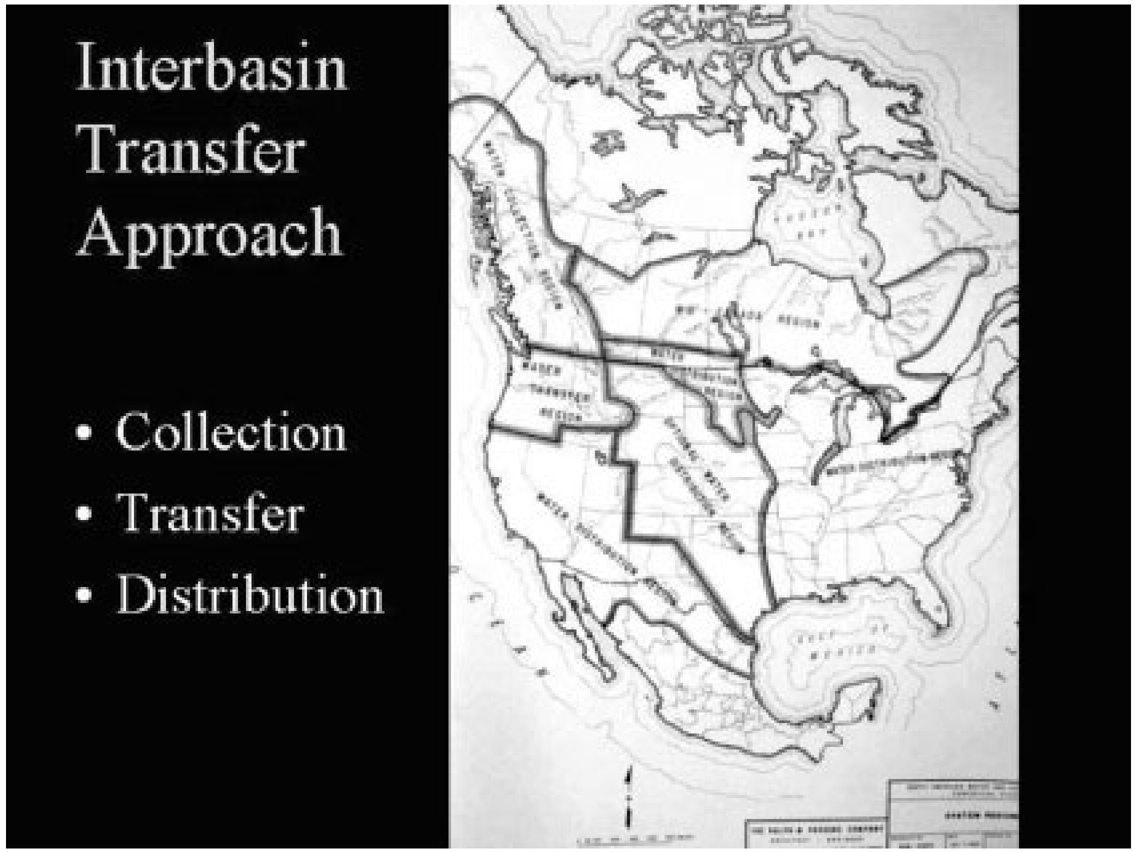

Total Water Withdrawals
USGS Circular 1268, (released March 2004 and revised April and May 2004)
Available at: http://water.usgs.gov/pubs/circ/2004/circ1268/index.html

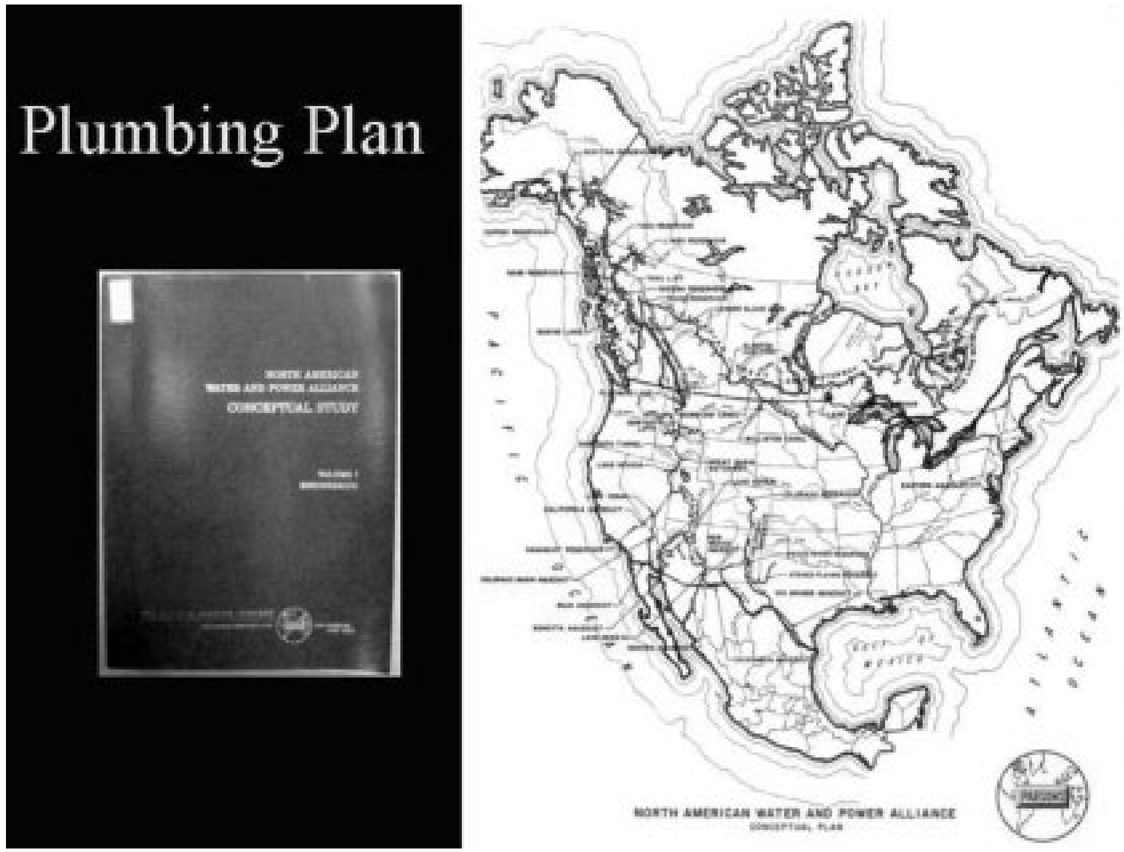

Water Supply
Many water systems in the U.S. are over-allocated and stressed.
Every major water supply system in California is over-allocated.

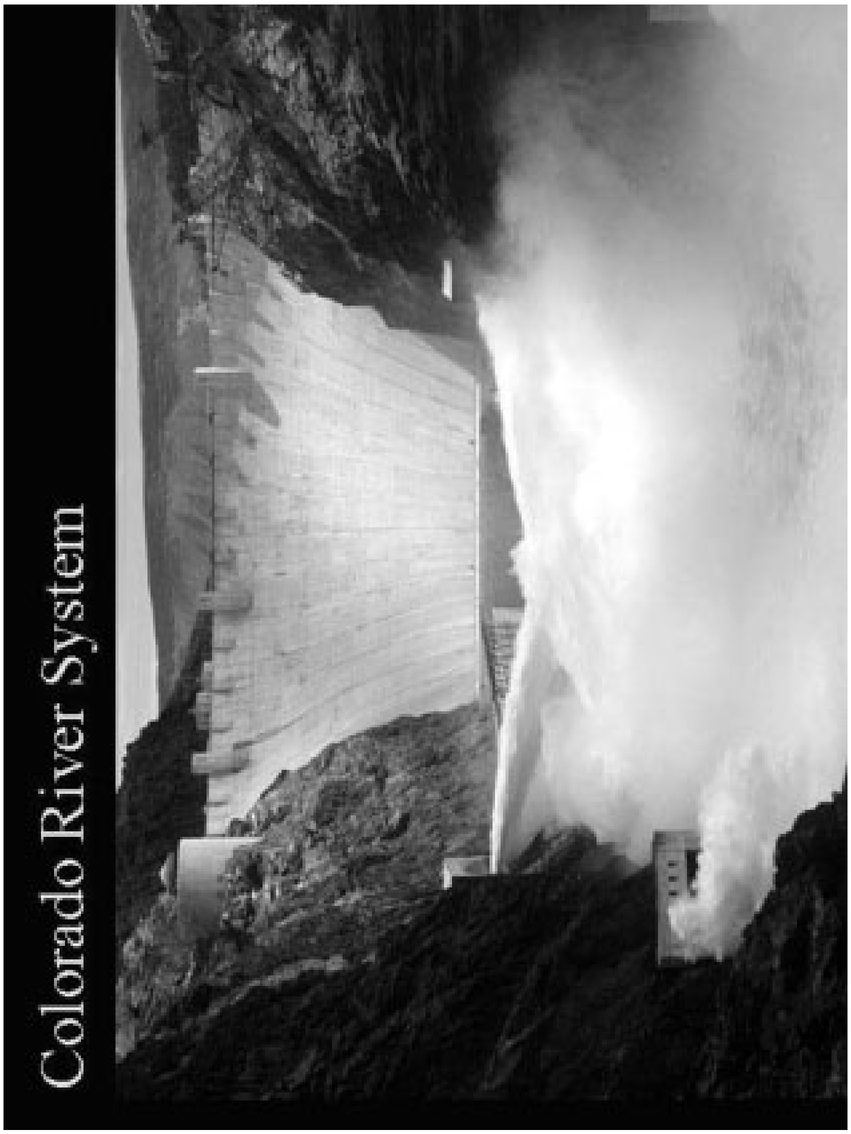

Water Resources and Population Growth, 2000-2020
Less Water
More Water
Source: DOE/NETL (M. Chan, July 2002)

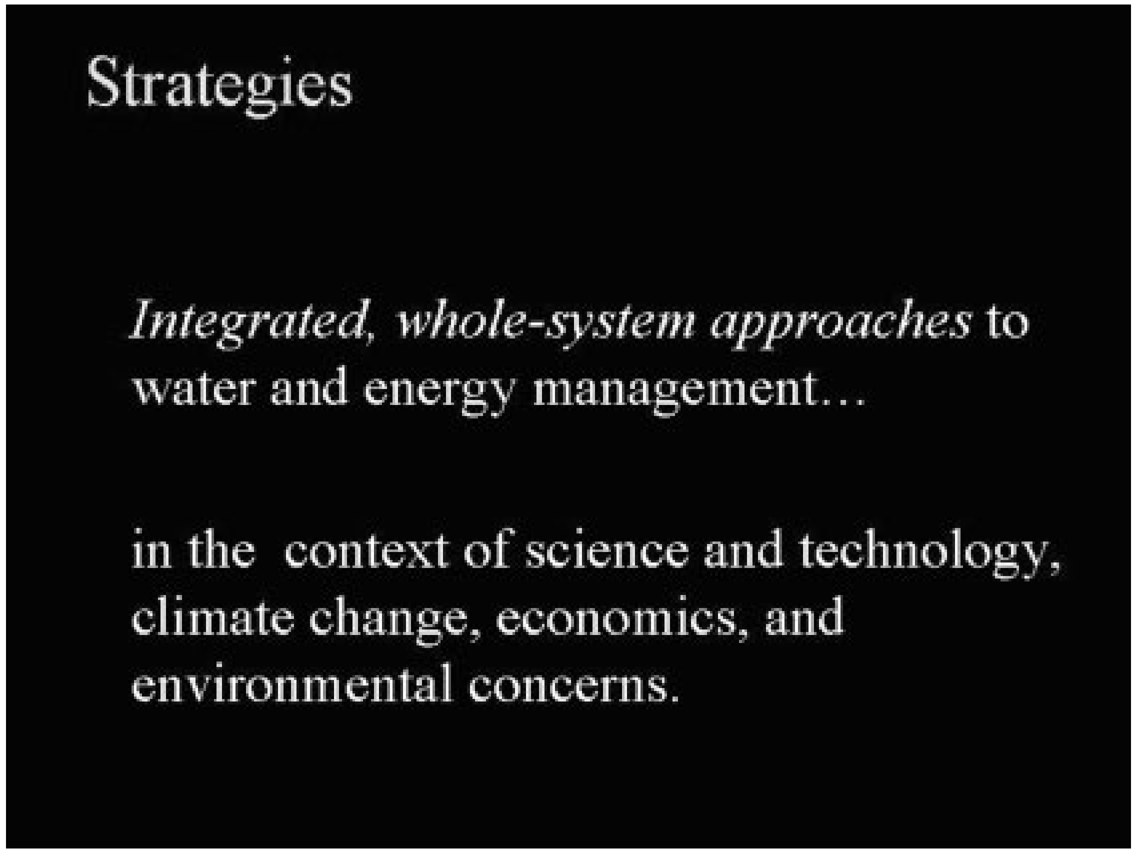

U.S. Drought Monitor
March 4, 2008
Valid 7 a.m. EST
Intensity:
D0 Abnormally Dry
D1 Drought - Moderate
D2 Drought - Severe
D3 Drought - Extreme
D4 Drought - Exceptional
Drought Impact Types:
Delineates dominant impacts
A = Agricultural (crops, pastures, grasslands)
H = Hydrological (water)
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.
http://drought.unl.edu/dm
USDA
Released Thursday, March 6, 2008
Author: Brian Fuchs, National Drought Mitigation Center

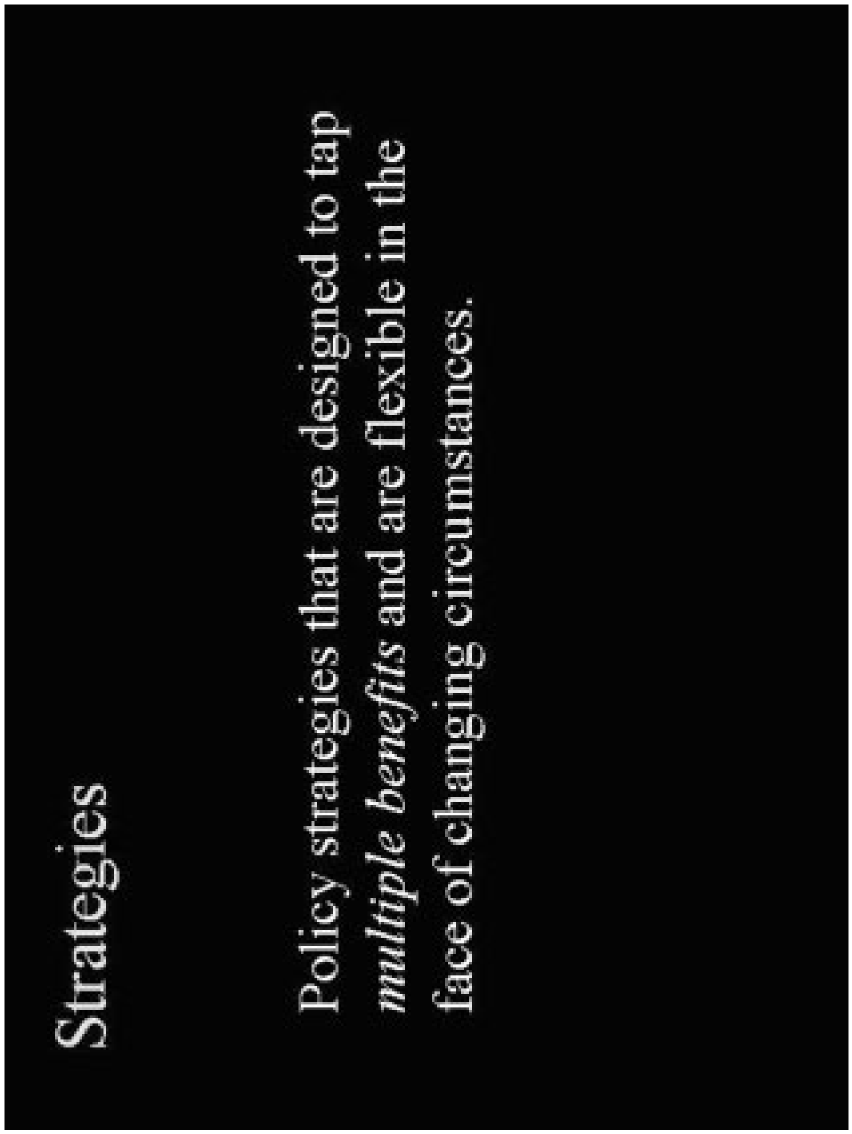

Design for Flexibility
“Governments at all levels should reevaluate legal, technical, and economic procedures for managing water resources in the light of climate changes that are highly likely.”
Roger Revelle and Paul Waggoner
Climate Change and U.S. Water Resources 1990.

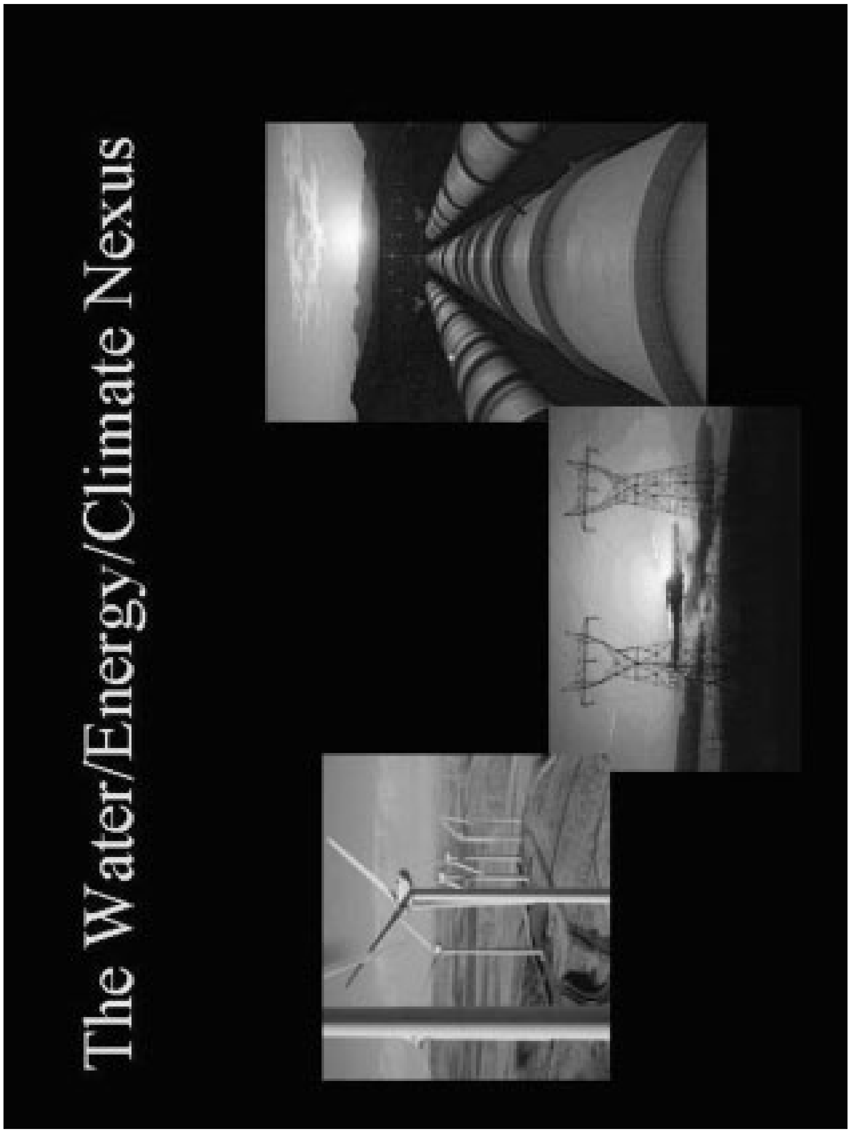

Interbasin
Transfer
Approach
• Collection
• Transfer
• Distribution

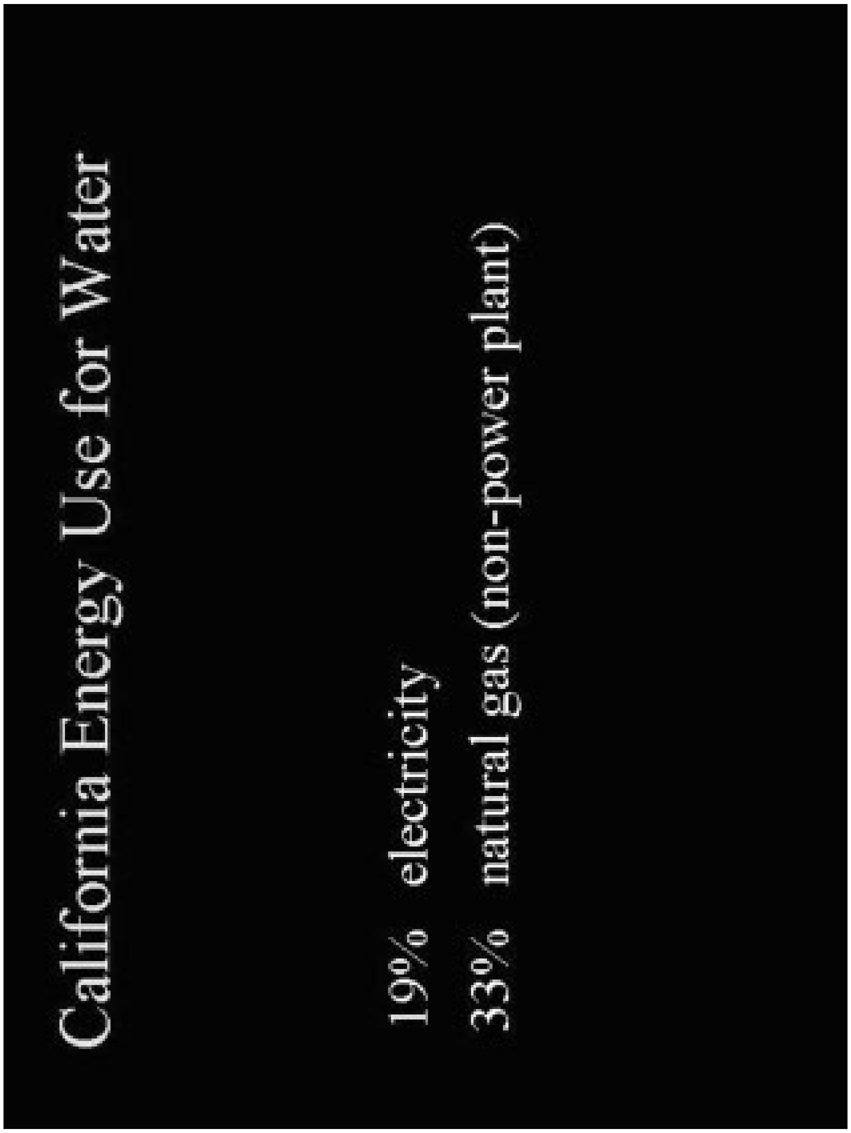

Plumbing Plan
NORTH AMERICAN
WATER AND POWER ALLIANCE
CONCEPTUAL STUDY
PACIFIC
ATLANTIC OCEAN
NORTH AMERICAN WATER AND POWER ALLIANCE
CONCEPTUAL PLAN

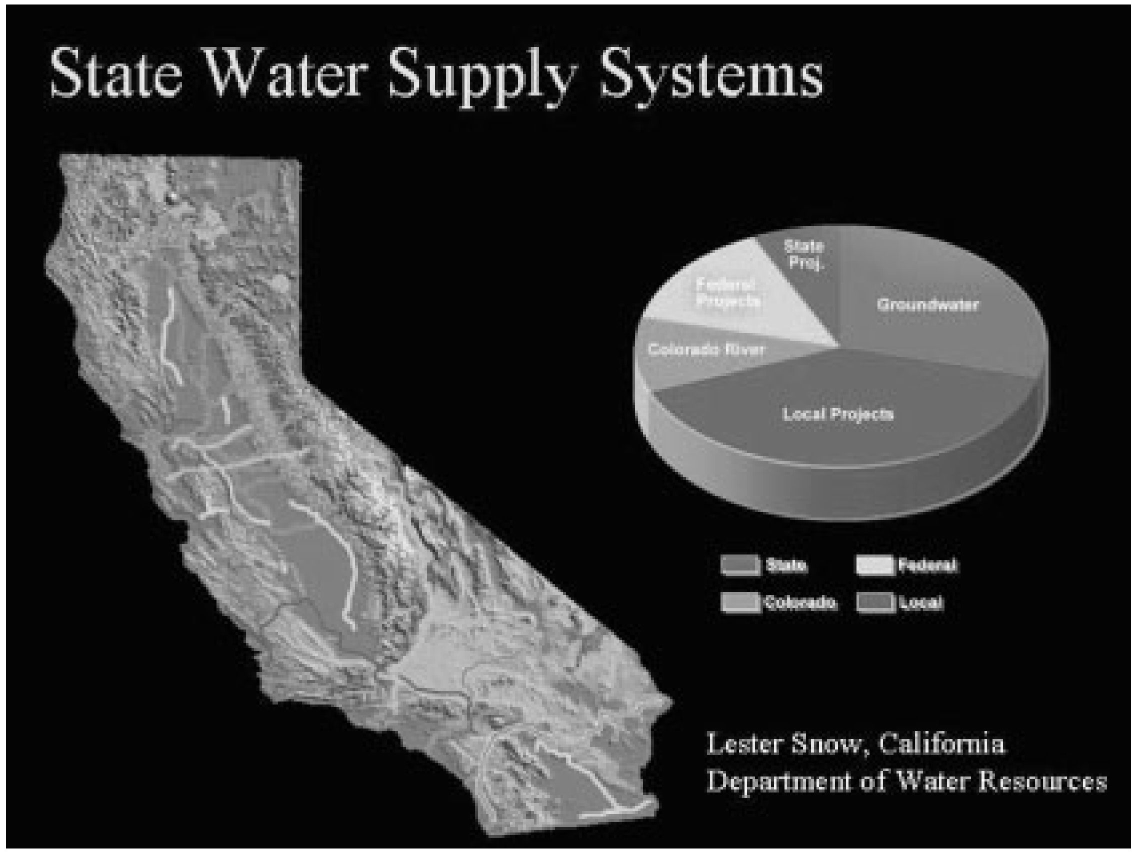

Colorado River System

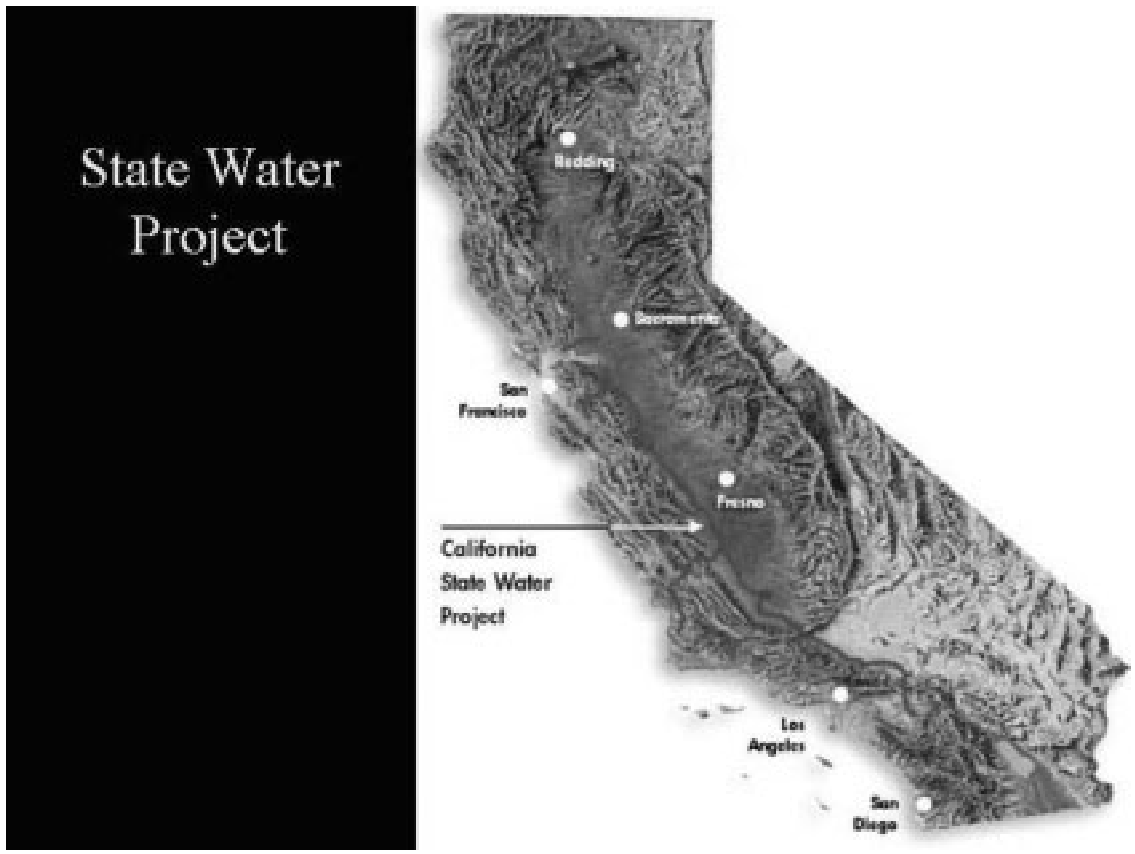

Strategies
Integrated, whole-system approaches to water and energy management…
in the context of science and technology, climate change, economics, and environmental concerns.

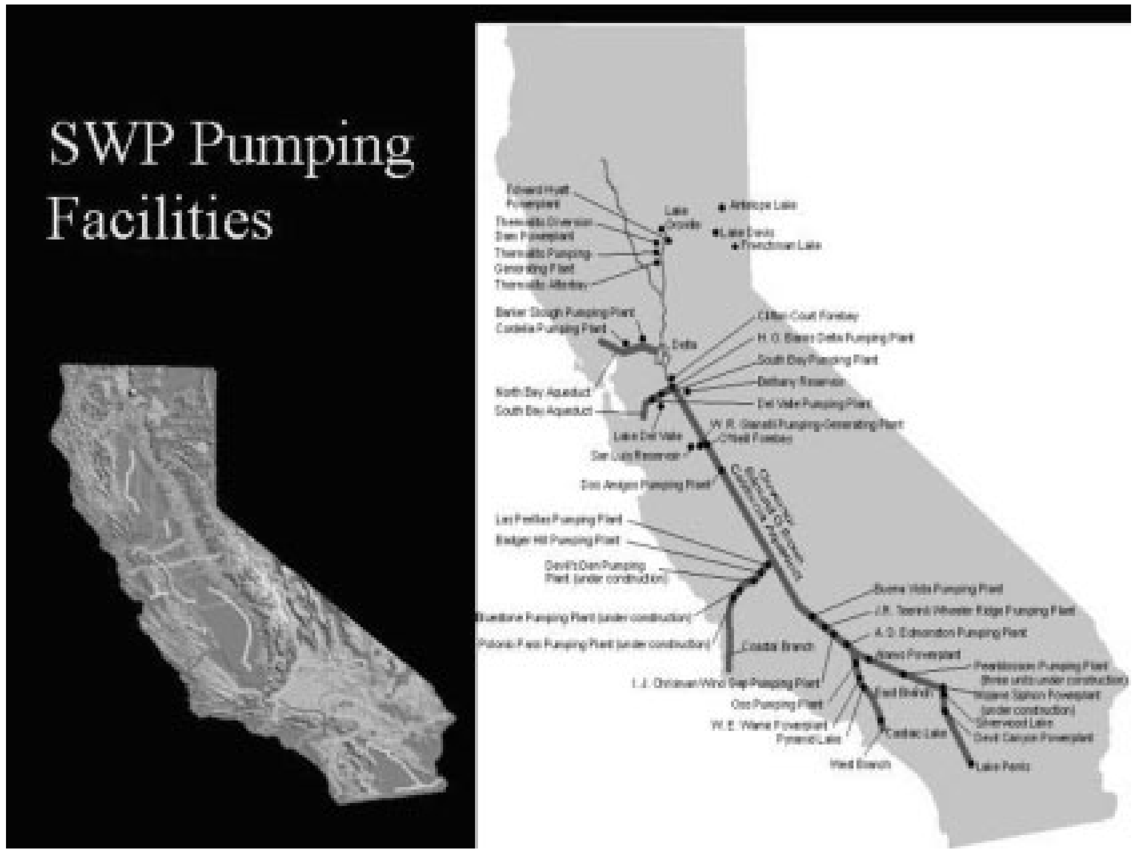

Strategies
Policy strategies that are designed to tap *multiple benefits* and are flexible in the face of changing circumstances.

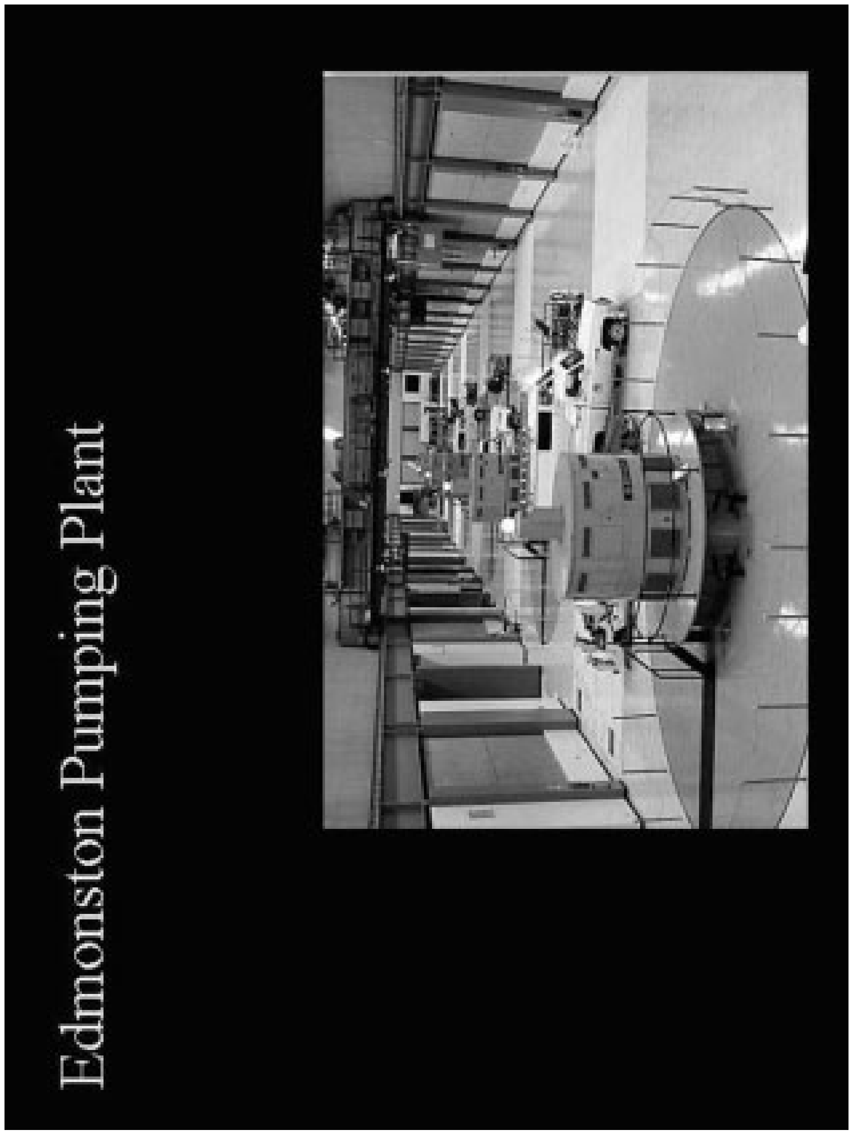

The Water/Energy/Climate Nexus

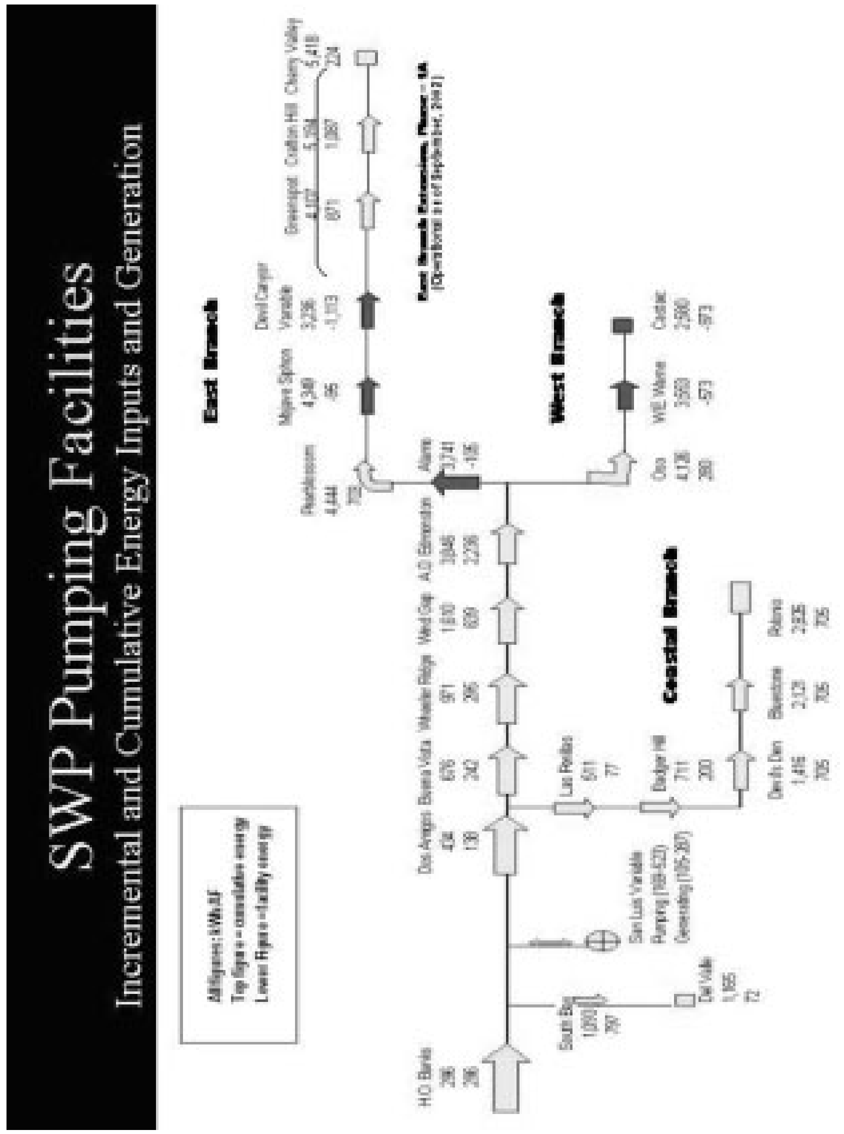

California Energy Use for Water
19% electricity
33% natural gas (non-power plant)

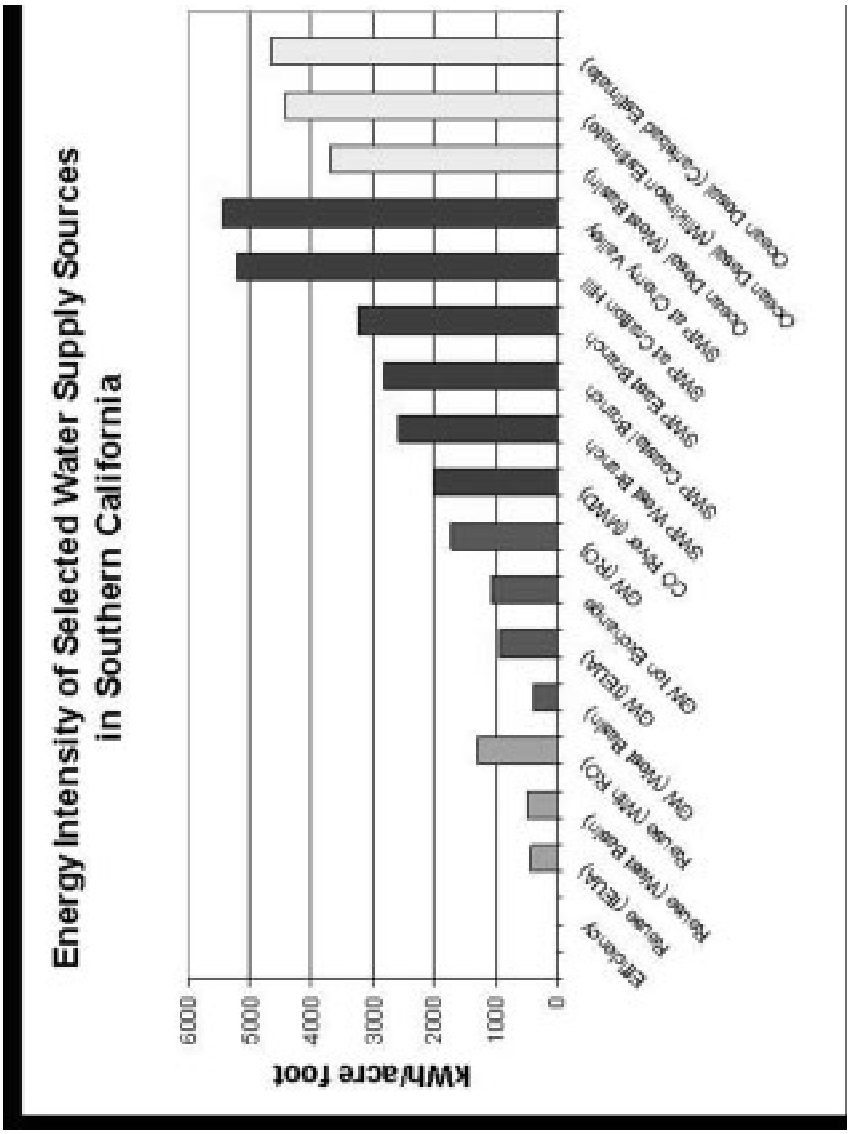

State Water Supply Systems
State Proj.
Federal Projects
Groundwater
Colorado River
Local Projects
State
Federal
Colorado
Local
Lester Snow, California
Department of Water Resources

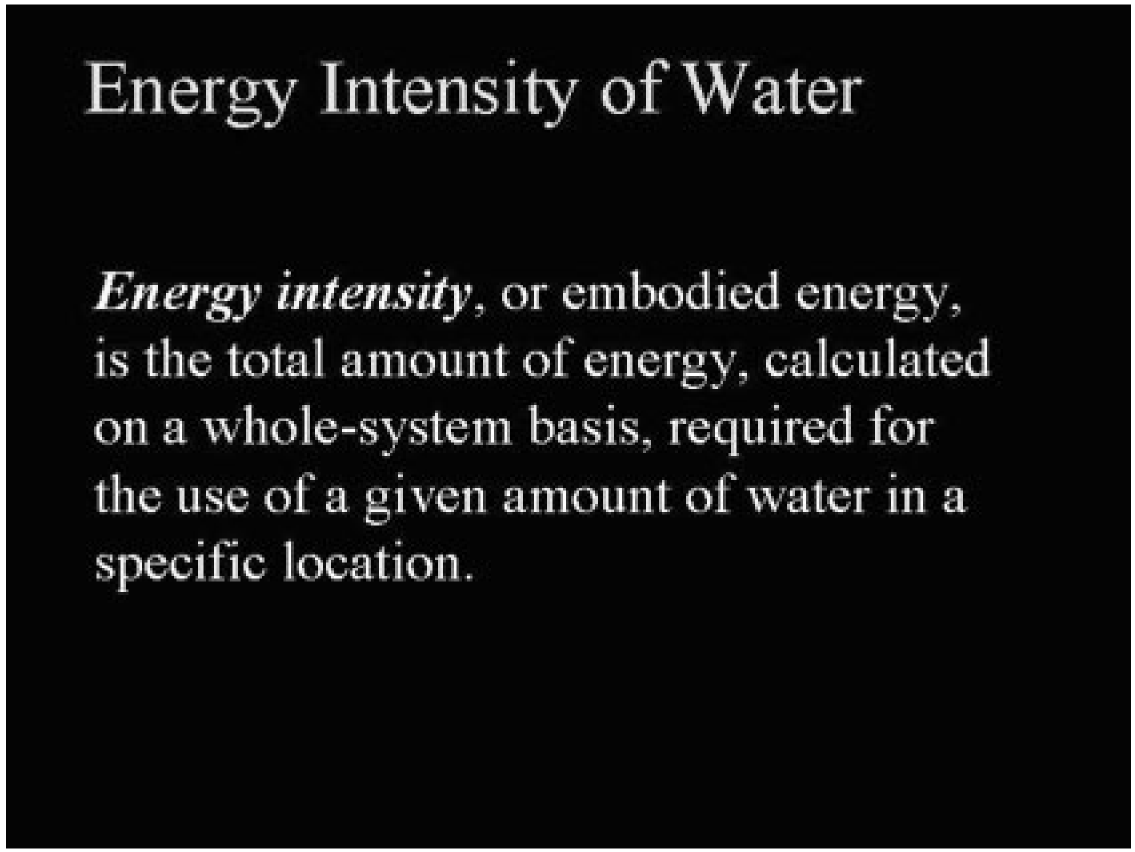

State Water
Project
Redding
Sacramento
San
Francisco
Fresno
California
State Water
Project
Los
Angeles
San
Diego

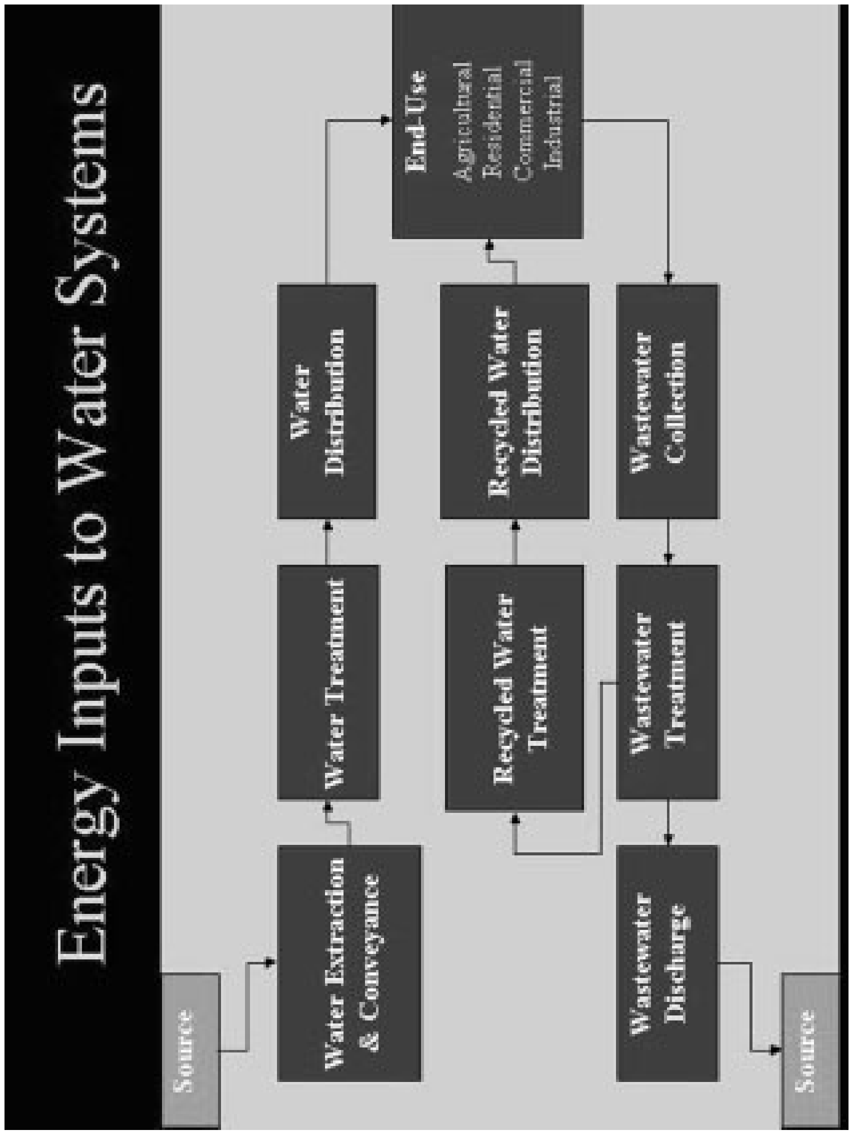

SWP Pumping
Facilities
Lake Oroville
Delta
North Bay Aqueduct
South Bay Aqueduct
Lake Del Valle
San Luis Reservoir
Dos Amigos Pumping Plant
Las Perillas Pumping Plant
Badger Hill Pumping Plant
Devil's Den Pumping Plant (under construction)
Coastal Branch
Buena Vista Pumping Plant
A. D. Edmonston Pumping Plant
Alamo Powerplant
Oso Pumping Plant
W. E. Warne Powerplant
Pyramid Lake
Castaic Lake
West Branch
East Branch
Silverwood Lake
Devil Canyon Powerplant
Lake Perris
H. O. Banks Delta Pumping Plant
South Bay Pumping Plant
Bethany Reservoir
Del Valle Pumping Plant
W. R. Gianelli Pumping-Generating Plant
O'Neill Forebay


Edmonston Pumping Plant

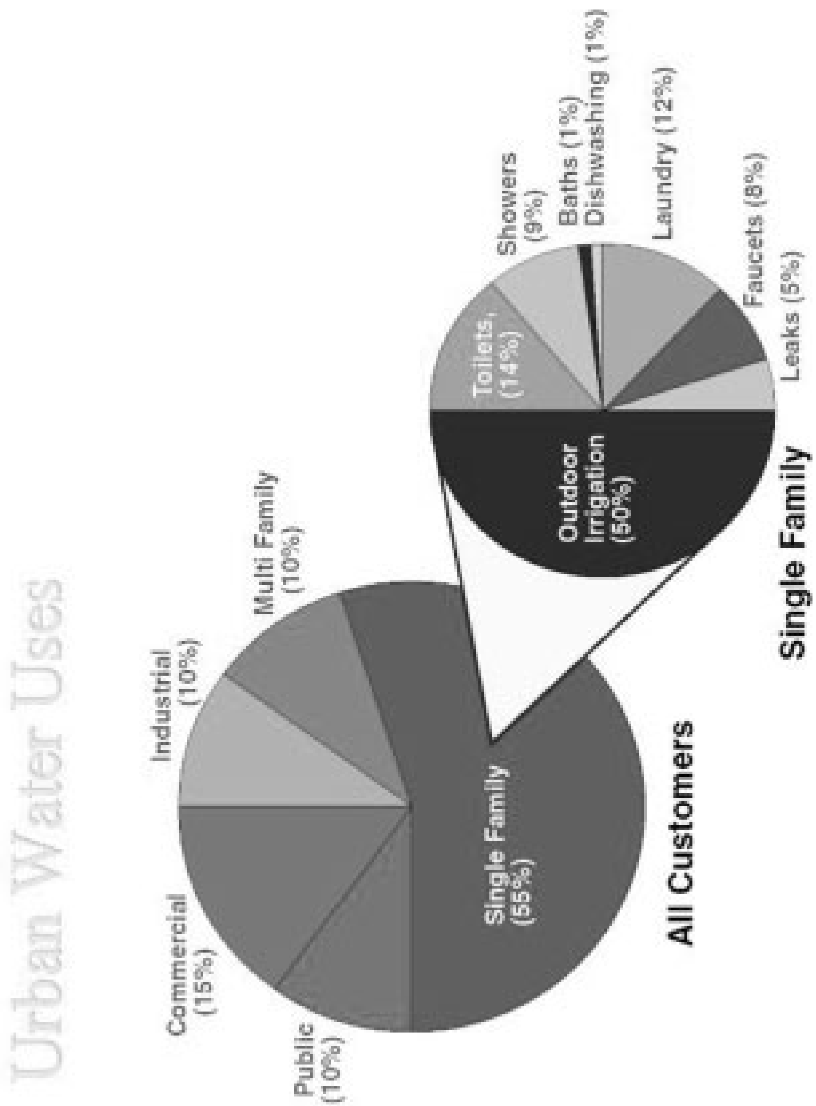

SWP Pumping Facilities
Incremental and Cumulative Energy Inputs and Generation
East Branch
West Branch
Coastal Branch
H.O. Banks
South Bay
Del Valle
San Luis Variable
Dos Amigos
Buena Vista
Wheeler Ridge
Wind Gap
A.D. Edmonston
Alamo
Pearblossom
Mojave Siphon
Devil Canyon
Greenspot
Crafton Hill
Cherry Valley
Oso
Castaic
Las Perillas
Badger Hill
Devil's Den
Bluestone
Polonio

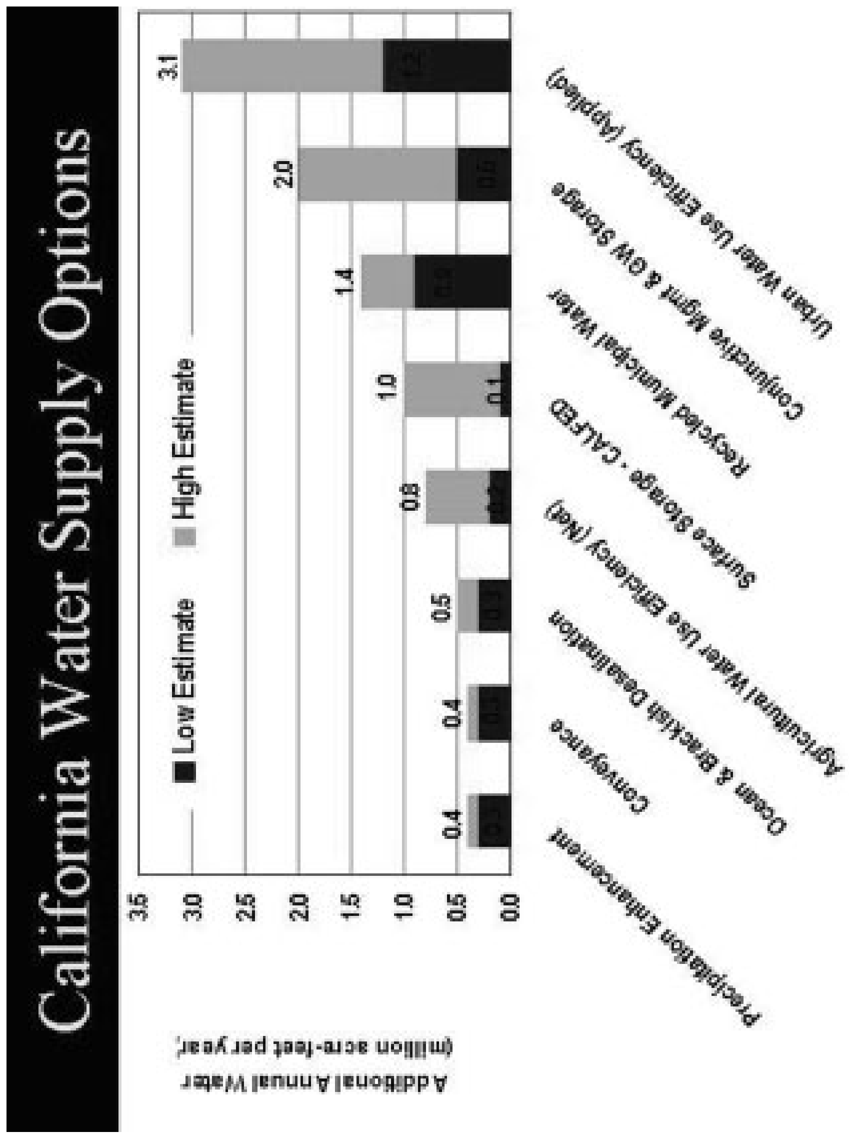

Energy Intensity of Selected Water Supply Sources
in Southern California
kWh/acre foot
0
1000
2000
3000
4000
5000
6000
Efficiency
Reuse (IEUA)
Reuse (West Basin)
Reuse (With RO)
GW (West Basin)
GW (IEUA)
GW Ion Exchange
GW (RO)
CO River (MWD)
SWP West Branch
SWP Coastal Branch
SWP East Branch
SWP at Cherry Valley
Ocean Desal (West Basin)
Ocean Desal (Carlsbad Estimate)


Energy Intensity of Water
Energy intensity, or embodied energy, is the total amount of energy, calculated on a whole-system basis, required for the use of a given amount of water in a specific location.



Energy Inputs to Water Systems
Source
Water Extraction & Conveyance
Water Treatment
Water Distribution
End-Use
Agricultural
Residential
Commercial
Industrial
Recycled Water Treatment
Recycled Water Distribution
Wastewater Collection
Wastewater Treatment
Wastewater Discharge
Source

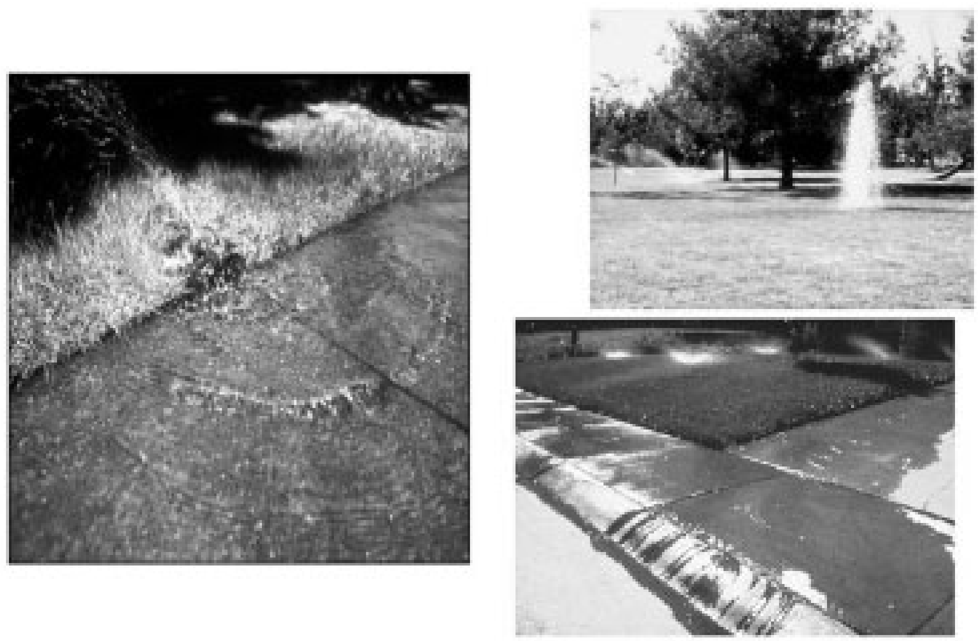

Urban Water Uses
Commercial (15%)
Public (10%)
Industrial (10%)
Multi Family (10%)
Single Family (55%)
All Customers
Outdoor Irrigation (50%)
Toilets, (14%)
Showers (9%)
Baths (1%)
Dishwashing (1%)
Laundry (12%)
Faucets (8%)
Leaks (5%)
Single Family


California Water Supply Options
Low Estimate
High Estimate
Additional Annual Water
(million acre-feet per year)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.4
0.4
0.5
0.8
1.0
1.4
2.0
3.1
0.1
1.2
Precipitation Enhancement
Conveyance
Ocean & Brackish Desalination
Agricultural Water Use Efficiency (Net)
Surface Storage - CALFED
Recycled Municipal Water
Conjunctive Mgmt & GW Storage
Urban Water Use Efficiency (Applied)

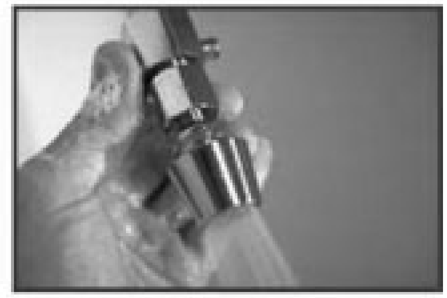
Integrated Management and Multiple Benefits

Integrated water management strategies and improved end-use efficiency can provide significant *multiple benefits* including economic efficiency, energy savings, improved environmental quality, and increased water supply reliability.

Waste = Opportunity



Efficiency Options



Irrigation Efficiency

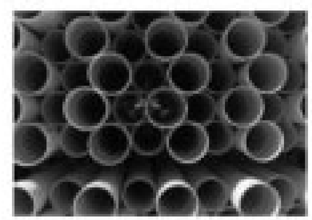
Stormwater Flows

Infiltration Islands

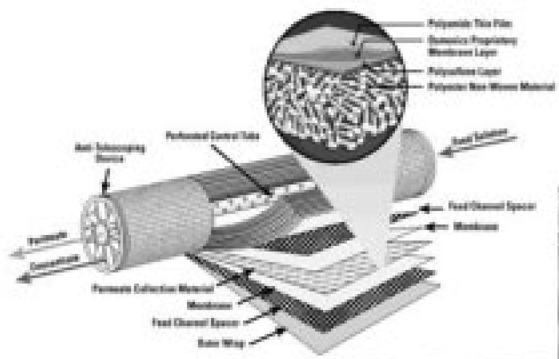
Courtesy of Bruce Ferguson

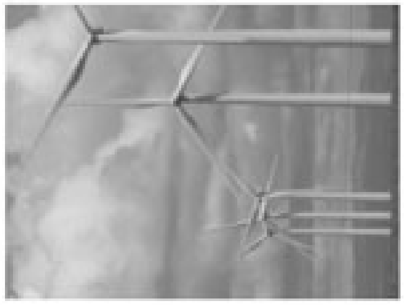
Rain Gardens

Recycled Water

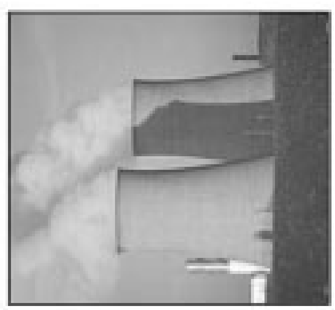


Advanced Water Treatment





Water Intensity of Energy

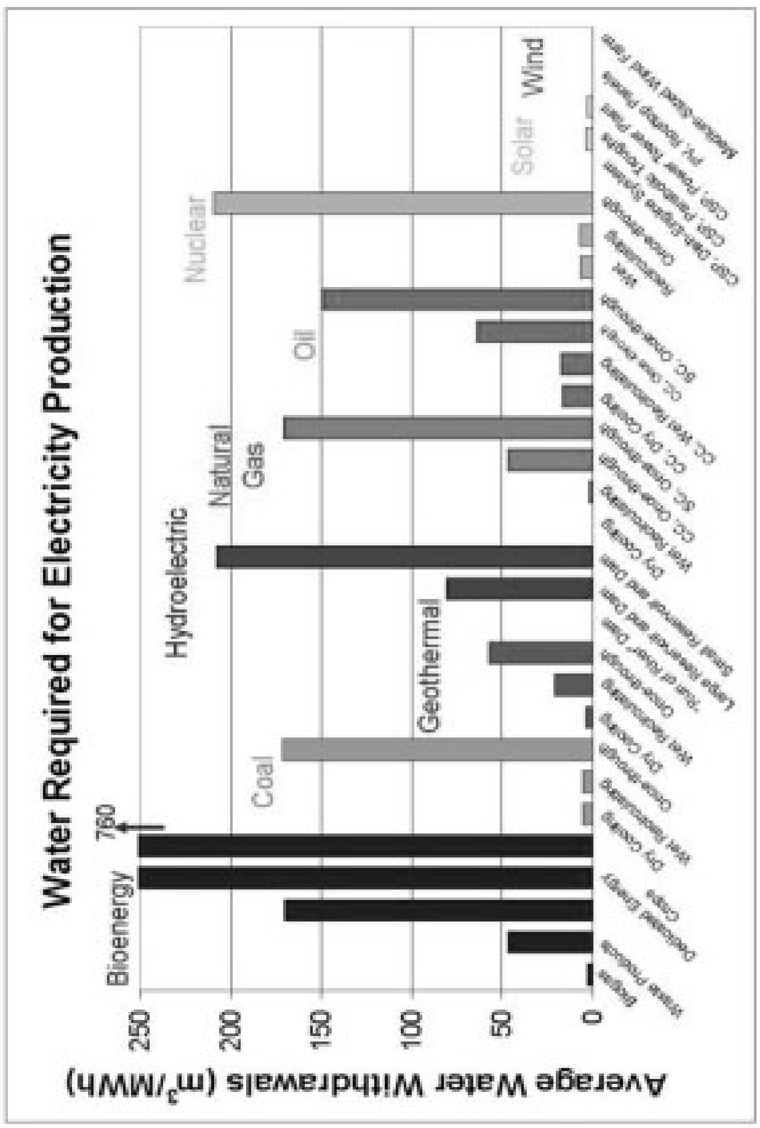


Water Intensity of Energy

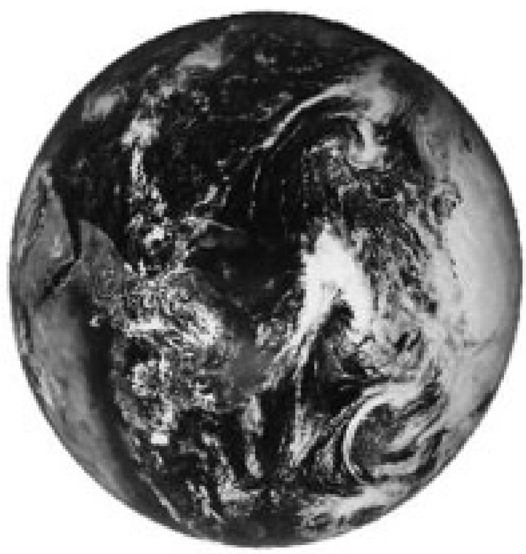
Thermoelectric power generation accounts for about 38% of U.S. freshwater withdrawls, and about 3% of water consumption.

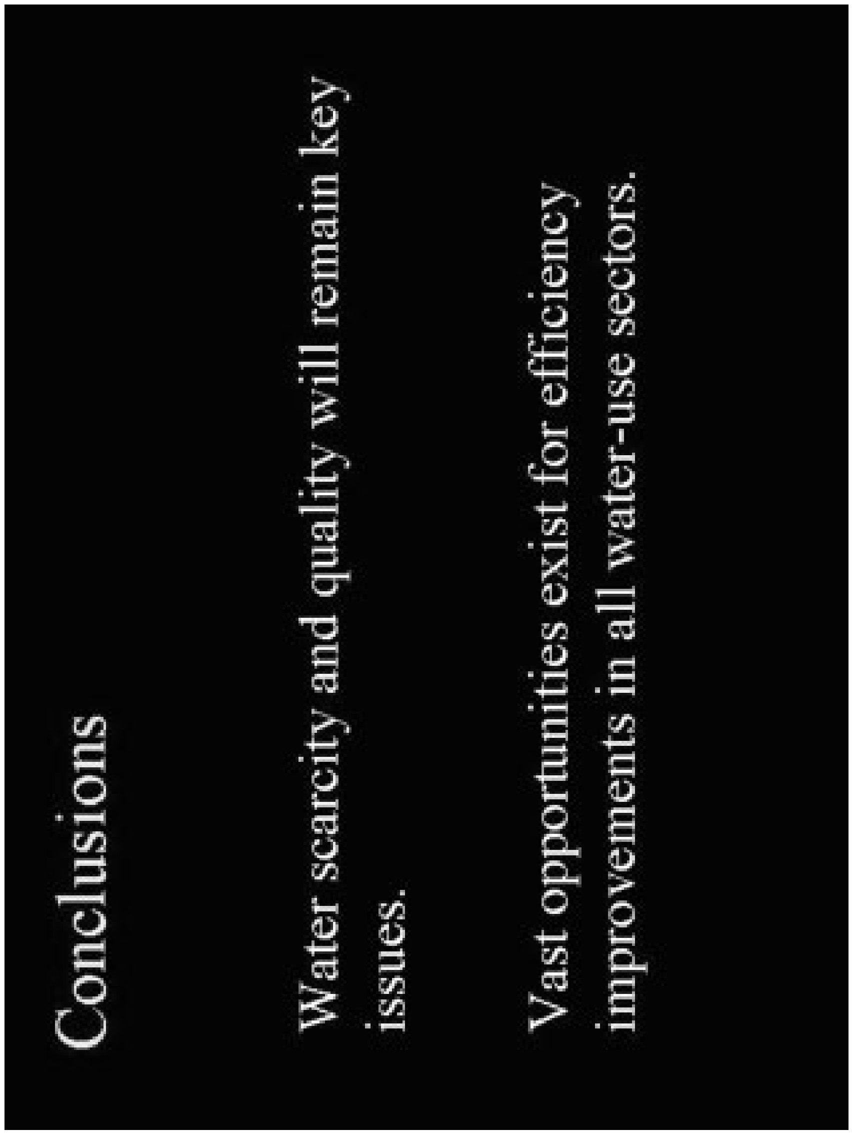
USGS Circular 1268, (released March 2004 and revised April and May 2004)
Available at: http://water.usgs.gov/pubs/circ/2004/circ1268/index.html


completing the energy sustainability puzzle
THE ENERGY-WATER NEXUS
a strategy for energy and water security

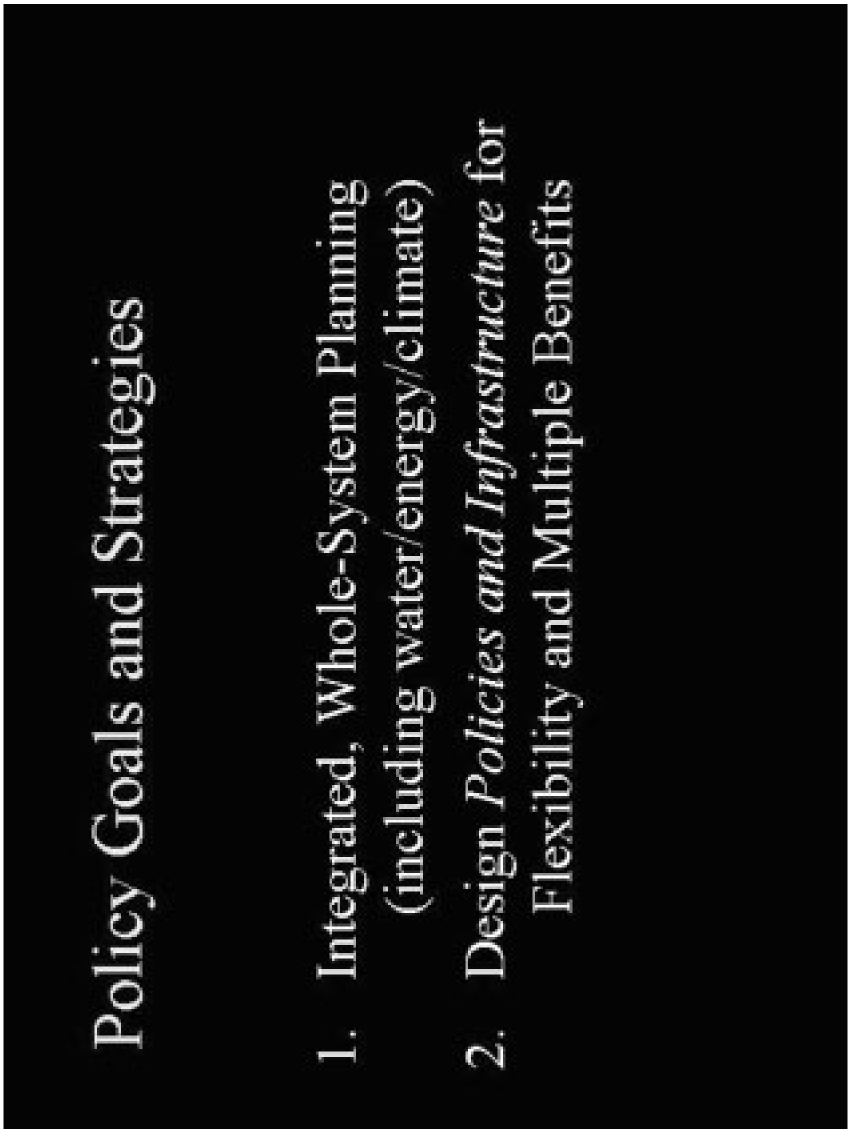

Water Required for Electricity Production
Average Water Withdrawals (m³/MWh)
250
200
150
100
50
0
760
Bioenergy
Coal
Geothermal
Hydroelectric
Natural Gas
Oil
Nuclear
Solar
Wind

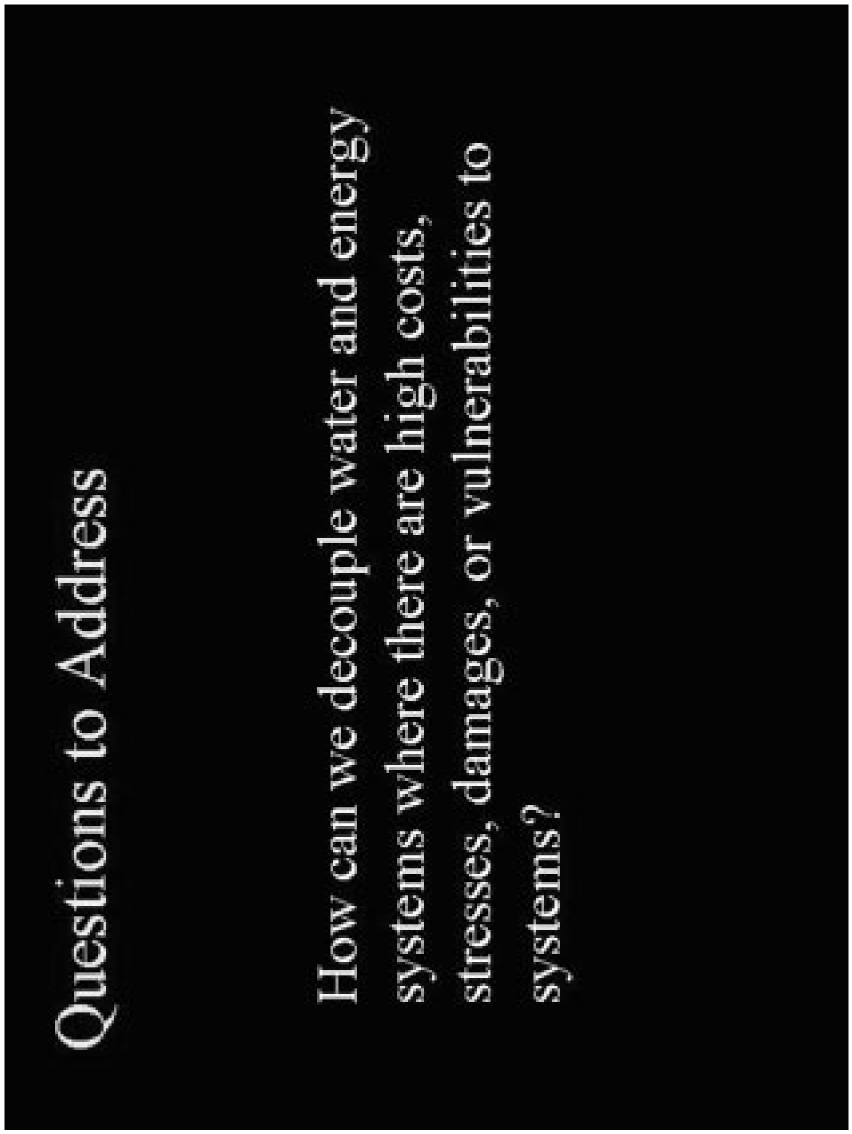
Conclusions

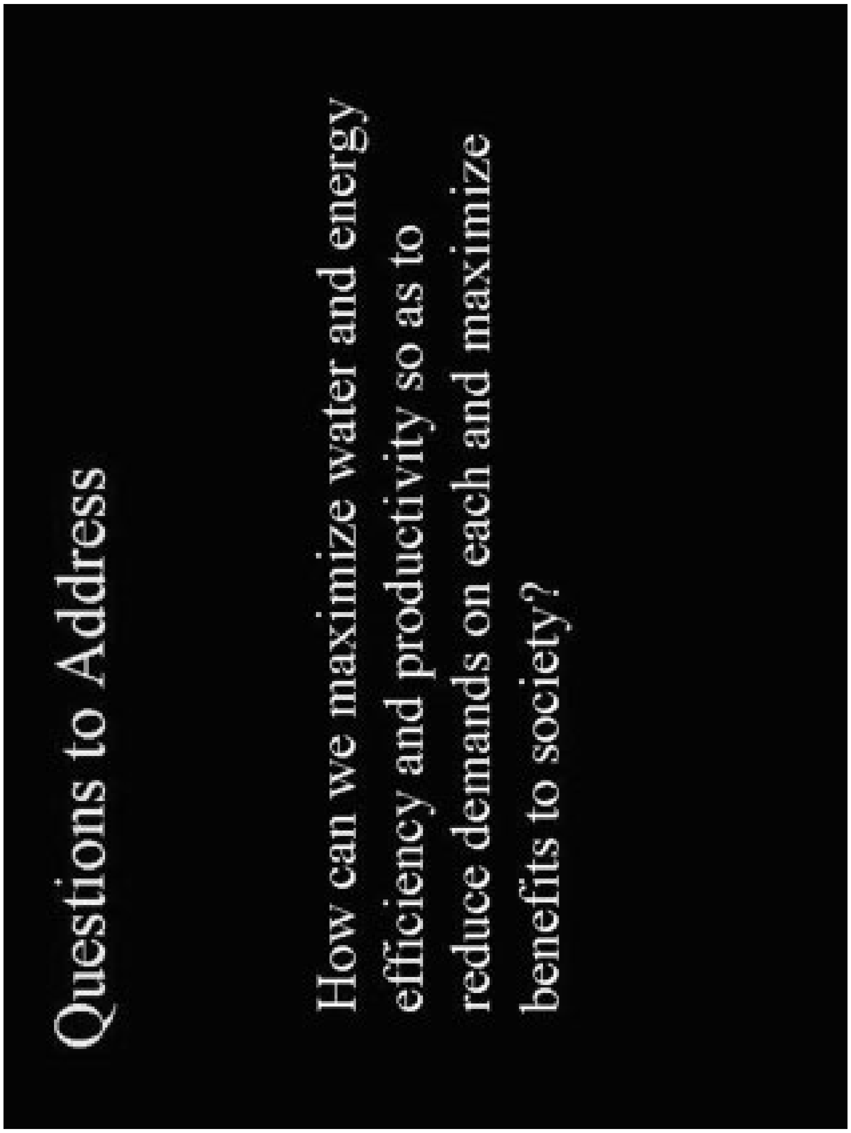



Conclusions
Water scarcity and quality will remain key issues.
Vast opportunities exist for efficiency improvements in all water-use sectors.


Conclusions
Science and technology are critically important to addressing water supply and quality challenges,
and…
Policy design and implementation is equally important in meeting these challenges.


Policy Goals and Strategies
1. Integrated, Whole-System Planning (including water/energy/climate)
2. Design *Policies and Infrastructure* for Flexibility and Multiple Benefits


Questions to Address
How can we decouple water and energy systems where there are high costs, stresses, damages, or vulnerabilities to systems?


Questions to Address
How can we maximize water and energy efficiency and productivity so as to reduce demands on each and maximize benefits to society?

BIOGRAPHY FOR ROBERT C. WILKINSON

Dr. Robert C. Wilkinson is Director of the Water Policy Program at the Bren School of Environmental Science and Management at the University of California, Santa Barbara, and he is a Lecturer in the Environmental Studies Program at UCSB. Dr. Wilkinson's teaching, research, and consulting focus on water policy, energy, climate change, and environmental policy issues. Dr. Wilkinson is also a Senior Fellow with the Rocky Mountain Institute.

Dr. Wilkinson advises businesses, government agencies, and non-governmental organizations on water policy, climate research, and environmental policy issues. He serves on the Task Force on Water and Energy Technology for the California Climate Action Team and as an advisor to State agencies including the California Energy Commission, the California State Water Resources Control Board, the Department of Water Resources, and others on water, energy, and climate issues. He served on the advisory committee for California's 2005 State Water Plan, and he represented the University of California on the Governor's Task Force on Desalination. Dr. Wilkinson advises various federal agencies including the, U.S. DOE National Renewable Energy Laboratory and the U.S. EPA on water and climate research, and he served as coordinator for the climate impacts assessment of the California Region for the US Global Change Research Program and the White House Office of Science and Technology Policy.

In 1990, Dr. Wilkinson established and directed the Graduate Program in Environmental Science and Policy at the Central European University based in Budapest, Hungary. He has worked extensively in Western Europe, every country of Central Europe from Albania through the Baltic States, and throughout the former Soviet Union including Siberia and Central Asia. He has also worked in Australia, New Zealand, Canada, Japan, South Africa, and China.

Chairman GORDON. Thank you, Dr. Wilkinson.

And Mr. Levinson, you are recognized.

STATEMENT OF MR. MARC LEVINSON, ECONOMIST, U.S. CORPORATE RESEARCH, J.P. MORGAN CHASE

Mr. LEVINSON. Thank you, Mr. Chairman. It is quite an honor for me to be with such a distinguished panel today. I am going to speak about water supply risks and their impact on investors.

First, it might help if I explain exactly where I fit in the Wall Street ecosystem. I specialize in economic issues, including environmental regulation, and my clients are institutional investors who buy publicly-traded stock and bonds. I say that to make clear that I have no connection whatsoever to our mergers and acquisitions business or to the lending business or to the many other things that an investment bank does.

In my opinion, investors are much less concerned about water supply risks than they should be. We recently published a report, to which the Chairman alluded, contending that water-supply risks are far more important to many companies than investors believe. We also found that very few companies are fully aware of these risks.

A lot of companies now produce PR brochures that talk about how they are reducing water use per unit of output, but almost none of these companies thoroughly assesses what we call its water footprint, which is the total usage of water in its supply chain, clear through to the consumption of its products. Investors really have no way of evaluating the risk of business disruption due to water scarcity or of comparing risks among companies.

We think these risks take three forms. One is physical risk. That is the most obvious. This is the risk to which the Chairman alluded earlier that occurred with the Brown's Ferry Reactor last year. It simply had to be shut down because there was not enough water in the Tennessee River to cool it adequately.

The second is a different situation. It is regulatory risk. Regulatory risks involve government decisions to allocate and price water in response to scarcity. Perhaps the best U.S. example occurred in 2001, when lack of water in the Columbia and Snake Rivers caused the Bonneville Power Administration to curtail electricity sales to aluminum smelters in Montana, Oregon, and Washington. In the short run, aluminum production plummeted in the U.S. In the long run, the aluminum industry is leaving the region because regulators responded to water scarcity by raising the price of a key input, electricity. In 2001, there were ten aluminum smelters in the Northwest. Today there are three still operating.

The third set of corporate risks is reputational. In a number of places around the world consumers are taking environmental considerations into account in deciding which goods and services to buy, and we think companies that are perceived as bad actors face a serious risk of consumer backlash.

The risks of water scarcity, of course, are not evenly spread through the economy. In addition to semiconductors and power generation, water sensitivity is particularly acute in the food processing and in oil and gas production.

I think food processing risks are well known to people, perhaps less so in oil and gas where there is now a lot of interest in shale formations. Shale rock contains very small pores. Basically the oil or gas cannot migrate to the well readily. The way this oil is recovered is by injecting large amounts of water under high pressure, a technology called fracture stimulation. This runs afoul of a lack of water in many places, and so the lack of water is actually inhibiting the recovery of oil that would otherwise be available.

The Committee asked me what the Federal Government might do to facilitate the equitable and efficient allocation of water supplies, and I wanted to give you three thoughts here.

First, if you look at overall U.S. water consumption, it has actually been fairly flat, but there are some disturbing trends. An increasing share of this consumption comes from groundwater, which suggests that surface water resources have been tapped out.

Irrigation accounts for about two-thirds of U.S. groundwater withdrawals, and this share is probably growing. I would point out that the effort to increase production of ethanol actually increases the draw on groundwater by encouraging the planting of corn and other crops in fairly arid regions where it has to be irrigated.

There are more than 100,000 irrigation wells in the United States, and only one-seventh of them, according to the Agriculture Department, only one in seven irrigation wells has a meter on it. If something is not metered, it is not being paid for. And there is very little incentive to conserve something that you are getting for free.

So I would suggest that here is an area for the Committee to look at. I understand that State law rather than federal law governs groundwater, but excessive use of groundwater clearly affects interstate commerce, and so there is a federal interest here. And in my view it would be useful for Congress to encourage the states to apply methods of pricing groundwater withdrawals to stimulate conservation. This should apply not just to agriculture but to all groundwater withdrawals.

A second subject in which Congressional involvement might be useful is localized water treatment. Almost all of our public supplies are now treated centrally. As a result, we are using drinking water to water roses and wash down parking lots. This represents a huge waste of resources. There is now a lot of work going on in developing decentralized water treatments. This is in the R&D stage by many private companies. It might be an area in which federal research funds or changes in federal water treatment regulations would be helpful.

There is one other subject I want to touch on, and this is power generation. I know there is a lot of talk on Capitol Hill now about federal loans or guarantee programs for new-generation nuclear plans and for coal plants with carbon capture and sequestration. Both of these technologies require large amounts of water. I think it important that the social costs of these large water withdrawals be reflected in the prices users pay for the electricity from these plants. It is just bad policy for the government to be subsidizing water usage, and this applies to power plants as much as to agriculture and other industries.

Thank you very much.

[The prepared statement of Mr. Levinson follows:]

PREPARED STATEMENT OF MARC LEVINSON

Thank you, Mr. Chairman. My name is Marc Levinson, and I'm an economist at JPMorgan Chase in New York. I appreciate the opportunity to speak with you today about water-supply risks and their impact on investors.

First, let me explain just where I fit in the Wall Street ecosystem. I specialize in economic issues, including environmental regulation, and my clients are institutional investors who buy publicly traded stocks and bonds. I have no connection whatsoever to our loan officers or to our investment bankers. My perspective is strictly that of investors in public companies.

In my opinion, investors are much less concerned about water supply risks than they should be. We recently published a report contending that water-supply risks are far more important to many companies than investors believe. We also found that very few companies seem fully aware of these risks. While many companies now produce public relations brochures that tell how they are reducing water use per unit of production, almost none of these companies thoroughly assesses what we call its water "footprint," the total usage of water in the production and consumption of its product. Investors have no way of evaluating the risk of business disruption due to water scarcity, or of comparing risks among companies.

We think these risks take three forms. The most obvious is physical risk, which means an actual lack of water. This could have heavy costs for an industry such as semiconductor manufacturing, which needs massive quantities of clean water. Intel Corporation alone uses as much water each year as a city the size of Rochester, New York. We estimate that a single production interruption at a semiconductor plant could cost $200 million in lost revenue and badly hurt the company's share price. The customers waiting for those semiconductors would suffer financial losses as well.

Physical risk is more common than generally realized. In 2007, for example, the Tennessee Valley Authority was forced to shut a nuclear plant because there simply wasn't enough acceptable cooling water in the Tennessee River. We don't think the TVA is the only utility that will experience this problem.

The second set of risks that companies face is regulatory. Regulatory risks involve government decisions to allocate and price water in response to scarcity. Perhaps the best US example occurred in 2001, when lack of water in the Columbia and Snake Rivers caused the Bonneville Power Administration to curtail electricity sales to aluminum smelters in Montana, Oregon, and Washington. In the short run, US aluminum production plummeted. In the long run, the aluminum industry is leaving the region, because regulators responded to water scarcity by raising price of a key input, electricity. In 2001, there were 10 aluminum smelters in the Northwest. Today, there are only three.

The third set of corporate risks arising from water shortage is reputational. In a number of places around the world, consumers are taking environmental considerations into account in deciding which goods and services to buy. We think companies that are perceived as "bad actors" by wasting water face a serious risk of consumer backlash.

The risks of water scarcity are not evenly spread through the economy. In addition to semiconductors and power generation, water sensitivity is particularly acute in food processing and in oil and gas production.

The food processing sector requires large amounts of water in its supply chain, principally for crop production. Getting one pound of beef to the consumer's table in the United States requires, on average, about 2,200 gallons of water. Higher input costs, due in part to increased competition for and uncertainty about water supply, already are hurting food manufacturers.

In the oil-and-gas sector, there is a lot of excitement now about shale formations. Shales contain rock with very small pores, such that the oil and gas within the rock cannot readily migrate to wells. A technology called fracture stimulation can help recover these resources—but it does so by injecting large amounts of water under high pressure. Water scarcity is already limiting the development of energy shales in several parts of the country.

The Committee has asked me what the Federal Government might do to facilitate the equitable and efficient allocation of water supplies. Here are a few thoughts.

If you look at the aggregate numbers, U.S. water use has been fairly flat since the 1980s, at about 400 billion gallons per year. But there are disturbing trends. An increasing share of those 400 billion gallons per year is groundwater rather than surface water. Annual groundwater withdrawals rose 14 percent between 1985 and 2000, while surface water withdrawals were flat. This suggests that many rivers and reservoirs are being fully utilized, so water users are increasingly relying on groundwater, which is subject to less regulation. This shift will probably continue, because climate change is expected to reduce the flow of surface water, especially in the Southwest.

Irrigation accounts for about two thirds of U.S. groundwater withdrawals. Government promotion of biofuels has led to large increases in corn plantings in some fairly arid states, especially on the Great Plains, and it's likely that a lot of this increased acreage is irrigated. This means even more demands on groundwater.

There more than 100,000 irrigation wells in the U.S., and only one-seventh of them have meters. An unmetered well is likely to be a well that a farmer can use without paying for the water. Of course, there is little incentive to conserve something that is free. When the Department of Agriculture asked farmers about barriers to reducing energy use or conserving water, the most common response was that conservation would not save enough money to cover its own costs. The second most common response was that conservation measures are not affordable. Both of these responses are ways of saying that water is so cheap that it's not worth conserving.

I recognize that State law, rather than federal law, usually governs groundwater. But excessive use of groundwater clearly affects interstate commerce, so there is a federal interest here. In my view, it would be useful for Congress to encourage the states to adopt methods of pricing groundwater withdrawals to stimulate conservation. Pricing should apply not just to agriculture, but to all users withdrawing groundwater.

A second subject in which Congressional involvement might be useful is localized water treatment. Almost all of our public water supplies are treated in centralized treatment plants. As a result, drinking water is being used to water rose bushes and wash down parking lots. This represents a large waste of resources. It might be more cost effective to treat water at individual buildings rather than centrally, so that only water needed for human consumption is treated. Several companies are looking into technologies for decentralized water treatment, and this may be an area in which federal research funds or changes in federal water-treatment regulations would be helpful.

There is one other subject I want to touch on, and that is power generation. I know there is a great deal of talk on Capitol Hill about federal loans or loan guarantees for new-generation nuclear plants and for coal plants with carbon capture and sequestration. Both of these technologies require very large amounts of water. I think it is important that the social cost of those large water withdrawals be reflected in the prices users pay for electricity from those plants. It's simply bad policy for the government to be subsidizing water usage, and that applies just as much to power plants as to agriculture and other industries.

Thank you for the opportunity to testify this morning.

BIOGRAPHY FOR MARC LEVINSON

Marc Levinson is an economist at JPMorgan Chase in New York. He specializes in microeconomic issues, including industry structure and regulation, and works closely with JPMorgan's equity and credit analysts and their clients in understanding the impact of economic developments on publicly traded securities. He is accredited both as a supervisory credit analyst and as an equity analyst, although he does not make investment recommendations with respect to individual companies.

Mr. Levinson frequently publishes investment research on energy, climate change, and environmental regulation. In 2007, he participated in drafting the National Petroleum Council's report to the U.S. Secretary of Energy, entitled *"Facing the Hard Truths About Energy."* He also contributed to the London Accord, a collaborative effort among several major investment banks to examine the investment implications of climate change.

Prior to joining one of JPMorgan's predecessor companies in 1999, Marc Levinson was finance and economics editor of *The Economist* in London. He was formerly a writer on business and economics for *Newsweek.* His articles have appeared in such publications as the *Harvard Business Review,* the *Financial Times,* and *Foreign Affairs.* He is the author of four books, most recently *The Box: How the Shipping Container Made the World Smaller and the World Economy Bigger* (Princeton University Press, 2006), which has received numerous awards.

Chairman GORDON. Thank you, Mr. Levinson, and Dr. Pulwarty, Dr. Pulwarty, you are recognized.

STATEMENT OF DR. ROGER S. PULWARTY, PHYSICAL SCIENTIST, CLIMATE PROGRAM OFFICE; DIRECTOR, THE NATIONAL INTEGRATED DROUGHT INFORMATION SYSTEM (NIDIS), OFFICE OF OCEANIC AND ATMOSPHERIC RESEARCH, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, U.S. DEPARTMENT OF COMMERCE

Dr. PULWARTY. Good morning, Chairman Gordon, Ranking Member Hall, and the Members of the Committee. Thank you for inviting me to speak with you today on the National Integrated Drought Information System and its role in addressing some of our water supply challenges in the 21st century.

My name is Roger Pulwarty. I am a climate scientist in the National Oceanic and Atmospheric Administration and the Director of the National Integrated Drought Information System or NIDIS Program. I have also been fortunate to be a lead author on adaptation in the Intergovernmental Panel on Climate Change Fourth Assessment report and on the recently released IPCC technical report on climate and water resources, the results of which I was fortunate to have presented before this committee last year.

As is widely acknowledged, drought is not a purely physical phenomenon, but is an interplay between water availability and the needs of humans and the environment. Drought is slow in onset and its effects, such as impacts on energy including hydropower, tourism, and commodity markets, can continue to be felt long after an event is over.

As outlined in Public Law 109–430, NIDIS is envisioned to serve as an early warning information system for managing drought-related risks in the 21st century. Impetus for information services to support federal, State, and local responses has risen from ongoing concerns over water security and scarcity as mentioned before in the Southwest since 1999, and the Southeast since early 2007, along with declining water levels in the three largest Great Lakes since the late 1980s.

A great deal of progress has been made since the NIDIS Program was established in December 2006. A national interagency and interstate program implementation team has been developed, the web-based drought portal was launched in November 2007. It now provides comprehensive national-level information on ongoing drought conditions and emerging conditions. NOAA and NIDIS are accelerating their improvements of operational climate forecasts and information on past droughts tailored to watersheds and local scales such as the upper basin of the Colorado and the Southeast, including Tennessee, Georgia, Florida, Alabama, and the Carolinas.

NIDIS works through numerous federal agencies, tribes, states, and local governments. As such, there is significant leveraging of existing observing system infrastructure and products such as the drought monitor to provide improved data streams at the level of detail needed for decision-making at watersheds, Colorado basin, and at regional scales such as the Southeast.

Data and predictions are by themselves insufficient to ensure adaptation and flexibility in the water resources sector. A hallmark, no pun intended, of NIDIS is the provision of decision support tools and training, coupled with the ability of users to report local conditions back to the portal. Near-term activities include tailoring of the drought portal to add locally-specific data and information at the watershed and county levels. Water managers are already explicitly considering how to incorporate the potential effects of a changing climate into specific designs.

For example, in the California Southern Metropolitan Water District and Seattle and Las Vegas, adaptive measures have been undertaken. But the barriers to implementing adaptive measures include the inability of some natural systems to adapt at the rate of combined demographic pressures and climate, understanding and quantifying our water demands and impediments to the flow of timely and reliable information relevant for decision-making.

Climate services designed to support adaptation, of which NIDIS is an example, will be important in coping with current and future extremes and their effects on water resources, regardless of how that change is derived. As part of their drought management, municipalities and State agencies will have improved climate information and forecasts at key entry points for allocating domestic and industrial water usage.

Water resource managers will have access to more detailed information on low-flow conditions when balancing irrigation and hydropower with the needs of wildlife and flows to support coastal economies. Emergency declarations can now better reach out to those communities in need of assistance with improved information on the aerial extent and severity of developing droughts.

So while per-capita water use is declining in some parts of the country, trends and demand, observational records, and climate projections provide abundant evidence that our fresh water resources are vulnerable. Priorities for drought early warning information and decision support tools to prepare our nation for these challenges requires a mixed portfolio of approaches, including: enhancing the networks of systematic observations of key elements in the human, ecological, and physical systems, including monitoring groundwater and vegetation stress; promoting drought plans that maintain State sovereignty but responds to the needs of shared watersheds, including developing trans-boundary monitoring and early-warning information for our internationally-shared watersheds with our neighbors to the north and the south; developing drought information impact assessment tools that include the costs and benefits of various adaptations and changing water demands; and finally, developing usable drought management triggers for specific planning thresholds and scenarios in agriculture, water, energy, and the coast.

The challenges of managing water supplies to meet social, economic, and environmental needs requires matching what we do with what we actually know. NIDIS offers the Nation a mechanism to achieve this service requirement by providing a basis for integrating drought monitoring, research, and information for decision support.

Thank you for inviting me to testify at this hearing today, and I am happy to answer any questions you might have.

[The prepared statement of Dr. Pulwarty follows:]

PREPARED STATEMENT OF ROGER S. PULWARTY

Good morning, Mr. Chairman and Members of the Committee. Thank you for inviting me to speak with you today about the National Integrated Drought Information System (NIDIS); the information/data currently available to local, State and regional water decision-makers; and how we can improve the information available to these decision-makers for adapting to current and future drought conditions.

My name is Roger Pulwarty; I am a Physical Scientist in the National Oceanic and Atmospheric Administration's (NOAA's) Climate Program Office and the Director for the U.S. National Integrated Drought Information System (NIDIS). I had the honor of serving as a lead author on the Intergovernmental Panel on Climate Change (IPCC) Working Group II, in Chapter 17, *Assessment of Adaptation Practices, Options, Constraints and Capacity,* and on the *IPCC Special Report on Climate Change and Water Resources* released this past April. I am also a lead author of the U.S. Climate Change Science Program (CCSP), *Synthesis and Assessment Report on Weather and Climate Extremes in a Changing Climate* and the Unified Synthesis Report. My role in these reports focuses on impact assessment and adaptation responses.

In general, NOAA's climate programs provide the Nation with services and information to improve management of climate sensitive sectors, such as energy, agriculture, water, and living marine resources, through observations, analyses and predictions, decision support tools, and sustained user interaction. Our services include assessments and predictions of climate change and variability on time scales ranging from weeks to decades for a variety of phenomena, including drought. In this testimony I will highlight: (1) present drought-related adaptation measures being undertaken in the water sector across the U.S., and (2) the role of the NIDIS in improving our capacity for responding to drought.

Drought is not a purely physical phenomenon, but is an interplay between water availability and the needs of humans and the environment. Drought is a normal, recurrent feature of climate and while its features vary from region to region, drought can occur almost anywhere. Because droughts can have profound societal and environmental impacts, there are several definitions of drought, each correct in its use. These definitions include meteorological drought, which is defined by the magnitude of precipitation departures below long-term average values for a season or longer; agricultural drought, which is defined as the soil moisture deficit that impacts crops, pastures, and range lands; and hydrological drought, which is defined by significant impacts on water supplies. NOAA provides information on all three types of droughts in its U.S. drought information products.

Drought is a unique natural hazard. It is slow in onset, does not typically impact infrastructure directly, and its secondary effects, such as impacts on tourism, commodity markets, transportation, wildfires, insect epidemics, soil erosion, and hydropower, are frequently larger and longer lasting than the primary effects. Primary effects include water shortages and crop, livestock, and wildlife losses. Drought is estimated to result in average annual losses to all sectors of the economy of between $6 to $8 billion (in 2002 dollars; *Economic Statistics for NOAA,* April 2006, 5th edition). The costliest U.S. drought of the past forty years occurred in 1988 and caused more than $62 billion (in 2002 dollars) of economic losses (*Economic Statistics for NOAA,* April 2006, 5th edition). Although drought has not threatened the overall viability of U.S. agriculture, it does impose costs on regional and local agricultural economies. Severe wild fires and prolonged fire seasons are brought on by drought and strong winds. These fires, similar to the ones in California this past year, can cause billions of dollars in additional damages and fire suppression costs.

Recent IPCC reports, including the recent *Technical Report on Climate Change and Water Resources,* highlight emerging needs for the development and communication of climate and climate impacts information to inform adaptation and mitigation across sectors when changes are beyond average climate conditions and extremes. Drought risk management provides an important prototype for testing adaptation strategies across the full spectrum of climate time scales. Most communities (and countries) currently manage drought through reactive, crisis-driven approaches. Experience shows that effecting change in managing climate-related risk is most readily accomplished when: (1) a focusing event (climatic, legal, or social) occurs and creates widespread public awareness; (2) leadership and the public are engaged; and (3) a basis for integrating monitoring, research, and management is established. The NIDIS offers the Nation a mechanism to achieve this latter service requirement. The IPCC Fourth Assessment (2007) and the CCSP reports offer impetus for integrating knowledge about the nature of societal and environmental vulnerability, attribution of the relative influences of climate variability and change, and for services to support federal, State and local adaptive responses to the full spectrum of climate. This impetus is further strengthened by the ongoing debates as seen occurring in connection with water scarcity in the West since 1999 and in the Southeast since 2007, along with declining Great Lake water levels since 1986.

Given that a drought occurs when water supply is insufficient to meet water demand, drought impacts are evaluated relative to the demand from environmental, economic, agricultural, and cultural uses. The impacts of past droughts have been difficult to estimate. This problem results from the nature of drought, which is a phenomenon with slow onset and demise that does not create readily-identified and discrete short-term structural impacts. Drought may be the only natural hazard in which the secondary impacts can be greater than the more identifiable primary impacts, such as crop damage. Impacts may continue to be felt long past the event itself as secondary effects cascade through economies, ecosystems, and livelihoods.

The *National Integrated Drought Information System Act of 2006* (NIDIS Act; 15 U.S.C. § 313d and § 313d note) prescribes an approach for drought monitoring, forecasting, and early warning at watershed, State and county levels across the United States. Led by NOAA, this approach is being developed through the consolidation of physical/hydrological and socioeconomic impacts data, engaging those affected by drought, integration of observing networks, development of a suite of drought decision support and simulation tools, and the interactive delivery of standardized products through an Internet portal (*www.drought.gov*). NIDIS is envisioned to be a dynamic and accessible drought risk information system that provides users with the capacity to determine the potential impacts of drought, and the decision support tools needed to better prepare for and mitigate the effects of drought.

As requested in the 2004 Western Governors' Association Report, *Creating a Drought Early Warning System for the 21st Century: The National Integrated Drought Information System,* NIDIS is being designed to serve as an early warning system for drought and drought-related risks in the 21st century. With these guidelines in mind, the explicit goal of NIDIS is to enable society to respond to periods of short-term and sustained drought through improved monitoring, prediction, risk assessment, and communication.

Over the next five years, NIDIS will build on the successes of the U.S. Drought Monitor, Seasonal Outlooks, and other tools and products provided by NOAA and other agencies to effect fuller coordination of relevant monitoring, forecasting, and impact assessment efforts at national, watershed (e.g., the Colorado Basin), states (e.g., GA, AL, FL), and local levels. NIDIS is beginning to provide a better understanding of how and why droughts affect society, the economy, and the environment, and is improving accessibility, dissemination, and use of early warning information for drought risk management. The goal is to close the gap between the information that is available and the information that is needed for proactive drought risk reduction. Federal monitoring and prediction programs that feed into NIDIS are also working with universities, private institutions, and other non-federal entities to provide information needed for effective drought preparedness and mitigation.

NIDIS will provide more comprehensive and timely drought information and forecasts for many users to help mitigate drought-related impacts. For example, hydropower authorities will benefit from enhanced water supply forecasts that aim to incorporate improvements in monitoring soil moisture, precipitation, and temperature for snowpack conditions into forecasting efforts and drought information for water management decisions. Municipalities and State agencies will have improved drought information, based on present conditions and past events, and forecasts when allocating both domestic and industrial water usage. Water resource managers will have access to more information when balancing irrigation water rights with the needs of wildlife. Purchasing decisions by ranchers for hay and other feed supplies will be enhanced through the use of drought information to identify areas of greatest demand and the potential for shortages. Changes in water quantity and quality due to climate change and other factors are expected to affect food production and prices. Farmers will be better positioned to make decisions on which crops to plant and when to plant them. Since drought information is used in allocating federal emergency drought relief, improvements in monitoring networks will also lead to more accurate assessments of drought and, as a result, emergency declaration decisions that better reach out to those communities in need of assistance. An example of a specific improvement in monitoring networks is the addition of soil moisture sensors to the climate reference network by NOAA/NIDIS. The identification of gaps in monitoring needed for early warning system development, primarily within snow cover, soil moisture, stream gauge, and ground water networks (in partnership with the U.S. Geological Survey), will be identified in NIDIS early warning pilot programs in selected locations. Also, in partnership with Department of Agriculture (USDA), priorities for snow cover/snow telemetry sites will be updated as need arises. Cross-agency partnerships to fill monitoring gaps will be developed with the interagency NIDIS Executive Council.

Data alone is not sufficient to ensure effective adaptation. A hallmark of NIDIS is the provision of decision support tools coupled with the ability for users to report localized conditions. To this end, NIDIS will link multi-disciplinary observations from a number of sources to 'on-the-ground' conditions that will yield value-added information for agricultural, recreational, water management, commercial, and other sectors. Multi-disciplinary observations include land surface conditions (e.g., for fire/fuel risk and soil moisture), streamflow and precipitation observations, climate models, and sectoral and environmental impacts information (to identify potential high impact areas or sectors for different types of drought events). Also, impacts information (i.e., how drought is affecting a location, how similar/past droughts have affected the location) will be provided by NIDIS, as required in the NIDIS Act, and as recommended by the Western Governors Report, and decades of study on the types of information leads to effective early warning triggers for response.

The first step towards accomplishing these goals was to produce an implementation plan. With the results of deliberate and broad-based input from workshops held with federal, State, and local agencies, academic researchers, and other stakeholders, the NIDIS implementation plan was produced and published in June 2007. To provide guidance on system implementation, technical working groups were formed to focus on five key components of NIDIS. These components are public awareness and education, engaging preparedness communities, integrated monitoring and forecasting, interdisciplinary research and applications, and the development of a national drought information portal.

A great deal of progress has been made since the NIDIS program was established in December 2006. The U.S. Drought Portal, launched in November 2007 and hosted on the NIDIS website (*www.drought.gov*), is operational and providing comprehensive information on emerging and ongoing droughts, and enhancing the Nation's drought preparedness. Other Current NIDIS activities include conducting the first national workshop to assess the status of drought early warning systems across the United States, 17–19 June, Kansas City, MO. A NIDIS Southeast drought workshop was recently held in Peachtree City, Georgia, 29–30 April 2008 to begin coordinating drought early warning information systems for the Southeast region especially for the Appalachicola-Chattahoochee-Flint and the Alabama-Coosa-Tallapoosa basins encompassing the upper watersheds of Georgia to the coastal resources of Alabama and Florida.

While NOAA is the lead agency for NIDIS, NOAA works with numerous federal agencies, emergency managers and planners, State climatologists, and State and local governments, to obtain and use drought information. NOAA routinely disseminates drought forecast information via its National Weather Service (NWS) drought statements, and collaborates with State drought committees and the media to assure NOAA information is correctly understood and used. NOAA strives to provide an end-to-end seamless suite of drought forecasts, regional and local information, and interpretation via its Climate Prediction Center, six Regional Climate Centers, Regional Integrated Sciences and Assessments (RISA) including the Southeastern Climate Consortium, local NWS field offices and State climatologists. Efforts are underway to improve drought early warning systems including coordinating interagency drought monitoring, forecasting, and developing indicators and management triggers for societal benefit. The other major federal agencies involved in NIDIS are the Department of the Interior, USDA, the National Aeronautic and Space Administration, the Department of Energy, the Department of Homeland Security, the Department of Transportation, the Army Corps of Engineers, the Environmental Protection Agency, and the National Science Foundation. There is significant leveraging of existing observing system infrastructure, data, and products produced by operating agencies, for example, stations of the NOAA National Weather Service Cooperative Observer Program, USDA Natural Resources Conservation Service SNOTEL (SNOpack TELemetry) network, Soil Climate Analysis Network, National Climate Data Center Climate Reference Network, and the United States Geological Survey streamflow and ground-water networks, as well as the USDA-Joint Agricultural Weather Facility and the USDA–Natural Resources Conservation Service/Water and Climate Center Weekly Report—Snowpack/Drought Monitor Update. NIDIS also provides a framework for coordinating the research agenda among these agencies.

At present NOAA/NIDIS is supporting the development of new drought monitoring and prediction products and accelerating future improvements of NOAA's operational climate forecast and application products through the use of competitive grants, and through the tailoring of the U.S. Drought Portal to add locally specific data and information at the level of watersheds and counties. Questions being addressed include early warnings of low flow conditions on the Colorado, on drought and fire risk, agriculture on the Southern Great Plains and the reliability of water supplies in the Southeast U.S.

Information services for adaptation on short-term (seasonal) or longer-term (multi-year) drought, will be important in coping with current climate vulnerabilities and early impacts in the near-term, and will help build resilient economies as our climate changes, regardless of how that change is derived. It is important to note that unmitigated climate change could, in the long-term, exceed the capacity of some natural, managed and human systems to adapt especially in drought prone—heavily developing regions such as the Southwest. If climate change results in increasing water scarcity relative to demands, future adaptations may include technical changes that improve water use efficiency, demand management (e.g., through metering and pricing), and institutional changes that improve the tradability of water rights. If climate change affects water quality, adaptive strategies will have to be developed to protect the ensuing human uses, ecosystems and aquatic life uses. It takes time to fully implement such changes, so they are likely to become more effective as time passes. The availability of water for each type of use may be affected or even limited by other competing uses of the resource.

Climate is one factor among many that produce changes in our environment. Demographic, socioeconomic and technological changes may play a more important role in most time horizons and regions. As the number of people and attendant demands upon already stressed river basins and groundwater sources increase, even small changes in our climate, induced naturally or anthropogenically, can trigger large impacts on water resources. Present hydrological conditions are not anticipated to continue into the future (the traditional assumption). It will be difficult to detect a clear climate change effect within the next couple of decades, even if there is an underlying trend. Consequently, methods for adaptation in the face of these uncertainties are needed. Early warnings of changes in the physical system and of thresholds or critical points that affect management priorities become important. Water managers in some states are already considering explicitly how to incorporate the potential effects of climate change into specific designs and multi-stakeholder settings. Integrated water resources and coastal zone management are based around the concepts of flexibility and adaptability, using measures which can be easily altered or are robust to changing conditions. For example, in California and Nevada adaptive management measures (including water conservation, reclamation, conjunctive use of surface and groundwater, and desalination of brackish water) have been advocated as means of pro-actively responding to climate change threats on water supply. Consequently a complete analysis of the effects of climate change on human water uses should consider cross-sector interactions, including the impacts of and opportunities for changes in water use efficiency and intentional transfers of the use of water from one sector to another. For example, voluntary water transfers (including short-term water leasing and permanent sales of water rights) from agricultural to urban or environmental uses are becoming increasingly common in the Western United

States. An additional major challenge in the coming decades will be maintaining water supplies for environmental services, which support tourism, hunting, fishing and other recreational economies throughout the United States.

Adaptation is unavoidable because climate is always varying even if changes in variability are amplified or dampened by anthropogenic warming. Moreover, adaptation will be necessary to meet the challenge of demographic pressures and climate trends which we are already experiencing. There are significant barriers to implementing adaptation in complex settings. These barriers include both the inability of natural systems to adapt at the rate and magnitude of demographic, economic, climatic and other changes, as well as technological, financial, cognitive, behavioral, social and cultural constraints. There are also significant knowledge gaps for adaptation, as well as impediments to flows of knowledge and information relevant for decision-makers. In addition, the scale at which reliable information is produced (i.e., global) does not always match with what is needed for adaptation decisions (i.e., watershed and local). New planning processes are attempting to overcome these barriers at local, regional and national levels in both developing and developed countries.

Adaptive capacity to manage climate changes can be increased by introducing adaptation measures into development planning and operations (sometimes termed 'mainstreaming'). This can be achieved by including adaptation measures in land-use planning and infrastructure design, or by including measures to reduce vulnerability in existing disaster preparedness programs (such as introducing drought warning systems based on actual management needs).

Major barriers to implementing adaptive management measures are adaptation itself is not yet a high priority, and that the validity of local manifestations of global climate change remains in question. Coping with the uncertainties associated with estimates of future climate change and the impacts on economic and environmental resources means we will have to adopt management measures that are robust enough to apply to a range of potential scenarios, some as yet undefined. Greenhouse gas mitigation is not enough to reduce climatic risks, nor does identifying the need for adaptations translate into actions that reduce vulnerability. By implementing mainstreaming initiatives, adaptation to demographic and climate change will become part of, or will be consistent with, other well-established programs to increase societal resilience, particularly environmental impacts assessments, adaptive management and sustainable development.

Climate variability and change affect the function and operation of existing water infrastructure—including hydropower, structural flood defenses, drainage, and irrigation systems—as well as water management practices. Observational records and climate projections provide abundant evidence that freshwater resources are vulnerable and have the potential to be strongly impacted by climate variability and change, with wide-ranging consequences on human societies and ecosystems. Observed warming over several decades has been linked to changes in the large-scale hydrological cycle. Several gaps in knowledge exist in terms of observations and research required to better understand the relationship between climate change and water issues. Observational data and data access are prerequisites for adaptive management, yet many gaps exist in observational networks. It is important to improve understanding and modeling of changes in climate related to the hydrological cycle at scales relevant to decision-making. Information about the water-related impacts of climate change, including their socioeconomic dimensions, is incomplete, especially with respect to water quality, aquatic ecosystems, and groundwater.

Early warning information and decision support tools that are currently being developed to better prepare our nation, locally and regionally, for drought include:

- Enhancing networks of systematic observations of key elements of physical, biological, managed and human systems affected by climate variability and change particularly in regions where such networks have been identified as insufficient;
- Strengthening and expanding water conservation and efficiency programs;
- Adopting integrated strategies at the federal level (including high level advisory councils) and support a framework for collaboration between research and management;
- Promoting local watershed efforts;
- Improving groundwater monitoring and management strategies;
- Developing usable drought management triggers for planning in agriculture, water, energy, health, environment, and coastal zones;
- Developing economic impacts assessment tools including the costs and benefits of various adaptations;

- Coordinating among drought monitoring and forecasting efforts at federal regional, State, and local levels; and
- Actively engaging communities and states in monitoring, preparedness, and planning.

The challenges of managing water supplies to meet social, economic, and environmental needs requires matching what we know with what we do. NOAA and NIDIS provide mechanisms for the Federal Government to help agencies, states and local communities meet their economic, cultural, and environmental water management challenges in a timely and efficient manner.

Thank you for inviting me to testify at this hearing today and I will be happy to answer any questions the Members of the Committee may have.

Biography for Roger S. Pulwarty

Roger S. Pulwarty is a climate scientist and the Director of the National Integrated Drought Information System (NIDIS) at the Department of Commerce/National Oceanic and Atmospheric Administration in Boulder, Colorado. He also leads the risk management component of the World Bank/NOAA project on "Mainstreaming Adaptation to Climate in the Caribbean." From 1998–2002 Roger directed the NOAA/Regional Integrated Sciences and Assessments (RISA) Program. Roger's research interests are on climate in the Americas, assessing social and environmental vulnerability, and designing climate services to meet information needs in water resources, ecosystem and agricultural management in the United States.

Dr. Pulwarty has served in advisory capacities to various Federal and State agencies, the National Research Council, the Glen/Grand Canyon Adaptive Management Program, and to the UNDP, UNEP, World Bank and the Organization of American States. He is a lead author on the 2007 IPCC Fourth Assessment Report Working Group 2, the *IPCC Special Report on Climate Change and Water Resources,* and on the U.S. Climate Change Science Program Synthesis and Assessment reports. Roger is Professor Adjunct at the University of Colorado, Boulder and the University of the West Indies. He is the co-editor of *Hurricanes: Climate and Societal Impacts* (Springer, 1997).

Discussion

Expanding the Federal Government's Role in Water Research and Development

Chairman GORDON. Thank you, Dr. Pulwarty. At this point we will open our first round of questions. The Chair recognizes himself for five minutes.

When I was growing up, my father used to tell me about how really his life and life on our farm changed when the rural electrification came out there. At that time we had a good well. That is how we got our water, and my other grandparents, we had a good spring, and everybody had their own little tin can down at the, or cup rather down at the spring. But those times have gone. Even if you have a spring or a well, they probably are going to be contaminated now.

And so particularly in rural America, and when I saw rural America, I am not talking about way out farms like we were. I am talking about even small little subdivisions right outside of town, oftentimes they don't have water. And as we call it toting water is something that many, many Americans are doing right now.

And constantly folks are telling me, well, you know, the waterline is within a mile of our home, you know, but we can't get it the rest of the way. So this is a real problem. It is a problem as you pointed out with the nexus of water and energy and manufacturing. Wars have been fought and they will continue to be fought over water and probably more so in the future.

So what I would like to do is, using your cumulative wisdom, is to get some suggestions on a federal role. You have already, if any, and you have given us some of those ideas, but I want to be more narrow in the sense that this committee really only has jurisdiction over federal research and development, I think, in this area.

And so I think we have been, done a pretty good job of trying to take good ideas and build a consensus and move them forward. So what I would like for you to do, what I might say in the longer-term, is to submit back to us any suggestions you might have that this committee can do.

But right now I would like to hear you cumulatively talk about one, two, or three of the maybe most significant things that this committee could come forward with in terms of federal R&D. Mr. Matheson and Mr. Hall already have a bill on that, and we would like to see how that, you know, that role could be expanded.

So I will open the floor to whoever wants to start off. Anyone want to start?

Dr. OVERPECK. Without any doubt research and development can play a huge role in how we manage our water. I think what is really the biggest problem is what we don't know. We don't know what water lies underground. We don't really know how to predict what kind of stream flows will occur in the future, or how groundwater infiltration will change in the future at the scales that are important for decision-makers, that is, at the scale of your farm or watershed.

We don't know how climate is going to vary in the future with enough precision to be able to forecast it, and we don't know how climate change is going to affect our water reserves.

So all of these things require more research and development to get the clear answers so that we develop our country and move populations around and grow in a way that is sensible and makes sense with regards to our true future water supply.

And I think my colleagues will talk about also as we start to develop new energy economy, that has to take into account water. Water is far more valuable, I think, than many of our citizens realize. We have to provide the underlying framework for making good decisions, and I think much of that stems from research and development.

I applaud the bill that your colleagues have put together. I think it is very important to be looking at efficiency and conservation because certainly we can save a lot of water that way. Thank you.

Dr. PARKER. I would like to compliment you on the creation of this H.R. 3957 bill that I was handed. I was just scanning it and realized that it covers everything from water pricing for conservation and water reuse for efficiency of use of the resource. I think Dr. Wilkinson mentioned water reclamation in California and the use of perhaps dual systems and the use of water of various qualities for various purposes.

Now, it is an infrastructure challenge, but I think we better be heading in that direction, particularly in the arid West where I think the availability of the resource probably may, is becoming a limiting factor.

Chairman GORDON. Anyone else?

Dr. PARKER. I think it is a terrific bill.

Chairman GORDON. Well, Mr. Matheson, being from Utah, has a firsthand interest and knowledge of that.

Dr. WILKINSON. Just quickly, I think there is some obvious opportunities in technology development for efficiency. We have come a long way just in the last decade or two with the efficiency of a lot of plumbing fixtures and a lot of other opportunities for laser leveling of fields and irrigation technologies and the rest. So I think there is a long way to go, and there is a lot of opportunities there.

The other is water efficiency of our energy systems. What can we do to develop energy systems that require less water or no water, and how can we develop portfolios of energy systems that take pressure off of our water systems. I think those two are important areas.

Finally, filtering technology. A lot of our water now with concerns about pharmaceuticals and the rest is going to be treated to greater degrees, and looking for efficient ways to use water and to filter and treat it in ways that meet the health standards that we all want to see but do that efficiency I think is going to be very important.

Chairman GORDON. I will try to abide by the rules here. Does anyone else have a real quick suggestion?

Mr. LEVINSON. Yes, sir. I did want to touch on the point that water availability is not simply an engineering issue and an issue of R&D. I think that while the Committee clearly doesn't have a tax jurisdiction, the Committee can do a great deal to bring into public discussion the point that water is, in fact, a scarce resource and needs to be priced. Because, frankly, without pricing the possibilities are quite limited.

Chairman GORDON. But right now with our limited time, but I am trying to be more specific to what we can do from this committee right now, getting suggestions.

Mr. LEVINSON. Yes. I think that to, while certainly there is a need to promote conservation technology and that is all well and good, you really also have a bully pulpit here to use in order to make clear that this is a scarce resource. There does need to be action on the pricing front if we are actually going to have conservation.

Chairman GORDON. We are going to have a variety of hearings, and we hope to do that.

Dr. Pulwarty, did you have anything you want to add?

Dr. PULWARTY. One of the major issues is developing some of the new technologies, not only for efficiency but for the transfer of technology into practice, and I think the bills make that case.

Chairman GORDON. Thank you. There will be a point where we are going to have, as was pointed out, a megadrought or other problem that will bring the whole Congress, the Presidency all together for a water program, and what happens oftentimes is that is, you know, the cow is out of the barn.

So what I hope that we can do is lay a foundation with R&D so that at that time we can really start to implement it. What I would request that you do is get back to the Committee any suggestions in that area that you think, again, that there is either a legislative role or a role for us to request different agencies to be involved. We will then try to take those ideas and build a consensus and do some good work here.

Ms. Johnson is recognized for five minutes. Oh, excuse me. I am sorry. Mr. Hall is recognized for five minutes.

WATER INFORMATION AND TECHNOLOGY ABROAD

Mr. HALL. I would always yield to Ms. Johnson if she wanted me to, but let me get mine behind us here, and thanks for that peek into your background, Mr. Chairman. I enjoyed that. No telling how good you could have done if you would have had more opportunities as a young man.

One of the old references I have always heard and any time you get a speech as long as 15 or 20 minutes, someone always refers to water and fire as wonderful friends but fearful enemies. And we have sure experienced that on more than one time on the plains of Texas and in the drought that we had and then the over-availability of water. So I guess, Dr. Parker, availability is important, and it is also important to manage it.

So I would ask Dr. Parker, we have to operate on information and knowledge, and what, how would you compare the information and technology available to water managers in the United States to those in other nations that face similar problems to what we face?

Dr. PARKER. I would say the short answer is I think we have got better information. I think that there are nations such as Germany that we might be lagging behind in terms of pushing innovative alternative green technologies, that kind of thing, but in terms of hydrologic information, et cetera, I think we are a little better off.

Mr. HALL. Well, you very ably pointed out, I think, in your testimony that when you discussed water quality and how it has improved since the passage of several federal water laws or water acts.

What else can we do to ensure the quality and security of our water supply? We have you here to testify, and the Chairman and others here will take your testimony, study it, and everything you say is available to every Member of Congress because of the court reporter that is taking it down somewhere here that will report it.

What else can we do to ensure the quality and security of our water supply? We can pass laws. What is the next step?

Dr. PARKER. I actually edited it out of my spoken testimony some ideas about non-point source pollution, which is, it is not only a technical and a management issue, but it is also a legal issue in the sense that where I referred to some of our laws and practices as becoming obsolete. There is a prime example of an issue that isn't dealt with very well within the legislation.

We have done some work for EPA. Now, this isn't the, probably the appropriate thing for me to say, advising them on urban water supply system security. They have a research program in Cincinnati. It is a very good one. It is under-funded. It ought to be well supported. It was driven by concerns about deliberate acts of harm to water supply systems. They are doing good work. It has brought application beyond the terrorism context, but I think it is kind of a hand-to-mouth operation that each year has to fight for the limited resources. It seems under-appreciated to me to the extent that you have any influence over that.

Mr. HALL. I thank you.

BIOFUELS

Quickly, Dr. Pulwarty, one of the benefits of NIDIS that you described in your testimony is that farmers would be better positioned to make decisions on which crops to plant and when to plant them. Now, given the overwhelming incentives we passed last year for biofuels and the reference to other crops that they ought to plant and those that planted other crops including corn followed the market and the increase in reception of the benefits of planting that. Have you seen caution or hesitation on the part of farmers to plant fuel crops after seeing the information that NIDIS has provided? Or is the monetary incentive overwhelming the risk of the natural environment?

Got an answer for that?

Dr. PULWARTY. The latter.

Mr. HALL. That is a good answer, and I think my time is up.

Chairman GORDON. You are a very good witness.

Now the gentlelady from Texas is recognized.

CLIMATE AND WATER QUALITY AND QUANTITY

Ms. JOHNSON. Thank you very much, Mr. Chairman.

To the panel, I chair the Subcommittee of Water Resource and Development on transportation infrastructure, and we are dealing a great deal with supply. I am wondering what about the temperature change affects water supply, quality or quantity?

Dr. OVERPECK. Well, temperature change certainly has a major effect on water supply. As temperature goes up, there is an increase, and it is not a linear increase, in the amount of moisture that the atmosphere can hold. So the atmosphere will demand more moisture, and where will it get that moisture? It will get it from soil, it will get it from forests, it will get it from agricultural plants. It will get them from reservoirs. It will get them from any open source of water, and it will draw that water out.

So these temperature changes that are coming are huge, just gigantic, and they will demand a lot of water, and they will make the droughts of the past look pale, because it will be so much hotter.

Ms. JOHNSON. Yes.

Dr. PULWARTY. I wanted to complement Dr. Overpeck's statement. One of the impacts on temperatures is on snowpack, and what we have seen not only in terms of early runoff, there has been an impact on the actual quality, the amount of water that is in the snow. In 2005, 2006, on the upper Colorado we received 105 percent of precipitation. Because of the dryness before that and because of the warmth of that spring, 105 percent of precipitation was reduced to about 70 percent of the reliable stream flow.

We have been seeing that in different years based on temperature, evaporation, and sublimation, and vegetation stress.

WORKFORCE AND EDUCATION

Ms. JOHNSON. I know that every major body of water in this country is contaminated, and I also know that we have a shortage of expertise in addressing this issue. And we have dealt with that somewhat in this committee, because we know there is such a shortage of science and math engineering students.

I am wondering how would you determine that we would address many of the problems now as it relates to the research here with such a shortage of people? Of qualified people?

Dr. OVERPECK. I think this goes back to Congressman Hall's question between the United States and other countries of the world, our advantage is that we are an advanced country. That means that we ought to be able to bring to bear much more knowledge. Knowledge is power. But it is not just knowledge, power for our country, it is power for every individual that has to make decisions in their day-to-day life about water.

And so we really need programs that educate everybody, not just the water managers, but the people who use water, because so many of the solutions will require cooperation of the citizens of the United States and that we work together. There are huge discrepancies between the per-person water use in cities in the West that really are astounding, and we need to learn how to use our very valuable water treasure more carefully.

Ms. JOHNSON. Thank you very much. I am doing a series of cable shows on subjects to try to begin to educate the public, and one of the major questions I still have is how do we pay for all of this? We are looking at creating a dedicated fund or maybe the economist——

Mr. LEVINSON. If I may, being the economist in the room, offer two thoughts on this. One is that this all doesn't have to be in the public sector. There is in certain areas a lot of potential for private investment in water conservation, if it pays off. And I, you know, hate to sound like a broken record, but to a certain extent you get back into pricing here because that is what makes it interesting for people to buy conservation equipment.

And to the extent that there is a demand for water conservation, there will be a lot of private initiative in developing ways to conserve water and process technologies in particular industries, for example, or improving irrigation or that sort of thing. And there will be private people paying for this R&D. It doesn't have to be done by the government.

And second, to the extent that it is priced, part of the amount that people pay for water can, in fact, be used for public sector research and public sector infrastructure in this area.

Chairman GORDON. Thank you, Mr. Levinson.

Ms. JOHNSON. Thank you very much.

Chairman GORDON. And Mr. Rohrabacher, you are recognized.

MORE ON CLIMATE AND WATER QUALITY AND QUANTITY

Mr. ROHRABACHER. Thank you very much, Mr. Chairman, and coming from California I certainly understand the significance of what has been presented to us today. We live on a desert that goes right up to the ocean, and a lot of times we forget about that and

Mulholland and other great champions of California, well known and appreciated, and I wonder if we are, our generation is going to have, create a better future as the Mulhollands did for us in the past.

Dr. Wilkinson, let me just ask you, and I did really appreciate your detailed analysis of the California situation. What, this year and the last couple of years, have we had trouble with snowfall in California?

Dr. WILKINSON. Yes, indeed.

Mr. ROHRABACHER. We did? We do? Okay. Tell me about it. Do we, is the snowpack, I understand the snowpack in the Sierra Nevada is actually higher this year than it was.

Dr. WILKINSON. Well, we have considerable variability. We had good snowpack earlier in the year. For the last two months we have had very little, and actually it started quite late. I took my graduate students up to Yosemite in December, and we drove across the pass. Over the mountains there was virtually no snow at all in early December. Normally, of course——

Mr. ROHRABACHER. In December?

Dr. WILKINSON. In December. Normally we would have a lot of snow.

Mr. ROHRABACHER. Right. Okay.

Dr. WILKINSON. But between early December then when it started snowing and about two months ago we got a pretty good snowpack.

Mr. ROHRABACHER. And on the average is it higher this year than last year?

Dr. WILKINSON. It is a little bit——

Mr. ROHRABACHER. Than years in the past?

Dr. WILKINSON.—below the average level but not a huge amount. The problem is that with very little for the last two months, we are now facing very serious water situation. Of course, you probably know last week they did the snow survey at the Summit by Echo Lake, and they were walking on soil. There was virtually no snow. So it is quite troubling.

Now, in terms of a water supply situation this year, we certainly are seeing a very clear signal that we are getting a shift at mid-elevations from snow to rain because of warmer conditions. So that pattern is already evident.

Mr. ROHRABACHER. Okay. I just note, Dr. Overpeck, that you did mention that the droughts were so much worse in the past than we are experiencing today, and while I certainly, you know, I am clearly one who disagrees with the idea that we have man-made climate change going on, but why is it, why are you convinced that these droughts in the past have, which, of course, obviously had nothing to do with human activity, why are you so convinced that today it is all a result of human activity even though the droughts in the past were worse than they are today?

Dr. OVERPECK. Good question. In my testimony where I was able to expound a little bit longer, I tried to highlight that we don't know the origin of the current droughts. We do know that they are being made worse by the higher temperatures. That is causing the rain on snow problem and the early melting of the snow that is giving California a little fit this year. But we really don't know the origin of these droughts that are going on now, and that is why I tried to emphasize this idea of a no-regrets approach.

Mr. ROHRABACHER. Okay. I would suggest that we also don't know the cause of the temperature rise. I have a lot of sympathy with people who say, "Look, this is what the climate is, and we got to prepare for it because there will be droughts, we need to do water, et cetera." But when people have to lace their testimony with a reconfirmation of the man-made global warming theory, it doesn't add to the validity here. It doesn't. To me it seems, frankly, it takes away from the presentation.

One last thing here, and I would like to note this, and Mr. Levinson mentioned that nuclear energy uses water. Have you looked at the high-temperature gas cool reactor as a new type of reactor, and does that use the same water?

Mr. LEVINSON. I am probably not the best one here to talk about that.

Mr. ROHRABACHER. Let me note, Mr. Chairman——

Mr. LEVINSON. Others may be more familiar.

Mr. ROHRABACHER.—traditional nuclear power plants do use water, obviously, because they are based on steam. There is a, and I keep pushing this because I want people to take a look at this alternative, there is a high-temperature gas cool reactor. My friends who believe in global warming will love it as well, I might add, because it is, of course, clean and does not produce "greenhouse gases," but it does not use the water that the traditional nuclear power plants do.

And I would suggest it is something we should look at, because I do understand there is a direct relationship between the amount of energy and water, and Dr. Wilkinson, your testimony was very insightful in that. In fact, the desalinization now actually uses less water than we use in pumping water throughout the State of California, and I think that is a significant fact that we need to take into consideration.

Thank you very much to the whole panel.

POPULATION GROWTH AND WATER SUPPLY CONCERNS

Mr. BAIRD. [Presiding] I thank the gentleman. I will fill in for, as Chair until Mr. Gordon returns.

I will recognize myself for five minutes.

Do we have a sense of carrying capacity of our country in terms of how big our population can get? You know, population is growing rather rapidly right now, and we are talking about already seeing shortfalls of water. Any thoughts of that in terms of what the tradeoffs would be? Do we have some numbers that say if our population grows by X, then we are going to have to reduce water consumption by Y? Any thoughts about that?

Dr. Wilkinson.

Dr. WILKINSON. I don't know the specific answer in terms of what number we might accommodate. I can give you, though, some breakdown. In California we use about 80 percent of the water for agriculture and about 20 percent for the urban system for people directly. In much of the west it is even more for agriculture, on the order of 90 percent. This varies, of course, tremendously around the country and the type of agriculture and so forth. In California, a lot of the discussion revolves around transfers of water from agriculture to urban.

So in theory, one could double the state's population and only take 20 percent of the water currently going to agriculture. That would leave another 60 percent still. That is in theory. I am not sure anybody really wants twice as many people in California or anywhere else. We have a lot of crowding already.

But the transfer of water back and forth becomes in terms of a limiting factor and carrying capacity an interesting question. I will say that Los Angeles has increased by one million people and held water use level. That means per capita use has gone down considerably, and that is mainly through these efficiency programs, more efficient plumbing fixtures and the rest.

Mr. BAIRD. Mr. Levinson.

Mr. LEVINSON. Yes, Mr. Chairman. I wanted to mention there is our recent report that was referred to earlier a very interesting picture of population growth and water consumption in southern Nevada. The story there is that the local water authorities simply imposed very draconian measures right at the start of this decade, basically telling people, no, they couldn't plant grass anymore, golf courses couldn't draw public water supplies anymore, that sort of thing. They experienced quite rapid population growth during the past seven or eight years, and at the same time they experienced a fairly sharp decline in water consumption.

So I think that the notion that there is a necessary correlation between population growth and the growth of water consumption isn't right.

Mr. BAIRD. Dr. Pulwarty.

Dr. PULWARTY. To complement that, there has been changes in the efficiency of use. We know that it took 200 tons of water to create a ton of steel years ago. Now it takes three to four. We are seeing lots of reductions in the per capita use of water. But that does not mean that demand is not increasing because population is increasing, even if we are leveling off in terms of per capita use.

One of the things we do have to keep in mind when we talk about carrying capacity is also we are ingenious, you know. One hundred years ago we talked about some of these issues, and we did have a lot of adaptive strategies in place. Where we are seeing the most immediate threats are in the environmental services provided by the natural environment in terms of recreation and tourism and the sources of our water supply. That I think is where we will bear the brunt of immediate pressure.

WATER QUALITY CONCERNS

Mr. BAIRD. We had a rather disturbing report here in the D.C. Metro area about a month and a half or so ago about contamination of the drinking water. Admittedly in parts of a trillion but reports of anti-seizure medications, a host of other medications, et cetera.

Two questions. How common is this across the U.S. water supply, and what technologies exist today to get us actually pure water? If somebody has twin boys at home and any parent here could get him water out of the drinking fountain, and you say to yourself, so what meds am I giving my kids today with their glass of water in their sippy cup? You would feel a little bad about that.

What can you tell us about what we can do to purify the water further and how common this problem is?

Dr. OVERPECK. Well, I don't think we have any experts here on that side of water, but I certainly share your concern as a parent. And I know from my colleagues at the University of Arizona that there is lots we can do in terms of researching out what is in our water and how we then treat it to remove unwanted contaminants, because most of our water treatment doesn't deal with that. And one of the solutions down the road, which my colleagues in California are already adopting is essentially toilet-to-tap. We are having to use this water that has been used before, and we will do that more and more into the future.

So we better get some research going to figure this out. That is all I can say.

Mr. BAIRD. A more appetizing terminology might help advance that effort.

OCEAN DESALINIZATION'S ENVIRONMENTAL IMPACTS

One last question. We read in some of your testimony about desalinization. What are the adverse, or are there adverse environmental impacts to desalinization if you have got a bunch of, you know, are we changing the mineral makeup of the near-shore environment?

And any thoughts on that? I am particularly thinking about as we look at ocean acidification as a byproduct of climate change and the reduction of available carbonate. Does desalinization also take carbonate out of the, as a mineral, take it out of the system or——

Dr. WILKINSON. There are two primary concerns about environmental impacts from ocean desalinization. One is the entrapment and entrainment of marine organisms on the intake side of the equation, and there are ways to remedy that by drawing in the water through the sand and beach wells and so forth. But there are concerns about that.

And then on the flip, as you mentioned, is discharge, the brine discharge back to the ocean, which is more saline than what was taken out because we are taking some fresh water and then returning a saltier mix back in. Some of the solutions to that proposed are to mix that with effluent from waste water systems so actually the salinity is closer to the ocean, may not be a bad solution. But both of those are challenges for ocean deals.

Mr. BAIRD. Thank you very much.

Mr. Smith.

WATER STORAGE

Mr. SMITH. Thank you, Mr. Chairman. Thank you to the panel for your insight on the issues.

It is interesting. I come from rural Nebraska, where irrigation is very important. It is actually helping feed the world I would argue. Yet I only heard a little bit about surface storage.

Dr. Wilkinson, would you say that surface storage can perhaps help us mitigate climate change?

Dr. WILKINSON. Surface storage clearly plays an important role already in our water supply systems around the country. One of the concerns with surface storage is with increased variability in the system, as Dr. Overpeck described, we may need, where we have surface systems that are providing both flood control as well as water supply, we may need to hold those systems at lower levels to provide that flood control or take further risks because of pattern changes in precipitation.

So that becomes problematic. We would sacrifice water supply and hydropower for those systems that provide those services if we are to operate those systems to deal with increased flood control risks.

The other issue with surface storage——

Mr. SMITH. Wait. If I could have clarification. I am sorry.

Dr. WILKINSON. Uh-huh.

Mr. SMITH. I am trying to follow you. You are saying that we need to draw down?

Dr. WILKINSON. We will have to leave more flood control space during the flood.

Mr. SMITH. Because of——

Dr. WILKINSON. Because of concerns that we may have strong precipitation events that would fill them up quickly and then spill into flood, and we have experienced some of that. We have had some problems around the country, and so one of the concerns when you have less certainty as to what might happen with precipitation, but an increased chance that you may have high precipitation events, then to maintain that flood control system you begin to lose, there is a tradeoff there. You begin to lose some of that water storage.

The other big issue, of course, as Jonathan mentioned, with increased temperatures, we are going to have increased evaporation, and that is actually quite a serious issue with surface storage, especially in arid areas. We are losing a lot of water. Now, that doesn't mean we are not going to continue to use surface storage systems, but we may need to recalibrate our rural curves and our expectations of water supply coming out of them based on climate change.

Mr. SMITH. Can you give any numbers for what you think the difference is today? It is, I think we might be able to agree that climate change is a bit of a moving target in terms of defining it. We are even getting away from the global warming terminology and going to climate change based on some of the numbers of the last 24 months or so.

Can you paint a picture with numbers, easily understood, perhaps, of where we are with surface storage today, where we need to be, compared to the past 100 years or so?

Dr. WILKINSON. I can't give you a specific number, we need X amount more. Of course, it depends around the country what our water supply situation is. Let me suggest two other considerations, though, in addition to and coupled with surface storage, and that is groundwater management. We have tremendous opportunities right now around the country, certainly in California we have huge opportunities to manage groundwater more effectively and to use groundwater storage. Picture it as an empty bucket underground, storage potential, that can be managed. That is an opportunity, I think, we pretty much all agree is a priority for water management. Of course, that means maintaining quality of what gets into the ground and once it is in the ground, maintaining that quality so we don't have the kinds of issues that were just mentioned, the concerns about water quality and what is safe to drink.

Mr. SMITH. Now, you said we needed X amount more of what? I think you said something like we need X amount more.

Dr. WILKINSON. I can't tell you exactly how much more surface storage the country would need, and part of that would depend on how well we use groundwater and how efficiently we use water. That would, in turn, reflect what our surface storage requirements would be nationwide.

So I would have to think about it in the context of the demand side, how are we using water, the other options for storage, including groundwater, and then what we need to do with our surface storage systems. I would suggest we would need to consider that as a package in the integrated way.

Mr. SMITH. And would you suggest that we need more reservoirs?

Dr. WILKINSON. I think in some places we might and some places there is serious discussion of removing reservoirs. So I think you probably have everything on the table. Where do we need more? Where do we have systems that may not be cost effective and may need to come out.

Mr. SMITH. Very good. Very good.

Dr. Overpeck.

Dr. OVERPECK. Yeah. Thank you. I mean, I think what we really are running up against here is we don't have the knowledge to answer your questions. We don't know exactly how the water supply from the atmosphere will change in the future and how the demand by the atmosphere in terms of evaporation will change in the future. We need to nail that down and factor that into our models of both above ground and below ground storage.

But I do agree with Dr. Wilkinson that below ground storage might turn out to be a much more advantageous approach, particularly in states like your own that have abundant aquifers. We are already doing this in Arizona and many other states, such as Texas, are putting the water underground. And you don't always get out what you put in, but nonetheless, you don't have the problem of evaporation or some of the other problems that are associated with above-ground storage.

And one of the ironies of climate change is that with the probability of increased frequency of drought comes a probability of increased flood as well. This is because the hydrologic cycle of the atmosphere is getting accelerated, and there is more moisture up there, more energy, and it gives us both extremes in greater frequency.

And we are already seeing this around the world.

Chairman GORDON. Thank you, Mr. Smith. We are trying to beat a vote here, and Ms. Richardson has been gracious enough to yield to Mr. Matheson, who has another commitment, and you are recognized for five minutes.

THE ENVIRONMENTAL PROTECTION AGENCY'S ROLE

Mr. MATHESON. Thanks, Mr. Chairman. I will be brief and maybe not use all five minutes.

You had a discussion with the Chairman earlier about the bill I introduced, the *Water Use Efficiency and Conservation Research Act of 2007.* As you probably know, it would establish a research, development, and demonstration program within the EPA's office of research and development to promote efficiency in conservation.

I was curious what role that the people on the panel would envision the EPA should have in supporting our long-term water efficiency and conservation effort policies in this country?

I don't know who wants to answer. Anyone can answer.

Dr. WILKINSON. Let me just start out briefly, I think that EPA deserves a lot of credit for some very good work over the years. The low-impact development, some of the slides I was showing, storm water capture and attenuation of pollution, for example. That they are doing very good work on water use efficiency.

Of course, it is the 1992 *Energy Act* that includes the requirements for efficiency in plumbing fixtures, and that has made a huge difference. EPA has done a lot to follow up on that, so I think they have already done a lot of good work. I think it is a very helpful move in what you have proposed here to take it a step further.

Dr. PARKER. I see EPA as a very visible entity throughout the water supply community. I see them as advocates as various approaches to water supply and completion. They are out at conferences, they are in regulatory situations, they are in planning activities. There is only so much that they can do, though, to advocate without putting a little money on the table. And their research budget has been cut back so severely in the last few years they are losing their credibility.

I think you have nailed it with this, to give them a little bit of money to push just what is needed.

Mr. MATHESON. I appreciate that, and I notice in your testimony and reports from your organization, Dr. Parker, you make a number of recommendations for additional research.

Could you maybe offer just your opinion about what you think are the highest priorities or the most critical areas where we ought to be investing in R&D, looking out over the next 20, 30 years for where we want to go? What do you think are the best priorities for R&D on water conservation and water use?

Dr. PARKER. I think we need to invest more in dual water systems. I think we need to invest more in the institutional side of the house. It is severely neglected. Ms. Johnson from Texas was talking about her concern about human resources, and I interpreted her concern as being professionals in the field but then the conversation took sort of the direction of public, the level of how informed the public is.

But the truth is is that in terms of having professionals available to address problems and staff our agencies and our consulting companies, et cetera, is really in sorry shape. The dwindling research budget for graduate students in universities is not adequate to produce the people that we need in our field just when the problems are becoming most challenging. And the social science side of it has always been neglected. The water policy experts that I know are all in their 60s. So we are losing the few that we have.

So the social sciences, innovative supply technologies, conservation, I think our hydrologic networks are probably adequate, but they have been allowed to be eroded.

Mr. MATHESON. I appreciate that.

Mr. Chairman, I appreciate my colleague letting me go.

Chairman GORDON. Thank you, and now Mr. Hall is recognized for a quick question, and then we are going to finish up with Ms. Richardson.

CAN WE CAPTURE AND STORE RAIN WATER?

Mr. HALL. I ask the question of Dr. Pulwarty. Something that has been bothering me for a long time, and you know, need spawns breakthroughs and wars bring on weaponry like the Manhattan Project and things like that. And shouldn't we be thinking in the long-term thinking in the future of how to save water?

And it worries me, I have been working on a bill trying to put together something for a future, a study for the future of working on a bill, maybe even a sense of Congress or something that or some study group, when a bottle of water gets to be worth more than a good bottle of beer or a bottle of oil, you know, we got to go to thinking more about it.

And I see in Texas and west Texas the rains fall, and in east Texas rain is falling, and it goes on down to the sea. Shouldn't we be capturing that someday, even at 100,000 acres at a time to have it? And we don't have that need yet, and it is too expensive now, but I remember when it was too expensive to have a module for astronauts to escape a shuttle from. And we shouldn't ever think anything is too expensive to save lives, but it was also too heavy. Engineers couldn't prove it, but someday is there, I will just leave this thought with you gentlemen.

Be thinking about a way to, giant sumps or something, to capture that water and not let it run off to the sea and have it for the time when we have the droughts.

Yes, sir.

Dr. PULWARTY. I think this is an extremely important question as to what mix and types of storage mechanisms that we are, in fact, talking about, and at the same time have enough left over in the system to make sure that the coastal economies that depend on fresh water and flow for oyster beds, mussels, and other things like that are themselves supported as a result.

One of the issues we have with withdrawing water for storage is we then increase saline intrusion from salt water into the near-shore aquifers. So as long as we are balancing all of those kinds of issues, then I think, yes, storage is one of the options.

And we do have to think in terms of groundwater as well, simply because if you can't fill the reservoirs you have, extra storage does not help us.

Mr. HALL. One day I think we will see a huge metal or otherwise sumps under there, and at my age I don't even buy green bananas, so I can't look that far. I can't see that far ahead, but you younger men, and this young Chairman here, I am going to get him to work with me on something to set up some kind of a study like that so we have a plan for 30 years from now.

And I will try to stay in Congress that long to see that they carry it out.

Mr., I yield back my time.

Chairman GORDON. Thank you, Mr. Hall. I have already made arrangements for Mr. Hall to say my obituary so, Ms. Richardson, you are recognized.

MORE ON OCEAN DESALINIZATION'S ENVIRONMENTAL IMPACTS

Ms. RICHARDSON. Thank you, Mr. Chairman.

Dr. Parker, as you can hear from Mr. Hall and our Chairman here, you are in need of the next generation of water folks. As you can see, we have got great folks here that I am really concerned of the day when we won't have Mr. Hall here to give us good analogies.

Mr. Chairman, I would like to invite you and or maybe one of the hearings we could have in the future would be about desalination. The largest home of the country's largest and most advanced federally-sponsored seawater desalination research and development project is in my district. Dr. Wilkinson, I was a little surprised with your comment because back on January 30, 2008, the Long Beach Water and the United States Department of Interior, Bureau of Reclamation constructed an under-ocean floor intake and discharge demonstration system, which I happened to view because it is right there at the Bluff Park where I walk my dogs on the weekend. And the only other similar facility is in Japan, and I was particularly, caught your comment because it was founded that essentially the underwater ocean floor intake system, the ecological impacts of entrainment and impingement typically associated with open ocean intakes are avoided with this system, which is what when you were asked the question. And this natural biological filtration process reduces the organic and suspended solids largely eliminating the need for additional pretreatment, which reduces the overall energy footprint and cost of operation.

So I am not sure if you are familiar with the success of what we recently had. The project was, as I said, recently completed. I think, Mr. Chairman, it would be well worth either one of us taking a trip. We can take a Tennessee guy and have you have a real good time in California, or we could have a hearing here. I think there has been some very recent information.

And Dr. Wilkinson, I am not sure if you are familiar with those results, but they have been substantial to the impacts of being nearly 30 percent more energy efficient than the reverse osmosis technology system.

Dr. WILKINSON. I think you are exactly right. The Long Beach project is quite good, and the Bureau of Reclamation has been helping.

My point was that using that kind of an intake avoids the entrainment and impingement, so that is one of the opportunities where the geology supports it to use that kind of system. I think that is a success, and I think they are doing some very good work in Long Beach.

Ms. RICHARDSON. So, in terms of funding and research and things that we can do, I think it is a valid area for us to consider.

Chairman GORDON. I certainly agree. I just talked to our staff and she said that we need to be sure to get somebody in on a future hearing. Her response was that we have been talking with them extensively, and the term she used about what they are doing was "fascinating." So I am glad that is coming out of Long Beach, and we want to continue to learn more about it.

Ms. RICHARDSON. Thank you.

I yield back the balance of my time.

Chairman GORDON. Thank you. We are maybe eight minutes away from a vote, so let me thank our witnesses for appearing here today. Under the rules of the Committee the record will be held open for two weeks for Members to submit additional statements and additional questions that they might have of the witnesses. I ask witnesses if you will respond to us if you see particular areas of federal R&D and also if you know a particular agency you think where that should be carried out. Such information would be most welcome, and it will be a part of our thought process.

And this hearing is now adjourned.

[Whereupon, at 11:31 a.m., the Committee was adjourned.]

Appendix:

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Stephen D. Parker, Director, Water Science and Technology Board, National Research Council

Questions submitted by Chairman Bart Gordon

Q1. Please provide the Committee with recommendations of additional Federal research and development to increase water supply and water use efficiency.

A1. See *Confronting the Nation's Water Problems* (2004)[1] by a committee of the Water Science and Technology Board. This report was called for by a Congressional mandate and would seem to provide a very complete response to this question. See in particular the executive summary and Table 3–1 for particulars.

Questions submitted by Representative Ralph M. Hall

Q1. In your testimony, you point out a number of issues that exist do to aging infrastructure and outdated water management systems. If you were to prioritize these issues, which we are often called on to do as lawmakers with limited funds, which of these issues would you address first? What viable solutions exist that need to be adopted on a broad scale? Which area has been lacking research that we now need to devote resources to?

A1. Personally, I believe federal leadership through EPA programs or research funding should give priority to (not necessarily in order):

- water reuse for potable and non-potable purposes, including use of dual water supply systems;
- alternative, innovative, green urban stormwater and combined sewer overflow system design and management; and
- water demand management approaches.

Q2. In recent years we have been exploring a number of new energy sources to try to reduce greenhouse gas emissions from fossil fuels; however, as you know, a number of these alternative energy sources require large amounts of water. How do those changes in societal preferences affect your calculations on available water resources?

A2. The "water-energy" nexus presents many challenges to those concerned with water requirements for energy development and energy requirements for water supply. The WSTB has been unsuccessfully trying to develop a *comprehensive* study in this area. We have few positions as an entity and my personal experience is limited. My only recommendations would be that consideration of energy alternatives take into account very carefully the water implications. This does not appear to have been the case in the crafting of biofuels policy as indicated in a 2007 WSTB report *Water Implications of Biofuels Production in the United States* (summary attached).

Q3. In order to face the coming challenges in water availability and quality, we need qualified scientists and engineers. Could you discuss the number of graduate and post-graduate students going into water issues versus other scientific pursuits? Is this enough to provide critical information to decision-makers over the next few decades? What can be done to encourage greater interest in this subject?

A3. The issue you identify is worrisome. I have no real numbers, as perhaps the National Science Foundation might, but it appears that new folks are not entering the water field and that our workforce is aging. It seems that restoration of respectable funding levels for water resources research might reverse the problem, as we certainly are going to have well qualified people in many disciplines, including the social sciences, to help address the increasingly complex problems that are emerging. The attached *Confronting the Nation's Water Problems* (2004) should help shed some light.

[1] National Academies of Science, 2004. *Confronting the Nation's Water Problems: The Role of Research.* Water Science and Technology Board, Committee on Assessment of Water Resources Research, National Research Council, Washington, DC.

Questions submitted by Representative Adrian Smith

Q1. Federal drinking-water quality regulations for naturally occurring toxins, such as arsenate, can be burdensome to small communities, as costs of remediation are very high and far beyond the budget of a small town. Are these challenges best addressed at the local, State, or national level, and what types of solutions should be proposed?

A1. This question identifies a very large and challenging issue that affects a fifth of the U.S. population. It is also a problem being addressed by EPA. In 1997 the WSTB published *Safe Water from Every Tap: Improving Water Service to Small Communities,* a report that provides guides on relevant technological, financial, institutional, and operational issues. The report is attached in pdf; I personally have not tracked EPA follow through. You might peruse this report or its summary and then ask EPA for information and opinions.

Q2. What are your views on balancing the demand for various uses of water, including, drinking water; agricultural uses; energy generation; habitat, especially for endangered species; and recreation?

A2. Conflicting demands are presenting themselves in many regions of the Nation, and conflicts are not limited to arid areas. The ACF–ACT basins in GA–FL–AL provide a vivid example and there will be more of this in the future. Each case is unique and it is hard to generalize, but in my opinion decisions must be informed by advanced simulation/optimization models, with visualization capabilities, to produce results for discussions by experts in all relevant disciplines and decision-makers along with all stakeholders. Not everyone is going to get everything they desire but consensus on outcomes can be achieved. It is unfortunate that the venues for such decision-making were effectively eliminated with the demise of the many river basins in the early 1980s. In my opinion, such river basin commissions may have been ahead of their time and should be resurrected.

Question submitted by Representative Russ Carnahan

Q1. Could better data and monitoring improve water quality and quantity for St. Louis and surrounding areas?

A1. Yes. Such data would be necessary but insufficient. The attached 2008 WSTB report *Mississippi River Water Quality and the Clean Water Act: Progress, Challenges, and Opportunities* discusses this and describes several implementation actions that should be pursued at the federal, State, and local levels.

Question submitted by Representative David Wu

Q1. It is important that states and local communities are part of the discussion regarding water challenges. However, I am worried that some stakeholders may have been overlooked. The United States has unique political relationships with more than 560 tribes. Many of these tribes have treaties with the United States that recognize tribes continue to have certain rights; in some cases this includes water. This is a very important topic we are discussing here today and all stakeholders should have a voice at the table. Has your board included tribes in its work? If not, why has this not been done? Will you include tribes in the future?

A1. Yes. The WSTB has engaged tribes and other relevant stakeholders in its work—both as committee members and as "resource people" to help inform our process.

Prepublication Copy

Confronting the Nation's Water Problems: The Role of Research

Committee on Assessment of Water Resources Research

Water Science and Technology Board
Division on Earth and Life Studies

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Executive Summary

Nothing is more fundamental to life than water. Not only is water a basic need, but adequate safe water underpins the nation's health, economy, security, and ecology. The strategic challenge for the future is to ensure adequate quantity and quality of water to meet human and ecological needs in the face of growing competition among domestic, industrial–commercial, agricultural, and environmental uses. To address water resources problems likely to emerge in the next 10–15 years, decision makers at all levels of government will need to make informed choices among often conflicting and uncertain alternative actions. These choices are best made with the full benefit of research and analysis.

In June 2001, the Water Science and Technology Board of the National Research Council (NRC) published a report that outlined important areas of water resources research that should be addressed over the next decade in order to confront emerging water problems. *Envisioning the Agenda for Water Resources Research in the 21st Century* was intended to draw public attention to the urgency and complexity of future water resource issues facing the United States. The report identified the individual research areas needed to help ensure that the water resources of the United States remain sustainable over the long run, with less emphasis on the ways in which the setting of the water research agenda, the conduct of such research, and the investment allocated to such research should be improved.

Subsequent to release of the *Envisioning* report, Congress requested that a new NRC study be conducted to further illuminate the state of the water resources research enterprise. In particular, the study charge was to (1) refine and enhance the recent findings of the *Envisioning* report, (2) examine current and historical patterns and magnitudes of investment in water resources research at the federal level, and generally assess its adequacy, (3) address the need to better coordinate the nation's water resources research enterprise, and (4) identify institutional options for the improved coordination, prioritization, and implementation of research in water resources. The study was carried out by the Committee on Assessment of Water Resources Research, which met five times over the course of 15 months.

The committee was motivated by considering the following central questions about the state of the nation's water resources: (1) will drinking water be safe; (2) will there be sufficient water to both protect environmental values and support future economic growth; (3) can effective water policy be made; (4) will water quality be enhanced and maintained; (5) will our water management systems adapt to climate change? If the answers to even some of the questions above are "no," it would portend a future fraught with complex water resource problems but with limited institutional ability to respond. Knowledge and insight gained from a broad spectrum of natural and social science research on water resources are key to avoiding these undesirable scenarios.

Two realities helped to shape the scope of the study and have illuminated the inherent difficulties in creating a national agenda for water resources research. First, the type and quantity of research that will be needed to address current and future water resources problems are unlikely to be adequate if no action is taken at the federal level. For many reasons (as discussed in Chapter 1), the states and nongovernmental organizations have limited incentives and resources to invest in water resources research. Furthermore, most states are experiencing an increasing number of complex water problems—some of which cross state lines—and they have to respond to important federal mandates. This suggests a more central role for the federal government in producing the necessary research to inform water resources issues. Second, water resources problems do not fall logically or easily within the purview of a single federal agency, but rather are fragmented among nearly 20 agencies. As water resource problems increase in complexity, even more agencies may become involved. The present state of having uncoordinated and mission-driven water resources research agendas within the federal agencies will have to be changed in order to surmount future water problems.

Chapter 2 of this report analyzes the history of federally funded water resources research in an effort to understand how the research needed to solve tomorrow's problems may compare with the research undertaken in the past, and to illuminate how U.S. support for water resources research in the 20th century has fluctuated in response to important scientific, political, and social movements. Federal support of water-related research developed slowly during much of the 1800s and early 1900s, beginning with federal involvement in the development of rivers for navigation, flood control, and storage of water for irrigation. It was not until the 1950s that Congress committed to supporting a comprehensive program of water resources research. The short-lived commitment peaked during the 1960s when Congress and the executive branch shared a similar view that the federal role in water entailed funding its development for human use while reducing problems of pollution. By the 1970s, growing interest in environmental protection conflicted with water development, which splintered the policy consensus and cast the federal government into more of a regulatory role while deemphasizing its role in promoting economic growth through water resources development.

Administrations of the 1980s and 1990s asserted a more limited federal role in water resources research, believing that research should be closely connected to helping to meet federal agency missions or to addressing problems beyond the scope of the states or the private sector. Congress, on the other hand, generally supported a broader approach to water research, but one that it could actively supervise through the legislative and appropriations process. A consequence of the devolving of responsibility for water resources research back to the states was the neglect of long-term, basic research as opposed to the favoring of applied research that would lead to more immediate results.

Over the last 50 years, the priority elements of a national water resources research agenda have been identified in widely varying ways by many organizations and reports. Many general topics of concern—for example, water-based physical processes, availability of water resources for human use and benefit, and hydrology–ecology relationships—have appeared repeatedly over the decades, while others, such as the impact of climate change and newly discovered waterborne contaminants, are recent topics. The reappearance of some of the same topics over time suggests that the nation's research programs, both individually and collectively, have not responded in an adequate manner and that there is no structure in place to make use of the research agendas generated by various expert groups. Indeed, at the national level there is no coordinated process for considering water resources research needs, for prioritizing them for funding purposes, or for evaluating the effectiveness of research activities.

In the face of the historical inability to mount an effective, broadly conceived national program of water resources research, it is reasonable to ask, "Why bother with yet another comprehensive proposal?" The answer lies in the sheer number of water resource problems (as illustrated in Chapter 1) and the fact that these problems are growing in both number and intensity. To address these problems successfully, the nation must invest not only in applied research but also in fundamental research that will form the basis for applied research a decade hence. A repeat of past efforts will likely lead to enormously adverse and costly outcomes for the status and condition of water resources in almost every region of the United States.

A METHOD FOR SETTING PRIORITIES OF A NATIONAL RESEARCH AGENDA

The solution to water resource problems is necessarily sought in research—inquiry into the basic natural and societal processes that govern the components of a given problem, combined with inquiry into possible methods for solving these problems. In many fields, the formulation of explicit research priorities has a profound effect on the conduct of research and the likelihood of finding solutions to problems.

Water resources research areas were extensively considered in the *Envisioning* report, resulting in a detailed, comprehensive list of 43 research needs, grouped into three categories. The category of *water availability* emphasizes the interrelated nature of water quantity and water quality problems, and it recognizes the increasing pressures on water supply to provide for both human and ecosystem needs. The category of *water use* includes not only research questions about managing human consumptive and nonconsumptive use of water, but also about the use of water by aquatic ecosystems and endangered or threatened species. The third category, *water institutions*, emphasizes the need for research into the economic, social, and institutional forces that shape both the availability and use of water. Interestingly, input from federal and state government representatives gathered during the course of this project confirmed the importance of many of the 43 topics.

Rather than focusing on a topic-by-topic research agenda, this report identifies overarching principles to guide the formulation and conduct of water research. Indeed, statements of research priorities developed by a group of scientists or managers can, depending on the individuals, have a relatively narrow scope. In recent years, the limitations of discipline-based perspectives have become clear, as researchers and managers alike have recognized that water problems relevant to society necessarily integrate across physical, chemical, biological, and social sciences. Furthermore, research priorities should shift as new problems emerge and past problems are mitigated or brought under control through scientifically informed policy and actions. Thus, Chapter 3 provides a mechanism for reviewing, updating, and prioritizing the current water resources research agenda (as expressed in the *Envisioning* report) and subsequent versions of the agenda. This mechanism is much more than a summing up of the priorities of the numerous federal agencies, professional associations, and federal committees. Rather, it consists of six questions or criteria (listed below) that can be used to assess individual research priorities and thus to assemble (and periodically review) a responsive and effective national research agenda.

1. **Is there a federal role in this research area?** This question is important for evaluating the "public good" nature of the water resources research area. A federal role is appropriate in those research areas where the benefits of such research are widely dispersed and do not accrue only to those who fund the research. Furthermore, it is important to consider whether the research area is being or even can be addressed by institutions other than the federal government.

2. **What is the expected value of this research?** This question addresses the importance attached to successful results, either in terms of direct problem solving or advancement of fundamental knowledge of water resources.

3. **To what extent is the research of national significance?** National significance is greatest for research areas (1) that address issues of large-scale concern (for example, because they encompass a region larger than an individual state), (2) that are driven by federal legislation or mandates, and (3) whose benefits accrue to a broad swath of the public (for example, because they address a problem that is common across the nation). Note that while there is overlap between the first and third criteria, research may have public good properties while not being of national significance, and vice versa.

4. **Does the research fill a gap in knowledge?** If so, it should clearly be of higher priority than research that is duplicative of other efforts. Furthermore, there are several common underlying themes that, given the expected future complexity of water resources research, should be used to evaluate research areas:

- the **interdisciplinary** nature of the research
- the need for a **broad systems context** in phrasing research questions and pursuing answers
- the incorporation of **uncertainty** concepts and measurements into all aspects of research
- how well the research addresses the role of **adaptation** in human and ecological response to changing water resources

These themes, and their importance in combating emerging water resources problems, are described in detail in Chapter 3.

5. **How well is this research area progressing?** The adequacy of efforts in a given research area can be evaluated with respect to the following:

- current funding levels and funding trends over time
- whether the research area is part of the agenda of one or more federal agencies
- whether prior investments in this type of research have produced results (i.e., the level of success of this type of research in the past and why new efforts are warranted)

6. **How does the research area complement the overall water resources research portfolio?** When applied to federal research and development, the portfolio concept is invoked to mean a mix of fundamental and applied research; of shorter-term and longer-term research; of agency-based, contract, and investigator-driven research; and of research that addresses both national and region-specific problems—with data collection to support all of the above. Indeed, the priority-setting process should be as much dedicated to ensuring an appropriate balance and mix of research efforts as it is to listing specific research topics.

The following conclusions and recommendations are made about the creation and refinement of a national portfolio of water resources research.

The 43 research topics from the *Envisioning* report are the current best statement of research needs, although this list is expected to change as circumstances and knowledge evolve. Water resource issues change continuously, as new knowledge reveals unforeseen problems, as changes in society generate novel problems, and as changing perceptions by the public reveal issues that were previously unimportant. Periodic reviews of and updates to the priority list are needed to ensure that it remains not only current but proactive in directing research toward emerging problems.

An urgent priority for water resources research is the development of a process for regularly reviewing and revising the entire portfolio of research being conducted. The six questions listed above are helpful for assessing both the scope of the entire water resources research enterprise and the nature, urgency, and purview of individual research areas. Addressing these questions should ensure that the vast scope of water resources research carried out by the numerous federal and state agencies, nongovernmental organizations, and academic institutions remains focused and effective.

The research agenda should be balanced with respect to time scale, focus, source of problem statement, and source of expertise. Water resources research ranges from long-term and theoretical studies of basic physical, chemical, and biological processes to studies intended to provide rapid solutions to immediate problems. The water resources research enterprise is best served by developing a mechanism for ensuring that there is an appropriate balance among the different types of research, so that both the problems of today and those that will emerge over the next 10–15 years can be effectively addressed.

The context within which research is designed should explicitly reflect the four themes of interdisciplinarity, broad systems context, uncertainty, and adaptation. The current water resources research enterprise is limited by the agency missions, the often narrow disciplinary perspective of scientists, and the lack of a national perspective on perceived local but widely occurring problems. Research patterned after the four themes articulated above could break down these barriers and promise a more fruitful approach to solving the nation's water resource problems.

STATUS AND EVALUATION OF WATER RESOURCES RESEARCH IN THE UNITED STATES

In order to evaluate the current investment in water resources research, the committee collected budget data and narrative information in the form of a survey from the major federal agencies and significant nonfederal organizations that are conducting water resources research. The format of the survey was similar to an accounting of water resources research that occurred from 1965 to 1975 by the Committee on Water Resources Research of the Federal Council for Science and Technology. This earlier effort entailed annually gathering budget information from all relevant federal agencies in 60 categories of water resources research. In order to support a comparison of the current data with past information, the NRC committee adopted a modified version of the earlier model, using most of the same categories and subcategories of water resources research. In January 2003, the survey was submitted to all of the federal agencies that either perform or fund water resources research and to several nonfederal organizations that had annual expenditures of at least $3 million during one of the fiscal years covered by the survey. See Table 4-1 for a complete list of respondents.

The survey consisted of five questions related to water resources research (see Box 4-1). In the first question, the liaisons were asked to report total expenditures on research in fiscal years 1999, 2000, and 2001 for 11 major categories (and 71 subcategories) of water resources research. (All data collection activities were explicitly excluded from the survey.) The remaining questions were posed to help give the committee a better understanding of current and projected future activities of the agencies, to provide a qualitative understanding of how research performance is measured, and to gauge the agencies' mix of research, in terms of fundamental vs. applied, internal vs. external, and short-term vs. long-term research. Responses to the survey were submitted in written form and orally at the third committee meeting, held April 29–May 1, 2003, in Washington, D.C.; revised survey responses submitted by the liaisons in summer 2003 reflected corrections and responded to specific requests from the committee.

Evaluation of the submitted information included a trends analysis for the total amount of water resources research funding and for the funding of the 11 major categories of water resources research. The total budget for water resources research from 1965 to 2001 and the year 2000 breakdown by federal agency are shown in Figures ES-1 and ES-2. The budget data were also analyzed to determine the extent to which the 43 high-priority research areas in the *Envisioning* report are being addressed. Finally, the committee qualitatively assessed the balance of the current national water resources research portfolio (defined as the sum of all agency-sponsored research activities). The following conclusions and recommendations stem directly from these evaluations.

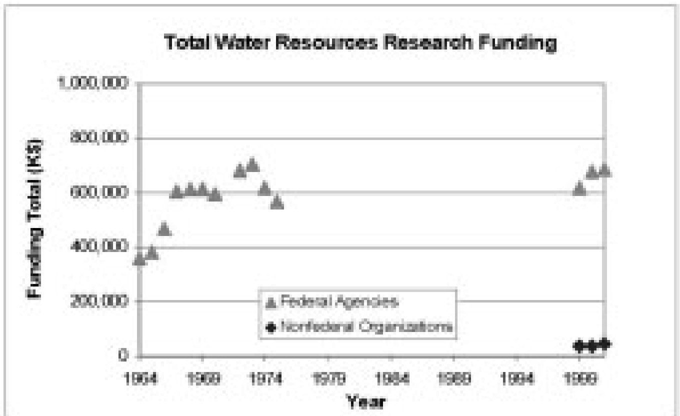


FIGURE ES-1 Total expenditures on water resources research by federal agencies and nonfederal organizations, 1964–2001. Values reported are FY2000 dollars. No survey data are available for years 1976 to 1998.

Real levels of total spending for water resources research have remained relatively constant (around $700 million in 2000 dollars) since the mid 1970s. When Category XI (aquatic ecosystems) is subtracted from the total funding, there is a very high likelihood that the funding level has actually declined over the last 30 years. It is almost certain that funds in Categories III (water supply augmentation and conservation), V (water quality management and protection), VI (water resources planning and institutional issues), and VII (resources data) have declined severely since the mid 1970s. All statements about trends are supported by a quantitative uncertainty analysis conducted for each category.

Water resources research funding has not paralleled growth in demographic and economic parameters such as population, gross domestic product (GDP), or budget outlays (unlike research in other fields such as health). Since 1973, the population of the United States has increased by 26 percent, the GDP and federal budget outlays have more than doubled, and federal funding for all research and development has almost doubled, while funding for water resources research has remained stagnant. More specifically, over the last 30 years water resources research funding has decreased from 0.0156 percent to 0.0068 percent of the GDP, while the portion of the federal budget devoted to water resources research has shrunk from 0.08 percent to 0.037 percent. The per capita spending on water resources research has fallen from $3.33 in 1973 to $2.40 in 2001. Given that the pressure on water resources varies more or less directly with population and economic growth, and given sharp and intensifying increases in

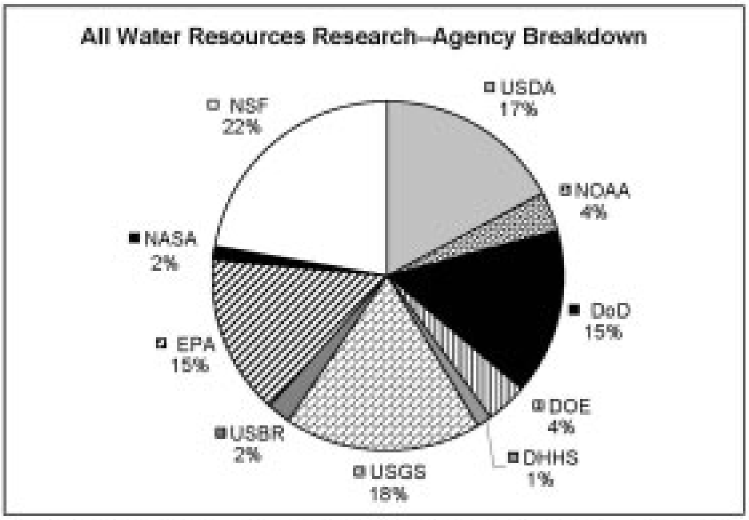


FIGURE ES-2 Agency contributions as a percentage of the total federal funding for water resources research in 2000.

conflicts over water, a new commitment will have to be made to water resources research if the nation is to be successful in addressing its water and water management problems over the next 10–15 years.

The topical balance of the federal water resources research portfolio has changed since the 1965–1975 period, such that the present balance appears to be inconsistent with current priorities as outlined in Chapter 3. Research on social science topics such as water demand, water law, and other institutional topics, as well as on water supply augmentation and conservation, now garners a significantly smaller proportion of the total water research funding than it did 30 years ago. When the current water resources research enterprise is compared with the list of research priorities noted in the *Envisioning* report, it becomes clear that significant new investment must be made in water use and institutional research topics if the national water agenda is to be addressed adequately. If enhanced funding to support research in these categories is not diverted from other categories (which may also have priority), the total water research budget will have to be enhanced.

The current water resources research portfolio appears heavily weighted in favor of short-term research. This is not surprising in view of the de-emphasis of long-term research in the portfolios of most federal agencies. It is important to emphasize that long-term research forms the foundation for short-term research in the future. A mechanism should be developed to ensure that long-term research accounts for one-third to one-half of the portfolio.

The Office of Management and Budget (OMB) should develop guidance to agencies on reporting water resources research by topical categories. Understanding the full and multiple dimensions of the federal investment in water resources research is critical to making judgments about adequacy. In spite of clearly stated OMB definitions of research, agencies report research activity unevenly and inconsistently. Failure to fully account for all research activity undermines efforts by the administration and Congress to understand the level and distribution of water resources research. This problem could be remedied if OMB required agencies to report all research activity, regardless of budget account, in a consistent manner.

DATA COLLECTION AND MONITORING

Although data collection was excluded from the water resources research survey conducted by the committee, the long-term monitoring of hydrologic systems and the archiving of the resulting data are critical to the water resources research enterprise of the nation. Data are essential for understanding physicochemical and biological processes and, in most cases, provide the basis for predictive modeling. Long-term consistent records of data, which capture the full range of interannual variability, are especially essential to understanding and predicting low-frequency, high-intensity events. Furthermore, federal agencies are instrumental in developing new monitoring approaches, in validating their efficacy through field studies, and in managing nationwide monitoring networks over long periods. The following conclusions and recommendations address the need for investments in basic data collection and monitoring.

Key legacy monitoring systems in areas of streamflow, groundwater, sediment transport, water quality, and water use have been in substantial decline and in some cases have nearly been eliminated. These systems provide data necessary for both research (i.e., advancing fundamental knowledge) and practical applications (e.g., for designing the infrastructure required to cope with hydrologic extremes). Despite repeated calls for protecting and expanding monitoring systems relevant to water resources, these trends continue for a variety of reasons.

The consequences of the present policy of neglect associated with water resources monitoring will not necessarily remain small. New hydrologic problems are emerging that are of continental or near continental proportions. The scale and the complexity of these problems are the main arguments for improvements to the *in situ* data collection networks for surface waters and groundwater and for water demand by sector. It is reasonable to expect that improving the availability of data, as well as improving the types and quality of data collected, should reduce the costs for many water resources projects.

COORDINATION OF WATER RESOURCES RESEARCH

Coordination of the water resources research enterprise is needed to make deliberative judgments about the allocation of funds and scope of research, to minimize duplication where appropriate, to present Congress and the public with a coherent strategy for federal investment, and to facilitate the large-scale multiagency research efforts that will likely be needed to deal with future water problems. Unfortunately, water resources research across the federal enterprise has been largely uncoordinated for the last 30 years, although there have been periodic ad hoc attempts to engage in interagency coordination during that time. The lack of coordination is partly responsible for the topical and operational gaps apparent in the current water resources research portfolio. Thus, although the federal agencies are carrying out their mission-driven research, most of this work focuses on short-term problems, with a limited outlook for cross cutting issues, longer-term problems, and more basic research that often portends future solutions. As a result, it is not clear that the sum of individual agency priorities adds up to a truly comprehensive list of national needs and priorities.

There are few areas of research as broadly distributed across the federal government as water resources research, resulting in few examples of how to effectively coordinate large-scale research programs. Nonetheless, the committee identified those factors that encourage or discourage effective coordination of large-scale research programs after hearing about programs for highway research, agricultural research, earthquake and hazard reduction research, and global change research. These factors helped shed light on an effective model for coordination of water resources research, which relies on some entity performing the following functions:

- doing a regular survey of water resources research using input from federal agency representatives
- advising OMB and Congress on the content and balance of a long-term national water resources research agenda every three to five years
- advising OMB and Congress on the adequacy of mission-driven research budgets of the federal agencies
- advising OMB and Congress on key priorities for fundamental research that could form the core of a competitive grants program
- engaging in vertical coordination with states, industry, and other stakeholders, which would ultimately help refine the agenda-setting process

The first three activities are intended to make sure that there is a national agenda for water resources research, that it reflects the most recent information on emerging issues, and that the water resources missions of the federal agencies are contributing in some way to national agenda items. A competitive grants program (the fourth activity) is proposed as a mechanism for filling critical gaps in the research portfolio, in the event that certain high priority research areas are not being adequately addressed by the federal agencies and to increase the proportion of long-term research. This program would require new (but modest) funding. Given the topical gaps noted earlier and in Chapter 4, **funding would be needed on the order of $20 million per year for research related to improving the efficiency and effectiveness of water institutions and $50 million per year for research related to challenges and changes in water use.**

Three institutional models that could conceivably carry out the bulleted activities listed above are described in Chapter 6. The first model relies on an existing interagency body—the Subcommittee on Water Availability and Quality administered by the Office of Science and Technology Policy. This coordination option is attractive because arrangements are already in place and agency roles and responsibilities are well defined. However, this approach has yet to demonstrate that it can be an effective forum for looking beyond agency missions to fundamental research needs. The second option involves Congress authorizing a neutral third party to perform the functions above, which would place the outside research and user communities on equal footing with federal agency representatives. The independence from the agencies afforded by this option makes it possible to focus the competitive grants program on longer-term research needs, particularly those falling outside agency missions. A disadvantage is that it may engender resentment from the agencies, and OMB may be reluctant to establish such a formal advisory body. A third option is a hybrid model that would be led by OMB and formally tied to the budget process. For more detailed descriptions the reader is referred to Chapter 6, which comprehensively discusses the three options.

Any one of the three coordination options could be made to work in whole or part. Each has strengths and weaknesses (described in detail in Chapter 6) that would need to be weighed against the benefits and costs that could accrue from moving beyond the status quo. In the end, decision makers will choose the coordination mechanism that meets perceived needs at an acceptable cost in terms of level of effort and funding. It is possible that none of the options is viable in its entirety. However, it may be possible to partially implement an option, which in itself would be an improvement over the status quo. For example, the initiation of a competitive grants program targeted at high-priority but underfunded national priorities in water resources research could occur under any one of the options and in lieu of the other activities listed above.

***

Publicly funded research has played a critical role in addressing water resources problems over the last several decades, both for direct problem solving and for achieving a higher level of understanding about water-related phenomena. Research has enabled the nation to increase the productivity of its water resources, and additional research can be expected to increase that productivity even more, which is critical to supporting future population and economic growth. Managing the nation's water resources in more environmentally sensitive and benign ways is more important than ever, given the recognition now afforded to aquatic ecosystems and their environmental services. A course of action marked by the creation and maintenance of a coordinated, comprehensive, and balanced national water resources research agenda, combined with a regular assessment of the water resources research activities sponsored by the federal agencies, represents the nation's best chance for dealing effectively with the many water crises sure to mark the 21st century.

TABLE 3-1 Water Resources Research Areas that Should Be Emphasized in the Next 10–15 Years

1. Develop new and innovative supply enhancing technologies
2. Improve existing supply enhancing technologies such as wastewater treatment, desalting, and groundwater banking
3. Increase safety of wastewater treated for reuse as drinking water
4. Develop innovative techniques for preventing pollution
5. Understand physical, chemical, and microbial contaminant fate and transport
6. Control nonpoint source pollutants
7. Understand impact of land use changes and best management practices on pollutant loading to waters
8. Understand impact of contaminants on ecosystem services, biotic indices, and higher organisms
9. Understand assimilation capacity of the environment and time course of recovery following contamination
10. Improve integrity of drinking water distribution systems
11. Improve scientific bases for risk assessment and risk management with regard to water quality
12. Understand national hydrologic measurement needs and develop a program that will provide these measurements
13. Develop new techniques for measuring water flows and water quality, including remote sensing and *in situ*.
14. Develop data collection and distribution in near real time for improved forecasting and water resources operations
15. Improve forecasting the hydrological water cycle over a range of time scales and on a regional basis
16. Understand and predict the frequency and cause of severe weather (floods and droughts)
17. Understand recent increases in damages from floods and droughts
18. Understand global change and its hydrologic impacts
19. Understand determinants of water use in the agricultural, domestic, commercial, public, and industrial sectors
20. Understand relationships between agricultural water use and climate, crop type, and water application rates
21. In all sectors, develop more efficient water use and optimize the economic return for the water used

22. Develop improved crop varieties for use in dryland agriculture
23. Understand water-related aspects of the sustainability of irrigated agriculture
24. Understand behavior of aquatic ecosystems in a broad, systematic context, including their water requirements
25. Enhance and restore of species diversity in aquatic ecosystems
26. Improve manipulation of water quality and quantity parameters to maintain and enhance aquatic habitats
27. Understand interrelationship between aquatic and terrestrial ecosystems to support watershed management
28. Develop legal regimes that promote groundwater management and conjunctive use of surface water and groundwater
29. Understand issues related to the governance of water where it has common pool and public good attributes
30. Understand uncertainties attending to Native American water rights and other federal reserved rights
31. Improve equity in existing water management laws
32. Conduct comparative studies of water laws and institutions
33. Develop adaptive management
34. Develop new methods for estimating the value of non-marketed attributes of water resources
35. Explore use of economic institutions to protect common pool and pure public good values related to water resources
36. Develop efficient markets and market-like arrangements for water
37. Understand role of prices, pricing structures, and the price elasticity of water demand
38. Understand role of the private sector in achieving efficient provision of water and wastewater services
39. Understand key factors that affect water-related risk communication and decision processes
40. Understand user-organized institutions for water distribution, such as cooperatives, special districts, and mutual companies
41. Develop different processes for obtaining stakeholder input in forming water policies and plans
42. Understand cultural and ethical factors associated with water use
43. Conduct *ex post* research to evaluate the strengths and weaknesses of past water policies and projects

SOURCE: Adapted from NRC (2001a), which identifies the researchable questions associated with each topic.

THE NATIONAL ACADEMIES

REPORT IN BRIEF

October 2007

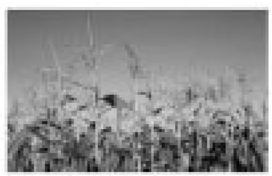
Water Implications of Biofuels Production in the United States

National interests in greater energy independence, concurrent with favorable market forces, have driven increased production of corn-based ethanol in the United States and research into the next generation of biofuels. The trend is changing the national agricultural landscape and has raised concerns about potential impacts on the nation's water resources. This report examines some of the key issues and identifies opportunities for shaping policies that help to protect water resources.

Biofuels—fuels derived from biological materials—are likely to play a key role in America's energy future. In 2007, President Bush called for U.S. production of ethanol to reach 35 billion gallons per year by 2017, which would displace 15 percent of the nation's projected annual gasoline use. By 2030, the administration aims to increase that production to 60 billion gallons per year. Recent increases in oil prices in conjunction with subsidy policies have led to a dramatic expansion in corn ethanol production and high interest in further expansion over the next decade.

Increased use of biofuels offers many benefits, such as a decreased reliance on foreign oil, but it also presents some challenges. Among the challenges that may not have received appropriate attention are the effects of biofuel development on water and related land resources. Growing and processing biofuel crops to meet America's energy needs will alter how the nation's water resources are used. However, the water implications of biofuels production are complex, difficult to monitor, and will vary greatly by region.

To help illuminate these issues, the National Research Council held a colloquium on July 12, 2007 in Washington, DC to facilitate discussion among representatives from federal and state government, non-governmental organizations, academia, and industry. This report examines the water implications of biofuels



production based on discussions at the colloquium, written submissions of participants, the peer-reviewed literature, and the best professional judgments of the committee.

Types of Biofuels

Currently, the main biofuel in the United States is ethanol derived from corn kernels. Corn-based ethanol is made by converting the starch in corn to sugars and then converting those sugars into ethanol. Ethanol derived from sorghum and biodiesel derived from soybeans each currently make up a very small fraction of U.S. biofuels. Other potential sources of materials for use in biofuels include field crops such as soy; short-rotation woody crops such as poplar and willow; animal fats, vegetable oils, and recycled greases; perennial grasses, such as switchgrass; agricultural and forestry residues such as manure and cellulosic waste; aquatic products such as algae and seaweed; and municipal waste such as sewage sludge or solid waste. Different biofuel sources have

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National Academy of Sciences • National Academy of Engineering • Institute of Medicine • National Research Council unique implications for water resources.

One of the most promising new biofuels on the horizon is "cellulosic ethanol," derived from fibrous material such as corn stalks and wheat straw, native grasses, and forest trimmings. Because of technological limitations, cellulosic ethanol can currently be produced only at pilot and commercial demonstration-scales; however, production of cellulosic ethanol is expected to begin commercially within the next decade.

Implications for Water Supply

Water is an increasingly precious resource used for many critical purposes; in some areas of the country, water resources are already significantly stressed. For example, large portions of the Ogallala (or High Plains) aquifer, which extends from west Texas up into South Dakota and Wyoming, show water table declines of over 100 feet. Increased biofuels production will likely add pressure to the water management challenges the nation already faces as biofuels drive changing agricultural practices, increased corn production, and growth in the number of biorefineries.

Water Use for Irrigation

Whether or not biofuel crops will require more or less water will depend on what crop is being substituted and where it is being grown. Corn generally uses less water than soybeans in the Pacific and Mountain regions, but the reverse is true in the Northern and Southern Plains. Therefore, farmers switching from soybeans to corn will need more water in some regions and less water in others As this example demonstrates, there are many uncertainties in estimating the overall net impacts of biofuel crops on our water resources.

Another important consideration is how biofuel production might drive the expansion of agriculture into regions that currently support little agriculture. Expansion of agricultural lands, especially into dry western areas, has the potential to dramatically affect water use.

The report concludes that in the next 5 to 10 years, increased agricultural production for biofuels will probably not alter the national-aggregate view of water use. However, there are likely to be significant regional and local impacts where water resources are already stressed. Depending on what crops are grown, where the crops are grown, and whether there is an increase in overall agricultural production, significant acceleration of biofuels production could cause much greater water quantity problems than are currently experienced.

Water Use for Biorefineries

All biofuel facilities require water to convert biological materials into fuel. The amount of water used in the biorefining process is modest compared to the water used for growing the plants used to produce ethanol; however, because water use in biorefineries is concentrated into a smaller area, its effects can be substantial locally. A biorefinery that produces 100 million gallons of ethanol per year, for example, would use the equivalent of the water supply for a town of about 5,000 people. Ethanol producers are increasingly incorporating water recycling and use-reduction measures in order to maximize energy yields while reducing water use.

Implications for Water Quality

Shifting agricultural practices to incorporate more biofuel crops will impact water quality as well as water quantity. Converting pastures or woodlands into cornfields, for example, may exacerbate problems associated with fertilizer runoff and soil erosion.

Fertilizer Runoff and Nutrient Pollution

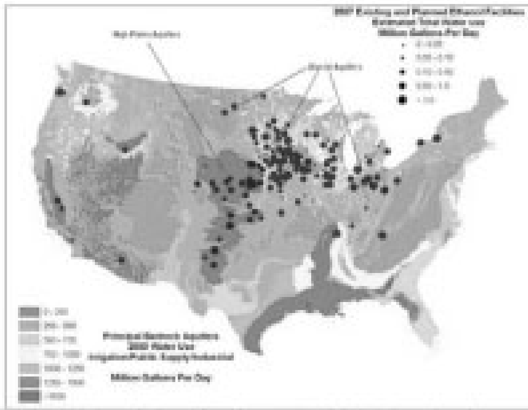
For most crops, it is standard agricultural practice to apply fertilizers such as nitrogen and phosphorus, as well as pesticides, which include herbicides and insecticides. However, these chemicals can wash into bodies of water and affect water quality. For example, excess nitrogen washing into the Mississippi River is known to be a cause of the oxygen-starved "dead zone" in the Gulf of Mexico, in which marine life cannot survive.

Different crops require different amounts of fertilizers. One metric that can be used to compare water quality impacts of various crops are the inputs

Fuel	Feedstock	U.S. Production in 2006
Ethanol	Corn	4.9 billion gallons
	Sorghum	< 100 million gallons
	Cane sugar	No production (600 million gallons imported)
	Cellulose	No production (one demonstration plant in Canada)
Biodiesel	Soybean oil	Approximately 90 million gallons
	Other vegetable oils	< 10 million gallons
	Recycled grease	<10 million gallons
	Cellulose	No production

(Left) 2006 U.S. production of different types of biofuels. SOURCE U.S. Congressional Research Service of fertilizers and pesticides *per unit of the net energy gain* captured in a biofuel. Of the potential biofuel crops, the greatest application rates of both fertilizer and pesticides per hectare are for corn. Per unit of energy gained, biodiesel requires a small fraction of the nitrogen and phosphorous used for corn-based ethanol. All else being equal, converting other crops or non-crop plants to corn will likely lead to much higher application rates of nitrogen.

However, there are many management practices that can improve the efficiency of fertilizer application and how they are used by plants. For example, recent advances in biotechnology have increased yields of corn per unit of applied nitrogen and phosphorous.



Existing and planned ethanol facilities (2007) and their estimated total water use mapped with the principal bedrock aquifers of the United States and total water use in year 2000. SOURCE: Janice Ward, U.S. Geological Survey.

Soil Erosion and Sedimentation

Sedimentation occurs when soil erodes from land and washes down into surface water bodies. Sediments impair water quality and also carry agricultural and other pollutants. The amount of sediment eroding from agricultural areas is directly related to land use—the more intensive the use, the greater the erosion. For example, more sediment erodes from row crop fields such as corn than from pastures or woodlands.

One of the most likely causes of increased erosion in the near term may be withdrawal of lands from the U.S. Department of Agriculture's voluntary Conservation Reserve Program due to an increase in overall agricultural production. The program pays farmers to convert environmentally sensitive or highly erodible acreage to native grasses, wildlife plantings, trees, filter strips, and riparian buffers and provides cost-share assistance for conservation practices.

Producing biofuels from perennial crops that hold soil and nutrients in place and require lower fertilizer and pesticide inputs, like switchgrass, poplars, willows, or prairie polyculture, is another option for reducing the deleterious effects of biofuel crops. There are, however, large uncertainties surrounding the production of cellulosic ethanol from such crops: such crops have very little history of use in large-scale cultivation. Therefore, even basic information such as water or nitrogen inputs needed, herbicide use, impact on soil erosion, and even overall yields is preliminary.

Reducing Water Impacts through Agricultural Practices

There are many agricultural practices and technologies that can simultaneously increase crop yields while reducing impacts on water resources. These technologies include a variety of water-conserving irrigation techniques, erosion prevention techniques, fertilizer efficiency techniques, and precision agriculture tools that take into account site-specific soil pH, moisture, and other measures. Such practices can have a large, positive environmental impact.

Surface cover is crucial in reducing sediment in runoff and limiting soil erosion. Farmers can employ a number of techniques that leave some portion of crop residues on the soil surface, helping to reduce erosion. In "no-till" systems, as the name implies, crops are simply planted into the previous year's crop residues. One of the issues for corn is what to do with the stalks and cobs left in the field after the grain has been harvested—called the corn stover. This material could potentially be converted to cellulosic biofuel, but leaving corn stover on the fields can greatly reduce soil erosion.

Key Policy Considerations

The water implications of biofuels production are complex, difficult to monitor, and will vary greatly by region. In general, however, crops that require less irrigation, less fertilizer and pesticides, and provide better erosion protection will likely produce fewer negative water impacts. Therefore, policy decisions that encourage such measures can have a significant positive impact on the protection of water resources as the demand for biofuels expands.

This report describes factors that shape the current policy context and raises some important considerations for future policy; however, it does not evaluate specific policy options or make any recommendations about policies to be implemented.

Current Policy Framework

The dramatic expansion of corn ethanol production over the past several years has largely been driven by subsidy policies for corn ethanol production coupled with low corn prices and high oil prices. These policies have been targeted to improving energy security and providing a clean-burning additive for gasoline. Staying the current policy path would likely result in the continued trend of expansion of corn-based ethanol production, driven by the economics of input costs and ethanol prices supplemented by the subsidy.

Future Policy Options

As biofuel production expands and technology advances, there is a real opportunity to shape policies to also meet objectives related to water use and quality impacts. To move toward a goal of reducing water impacts of biofuels, a policy bridge will likely be needed to encourage growth of new technologies that develop both traditional and cellulosic crops requiring less water and fertilizer and are optimized for fuel production.

Policy options that could help protect water resources include:

- *Alternative subsidies to reduce impacts of biofuels production on water use and quality.* To meet goals regarding overall water use, for example, performance incentives could be developed that encourage producers to increase water recycling in ethanol plants and farmers to adopt improved irrigation technology.
- *Policies to encourage best agricultural practices.* Several existing programs provide incentives to farmers specifically for improved nutrient management, for example. In addition, about $4 billion is spent annually on incentives for farmers to engage in practices to reduce soil erosion. Greater implementation of agricultural best practices could help maintain or even reduce water quality impacts.
- *Policies to encourage biofuels produced from cellulosic alternatives.* It is likely that cellulosic biofuels will have less impact on water quality per unit of energy gained; therefore, it would be prudent to encourage the transition from corn ethanol to the next generation of biofuels. The extent and intensity of water quality problems from biofuels will be partially driven by the conditions under which the cellulosic biofuels industry develops.

If projected future increases in use of corn for ethanol production do occur, the increase in harm to water quality could be considerable. In addition, expansion of corn production on fragile soils or can increase loads of both nutrients and sediments It is vitally important to pursue policies that prevent an increase in total loadings of nutrients, pesticides, and sediments to waterways. From a water quantity perspective, measures to conserve water and prevent the unsustainable withdrawal of water from depleted aquifers could be critical.

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Safe Water From Every Tap

Improving Water Service to Small Communities

Committee on Small Water Supply Systems

Water Science and Technology Board

Commission on Geosciences, Environment, and Resources

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Executive Summary

U.S. citizens generally expect to be able to drink their tap water with minimal health risk. While the quality of U.S. drinking water is superior to that in many parts of the world, not all U.S. citizens are receiving the same quality of water service. For example, during one recent 27-month period, 23.5 percent of U.S. community water systems violated safe drinking water standards one or more times for microbes that indicate the possible presence of bacteria, viruses, or parasites associated with human illnesses. Nearly 600 waterborne disease outbreaks have been reported in the past two decades.

Meeting drinking water standards is most difficult for water systems in small communities. Small communities often cannot afford the equipment and qualified operators necessary to ensure compliance with safe drinking water standards. Increases in both the number of drinking water regulations and the number of small community water systems over the past three decades have compounded the problem of providing safe drinking water to small communities. For example, the number of water systems serving 500 or fewer people increased sevenfold, from 5,000 to more than 35,000, between 1963 and 1993; the number of systems serving 501 to 10,000 people increased by more than 60 percent. Over this same time period, the number of contaminants regulated by federal drinking water standards increased from fewer than 20 to more than 100.

This report focuses on how to provide safe drinking water to small communities. It discusses technologies for small water systems, how to streamline pilot testing of these technologies to make them more affordable, financing and management of small systems to ensure their sustainability, and training of small system operators. The report was written by the National Research Council's Committee on Small Water Supply Systems. The committee was appointed in 1994 at the request of the U.S. Environmental Protection Agency (EPA) to study the problem of providing water service to small communities. Its membership consisted of 12 experts in water treatment, utility management, finance, and public health.

As discussed in this report, the solution to the problem of providing safe drinking water to small communities has three elements, each equally important: (1) providing affordable water treatment technologies, (2) creating the institutional structure necessary to ensure the financial stability of water systems, and (3) improving programs to train small system operators in all aspects of water system maintenance and management.

STATUS OF SMALL SYSTEMS

More than 54,000 small water systems (defined for this report as those serving 10,000 or fewer people) provide drinking water to approximately 20 percent of the U.S. population. Sixty-six percent of these systems serve communities with populations of 500 or fewer.

While some small communities are in wealthy areas, most small communities have difficulty raising the capital needed to upgrade their water systems and the revenue needed for day-to-day water system operation and maintenance. In extreme cases, these small communities can lack water service altogether. For example, as of 1990, more than 1.1 million U.S. households lacked plumbing.

Capital and adequate operating revenue are most difficult to obtain for small communities in nonmetropolitan areas. Average incomes in the smallest of these communities are one-third lower than incomes in larger, metropolitan areas. Unemployment rates can be more than 50 percent higher than those in metropolitan areas. Lenders are often unwilling to provide loans to rural communities because of the small profits generated by these loans. Whether a small system is located in a rural area or a metropolitan one, it will lack the economies of scale of larger communities in providing water service; per-person costs for water service must be higher in small communities than in larger ones to provide the same level of service because the costs are spread over a smaller population.

Small communities that lack adequate revenue for water treatment and distribution can have difficulty complying with the Safe Drinking Water Act. For example, systems serving fewer than 500 people violate drinking water standards for microbes and chemicals more than twice as often as those serving larger communities. Such violations leave these communities vulnerable to outbreaks of waterborne illness. In addition, the large number of violations in small communities poses a serious management problem for the state regulatory agencies responsible for implementing the Safe Drinking Water Act.

EVALUATING TECHNOLOGIES FOR SMALL SYSTEMS

Before looking to technological answers to water quality problems, small water supply systems should exhaust other available alternatives for improving water quality. One option is to find a higher-quality source water, such as by switching from surface water to ground water or relocating a well to a cleaner aquifer. In general, ground water sources are a better choice for small water systems than surface water sources because they are less turbid and have lower concentrations of microbiological contaminants than surface water. A second, nontechnical option for improving small system water quality is to purchase treated water from a nearby utility. Such options are often more cost effective than attempting to remove contaminants from a poor-quality source water.

When other options are not available and small systems must turn to water treatment processes in order to provide water that meets the requirements of the Safe Drinking Water Act, they may have difficulty raising revenue for capital improvements. One option available for reducing the costs of water treatment for these communities is the use of preengineered "package plants." Package plants are off-the-shelf units that group elements of the treatment process, such as chemical feeders, mixers, flocculators, sedimentation basins, and filters, in a compact assembly. Package plants do not eliminate the need for an engineer to design the specifics of the on-site application of water treatment equipment. Nevertheless, because package systems use standard designs and factory-built treatment units that are sized, assembled, and delivered to the customer instead of being custom built on site, such systems have the potential to significantly reduce the engineering and construction costs associated with a new water treatment system.

Site-specific pilot testing requirements can significantly increase the costs of package water treatment plants, partially offsetting the cost savings these systems offer. State regulators often require pilot tests of all new treatment systems other than chlorinators. Often package plants must be evaluated over and over again for source waters having similar quality but located in different communities. Pilot tests can last anywhere from several weeks to 1 year or more. Extensive pilot testing reduces the savings achieved by having the package plants designed and assembled at a central facility. Manufacturers have reported that pilot testing can increase the costs of their equipment by more than 30 percent. For example, according to one manufacturer, a 6-month pilot test can add $16,000 to the cost of a $45,000 package filtration system.

Certification of package plant performance by an independent third party would reduce package plant costs by reducing, although not eliminating, the need for site-specific testing. Currently, no national program exists for certifying drinking water treatment systems other than point-of-use (POU) and point-of-entry (POE) devices used in individual homes. The National Sanitation Foundation (NSF) International, which certifies in-home water treatment equipment, is currently cooperating with the EPA to develop a verification program for package plants. This program, launched in late 1995, is in its beginning phases and is currently funded for a 3-year period. Support for the program should continue, because it could reduce the costs of drinking water treatment technologies for small communities. Once the program is established, testing fees provided by equipment manufacturers will sustain most of its costs.

A key component of a national pilot testing and verification program for package plants is standard protocols for equipment testing. Currently, such protocols do not exist. Water treatment system designers generally conduct bench and pilot studies using their own individual methods and parameters for documenting water quality. As a consequence, it is difficult to compare data sets developed by different investigators. Establishment of standard protocols that measure the parameters covered in Safe Drinking Water Act regulations would allow data collected in one location to be applied elsewhere.

Another key component of a package plant testing and certification program is a national data base for reporting test results. Currently, no such data base exists. Considerable "reinvention of the wheel" occurs as new tests are required to verify technologies at each new location even if identical tests were performed elsewhere on water of a similar quality. Such a data base could be created by expanding the Registry of Equipment Suppliers of Treatment Technologies for Small Systems (RESULTS) data base at the National Drinking Water Clearinghouse in West Virginia. The expanded data base should cover all of the available technologies, use standard formats for reporting data, and include complete information about raw water quality, finished water quality, and operation and maintenance costs for each technology.

While development of standard protocols for testing drinking water treatment technologies is a desirable goal, it is essential to recognize that the degree to which pilot testing can be centralized in order to reduce site-specific testing varies considerably depending on the type of technology, the nature of the water to be treated, and the availability of data documenting the performance of the technology on waters of various qualities. For many technologies, some aspects of process performance can be tested in a central facility, while others need to be evaluated for each source water treated. Following are some general principles that apply to pilot testing of various classes of water treatment processes (see Chapter 4 for details):

- Site-specific pilot testing of *aeration systems* is not necessary; performance can be predicted with design equations.
- For *membrane systems*, much of the detailed evaluation can be based on pilot tests or full-scale applications elsewhere. However, systems using ground water will need to evaluate the potential for chemical scaling of the membranes. Surface water systems will need to test the potential for the source water to foul

the membranes and determine whether pretreatment is required to remove particulate matter ahead of the membranes.

- For *granular activated carbon adsorption systems*, some degree of source water-specific testing is necessary because the ability of the carbon to adsorb a target contaminant varies significantly with the chemical composition of the raw water. In cases where the raw water has a low concentration of organic matter, such as in ground water, inexpensive bench-scale columns can adequately predict performance; for surface water systems, pilot tests will be necessary.
- *Powdered activated carbon adsorption systems* need to be evaluated in bench-scale tests, at a minimum, to determine the effectiveness of the powdered activated carbon on the particular raw water and with the mixing characteristics present in the system.
- *Ion exchange* and *activated alumina* systems require some degree of source water-specific bench- or pilot-scale evaluation to determine the potential for competitive adsorption of ions other than the target contaminants, which can affect the life of materials used in treatment.
- Because of the complexity of the chemical processes involved, *coagulation/filtration systems* require site-specific testing unless an identical coagulation/filtration system is already being used successfully on the same source water. The degree of testing required depends in part on the design of the system and in part on the characteristics of the raw water. In some cases, bench-scale tests using jars to determine appropriate coagulant doses will be adequate.
- *Diatomaceous earth filtration systems* require a few weeks of pilot testing to establish the effectiveness of different grades of diatomaceous earth and to estimate the length of filter runs that might be expected with a full-scale plant.
- For *slow sand filtration systems*, site-specific pilot testing is necessary, unless a slow sand filter is already treating the same source water at another location, because understanding of these systems is insufficient to allow engineers to predict what filtered water turbidity an operating slow sand filter will attain. Piloting of these systems need not be expensive. Pilot test units can be constructed from manhole segments and other prefabricated cylindrical products.
- *Bag filters* and *cartridge filters* need not be pilot tested at each site. Performance of these filters depends on careful manufacture of the equipment and its use on waters of appropriate quality rather than on manipulation of the water or equipment during treatment.
- *Lime softening systems* need not be pilot tested for small systems using ground water sources; jar testing to determine appropriate process pH and chemical doses is sufficient. Lime softening systems do need to be pilot tested if used on surface water sources with variable quality.
- *Disinfection systems* using free chlorine, chloramine, chlorine dioxide, or ozone need not be tested at each individual site. The effectiveness of these systems is predicted based on laboratory test results, which regulators consider to be applicable to all systems.

- Current regulations allow small systems to base *corrosion control* strategies on desk-top reviews of water quality, rather than on pilot tests.

For the smallest of water systems, in particular those serving a few dozen homes or less, POE or POU water treatment systems may provide a low-cost alternative to centralized water treatment. In POE systems, rather than treating all water at a central facility, treatment units are installed at the entry point to individual households or buildings. POU systems treat only the water at an individual tap. If a source water has acceptable quality for drinking except for exceeding the nitrate or fluoride standards, for example, using a POU system to treat the small number of liters per day needed for drinking and cooking might be less costly than installing a central treatment system that could remove the nitrate or fluoride from all water used by the community. Similarly, POE systems can save the cost of installing expensive new equipment in a central water treatment facility. POU and POE systems can also save the considerable costs of installing and maintaining water distribution mains when they are used in communities where homeowners have individual wells.

Regulators often have significant objections to using POE and POU devices. Concerns include the potential health risk posed by not treating all the water in the household (a problem for POU systems), the difficulty and cost of overseeing system operation and maintenance when treatment is not centralized, and liability associated with entering customers' homes. These objections have merit, particularly as system size increases and the complexity of monitoring and servicing the devices increases. Using centralized water treatment should be the preferred option for very small systems, and POE or POU treatment should be considered only if centralized treatment is not possible.

Recommendations: Technologies for Small Systems

- Application of technology (other than disinfection) to improve water quality should be considered only after other options, such as finding a cleaner source of water or purchasing water from a nearby utility, have been exhausted.
- The EPA should continue support for the fledgling water treatment technology verification program that it recently initiated with the National Sanitation Foundation.
- The EPA should oversee development of standard protocols and reporting formats for pilot testing water treatment technologies, especially package plants.
- The EPA should establish a standard national data base for water treatment technology information by expanding the RESULTS data base at the National Drinking Water Clearinghouse. The data base should include complete information on source and finished water quality, in standard units, and costs for each technology. It should be made available electronically, via the Internet.
- State agencies responsible for regulating water systems should assign a

staff member to continually evaluate the status of knowledge relating to the performance of various water treatment processes of potential use in their jurisdictions. As more performance information is generated on waters of similar quality, the extent of preinstallation testing can be reduced, thus reducing the costs to the small system.

ENSURING SMALL WATER SYSTEM SUSTAINABILITY

Affordable technologies can help small communities provide better quality water, but technologies alone will not solve the problems of small water supply systems. Without adequate management and revenues, small communities will be unable to maintain even low-cost technologies. Many small communities lack a fee structure that is adequate to generate the necessary operating revenues, let alone funds for capital improvements. In other communities, the population is too small and average incomes are too low to provide sufficient revenue no matter what the fee structure. Lack of revenue leads to a vicious circle: without funding, water systems cannot afford to hire good managers, but without good managers, water systems will have trouble developing a plan to increase revenues. Institutional changes are needed to decrease the number of unsustainable water systems—that is, the number of systems lacking the resources needed to meet performance requirements over the long term.

Like businesses, small water systems are experiencing greater external pressure to change in response to the increasing number of regulations and increasing customer expectations. Unlike businesses, however, small systems have generally not done effective business planning. States should encourage small systems to do such planning by developing formal public health performance appraisal programs. Such programs should require each regulated water system in the state to assess its short- and long-term ability to provide adequate quantities of water that meets Safe Drinking Water Act standards. States should provide operating permits only to water utilities that have satisfactorily completed a performance appraisal. Where performance appraisals reveal problems, the states should assist the small water system in resolving the problems.

Performance appraisals should include analyses of the following types of information:

- existence of health orders (for example, boil water orders) issued to the water system or waterborne disease outbreaks in the community;
- the system's record of response to these orders and outbreaks;
- violations of water quality standards, including monitoring requirements;
- the water system's methods for keeping track of its compliance with Safe Drinking Water Act standards;
- the number of staff and their levels of training;

- responses to sanitary surveys (on-site visits by state regulators to inspect system source water, facilities, and operations); and
- whether the water system has an adequate plan specifying how it will meet present and future demands at an affordable cost while complying with the Safe Drinking Water Act and other regulations.

While regulators have long considered waterborne disease outbreaks, compliance with drinking water standards, operator certification, and sanitary surveys when evaluating small water systems, the importance of a comprehensive, forward-looking plan has often been overlooked. Proper planning and financing are key elements in ensuring the sustainability of water systems. Developing a water system plan will cause the utility to examine itself closely and develop a road map for the future. The plan should include information on future trends in service area, population, land use policies, and water demands on both a short-term (next 5 years) and long-term (next 20 years) basis. Based on this demographic information, it should evaluate needed system improvements, the current budget, the expected future budget, and projected future rates necessary to sustain the budget. The level of detail in such plans will vary with the size of the system, with very small systems requiring less detailed plans than larger systems.

If the performance appraisal uncovers problems that compromise the system's sustainability, then the water system either must improve service on its own or restructure by delegating some or all of its responsibilities to another entity, such as a rural electric utility, regional water authority, local government, or investor-owned utility. Restructuring arrangements generally fit one of four categories:

1. *direct ownership*, in which a small system reaches an agreement with another authority to take over system ownership or joins with other nearby systems to form a regional agency;
2. *receivership or regulatory takeover*, in which the state takes responsibility for transferring management of a failing water system to another authority in cases where the system owner does not voluntarily relinquish control;
3. *contract service*, in which a contractor provides specific services, such as operation and maintenance, water quality monitoring, emergency assistance, and billing, on a routine basis; and
4. *support assistance*, in which another utility provides support such as training the small system operator to repair a chlorinator, helping the small system develop a financial management plan, sharing water storage facilities, or making joint purchases of supplies or water to get volume discounts.

Each of these options consolidates some portion of the management and operation of several water systems within a larger agency, reducing costs to the consumer. For example, restructuring may mean that the community no longer needs to pay for a qualified full-time water system operator if, through restructuring, several systems can share an operator.

While restructuring can reduce the costs of providing water service to small communities, several barriers can stand in the way of restructuring. Organizations may be unwilling to take over deteriorated systems if they fear being responsible for financing all the necessary system improvements. Similarly, they may fear being held liable if the troubled system is in violation of the Safe Drinking Water Act. In other cases, small system owners may be unwilling to relinquish control to another authority. Incentives need to be provided to encourage qualified organizations to take over management of unsustainable small water systems and to encourage small systems to enter into such arrangements.

Recommendations: Small Water System Sustainability

- States should establish programs requiring all water systems to conduct public health performance appraisals. Only systems that have successfully completed a performance appraisal should be issued an operating permit.
- The federal government should limit state revolving fund (SRF) monies for drinking water systems to states with official performance appraisal programs. This will ensure that federal funds are not used to prop up unsustainable systems.
- SRF monies should be made available to public- and investor-owned utilities for assisting in the restructuring of small water systems.
- Federal, state, and local governments should provide tax incentives to organizations that assume responsibility for failing small water systems (see Chapter 5 for details).
- State public utility commissions should allow adjustments to the rate base of larger utilities that assume responsibility for insolvent water systems so that the rate base and depreciation practices can reflect the costs of acquiring the failing system.
- The EPA should provide temporary waivers to utilities for liabilities associated with Safe Drinking Water Act violations in cases where the utility has acquired a failing water company. These waivers should be tied to reasonable compliance schedules.

TRAINING OPERATORS FOR SMALL SYSTEMS

Even a well-financed water system with the most advanced treatment technologies cannot deliver its water reliably unless its operators are trained adequately. While all 50 states have regulations for certifying water system operators, the programs for training these operators are disjointed and often fail to meet the needs of small system operators.

Training of small system operators is provided through a mix of state-run workshops, informal instruction from equipment vendors and state regulators, courses at technical schools or universities, American Water Works Association courses, and rural water associations. These programs are not coordinated in any way. In addition, most operator training programs (and state certification requirements) cover the general theories underlying operation of numerous types of water treatment processes, some of them quite advanced, while operators of smaller systems need specific, hands-on training in only the treatment technologies their systems use. Training and certification programs are particularly deficient in teaching operators about water system management and administration—two areas that are as essential to small water system operation as are treatment and distribution.

The Safe Drinking Water Act Amendments of 1986 authorized the EPA to spend up to $15 million per year to provide technical assistance to small communities struggling to comply with the act's requirements. While the EPA provides $6.5 million annually to the National Rural Water Association and the Rural Community Assistance Program for technical assistance to small water systems, this spending has not resulted in the types of coordinated training programs needed to ensure that all water system operators are adequately trained. More leadership is needed at the national level to improve training programs for small water system operators.

Recommendations: Operator Training

- Funds should be provided to the EPA to establish an organizational work unit, based at EPA headquarters, responsible for identifying the knowledge and skills necessary to operate all aspects of drinking water systems.
- The new EPA work unit should arrange for an independent organization, such as the National Training Coalition or the National Environmental Training Center for Small Communities, to develop multimedia tools to deliver the needed training to system owners and operators across the country.
- The operator training programs should cover all of the areas necessary for running a small water system, including metering, customer service, financing, administration, and human resources management, as well as water treatment, water distribution, and public health.
- The states or their agents, with EPA support and coordination, should deliver the training programs to operators.
- States should rewrite their operator certification laws for small systems to allow small system operators to be certified only for the treatment processes employed in their systems. At the same time, states should institute a requirement that operators have knowledge of all of the skill areas (metering, finance, and so on) necessary for small system management.

In summary, water service to many of the nation's small communities is currently inadequate. Improving the quality of water service to these communities will require a combination of approaches: finding high-quality water sources, streamlining pilot testing requirements to make technologies more affordable, creating incentives to consolidate the management and financial administration of small systems, and improving programs to train small water system operators. Any one of these approaches alone will be insufficient to solve the problems of small water systems. A water system lacking adequate revenues and a well-trained operator will be unable to afford or maintain equipment, no matter how inexpensive, for water supply, treatment, and distribution. Conversely, a water system with a well-trained operator and sound financial plan may be unable to meet drinking water standards unless it can obtain treatment systems that are within its budget. National and state leadership are needed to improve the delivery of quality water to small communities.

MISSISSIPPI RIVER WATER QUALITY AND THE CLEAN WATER ACT

Progress, Challenges, and Opportunities

Committee on the Mississippi River and the Clean Water Act

Water Science and Technology Board

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Summary

Flowing approximately 2,300 miles from Lake Itasca to the Gulf of Mexico, the Mississippi River represents a resource of tremendous economic, environmental, and historical value to the nation. The Mississippi River drains the vast area between the Appalachian and the Rocky Mountains, making it the world's third-largest river basin, behind the Amazon and the Congo River basins. The river supports numerous economic and recreational activities including boating, commercial and recreational fishing, tourism, hiking, and hunting. Mississippi River water quality is of paramount importance for the sustainability of the many uses of the river and the ecosystems dependent on it. Numerous cities and millions of inhabitants along the river use the Mississippi as a source of drinking water. Water quality is also important for many recreational and commercial activities. The river's ecosystems and its avian and fish species rely on good water quality for their existence. These ecosystems and the species they support are highly valued and are especially important to communities and economies along the river and along the Louisiana Gulf Coast.

There are many differences between the upstream and downstream portions of the mainstem Mississippi River. Much of the upper Mississippi River is a river-floodplain ecosystem that contains pools, braided channels, islands, extensive bottomland forests, floodplain marshes, and occasional sand prairie. The upper river is home to the Upper Mississippi River National Wildlife and Fish Refuge, which covers 240,000 acres and extends 261 miles along the river valley from Wabasha, Minnesota, to Rock Island, Illinois. Further downstream, many large flood protection levees line the lower river and have severed natural connections between the river channel and its floodplain. There are fewer backwater areas and islands than along the upper river and fewer opportunities for river-related recreation. Moreover, the lower Mississippi River's larger flows and dangerous currents and eddies inhibit river-based recreation and impede water quality monitoring. These upstream-downstream differences affect the nature of water quality problems and the extent of water quality monitoring along the length of the river.

Mississippi River water quality is affected by land use practices, urbanization, and industrial activities across its large drainage basin. Many of these activities, including those that take place hundreds of miles away from the main river channel (or mainstem), can degrade Mississippi River water quality. The establishment of cities and commercial activities along the river has contributed to degraded water quality through increasing pollutant discharges from cities and industry. Congress first enacted the Federal Water Pollution Control Act (FWPCA) in 1948. Congress amended the FWPCA repeatedly from 1956 on; however, substantial amendments in 1972 created the contemporary structure of the act, which acquired the name Clean Water Act in 1977 amendments. An overarching objective of the Clean Water Act is to restore and maintain the chemical, physical, and biological integrity of the nation's waters.

The Clean Water Act has achieved successes in reducing point source pollution, or pollution discharged from a discrete conveyance or pipe (e.g., industrial discharge or a wastewater treatment plant), but nonpoint pollution, which originates from diffuse sources such as urban areas and agricultural fields, has proven more difficult to manage. Despite improvements since passage of the Clean Water Act, the Mississippi River today experiences a variety of water quality problems. Many of these problems emanate from nonpoint pollutant sources. Although the Clean Water Act can be used to address nonpoint source pollution problems, its provisions for doing so have less regulatory authority than its provisions for addressing point source pollution.

This report focuses on water quality problems in the Mississippi River and the ability of the Clean Water Act to address them. Data needs and system monitoring, water quality indicators and standards, and policies and implementation are addressed (the full statement of task to this committee is contained in Chapter 1). The geographic focus of this report is the 10-state mainstem Mississippi River corridor and areas of the Gulf of Mexico affected by Mississippi River discharge. Water quality in the Mississippi River and the northern Gulf of Mexico, however, is affected by activities from across the entire river basin. Comprehensive Mississippi River water quality management programs therefore must consider the sources of pollutant discharges in all tributary streams, as well as along the river's mainstem. This report therefore also discusses landforms, land use changes, and land and water management practices across the Mississippi River basin that affect mainstem water quality.

The committee was not specifically charged to consider possible statutory changes to the Clean Water Act. The committee discussed this topic and chose to conduct its investigations and present its findings and recommendations entirely within the framework of the existing Clean Water Act.

FINDINGS

Mississippi River Water Quality Problems

Numerous human activities across the Mississippi River basin affect the water quality of the mainstem Mississippi River and the northern Gulf of Mexico. These activities include discharges from industries, urbanization, timber harvesting, construction projects, agriculture, and landscaping practices. Along the mainstem Mississippi, major hydrologic modifications implemented over the past 150 years also affect water quality. These modifications include river channelization, locks and dams (and associated navigation pools) of the upper Mississippi River navigation system, many large levees along the lower river, and losses of large areas of natural wetlands.

These activities and modifications contribute to many water quality problems along the river's mainstem that vary and are of different magnitude in different parts of the river. These problems can be divided into three broad categories: (1) contaminants with increasing inputs along the river that accumulate and increase in concentration downriver from their sources (e.g., nutrients and some fertilizers and pesticides); (2) legacy contaminants stored in the riverine system, including contaminants adsorbed onto sediment and stored in fish tissue (e.g., polychlorinated biphenyls [PCBs]; dichlorodiphenyltrichloroethane [DDT]); and (3) "intermittent" water constituents that may or may not be considered contaminants, depending on where they are found in the system, at what levels they exist, and whether they are transporting adsorbed materials that are contaminants. The most prominent component in the latter category is sediment. In some portions of the river system, sediment is overly abundant and can be considered a contaminant. In other places it is considered a natural resource in deficient supply.

Differences in inputs of pollutants in different parts of the river basin contribute to varying water quality problems along the length of the river. For example, downstream sediment loads are greatly affected by sediment inputs from, and retention in, the river's many tributary streams. Nutrients enter the Mississippi River at many points along its course, primarily from nonpoint sources in agricultural areas in the upper Mississippi River basin that are not subject to Clean Water Act permit programs. Nitrogen and phosphorus are nutrients of special concern. These nutrients ultimately are discharged into the Gulf of Mexico, where nitrogen causes large-scale problems in the form of hypoxia and other coastal ecosystem disturbances, including impairment of Gulf fish populations. In other portions of the river system, primarily in the upper river, excessive loadings of phosphorus constitute a problem (e.g., in Lake Pepin in southern Minnesota).

Sediment problems are more complex. For example, in the upper Mississippi River, high rates of sediment input and deposition are key concerns. Sediment loads in the upper river today are greater than they were in the mid- to late eighteenth century, when the basin was being settled by European immigrants. The system of locks and dams and navigation pools put in place on the upper river in the early twentieth century affects sediment transport and deposition significantly. In the lower Mississippi River below Alton, Illinois, deprivation of sediments—due in large part to the trapping of large amounts of sediment behind a series of dams and reservoirs on the Missouri River—is a problem. Sediment deprivation is, for example, a key contributor to losses of coastal wetland systems in southern Louisiana. This problem is enhanced to some degree by extensive levee structures along the lower part of the river that do not allow sediments to spread into and across floodplains and wetlands adjacent to the river and its tributaries.

Identifying the most important water quality problems in the mainstem Mississippi River depends on the scale examined. At the local level, for instance, problems with toxic substances and bacteria may be of primary concern to citizens and regulators. However, **at the scale of the entire Mississippi River, including its effects that extend into the northern Gulf of Mexico, nutrients and sediment are the two primary water quality problems. Nutrients are causing significant water quality problems within the Mississippi River itself and in the northern Gulf of Mexico. With regard to sediment, many areas of the upper Mississippi River main channel and its backwaters are experiencing excess suspended sediment loads and deposition, while limited sediment replenishment is a crucial problem along the lower Mississippi River and into the northern Gulf of Mexico.**

Water Quality Monitoring and Assessment

The Mississippi River serves as a border between states along much of its course from Lake Itasca to the Gulf of Mexico. Some states along the river view Mississippi River water quality as primarily a federal responsibility—especially states in the lower stretch of the river. Many of the 10 states along the river thus allocate only small amounts of funds for water quality monitoring and related activities. Moreover, there is very limited coordination among the Mississippi River states on water quality monitoring activities. The Clean Water Act is relatively clear in delineating responsibilities for state-specific water quality monitoring and assessment; it is less clear in addressing issues of coordinated interstate river monitoring and assessment to ensure that water quality data are collected and analyzed in a consistent fashion. **As a result of limited interstate coordination, the Mississippi River is an "orphan" from a water quality monitoring and assessment perspective.**

The orphan-like nature of the Mississippi River entails several unique water quality monitoring and management challenges. One problem stems from the fact that individual states generally are responsible for monitoring the stretch of the Mississippi River that flows through or abuts them. The Mississippi River flows within only two states—Minnesota and Louisiana—of the ten states along its corridor. For the other eight states, the river forms a boundary between them. Although there are some important federally sponsored efforts in monitoring Mississippi River water quality—such as those conducted by the U.S. Army Corps of Engineers and the U.S. Geological Survey, especially on the upper river—there is no single water quality monitoring program or central water quality database for the entire length of the Mississippi. Thus, there are limited amounts of water quality and related biological and ecological data for the full length of the Mississippi River, especially the lower river. This limited amount of data inhibits evaluations of water quality problems along the river and into the Gulf of Mexico, which in turn inhibits efforts to develop, assess, and adjust water quality restoration activities. Moreover, the limited attention devoted to monitoring the river's water quality is not commensurate with the Mississippi River's exceptional socioeconomic, cultural, ecological, and historical value. **The lack of a centralized Mississippi River water quality information system and data gathering program hinders effective implementation of the Clean Water Act and acts as a barrier to maintaining and improving water quality along the Mississippi River and into the northern Gulf of Mexico.**

Effectiveness of the Clean Water Act

The Clean Water Act (CWA) is the cornerstone of surface water quality protection in the United States. It employs a variety of regulatory and nonregulatory tools designed to reduce direct pollutant discharges into waterways, finance municipal wastewater treatment facilities, protect wetlands, and manage polluted runoff. Congress designed the 1972 act "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." The act also called for zero discharges of pollutants into navigable waters by 1985 and "fishable and swimmable" waters by mid-1983. The U.S. Environmental Protection Agency (EPA) and the states are primarily and jointly responsible for implementing the act. The U.S. Army Corps of Engineers also plays a role in Clean Water Act implementation, because it shares responsibility with the EPA in the act's Section 404 wetlands permitting program.

The Clean Water Act aims to achieve water quality improvements by requiring categorical technology-based standards for point source dischargers. The Clean Water Act has been effective in addressing many point source pollution problems, such as discharges from industrial sources and publicly owned sewer systems and treatment works. Further improvements in control of point sources of pollution—notably in connection with urban stormwater and combined sewer overflows—are possible. Such changes, however, are likely to have limited effects on mainstem and northern Gulf of Mexico water quality because only approximately 10 percent of Mississippi River nitrogen loading is from point sources.

For waterbodies that remain impaired after the application of technology-based and water quality-based controls of point source discharges, the Clean Water Act requires application of water quality standards and Total Maximum Daily Loads (TMDLs). The TMDL represents both a planning process to implement standards and a numerical quantity for a pollutant load to receiving waters that will not result in violation of state water quality standards within an adequate margin of safety. The Clean Water Act requires states or the Environmental Protection Agency to develop TMDLs for waterbodies that do not meet water quality standards. **The Clean Water Act has been effective in addressing point sources of water pollutants. Notably, however, the Clean Water Act addresses nonpoint source pollution only in a limited, indirect manner. This is a crucial difference given the significance of nonpoint source water pollution throughout the nation and its special importance to Mississippi River and northern Gulf of Mexico water quality.**

The Total Maximum Daily Load framework is a key aspect of the Clean Water Act and is designed, in part, to address nonpoint source pollutants and to protect and restore water quality. The TMDL concept and its implementation have been used to address both point and nonpoint source inputs to many waterbodies in the United States. The TMDL framework is more easily implemented in smaller watersheds within individual states. Larger rivers and rivers with watersheds that encompass multiple states pose significant implementation challenges for the TMDL framework, particularly with respect to nonpoint source pollution. **For TMDLs and water quality standards to be employed effectively to manage water quality in interstate rivers such as the Mississippi, it is essential that the effects of interstate pollutant loadings be considered fully in developing the TMDL.**

A lack of coordination among federal- and state-level efforts, limited federal oversight of CWA implementation, and failure of some states to include the Mississippi River within their state water quality monitoring programs all contribute to the inability of the EPA and the states to address adequately water quality degradation in the Mississippi River and into the northern Gulf of Mexico. The Clean Water Act requires the EPA to establish water quality criteria; oversee and approve state water quality standards and TMDLs; take over the setting of water quality standards and the TMDL process when state efforts are inadequate; and safeguard water quality interests of downstream and cross-stream states. **The Clean Water Act assigns most interstate water quality coordination authority to the EPA. The Clean Water Act also encourages the EPA to stimulate and support interstate cooperation to address larger-scale water quality problems. The act provides the EPA with multiple authorities that would allow it to assume a stronger leadership role in addressing Mississippi River and northern Gulf of Mexico water quality.**

Despite the authority granted to the EPA in the Clean Water Act, one of the nation's key, large-scale water quality problems—the hypoxic zone in the northern Gulf of Mexico—continues to persist. The Gulf hypoxic zone is a large area that clearly is not meeting the CWA goal of fishable and swimmable waters. **The EPA has failed to use its mandatory and discretionary authorities under the Clean Water Act to provide adequate interstate coordination and oversight of state water quality activities along the Mississippi River that could help promote and ensure progress toward the act's fishable and swimmable and related goals.**

Programs and policies designed to achieve improvements in water quality for the Mississippi River and the northern Gulf of Mexico are affected by the following factors:

1. Resolution of many Mississippi River water quality issues is constrained by pre-CWA structural alterations to the river—for example, locks, dams, and levees, and the losses of wetlands—that the Clean Water Act cannot undo;
2. The Clean Water Act contains no authorities that directly regulate nonpoint sources of pollutants;
3. The Clean Water Act specifically exempts agricultural stormwater discharges and return flows from irrigated agriculture from being regulated as point source discharges and does not address agricultural nonpoint source pollution except as it leaves all nonpoint source pollution management to the states;
4. The interstate nature of the Mississippi River poses complications in coordinating water quality standards and monitoring programs among ten states and four EPA regions;
5. Large rivers such as the Mississippi are physically difficult to monitor, evaluate, and characterize; and
6. Pollutant loadings from ten states impact the Mississippi River and extend into the northern Gulf of Mexico.

Many structural and physical changes to the Mississippi River predate passage of the Clean Water Act. Moreover, Congress did not design the Clean Water Act to address every process that affects Mississippi River water quality. The Clean Water Act has been effective in reducing many pollutant discharges from point sources, but other processes such as levee construction, urbanization, and forestry activities affect Mississippi River quality and are not subject to the regulatory provisions of the Clean Water Act. **The Clean Water Act cannot be used as the sole legal vehicle to achieve all water quality objectives along the Mississippi River and into the northern Gulf of Mexico. Nevertheless, the Clean Water Act provides a legal framework that, if comprehensively implemented and rigorously enforced, can effectively address many aspects of intrastate and interstate water pollution, although the emphasis to date has been predominantly on the former.**

Nonpoint Source Pollution and Agriculture

Since agriculture contributes the major portion of nutrients and sediments delivered to the Mississippi River, reductions in pollutant loadings, especially nutrients, from the agricultural sector are crucial to improving Mississippi River water quality. Not all agricultural producers across the river basin contribute equal amounts of nutrients and sediments in runoff. Water quality protection programs thus need not be implemented in every watershed and on every farm to realize substantial water quality improvements further downstream. The careful targeting of programs to areas of higher pollutant loadings could enhance the effectiveness of conservation programs designed to reduce nutrient and sediment runoff.

The U.S. Department of Agriculture (USDA) administers a number of incentive-based programs designed to implement best management practices (BMPs) and/or reduce levels of nutrient and sediment inputs and runoff. USDA programs to reduce environmental impacts of agriculture include the Conservation Reserve Program (CRP), the Environmental Quality Incentive Program (EQIP), and the Conservation Security Program (CSP). These programs aim to balance incentives for crop production with incentives for land and water conservation. Participation is voluntary, but there are financial incentives for implementing BMPs.

A key issue in Midwest agriculture today is the potential increase in crop land and production dedicated to biofuels. Recent interest in biofuels production is encouraging producers to extend and intensify crop production in much of the upper Mississippi River basin. Much of this expanded production is in corn, which entails large applications of nutrient fertilizers. As a result, sediment and nutrient runoff from agricultural land in the upper basin is likely to increase. Although increases in grain production for biofuels, particularly on marginal agricultural lands that contribute high nutrient loads, may have substantial consequences for Mississippi River and northern Gulf of Mexico water quality, these potential impacts have not been fully evaluated.

RECOMMENDATIONS

Agriculture and Mississippi River Water Quality

Effective management of nutrient and sediment inputs and other water quality impacts from agricultural sources will require site-specific, targeted approaches involving best management practices. Existing USDA programs provide vehicles for implementing nonpoint source controls in agriculture, but they will require closer coordination with the EPA and state water quality agencies to realize their full potential for improving water quality. The EPA could assist the USDA to help improve the targeting of funds expended in the CRP, EQIP, and CSP. The national financial investment and scope of these USDA programs is large. A focus on these programs is important because the Clean Water Act does not authorize regulation of nonpoint sources of pollutants such as agricultural lands. Recent developments in the prospects for increased biofuels production, and the increased nutrient and sediment pollutant loads this would entail, provide an even stronger rationale to expedite targeted applications of USDA conservation programs and enhanced EPA-USDA coordination.

Targeting USDA conservation programs to areas of higher nutrient and sediment loadings can lead to BMPs for control of runoff containing sediment and nutrients being implemented on lands that are the primary sources of nonpoint pollutants. This provides an opportunity to strengthen EPA-USDA interagency collaboration: the EPA, for example, can assist USDA in identifying lands that should receive priority and can cooperate with USDA and producers in monitoring changes in water quality and making subsequent adjustments and improvements in nutrient management programs. The U.S. Geological Survey (USGS) also could play an important role in this collaboration by sharing its considerable expertise and data related to water quality monitoring.

It is imperative that these USDA conservation programs be aggressively targeted to help achieve water quality improvements in the Mississippi River and its tributaries. Programs aimed at reducing nutrient and sediment inputs should include efforts at targeting areas of higher nutrient and sediment deliveries to surface water. The EPA and the USDA should strengthen their cooperative activities designed to reduce impacts from agriculture on the water quality of the Mississippi River and the northern Gulf of Mexico.

State-Level Leadership

The 10 mainstem Mississippi River states have different priorities regarding the river and devote different levels of resources to water quality data collection. Broadly speaking, there is a distinction between priorities and approaches of the upper river states compared to the lower river states. One example of these differences is that the upper river states participate in a governor-supported interstate body—the Upper Mississippi River Basin Association (UMRBA). The five upper river state governors established the UMRBA in 1981 to help coordinate river-related programs and policies and to work with federal agencies with river responsibilities. The UMRBA has sponsored discussions and studies on many water quality issues. At a strategic level, the UMRBA represents an interstate commitment to cooperation on river management issues. There is no equivalent organization for the lower river states. The Lower Mississippi River Conservation Committee (LMRCC) is a multistate organization established to discuss issues of river biology and restoration, but it does not have gubernatorial appointees or employ full-time staff like the UMRBA.

Effective water quality protection and restoration requires that the Mississippi River be managed as an integrated system. Working together, the 10 Mississippi River states will achieve far more, with greater efficiencies, than each state working alone. Mississippi River states will have to be more proactive and cooperative in their water quality programs for the Mississippi River if marked improvements in water quality are to be realized. A mechanism for the lower river states to promote this coordination could take different forms, such as a forum for information exchange or an organization with a more formal status. **Better interstate cooperation on lower Mississippi River water quality issues is necessary to achieve water quality improvements. The lower Mississippi River states should strive to create a cooperative mechanism, similar in organization to the UMRBA, in order to promote better interstate collaboration on lower Mississippi River water quality issues.**

EPA Leadership

Several federal agencies maintain programs related to water quality monitoring across the Mississippi River watershed and into the northern Gulf of Mexico. For example, the National Oceanic and Atmospheric Administration (NOAA) collects water quality data for the Gulf of Mexico, the U.S. Army Corps of Engineers oversees the federal-state Environmental Management Program for the upper Mississippi River, and the USGS has collected water quality data for many years at select Mississippi River stations under different monitoring programs. All of these programs have merit, but there is no single federal program for water quality monitoring and data collection for the river as a whole. The past and current approach to water quality management in the Mississippi River is fragmented, with different agencies conducting their own monitoring programs and having different goals. This does not lend itself to a coherent program designed to monitor and consider the Mississippi River as a whole. The Mississippi River, with its extensive interstate commerce, its ecosystems that cross state boundaries, and its effects that extend into the northern Gulf of Mexico, clearly is a river of federal interest. There are compelling reasons for the federal government to promote the monitoring and evaluation of this river system as a single entity.

Better coordination and a greater degree of centralization of water quality monitoring and data collection along the Mississippi River are essential to ensure that similar parameters are being measured consistently along the entire length of the river; that similar methods, units, and timing of measurements are being used along the entire river; and that the placement and operations of monitoring stations are coordinated. There is an adequate scientific basis to undertake an expanded monitoring program for the Mississippi River. Better coordination is fundamental to streamlining federal expenditures and efforts for water quality monitoring along the river and, ultimately, to achieving water quality improvements in the Mississippi River and the northern Gulf of Mexico. This will help ensure an integrated program that enables consistent, science-based decisions about important water quality monitoring issues.

There is a clear need for federal leadership in system-wide monitoring of the Mississippi River. The EPA should take the lead in establishing a water quality data sharing system for the length of the Mississippi River. The EPA should place priority on coordinating with the Mississippi River states to ensure the collection of data necessary to develop water quality standards for nutrients in the Mississippi River and the northern Gulf of Mexico. The EPA should draw on the considerable expertise and data held by the U.S. Army Corps of Engineers, the USGS, and NOAA.

The EPA should act aggressively to ensure improved cooperation regarding water quality standards, nonpoint source management and control, and related programs under the Clean Water Act. This more aggressive role for EPA is crucial to maintaining and improving Mississippi River and northern Gulf of Mexico water quality and should occur at several levels. **The EPA administrator should ensure coordination among the four EPA regions along the Mississippi River corridor so that the regional offices act consistently with regard to water quality issues along the Mississippi River and in the northern Gulf of Mexico.**

Regarding cooperation and communication among the Mississippi River states, **the EPA should encourage and support the efforts of all 10**

Mississippi River states to effect regional coordination on water quality monitoring and planning and should facilitate stronger integration of state-level programs. The EPA has an opportunity to broker better interstate collaboration and thereby improve delivery of Clean Water Act-related programs, such as permitting, monitoring and assessment, and water quality standards development. The EPA should provide a commensurate level of resources to help realize this better coordination. One option for encouraging better upstream-downstream coordination would be through a periodic forum for state and regional water quality professionals and others to identify and act upon appropriate Clean Water Act-related concerns.

There are currently neither federal nor state water quality standards for nutrients for most of the Mississippi River, although standards for nutrients are under development in several states. Numerical federal water quality criteria and state water quality standards for nutrients are essential precursors to reducing nutrient inputs to the river and achieving water quality objectives along the Mississippi River and in the northern Gulf of Mexico. A TMDL could be set for the Mississippi River and the northern Gulf of Mexico. This would entail the adoption by EPA of a numerical nutrient goal (criteria) for the terminus of the Mississippi River and the northern Gulf of Mexico. An amount of aggregate nutrient reduction—across the entire watershed—necessary to achieve that goal then could be calculated. Each state in the Mississippi River watershed then could be assigned its equitable share of reduction. The assigned maximum load for each state then could be translated into numerical water quality criteria applicable to each state's waters.

Regarding cooperation with the Mississippi River states on water quality standards and criteria, **the EPA should develop water quality criteria for nutrients in the Mississippi River and the northern Gulf of Mexico. Further, the EPA should ensure that states establish water quality standards (designated uses and water quality criteria) and TMDLs such that they protect water quality in the Mississippi River and the northern Gulf of Mexico from excessive nutrient pollution. In addition, through a process similar to that applied to the Chesapeake Bay, the EPA should develop a federal TMDL, or its functional equivalent, for the Mississippi River and the northern Gulf of Mexico.**

The actions recommended in this report will not be easy to implement. They will entail a greater degree of collaboration and compromise among interest groups, states, and agencies than in the past. They are, however, necessary if the goals of the Clean Water Act are to be realized and the Mississippi River provided a level of protection and restoration commensurate with its integral commercial, recreational, ecological, and other values.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Jonathan Overpeck, Director, Institute for the Study of Planet Earth; Professor, Geosciences and Atmospheric Sciences, University of Arizona

Questions submitted by Chairman Bart Gordon

Q1. Please provide the Committee with recommendations of additional federal research and development to increase water supply and water use efficiency.

A1. Several federal research and development efforts would contribute to increasing water supply, and/or using our water supply more efficiently. These include:

1) A well-funded multi-year (I suspect at least 10 years would be needed) **National Water Supply Science and Assessment Program.** This effort would undoubtedly have to be multi-agency (e.g., NOAA, NSF, USGS, NASA, USDA), and ensure at least 50 percent of the funds were targeted at the extramural research community (e.g., universities and private firms)—to ensure maximum peer-review, regional focus, and interdisciplinarity. This Program could be part of, and would benefit greatly from, a **National Climate Service** (see more below) that was explicitly directed to include water supply in its mandate. Major foci should include:

1a) documenting the size and quality of current below-ground water resources at the scale of one kilometer or less. This is currently not known for most parts of the country, and would require drilling, geophysics, modeling and data synthesis.

1b) obtaining much improved estimates of likely future climate-related changes in water availability, in terms of rainfall, snow, evaporation run-off, streamflow, aquifer recharge and other metrics. This will require substantial climate research (e.g., to understand the dynamics of the North American monsoon and tropical storms), climate modeling and hydrological modeling. The goal should be to make substantial improvements on the climate and water projections included in the Fourth Assessment of the Intergovernmental Panel on Climate Change (2007). Close partnership between the scientific research community and regional water-related decision-makers is critical, and the program should focus significant funding on the *regional* science and assessment often neglected in federal R&D programs.

1c) a thorough investigation of how well the Nation's current water storage system is working, and how it can be augmented, e.g., by increased above-ground and below-ground storage. This investigation should factor in climate change (1b, above), as well as possible social and environmental issues that are, or could emerge as, problems. Although the promise of further above-ground storage is limited, below-ground storage potential has not been thoroughly evaluated.

1d) a complete interdisciplinary (e.g., natural science, social science, economics and law) examination of how water is currently used, and how greater efficiency could be achieved. Studies of this type have occurred, but they have tended to be small, short-term, and not interdisciplinary enough to guide effective policy at both national and regional scales. All aspects of water use need to be examined, understood, and optimized for maximum efficiency.

2) An improved **Integrated National Climate and Water Monitoring System** is needed to track water supply, water quality and water use projections, and to help update them as will inevitably be needed. The system should be designed to support water-use policy and to give stakeholders a comprehensive inventory of local to national water supplies (below and above ground) at any given point in time, from the present into the future. Over the past couple decades, streamflow monitoring (gauging) has declined due to funding cuts just as water supply concerns have become more acute. The same holds true for climate monitoring at the local to regional scales needed for water supply prediction. The proposed Integrated National Climate and Water Monitoring system should include monitoring of all underground resources, and should be designed to support the proposed (#1 above) National Water Supply Science and Assessment Program and other water storage programs.

3) A funded **National Water Oversight Program or Commission** is needed to ensure that all policy decisions made at local to national levels include scientifically robust assessments of their possible impact on water supply. For example, as the Nation explores alternative energy solutions, water requirements (savings or usage)

should be factored in. The same holds true for public lands and agricultural policy. Water supply is too important to be just an afterthought.

4) A national **Water Education** initiative is needed in order to make sure that our citizens understand water supply issues broadly (e.g., including climate and energy issues) and are prepared to work together to ensure the Nation's water supply into the future. Essential parts of this initiative should include K–12 education, informal programs, and university training, and—especially critical—the next generation of water supply scientists and engineers. As water supplies become more limited due to population increases, aquifer depletion, and/or climate change, the need for this expanded workforce will only increase.

Questions submitted by Representative Ralph M. Hall

Q1. One of the things that has been stressed in recent National Academies of Science reports is the need for more regional modeling and greater information resources at the regional level. You state in your testimony that the current warming has led to a decrease in spring snow-pack. Given that this year was a record year for snowfall in the Rockies, what is your confidence level regarding the fall off of spring snowpack attributable to climate change versus natural climate variability?

A1. I strongly concur with the NAS-stated need for great focus on regional climate and water research, observation, modeling and assessment. All of the research and development initiatives that I advocate in this document need to have greater regional focus than is the norm for federal programs. The reason for more regional focus is simply because most decisions, particularly with respect to water, are made at the regional-scale. Also, our scientific understanding of physical processes (e.g., climatic and hydrologic) at the regional scale lags understanding at broader scales. This limits effective regional decision-making.

Both natural climate variability and human-caused climate change are, and will increasingly be, water supply concerns, particularly in the U.S. West and Southwest. Because there is substantial climate variability from year to year, and particularly with respect to precipitation, it is dangerous to read much into what happens in any given year. The details of the most recent "water year" (starting in October, 2007) have not all been analyzed yet, but the trend over the last couple decades has been toward an increasingly small spring snowpack at the scale of the U.S. West. This has recently been attributed in the peer-reviewed scientific literature to warmer temperatures, and also—in the same study—connected to a trend toward smaller Colorado River flows. Thus, there may always be exceptions in any given year, but the longer-term trend is what we should be focused on and worried about.

Q2. In your written statement, you include a figure from the IPCC that illustrates the changes in runoff projected by the mid-21st century relative to the average run off from 1900–1970. Isn't it true that the early part of the 20th century is recognized as being an unusually wet period and that rainfall and water supply were at the high range of natural variability? Does this IPCC figure take into account such that this level of run off may not have been average, but in fact above average if looking over a longer period of time?

A2. Parts of the 20th century do appear to have been wetter than the long-term (e.g., 1000 year) average in some regions (e.g., much of the U.S. West, particularly the Southwest and region of the Colorado River). The figure in my testimony was not from the IPCC 4th Assessment, but rather was from the more recent work of Milly et al., 2008 (reference included in my written testimony). They probably used the 1900-1970 average because run-off records exist for this period across the U.S. (and much of the globe), and because they considered the period to be representative of what many people think of as "average." This period did include the extremely wet period of the 1920's (when the Colorado water allocations were made), but also the drier periods of the 1930's and 50's. In their work, Milly et al., do not compare projected future runoff with the longer-term average, perhaps because it is not possible to calculate the longer-term (multi-century) average for all of the U.S.

Q3. Dr. Overpeck, in your testimony you call for a national climate service designed to support local and regional decision-makers in dealing with climate-related reductions in water supply. How would such a service differ from NIDIS and its current mission? Would you envision expanding the role of NIDIS or creating another entity?

A3. Although it is still young, NIDIS should—in addition to being a valuable program in the face of drought—be considered an excellent "pilot" for some of what a

National Climate Service should be. NIDIS was designed to deal with drought, particularly at the regional scale so important to decision-making, and it should grow and flourish in that capacity. The design of a National Climate Service should learn from NIDIS, as well as other existing programs, but it should be a new program with a broader mission.

Without any doubt, a National Climate Service should be designed to be—first and foremost—responsive to the needs of regional decision-makers: those that have a true "stake" in climate variability and climate change. In this respect, a National Climate Service should be designed not just after the innovative aspects of NIDIS, but should also be heavily informed by the design and successes of the Regional Integrated Sciences and Assessment (RISA) Program funded out of the NOAA Climate Program Office (*http://www.climate.noaa.gov/cpo_pa/risa/*); indeed, much of NIDIS was informed by this NOAA RISA program. One of the key innovations of the RISA program is sustained partnership between regional science experts and regional decision-makers. Another innovation is that the RISA's enable interagency and interdisciplinary collaboration, and—first and foremost—serve to be constant champions of regional climate and water science. The needs of regional stakeholders should then drive a much larger integrated, multi-agency, National Climate Service that meets those needs via interdisciplinary climate system (including water!) research, observations, modeling and assessments.

Because NOAA is by far the strongest climate agency in the Federal Government, they should lead the National Climate Service. However, the trickiest part, perhaps other than funding, will be to devise a new mechanism to ensure that (1) multi-agency partners truly work together, (2) use their funding within, and among agencies as intended, and (3) work—as a priority—to meet the needs of the regional stakeholders. Some entity, such as a Commission of regional scientists and stakeholders, is needed that reports both to Congress and the White House, and that has a responsibility to verify that funds are being used to—first and foremost—meet the needs of the regional stakeholders. Otherwise, interagency cooperation and coordination will not be optimal, as many current "interagency" programs unfortunately demonstrate.

One of the primary benefits of a new National Climate Service would be to provide advantage to the Nation, and its regional stakeholders, in adapting to climate change as well as natural climate variability—including drought. I am currently working with a national group of regional climate (i.e., RISA) scientists to develop a more comprehensive plan for a regionally driven National Climate Service, and I will forward our proposed plan to you and your committee as soon as we have a complete document.

Q4. Dr. Overpeck, in your testimony you discuss the vulnerability of the Southwest to climate change related drought and you also point out the many times in the past the Southwest has dealt with drought. Given the susceptibility of this region to drought, would you say it is more important to invest in research to predict it or research to mitigate the effects and explore other ways to increase potential supply?

A4. The Southwest U.S., extending from California into Texas, and northward into the central Rockies, is going be increasingly challenged by water supply problems no matter what. The region is prone to more, and longer droughts, than the rest of the Nation, and climate change is already making the situation worse with higher temperatures, less spring snowpack, and declining river flow. It is safe to say, that the situation could easily get worse, but it is also safe to say that there are things we can do about it.

We need to take both climate change (and drought) adaptation and mitigation seriously. This means the region, hopefully with help from the Nation as a whole (which also has a stake in climate change and drought), must learn to use water more wisely, but also do whatever it can to reduce future threats—namely climate change—to water supply. In my response to Chairman Gordon's question above, I have outlined some important research and development initiatives that could help, and because of the inevitable climate and water challenges facing the Southwest, I am a strong advocate for a National Climate Service (also see above). For these same reasons, I think it is also imperative that the nations of the globe—with the United States in the lead—start working aggressively to reduce greenhouse gas emissions to 80 percent below 1990 levels by 2050. To say that Southwesterners—Arizonans and Texans alike—have a real stake in all these efforts is an understatement.

Questions submitted by Representative Adrian Smith

Q1. Nebraska's panhandle has experienced nearly a decade of severe drought. What steps or technologies are needed to prepare for and mitigate long-term drought?

A1. Clearly Nebraska has a major stake in seeing something done about drought, just as we in the Southwest do. Fortunately, what I have outlined above summarizes the national research and development efforts needed by Nebraska and neighboring states. In the past, I have researched what the Dust Bowl drought did to the Nebraska region, and I learned first-hand that the record-hot—and wilting—temperatures of the 1930's will seem cool in comparison with what will likely come if greenhouse gas emissions are not reduced dramatically and quickly. Nonetheless, the climate change already in the pipeline (due to inertia in the climate system) AND natural drought variability, means that the people of Nebraska and surrounding states must also prepare for, and adapt to, likely future drought. My foregoing responses should help understand what is needed.

Q2. What are your views on balancing the demand for various uses of water, including, drinking water; agricultural uses; energy generation; habitat, especially for endangered species; and recreation?

A2. This is as much a values question as it is scientific. I value each of the entities that you mention, and I also have faith that our country can figure out a way—using knowledge and technological innovation—to keep all of these entities healthy and in the balance. However, we cannot do this assuming business as usual, and that is why I have suggested a number of research and development programs in my foregoing responses. It is also why I am a strong supporter of cutting global greenhouse gas emissions to at least 80 percent below 1990 levels by 2050. We do not want to sacrifice any of these fundamental—and valued—entities.

Your question raises one additional critical point: the role of water in energy production. I note this in my above responses, but also would be a supporter of a massive (ca. $50–$100B/year) government effort to develop new and improved energy alternatives that will speed the much needed greenhouse gas emission reductions that are needed to curb climate change, as well as to make our country truly energy independent and a global leader in energy technology sales. I bring this up here because it is critical that we factor in water demand as we develop new sources of energy: the climate-water-energy nexus is critical not just for Nebraska, but for our entire nation.

Question from Representative David Wu

Q1. Western communities, specifically, have unique circumstances and relationships with tribal governments as it relates to water. Tribes often have priority water rights that states and local governments, and other users, must account for when creating water plans. As far as partnerships go, what types of opportunities exist for collaborative efforts that recognize tribal water rights and support both non-tribal and tribal efforts?

A1. I am not a Native Nations water rights specialist, but I live in state, and in a region, blessed with many Native American neighbors. In this context, I have worked with some of our regional Tribes on climate-related issues. In my foregoing responses, I have emphasized the need to drive research and development—including a National Climate Service—with the needs of regional decision-makers. In the Southwest, and across the U.S., the Tribes are at the table as important regional stakeholders. As it stands, we don't have the institutions that treat climate and water supply issues (including energy—another key issue in Indian Country) holistically, and that is what I am advocating in my foregoing responses. Any legislation that comes to pass needs to be crafted to ensure the Tribes, and their members, are fully invested partners in the activities that result.

On a slightly more personal side, I recently supervised a Navajo graduate student who just received her Master's degree after completing a Four-Corners climate and society (agriculture and ranching) thesis. Her focus included helping leaders and kids on the Navajo Nation learn about climate issues. There is a clear need for more such graduate students, and the Federal Government could help with funding at both the undergraduate and graduate levels. The desire is often there, but funding and appropriate opportunities can be harder to find—especially for the interdisciplinary knowledge creation and learning that is needed. Climate and water partnerships would undoubtedly benefit from such increased funding for education.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Marc Levinson, Economist, U.S. Corporate Research, J.P. Morgan Chase

Questions submitted by Chairman Bart Gordon

Q1. Please provide the Committee with recommendations of additional Federal research and development to increase water supply and water use efficiency.

A1. The greatest urgency involves exploration of pricing schemes to encourage conservation. Federal R&D money would be well spent in the agricultural area, developing crop varieties that require less irrigation, but there is little incentive for developing and planting such crops so long as most farmers are able to draw on water for free. It might also be worth considering a requirement for Congress to evaluate water impacts when considering legislation; such a requirement might have been useful during consideration of last year's law increasing the renewable fuels standard and this year's farm bill. I think there will be ample private funding available for R&D into water-conservation and decentralized water-treatment technologies if these are economically viable, and no federal R&D effort is required.

Questions submitted by Representative Ralph M. Hall

Q1. You mention in your testimony the concept of a water "footprint." Could you provide us with a couple of examples of companies that are aware of their water footprint and steps they may be taking to address their water footprint?

A1. We have examined a limited number of companies around the world and do not claim to have complete information on this subject. Among the companies we have examined, only Unilever has ever reported its water footprint. Subsequent to the publication of our recent report on this subject, other food and beverage companies have advised us that they intend to do further analysis of their water footprints. In general, large food manufacturers appear to recognize that they can achieve the largest reductions in their water footprints by encouraging greater water efficiency among agricultural suppliers, and some are starting to examine this issue.

Q2. You discuss in your testimony that companies face regulatory risks in the form of allocation and price controls when water becomes scarce. In your work, has JPMorgan Chase found any regulatory reform options that might address such problems such that water utilized responsibly while business can remain on track?

A2. Yes, we have seen two types of regulatory reforms that are important in this way. First, there are a number of jurisdictions that have imposed significant cost increases for water. Unfortunately, these increases often affect only customers drawing water from municipal systems, not agricultural and industrial users that draw water directly from rivers or groundwater sources. Better pricing schemes are urgently needed. Second, some jurisdictions have imposed strong non-price regulations that limit water usage, such as requiring the use of recycled water to irrigate golf courses or barring the use of grass in landscaping in desert areas. We are not aware of jurisdictions that have adopted regulations concerning allocation of water in the event of physical scarcity.

Q3. You mention nuclear power as an energy source that utilizes large amounts of water and therefore includes a "societal" cost that should be factored into the price users pay for electricity for these plants. Should the same hold true from other sources of power, including renewables, such as biofuels and solar?

A3. Certainly. Water is a scarce resource, and its cost should be borne by those who consume it. Biofuels impose very heavy water demand, particularly by encouraging the cultivation of corn in water-scarce areas. In the case of solar, the water-related cost is likely to occur mainly in the manufacturing process rather than at the generating site.

Q4. In your testimony you touch upon the impact increased biofuels production has on water usage. In examining the development of the biofuels industry, has JPMorgan Chase performed an analysis of the water usage associated with feedstocks other than corn for biofuels production? Are there drought resistant plants that could provide biofuels feedstock at lower "water" cost?

A4. We have not performed an analysis of the water usage associated with biofuels feedstocks. This would require complex modeling, as much of the impact is likely attributable to changed patterns of land use arising from higher crop prices. For example, ethanol has led to a large increase in cultivated corn acreage in the Great Plains states; whereas corn grown for ethanol in Ohio might not require extensive irrigation, corn grown for ethanol in Nebraska is likely to require heavy irrigation. The intrusion of cultivation into former conservation reserve areas, another consequence of U.S. biofuels policy, also increases water demand while potentially reducing the recharge of aquifers. Switchgrass and sorghum are frequently mentioned as plants with lower water requirements that are suitable for ethanol, but suitable varieties are not presently commercially available. In any event, their impact on water consumption would depend upon whether they supplant corn production in arid locations, or whether they are planted in even more arid locations and serve to increase the total amount of land under cultivation.

Q5. Please expand on your comments alluding to the fact that several companies are looking into technologies for decentralized water treatment and that federal R&D funds may be helpful? If we were to decentralize water treatment for human consumption, how would we ensure that all water for human consumption met baseline standards? What regulatory mechanisms would be needed? What would the costs associated with such a change from centralized to decentralized water treatment be for a city like Washington, DC?

A5. I'm not sure the need here is for federal funding, as I hear anecdotally that considerable venture capital is active in the field of decentralized water treatment. A more important issue may be whether federal water-treatment regulations inadvertently favor large-scale municipal plants over smaller-scale treatment. For the cost reasons you indicate, it is probably not cost-effective to decentralize water treatment in an area where centralized treatment is already in use. However, it may well be sensible to consider decentralized treatment for new housing subdivisions, large office complexes, and rural areas being connected to piped water for the first time. Decentralized treatment effectively requires two sets of supply pipes, one for purified water and the other for non-potable water, which would be connected to outdoor spigots, cooling towers, and similar uses, but not to indoor plumbing.

Questions submitted by Representative Adrian Smith

Q1. Many energy generation methods require water to produce power. Hydropower, nuclear energy, petroleum refining, clean coal technologies, and biofuels production all require large amounts of water. What steps should be taken in both the public and private sectors to address water-use challenges as energy demand increases?

A1. I think the big issue here is that subsidies encourage energy consumption without regard to the social costs involved in producing the energy. It would be desirable for Congress to pay more attention to the water impacts when crafting energy legislation, and for energy produces to be forced to pay a reasonable price for the water they draw. It is worth considering whether closed-loop recycling systems should be mandated at new energy facilities. This undoubtedly would raise energy costs, but is highly desirable from the viewpoint of water conservation.

Q2. If new hydropower facilities were to be built to meet the growing energy needs of the United States, what would be the main water-use challenges that would need to be addressed?

A2. I do not expect extensive construction of hydropower facilities in the U.S., due both to environmental concerns and to the fact that many of the most suitable locations are already in use. My comment on this is that in the past we have mistakenly relied almost entirely on supply-side measures to meet water demand. It is highly desirable to provide incentives to limit demand, and pricing is the best mechanism for this purpose.

Q3. Mr. Levinson, my home State of Nebraska has a large agricultural industry, and irrigation is a common practice in much of my district. You mentioned in your testimony that groundwater use should be governed by federal, rather than State, law. What federal legislation would you propose for the best allocation of ground- and surface-water, and what would be the major benefits of regulation on a federal level, instead of a State level?

A3. My testimony was not that the Federal Government should take control of groundwater use, but rather that the Federal Government should explore methods of requiring states to adopt groundwater pricing schemes. I note that the Federal Government uses its budgetary powers to impose many such obligations on states, by threatening to withhold grants for particular programs unless State governments take specific actions. This same approach could be used to force states to adopt schemes to price both groundwater and surface water. As a practical matter, I think it would be extremely difficult for the Federal Government to make detailed allocation and pricing decisions at a great remove from the affected communities, so I think it is wiser to leave this task to lower levels of government within broad parameters.

Q4. What are your views on balancing the demand for various uses of water, including, drinking water; agricultural uses; energy generation; habitat, especially for endangered species; and recreation?

A4. I have no particular views on this subject. Insofar as the subject of my testimony is concerned, I think it would be helpful if those responsible for planning for water scarcity were to outline in advance a series of emergency conservation measures in priority order, so that individuals and companies would be able to have a better sense of the likelihood that their supplies would be curtailed in the event of severe supply shortfalls.

Questions submitted by Representative David Wu

Q1. How do we ensure that rural minority communities are addressed when we build out water infrastructure? Many of these areas have little to no existing infrastructure in place, and I'm afraid if they are not a part of our plans, we will be significantly short-changing a large population. What roles can corporations play in this?

A1. Please see my response to Representative Hall's question concerning decentralized treatment, which may provide a more cost-effective alternative for rural communities than laying supply pipes for great distances. There has been considerable private investment in water-distribution systems, but whether such companies would find it attractive to invest in a relatively small-scale distribution system would depend on the specifics.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Roger S. Pulwarty, Physical Scientist, Climate Program Office; Director, The National Integrated Drought Information System (NIDIS), Office of Oceanic and Atmospheric Research, National Oceanic and Atmospheric Administration, U.S. Department of Commerce

Questions submitted by Chairman Bart Gordon

Q1. Please provide the Committee with recommendations of additional Federal research and development to increase water supply and water use efficiency.

A1. Some of the relevant priorities identified by the National Science and Technology Council's Subcommittee on Water Availability and Quality are: (1) Quantifying the future availability of freshwater in light of both withdrawal uses, and ecosystem uses; (2) Assessing and predicting the effectiveness of land use practices and watershed restoration on water quality and ecosystem health; (3) Developing information and efficiency tools to aid in water management including wastewater reuse and low-water-use crops; and (4) Improve linkages between climate and hydrologic prediction models and their applications.

To address these priorities, we will need to focus on improvements in the ability of climate models to recreate the recent past as well as make projections under a variety of forcing scenarios. Research should focus on the development of a better understanding of the physical processes that produce extremes and how these processes change with climate as well as the reconciliation of model projections of increasing drought severity, frequency, or duration for different regions of the U.S. The creation of annually-resolved, regional-scale reconstructions of the climate for the past 2,000 years would help improve our understanding of present rates of change in the context of very long-term regional climate variability.

Development of improved recharge monitoring techniques and social science research on the severity of drought impacts and institutional responses (to understand the effects of human activity on groundwater recharge) would provide information needed to increase our water supply.

In addition, it is important to understand the response of the biological community to changes in streamflow and stream temperature, clarity, and chemistry, which are key issues in addressing instream flows and aquatic needs. It is also important to understand the degree to which aquifer storage is changing and will change in the future (given various climate, land and water use patterns), in addition to how changes in groundwater will affect streamflow and surface-water flow as a result of water management activities, land-use change, climate change, diversions, and storage.

Adaptive measures include both demand and supply side approaches. Demand-side measures include water recycling, reducing irrigation demand, water markets, and economic incentives such as metering and pricing. Supply-side measures include conjunctive surface-groundwater use, increases in storage capacity, and desalination of sea water. Critical issues over the near term include: (1) ensuring adequate water to maintain environmental services that support economic and cultural benefits; (2) ensuring development, marketing, and adoption of efficient technologies, and (3) managing information needed to coordinate data collection and quality control, which will allow us to transform data and forecasts into accessible, credible, and usable information for early warning, risk reduction and adaptation practices in the water resources sector.

Questions submitted by Representative Ralph M. Hall

Q1. In his testimony, Mr. Levinson mentioned that the Tennessee Valley Authority had to shut a nuclear plant since there was not enough cooling water in the Tennessee River. What monitoring, prediction, risk assessment, and communication tools could NIDIS provide for existing plants to avoid such a circumstance? Similarly, what monitoring, prediction, risk assessment, and communication tools could NIDIS provide so that states and companies could make informed decisions as to where to site a nuclear power plant, or any other type of electrical power plant, in relation to water access?

A1. To clarify, and for the record, the Tennessee Valley Authority (TVA) advises that its Brown's Ferry Nuclear Plant was not shut down because of a lack of cooling water. The plant was derated because of a permitting agreement with the Alabama Department of Environmental Management that states TVA will not exceed a 24-hour downstream average temperature of more than 90 degrees.

Demand for energy increases demand for freshwater supplies, and increased demand on water requires additional energy to store and transport water. Freshwater withdrawals for energy account for 39 percent of total withdrawals in the United States. Transportation of water to produce energy introduces additional costs in plant design. Increases in water temperature in streams and reservoirs can reduce the water's effectiveness as cooling water for nuclear plants (as occurred at the Browns Ferry nuclear plant in Alabama in 2007).

As part of its forecast of precipitation, NIDIS communicates forecasts of ambient air temperature. This is useful because there is a close correlation between air and stream temperatures. The Department of the Interior (the U.S. Geological Survey and the U.S. Fish and Wildlife Service) and others can use NIDIS information to provide improved information regarding potential risks of high temperature instream events.

NIDIS could provide valuable information used to make more informed decisions for the siting of nuclear power plants. Plant sitings require assessments of municipal and industrial demands and associated water supply reliability. NIDIS can provide information on past drought records for a particular location, water supply reliability for projected uses, and air temperature-stream temperature relationships. NIDIS works with states, communities, and agencies to enable development of risk assessment tools based on past events and forecasted droughts.

Q2. In your testimony, you discuss the need to develop adaptive measures to increase the available water supply or use water more efficiently to address threats to the water supply. I have introduced legislation that would encourage research into treating water derived from underground when extracting oil and gas to utilize it for other purposes. Is this the type of adaptive measure you would encourage us to explore?

A2. NOAA does not have an established position on H.R. 2339, but as a researcher on adaptation strategies, my answer would be: Yes. Sixty-five percent of the produced water generated in the U.S. (over one trillion gallons in 1993) is injected back into the producing formation, 30 percent is injected into deep saline formations, and five percent is discharged to surface waters. The produced water typically contains a mix of contaminants, including high saline levels. Standards of treatment for reuse are set by industry technical organizations such as the American Petroleum Institute (API) and the Oil Producers Association. The API has listed carbon absorption, air stripping, filtration, biological treatment, ultraviolet light, and chemical oxidation as potential treatments.

Standards for produced water disposal are determined by State, national, and international regulatory bodies. Key questions to be addressed include:

(1) What technologies exist to treat produced water to disposal or re-injection standards and what water quality standards must be met?

(2) How much would this cost?

Q3. Several reports, and some of the witnesses who testified at the hearing, have called for the creation of a National Climate Service. Would NIDIS be a good platform to emulate for the collection, organization and dissemination of all climate information and products? Or does the shear volume of climate information require a larger or more complex set up? Would NIDIS be integrated into such a service, or would it stay a separate entity?

A3. The NIDIS structure could provide guidance for the development of a National Climate Service. NOAA and our partner agencies are still in the process of developing an operational definition of "climate" services (i.e., examining how these services are different from "weather" services) and completing its analysis of what is lacking in the way such services are currently delivered throughout the Federal Government. Any National Climate Service would likely focus on a broader class of issues and information users, and could provide an umbrella for programs such as NIDIS by developing a cross-agency partnership to sustain comprehensive observations and monitoring systems, and provide for state-of-the-art research, modeling, predictions, and projections.

NIDIS could function within this broader system, and would continue to inform collaborative coordination and planning and act to identify innovations in drought preparedness for transferability to other parts of the country. NIDIS is in essence a decision support system; its main function is to develop, deliver, and communicate drought information, forecasts impacts, information for preparedness and risk reduction (or more generally valued climate services).

Q4. The National Science and Technology Council's Subcommittee on Water Availability and Quality, or SWAQ, released a report last year about science and tech-

nology requirements for water availability and quality. This report was a follow-up to their 2004 report. In both papers, the Subcommittee strongly *recommends that the U.S. develop a standardized and integrated measuring measures and create an account of its water. Although they suggest that some agencies have been involved in bringing this project together, would NIDIS be an appropriate place for the dissemination of this type of data? Or should it be housed in a sister program, that would feed information into and receive information from NIDIS, but be separate for separate management and decision-making purposes?*

A4. NIDIS should not be tasked with the full collection and archiving of such data but as a recipient or client to help shape the collection by advising on priorities (e.g., key areas for monitoring improvements) through its focus on drought response and risk reduction; a separate program working with NIDIS would be most appropriate.

NIDIS would be a good coordinator for integrated information, acting as a clearinghouse for information that feeds into specific early warning and decision support systems, and would provide a catalyst for drought mitigation practice. Data on water availability and quality would feed into NIDIS' early warning design.

Q5. Would you give an example of what Federal, State and non-governmental monitoring programs feed into NIDIS? How much do these monitoring efforts cost? Are there gaps in the monitoring system? If so, where do they occur?

A5. Given its preliminary status, main inputs into NIDIS so far are from federal agencies, such as NOAA, the U.S. Geological Survey (e.g., Stream Gauge Network), and the U.S. Department of Agriculture (e.g., Soil Climate Analysis Network). In addition, recent efforts have begun to include water and reservoir levels in partnership with U.S. Army Corps of Engineers, the Bureau of Reclamation, and states. In June 2008, NIDIS convened a national workshop on the status of drought early warning system across the U.S. States, private sector (energy water, agriculture) and Tribal representatives at the conference agreed to engage with NIDIS on data provision and integration. These are actively being pursued for inclusion (with appropriate data standards) into the U.S. Drought Portal, and are important for supplementing and improving the U.S. Drought Monitor in locations with pilot early warning systems in development.

The original recommendations for NIDIS (in the 2004 Western Governors' Association report) included supporting county-level monitoring, because droughts are declared at the county level. At that recommended density, there are still gaps in our monitoring network. NOAA is addressing these through the Historical Climate Network Modernization and the Cooperative Observer Program (COOP) network.

The needs for improved monitoring are in groundwater quantity and quality, soil moisture, high elevation snowpack runoff timing, and ecosystems. These characteristics are important in modulating streamflow. Data on these variables are not yet collected using standardized approaches at similar spatial or temporal scales, and the long-term viability of the data collection efforts is uncertain. Recent initiatives such as the National Environmental Status and Trends Indicators action plan and pilot activity would provide guidance on assimilating and archiving existing data. A comprehensive groundwater-level network may be needed to assess groundwater-level changes, the data from which should be easily accessible in real time.

Soil moisture in the first one or two meters below the ground surface regulates land-surface energy and moisture exchanges with the atmosphere, and plays a key role in flood and drought genesis and maintenance. Soil moisture deficit partially regulates plant transpiration and, consequently, constitutes an effective diagnostic. Active and passive microwave data from polar orbiting satellites or reconnaissance airplanes provide some estimates of surface soil moisture with continuous spatial coverage. However, these approaches are limited in that they only measure soil moisture within the first few centimeters of the soil surface, and they are reliable only when vegetation cover is sparse or absent. NIDIS recently (February 2008) convened a small workshop to assess the reliability of such sensors for soil moisture measurements.

The lack of long-term soil moisture data over vast areas of the United States affects how well soil moisture is incorporated into hydrologic models for watersheds or large regions. NIDIS, in collaboration with the National Climatic Data Center (and with USDA Natural Resources Conservation Service (NRCS)'s Soil Climate Analysis Network to complement their network), is in the process of deploying over 100 soil moisture sites around the country. Even a few long-term monitoring networks of soil moisture would substantially decrease the uncertainty in predicting processes that are critically dependent on soil moisture levels (like flow, water chemistry, and plant response). Similarly, the uncertainty of predictive models for managing water supply in western streams reflects the density of stream flow and rainfall monitoring networks, because the amount and the quality of data in areas characterized by high spatial variability in precipitation determine the reliability and precision of such models. Inclusion of nonagricultural areas, along with a long-term commitment for high quality data will assist water resources analysis on climatic and regional scales.

The U.S. Geological Survey has the beginnings of a ground-water network in the Ground Water Climate Response Network. This network provides ground-water level data from 167 of the 366 Climate Divisions in the United States and Puerto Rico. About half of the data in this network are accessible in real time.

Q6. Recognizing that this is a fairly new effort, how successful has NIDIS been in predicting expected drought areas thus far? What resources or assistance would you need to improve your ability to make such predictions?

A6. Historically, skill in predicting drought has not been very high. However, there are climate regimes in which predictability of seasonal drought has improved, particularly during El Niño or La Niña conditions. NOAA's Climate Prediction Center has shown demonstrable skill in predicting drought at seasonal time scales, during El Niño or La Niña events (and in particular during the winter). However, El Niño and La Niña conditions are only active about half the time. Prediction of multi-season and multi-year drought has not been successful. NIDIS has been successful in developing a nascent system for monitoring the climate and identifying potential drought conditions as they evolve, but additional time will be required before we see great improvement in drought prediction.

Predictions could be improved through increased focus on multi-season and multi-year drought prediction capabilities, through focused research on drought prediction. In the interim, some significant improvements in prediction are possible through improved monitoring of all the components of the climate system related to drought. These components include estimates of rain and snow, snowpack depth and liquid water equivalent, as well as estimates of the soil characteristics, ground water, and vegetation. Improved monitoring requires better integration of data from observation systems that already exist (computers to store, merge, analyze and provide the data) as well as installation of additional observation equipments (e.g., *in situ* instruments and satellite sensors) where needed. Monitoring of the physical climate system must also be augmented by estimates of the demand for water resources imposed by agriculture, industry, and population shifts and growth. A "drought" is not felt until available water is insufficient to meet specific needs.

Q7. Have you received all the necessary information from State and local partners? What about federal agencies? What barriers have you encountered?

A7. Agencies and states have been very responsive by providing information and data sets to be linked to NIDIS activities.

As conceived in NIDIS, coordination includes:

- Establishment of a national research agenda,
- Efforts targeted at emerging problems, (e.g., as in the Southeast in 2007),
- Sustained attention on identifying monitoring and forecasting gaps, and
- A competitive grants and contracts program to addresses national research needs not addressed by specific agency missions.

Coordination can facilitate technology transfer from research organizations to user communities. However, agencies must maintain a high level of leadership, accountability and autonomy.

In the next few years NIDIS will begin to tailor the Drought Portal for multi-state watersheds. This will provide a mechanism for more fully understanding the barriers to integrating State and local partner data and information for early warning information needs.

Q8. In an ideal world, how far into the future would your predictions need to be able to reach to fully prepare or mitigate the effects of an impending drought?

A8. The time it takes to fully prepare or mitigate the effects of an impending drought varies depending on the specific problem(s) being addressed. For agriculture, predictions are required for three to six months ahead of an impending drought event. However, the sustainability of economic activities and environmental goals requires warnings of droughts onset, areal extent, and potential duration (a season, a year or a decade or longer), and potential impacts on each of these time scales. This is especially the case in regards to urban water needs in the west, forest health, low flow thresholds for meeting interbasin transfer requirements, energy plant siting, and environmental flows.

Q9. How well known is the drought portal? Does the website collect statistics on hits per month or types of users it is getting? What can be done to ensure that this portal becomes a well-known information source with farmers and local water managers as it is with universities and State governments?

A9. NIDIS is actively engaging all of its partnering agencies to help educate the public on the U.S. Drought Portal (USDP). Examples include the U.S. Department of Agriculture, which has agricultural extension agents in nearly every county in the Nation, and NOAA's National Weather Service, which has local weather experts in 135 offices around the country.

The USDP will provide education and outreach materials, publicly available, which will be geared toward local agency representatives engaging constituents at the local level and touting the benefits of USDP use. In addition, representatives of NIDIS are participating in numerous workshops, forums, and meetings around the country in order to communicate what is available on the USDP, to encourage its use and develop its role in proactive drought risk management, and to receive feedback on its content.

The USDP keeps track of web hits for users entering the Portal. Currently USDP receives 40,000 hits per month. Software is currently being developed to allow tracking of hits to web pages hosted as "portlets" within the USDP. The USDP cannot track its users by type at this time.

Q10. Have the droughts we have been experiencing strained our ability to meet international obligations regarding water resources?

A10. Please see the response to question 11 (below) for a combined response.

Q11. The U.S. shares not only its borders with Canada and Mexico, but it also shares watersheds. With respect to this geographical reality, how has U.S. water policy, particularly in the western half of the country, affected relations with our neighbors?

A11. These are critical concerns and have been broached in numerous constituent meetings and other public fora. Canada and Mexico are actively seeking to complement and link to NIDIS with their own information, since droughts cross these political boundaries.

The U.S. has treaties with Mexico over both the Rio Grande River and the Colorado River. The Rio Grande agreement, resulting from a 1994 treaty, stipulates that Mexico must allow a certain amount of water from the Rio Grande to reach the U.S. In return, the U.S. must provide Mexico with 1.5 million acre feet a year from the Colorado River. These commitments have not entirely been met on either side. Drought and growing economic development have affected the ability of both countries to meet their international commitments. Unfortunately, the treaty provisions for allocating shortages during a drought, and in fact what legally constitutes "exceptional drought," are ambiguous and no provisions in the treaty cover the possibility of a climatic change that could alter the long-term availability of water in the river. Research of the U.S. Climate Change Science Program (*Synthesis and Assessment Report* (SAP) 3.3, pp. 22–23; SAP 4.3, pp. 121–150) suggests that even modest climatic changes might have serious and dramatic impacts on the Colorado River flow. Critical concerns include changes in: (1) water availability from altered precipitation patterns or higher evaporative losses due to higher temperatures; (2) the seasonality of precipitation and runoff; (3) flooding or drought frequencies; and (4) the demand for and the supply of irrigation water for agriculture.

Changing water demands in the United States, combined with climate change, could seriously compromise hydroelectric power generation and other uses in Canada, especially in drier regions in southern areas of the Canadian part of the basin (e.g., Okanagan and Osoyoos lakes). There are several (at least 12) large bilateral drainage basins, or groups of small basins, for which the International Joint Commission has responsibility under the Boundary Waters Treaty of 1909. Many of these basins, and their sub-basins, have water-sharing agreements where rivers flow north or south across the border. In some basins, pollution control agreements are also in place to protect ecosystems and water quality (e.g., Great Lakes–St. Lawrence River). Climate affects both the quantity and quality of these waters, and the ability of one country to meet its present obligations to the other.

Thirty to thirty-five percent of the water in the Columbia River basin originates in Canada yet only 15 percent of the basin lies in Canada. On the Columbia River, the predicted trend towards greater flow in winter and less flow in spring is expected to continue affecting salmon migration as well as hydropower.

Increased evaporation (especially during winter) is expected due to warmer temperatures, which would lower Great Lakes water levels and reduce the flow of rivers in the system, including the St. Lawrence. In the scenario described above, adverse impacts on shipping, hydroelectric power generation, and water quality are projected. A recent amendment to the International Boundary Waters Treaty Act by Canada prohibits bulk-water removals and diversions from border and trans-border waters but does not deal with attempts to divert internal Canadian waters, an issue that a number of provinces have similarly addressed. There is also a risk that these disagreements will spill over into economic policy, trade agreements, and security arrangements.

International obligations have been met, but not without contention during drought situations. However, given trends in the Great Lakes, the Colorado, the Rio Grande and the Columbia Rivers, further strains are foreseeable in the near future and will be exacerbated during conditions of exceptional drought.

Questions submitted by Representative Adrian Smith

Q1. Nebraska's panhandle has experienced nearly a decade of severe drought. What steps or technologies are needed to prepare for and mitigate long-term drought?

A1. Mitigation options will be different for agricultural producers, municipal water suppliers, city and county land use planners, environmental interests, and State agencies, but ideally, all should be working in coordination. NIDIS works very closely with the National Drought Mitigation Center (NDMC) at the University of Nebraska, Lincoln. The NDMC director co-chairs the interagency and interstate NIDIS Implementation Team with the NIDIS director. The following are collaborative activities led by the NDMC using, in part, funds provided by NOAA Grants:

Mitigation measures already underway:

(1) Nebraska Rural Response Hotline: Interchurch Ministries of Nebraska, an interdenominational non-profit organization based in Lincoln, spearheaded the establishment of the Nebraska Rural Response Hotline during the farm crisis of the 1980s. The Hotline has grown steadily in both the number of calls it receives and in the resources and partnerships available to help callers, as responders listened to needs and found ways to meet them. In 2007 it took nearly 5,000 calls. Among the ways they assist are listening to individual farmers and ranchers to help identify options in a crisis, providing vouchers for counseling and referrals to other professional services, and organizing regular workshops around the state focusing on needs such as financial and legal planning. Drought is one of many stressors facing the agricultural community.
(2) Nebraska Health & Human Services is working with municipalities to reduce the vulnerability of their water supplies.
(3) Increased soil moisture monitoring.

Planned mitigation measures:

Nebraska has a drought mitigation plan that has identified more strategies, some of which will require additional funding, either for agency staff time or for assistance or incentives for farmers and ranchers. The planned mitigation activities are included in the appendices of the state's drought plan (*http://carc.agr.ne.gov/docs/NebraskaDrought.pdf*).

Some agricultural policies may lead to hazard-resistance or to practices that increase vulnerability. This is of increasing importance because of the disruptions in food security that may come about as a result of climate change (irrespective of what drives that change).

Q2. What are your views on balancing the demand for various uses of water, including, drinking water; agricultural uses; energy generation; habitat, especially for endangered species; and recreation?

A2. In addition to water supply planning, both urban and rural land-use practices can either contribute to drought vulnerability or to drought resistance. In most cases, practices that build resilience to drought can also build resilience to other possible threats, including wildfires, energy production reliability, and economic down-turns. In general, practices that lead to increased soil fertility, redundancy in natural systems, and increased biodiversity build resilience. Practices that encourage more risk-taking and deplete natural resources faster than they are replenished increase vulnerability.

Recreation forms the backbone of the economy for many western states. The impacts of impending changes are anticipated to be felt by the environment sector, and these will impact the environmental services that provide tourism, recreational and other economic generators for rural communities. Environmental requirements for water are actually minuscule compared with municipal, industry, and agricultural needs. In some regions environmental needs are less than 10 percent of supply with agriculture, household, and industrial needs accounting for the rest. The economic benefits of environmental services outweigh the costs of their water needs and as such, efficiency in the other three sectors will provide a large economic and social benefit. Multi-objective planning is a logical approach for developing strategies to pursue complex goals.

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