Winter 2011

SUSTAINABILITY OF WATER RESOURCES

The BRIDGE

LINKING ENGINEERING AND SOCIETY

NATIONAL ACADEMY OF ENGINEERING
OF THE NATIONAL ACADEMIES

Promoting the technological welfare of the nation by marshalling the knowledge and insights of eminent members of the engineering profession.

The BRIDGE

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Editor's Note

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Editor's Note

Stephen D. Parker

Protecting Our Most Precious Natural Resource

Global challenges related to water, a precious and limited resource, will become increasingly difficult over the coming decades. These challenges encompass: providing adequate amounts of clean water; controlling polluted runoff and groundwater; maintaining healthy hydro-ecosystems; managing the risks of floods and droughts; addressing competition for water among users; and maintaining aging water infrastructure, to name just a few.

The articles in this issue of *The Bridge* are based on presentations at a convocation of professional engineering societies hosted by the National Academy of Engineering (NAE) in Washington, D.C., on May 16, 2011. Approximately 100 leading engineers from industry, academia, and government, representing about 25 engineering societies, participated in a special session on water, a topic they had identified as critical to the nation and to engineering.

In opening remarks, NAE President **Charles Vest** reminded us that NAE had twice before identified water issues as a "grand challenge" for the future, not only for the United States but for the world. Indeed, *The Bridge* has previously featured a variety of water science and technology topics in "special issues" (most recently in fall 2008).

The availability and quality of water are greatly impacted by changes in land use and climate. Water is essential to life, as well as to economic productivity, and how its quantity and quality are managed affects the world population in many ways. Indeed, water resources and human activities are inextricably linked.

In organizing the convocation and preparing this issue of *The Bridge*, I turned to friends in the National Research Council (NRC) Water Science and Technology Board (*http://dels.nas.edu/wstb*) network to address topics of current and societal relevance. We did not attempt to be all-inclusive, nor did we focus on narrow technical topics. Instead, we selected topics that are interesting, complex, current, and require or reflect collaboration among engineers and physical, life, and social scientists.

The first article is by my colleague at the NRC, Jeffrey Jacobs, a geographer and water policy expert, who writes about water management in the Colorado River basin. Water from the Colorado, which is distributed throughout the southwestern United States, is critical to supporting life, the economy, and aquatic ecosystems throughout the region. Jeff's article covers a broad range of topics, from the significance of the latest developments in paleo-hydrologic science to water conservation. As he observes, even though the long-term availability of Colorado River water is limited and likely to decrease in the future, the region is concurrently experiencing rapid population growth and increased water demand.

Jeff's paper is followed by a contribution from NAE member **David Dzombak**, an environmental engineer whose research at Carnegie Mellon University is focused on water quality. Dave describes the challenges of understanding and controlling chemical nutrients, principally nitrogen and phosphorus, in our aquatic systems. He also discusses diffuse, "nonpoint" pollution, perhaps the nation's principal water quality challenge. His focus is on the impacts of, and efforts to control, nutrient inputs to the Chesapeake Bay and northern Gulf of Mexico.

Next, Professor Rutherford Platt, Emeritus Professor of Geography at the University of Massachusetts, Amherst, summarizes pathbreaking efforts, from 1840 to the present, by New York City and Metropolitan Boston to (1) develop large-scale hinterland, gravity-flow water sources; (2) reduce per capita demand since the 1980s to stay within the safe yields of existing water sources; and (3) implement a variety of nonstructural watershed-management measures to qualify for "filtration avoidance determinations" issued by the U.S. Environmental Protection Administration under the Safe Drinking Water Act.

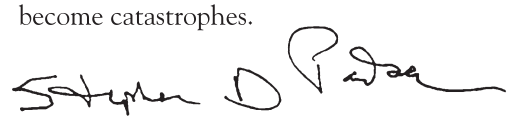
Mohammad Habibian, an environmental engineer at the Washington Suburban Sanitary Commission (WSSC), focuses on the challenges facing large urban water and wastewater utilities. WSSC is a progressive, not-for-profit utility that serves 1.8 million customers in the two Maryland counties adjacent to the District of Columbia. Habibian describes critical challenges at every step of the water-wastewater cycle from the perspectives of industry and sustainability. He covers source water quantity and quality, regulatory and treatment issues, contaminants of emerging concern, infrastructure maintenance, funding, communication in this era of social networking, and the need for collective wisdom and cooperation in addressing water issues.

To wrap up, NAE member **Gerald Galloway**, an engineer, geographer, and water policy expert at the University of Maryland, addresses a potpourri of water policy challenges facing the nation. He points out that climate change, on top of population growth and the growing need for infrastructure renewal and new development, will increase the stress on our water resources. He argues for national approaches to water governance and decries the absence of comprehensive national water policies that could enable integrated management of water resources. Gerry calls on the water community to embark on a campaign to improve communication with decision makers on all levels.

Taken together, the articles in this issue reinforce ideas that have been evident to water resource professionals for at least a decade. First, water resource challenges are directly proportional to population growth, changes in land use, and climate change. The challenges are most apparent in areas where competition for water resources is greatest.

Second, even though the most pressing water issues vary widely with local conditions, an increasing number of regions in the United States are confronted with critical issues that must be addressed to ensure the future well-being of our people and our environment.

Finally, no area in the United States is likely to face a sudden water crisis. Instead, crises will result from the accumulation of water resource problems that have been insufficiently dealt with over time. Lessons learned in one region about managing these problems will be increasingly useful to other regions as they strive to anticipate and respond to water problems before they become catastrophes.



Stephen D. Parker
Senior Director
Water Science and Technology Board
National Research Council

Ron Latanision Named New Editor-in-Chief of *The Bridge*


Dr. Ronald M. Latanision

With the publication of this issue, NAE welcomes Dr. **Ronald M. Latanision** as the new editor-in-chief of *The Bridge*. Dr. Latanision replaces former editor-in-chief and NAE Foreign Secretary George Bugliarello, who passed away in February 2011.

Dr. Latanision is currently corporate vice president at Exponent, an engineering consulting firm. Prior to joining Exponent in 2002, he was director of the H.H. Uhlig Corrosion Laboratory in the Department of Materials Science and Engineering at the Massachusetts Institute of Technology (MIT), where he held joint faculty appointments in the Department of Materials Science and Engineering and the Department of Nuclear Engineering. Dr. Latanision was a member of the MIT faculty from 1974 to 2002.

A member of NAE since 1985, Dr. Latanision has served on more than 20 National Research Council and NAE study committees. He has also served as a science advisor to the U.S. House of Representatives Committee on Science and Technology and a member of the Advisory Committee to the Massachusetts Office of Science and Technology. In June 2002, President George W. Bush appointed him a member of the U.S. Nuclear Waste Technical Review Board, a position he still holds under President Barack Obama.

The Bridge publishes articles on engineering research, education, and practice; science and technology policy; and the interface between engineering and technology and society. The intent is to stimulate debate and dialogue among NAE members and in the broader outside community of policy makers, educators, business leaders, and other interested individuals. *The Bridge* relies on its editor, a network of *ad hoc* advisors, and NAE staff to identify potential topics and authors and to review and select articles for publication. *The Bridge* has a quarterly distribution of more than 6,500, including NAE members, members of Congress, libraries, universities, and interested individuals. Past issues can be found at *http://www.nae.edu/Publications/Bridge.aspx*.

Studies of Colorado River flows have called into question traditional assumptions about long-term mean flows and availability.

The Sustainability of Water Resources in the Colorado River Basin

Jeffrey Jacobs

Jeffrey Jacobs is a scholar with the National Research Council Water Science and Technology Board.

The hydrologic limits of U.S. water supply systems, conflicts over shared water resources, and drought-induced water shortages are increasingly prominent topics of conversation, not only in the water science and engineering communities, but also in media and public policy discussions. Examples of recent books on these topics include *Unquenchable: America's Water Crisis and What To Do About It* (Glennon, 2009) and *Running Out of Water: The Looming Crisis and Solutions to Conserve Our Most Precious Resource* (Rogers and Leal, 2010). Whether or not the nation is indeed facing a water "crisis" may be open to debate, but there is a growing sense that providing reliable water and related services to a full range of diverse users, especially during periods of drought, is becoming increasingly difficult.

Supply, demand, and drought are prominent issues throughout the Colorado River basin. In 2005, the National Research Council (NRC) convened a panel of experts to review and evaluate the scientific database on the climate and hydrology of the Colorado River basin and the long-term implications of hydro-climate variability for operating water projects and meeting obligations for water delivery. This article provides a summary of findings and recommendations from the NRC report (NRC, 2007) and some observations about long-term prospects for providing water supplies in the rapidly growing southwest region of the country.

FIGURE 1 Map of the Colorado River basin. Source: NRC, 2007.

The Colorado River and Basin

The headwaters of the Colorado River are in Rocky Mountain National Park northwest of Denver (Figure 1). The river flows westward through Glenwood Canyon toward Grand Junction, Colorado, where it is joined by the Gunnison River. Once it enters Utah, the Colorado is joined by the Green River, a major tributary that drains parts of Colorado, Utah, and Wyoming. Just before it flows into Lake Powell, the Colorado is joined by the San Juan River, which drains the San Juan Mountains and the Four Corners region. Fifteen miles below Glen Canyon Dam, the river passes Lees Ferry, Arizona—a river gauging station that marks the legal demarcation point between the upper and lower Colorado River basin.

From there, the river flows through Grand Canyon National Park and then is joined by the Virgin River just before it flows into Lake Mead. Below Hoover Dam, the center of the Colorado streambed marks the boundary between Arizona and California. The Colorado then enters Mexico on its way to the Gulf of California. In Mexico, however, flows are often fully consumed by irrigated agriculture and, in some years, the river does not reach the gulf.

The river basin drainage area covers portions of seven U.S. states—Colorado, New Mexico, Utah, and Wyoming in the upper basin and Arizona, California, and Nevada in the lower basin. The Colorado River is primarily a snowmelt-driven hydrologic system. Roughly 90 percent of the river's flow is derived from snowmelt from precipitation in three upper basin states, Colorado, Utah, and Wyoming. However, most of the demand and use of the flows are in the lower basin states, Arizona, California, and Nevada (Hundley, 1975).

Based on measurements at Lees Ferry, the mean flow of the Colorado River is 15 million acre-feet (MAF) per year[1]—a much smaller volume of water than in other major U.S. river systems, such as the Columbia or Mississippi rivers. However, the Colorado flows through what author Wallace Stegner described as "the dry core" of the arid western United States and is the largest source of surface water in this very large region. Roughly 30 million people depend

[1] An acre-foot is the volume of water that covers an acre to a depth of one foot. It is roughly equivalent to 326,000 gallons.

on the Colorado for drinking water, and its waters are essential to farmers, tribes, industries, anglers, power distributors, and rafters.

Drought, Stream-flow, and Storage in the Early 2000s

Large variability in flow, both seasonal and inter-annual, is a prominent feature of the Colorado River. As Figure 2 shows, annual flows often depart substantially from 15 MAF/yr. The figure also shows some markedly wet and markedly dry periods during the 20th century. For example, there was a very wet period at the beginning of the century, a drought in 1976–1977, and El Niño conditions (which generally entail heavy winter precipitation in much of the western United States) in the early 1980s.

Figure 2 also reflects pronounced drought conditions throughout the upper basin in the early 2000s, especially in the (water) years[2] of 2000–2004 when inflows into Lake Powell were well below 15 MAF/yr; in water year 2002, for example, the flow was more than 50 percent below average (Fulp, 2005). These low-flow conditions had many hydrologic effects, including a sharp decrease in the amount of water stored in Lake Powell, which dropped to its lowest level since 1969 when the reservoir was initially filling. Water storage in Lake Mead also dropped to a level not experienced since the 1960s (Fulp, 2005).

Lake Powell and Lake Mead, which together represent roughly 90 percent of the surface water storage capacity in the Colorado River basin, are crucial to ensuring that legal water-delivery obligations are met during periods of drought. The most prominent of these obligations, which is enshrined in the Colorado River Compact of 1922, calls for the upper basin states to provide an aggregate flow of 75 MAF to the lower basin states over any 10-year period. Thus, a sharp drop in Lake Powell water storage is a legal, scientific, and public policy matter of the utmost concern and was an impetus for the NRC study and report.

Population Growth and Increasing Water Demands

A reliable water supply is a function of water-supply issues discussed above and water demand. Discussions during the NRC study with state water managers revealed that growing water demand was as important as drought and variability in the water supply. In the 1990s, the states in the Colorado River basin had the highest rates of population growth (by percentage) in the country. The four fastest growing states were Nevada,

[2] A "water year" begins on October 1 and ends on September 30 of the following year.

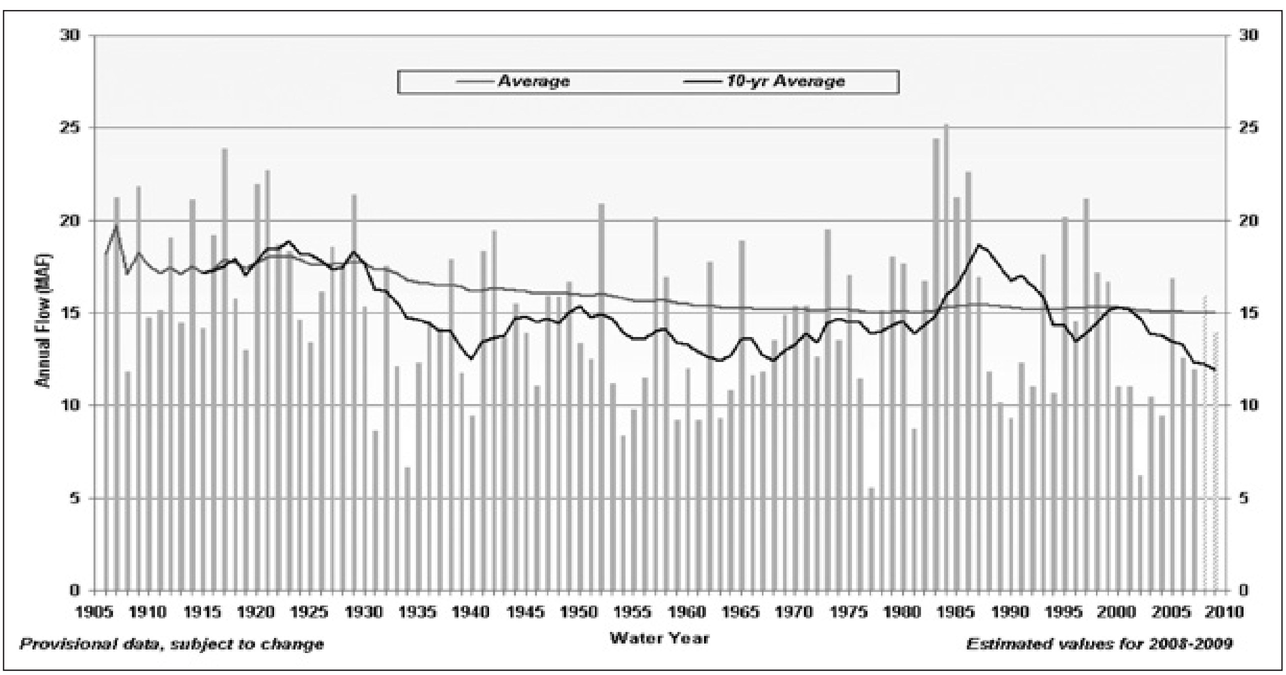


FIGURE 2 Natural Colorado River flows at Lees Ferry, Arizona. Source: Jerla et al., 2011.

Arizona, Colorado, and Utah. In terms of absolute growth, California added more than 4 million people (a 13.8 percent increase). The fastest growing major U.S. metropolitan area was Las Vegas, which increased at the remarkable rate of 83.3 percent.

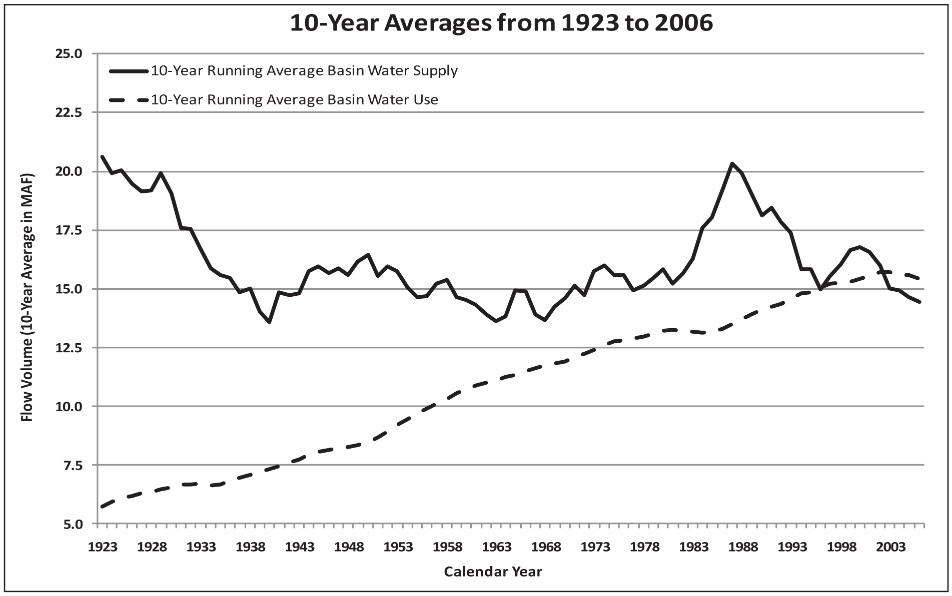


FIGURE 3 Colorado River basin water supply and use, 1923–2006. Source: U.S. Bureau of Reclamation, 2011.

Discussions about population growth and the limits of western water supplies—or lack thereof, depending on one's point of view—date back more than 100 years. Relationships between water supply and demand are complex, and trends can change in either or both, sometimes rapidly. Many water conservation programs in the Colorado River basin have successfully reduced per capita water demand and improved water efficiency. At the same time, as populations continue to grow, attendant increases in water demand eventually negate those savings.

Figure 3 shows the effects of population growth on water supplies in the southwestern United States. Population growth during the 20th century has steadily eroded the historic cushion between the region's water supply and water demand. Thus, for the first time, aggregate water demand has exceeded available water supplies in some years.

Regional Climate Trends

Because Colorado River flows are derived primarily from snowmelt in high elevations in the upper basin, precipitation in the lower basin, which can have significant local impacts, does not affect flows in the large upstream tributaries or water storage in Lakes Powell and Mead. Thus, changes in winter precipitation and temperature patterns in the upper Colorado River basin are of great concern in terms of long-term water availability.

The 2007 NRC report includes reviews of 20th century precipitation and temperature trends in the Colorado River basin. Although precipitation records for the upper basin show great variability over that period, the committee concluded that "there is no significant trend in inter-annual variability of precipitation over the past 110 years."

However, a review of temperature data for the entire river basin shows that "since the late 1970s, the Colorado River region has exhibited a steady upward trend in surface temperature. The most recent 11-year average exceeds any previous values in the over 100 years of instrumental records" (NRC, 2007). The report goes on to say that "the Colorado River basin has warmed more than any [other] region of the United States . . . This warming is well grounded in measured climatic data, corroborated by independent data sets, and widely recognized by climate scientists throughout the West."

In addition to instrumental records of past climate data, the report includes reviews and summaries of model-based climate forecasts based on studies of precipitation and temperature futures across the basin. An early study in 1979 estimated that a temperature increase of 2°C would, by itself, result in a decrease in mean Colorado River flows of 29 percent (Stockton and Boggess, 1979). Since then, numerous other climate modeling studies have also concluded that modest temperature increases in the upper basin could result in marked reductions in stream-flow and inflows into Lake Powell (e.g., Christensen et al., 2004).

The NRC committee came to the following conclusions:

> Collectively, the body of research on prospective future changes in Colorado River flows points to a future in

which warmer conditions across the region are likely to contribute to reductions in snowpack, an earlier peak in spring snowmelt, higher rates of evapotranspiration, reduced late spring and summer flows, and reductions in annual runoff and stream-flow.

Reconstructions of Stream-flow Based on Tree Rings

The NRC committee also reviewed studies reconstructing long-term (on the order of several centuries) stream-flow based on the annual growth rings of coniferous trees (pines and firs) in the region. Coniferous trees growing at lower elevations on well-drained slopes with southern exposures are particularly well suited for these reconstructions (Woodhouse et al., 2006). Dendrochronologists correlated annual increments of tree-ring growth in pines and firs with hydroclimatic variability, including reconstructed historic river flows.

The first tree-ring based reconstruction of Colorado River flow was published in 1976 (Stockton and Jacoby, 1976), and several more followed. An example of one reconstruction by Woodhouse and colleagues (2006) is shown in Figure 4. Based on this study and other tree-ring based reconstructions of past Colorado River flows, several conclusions may be drawn (NRC, 2007; Woodhouse et al., 2006):

1. Long-term Colorado River mean flow calculated over hundreds of years is significantly less than the 15 MAF/yr figure based on 20th century flows recorded at Lees Ferry.
2. The early decades of the 20th century, one of the wettest periods in the entire reconstruction, was characterized by high-flow conditions.
3. The reconstructed records reveal that droughts prior to the 20th century lasted much longer than droughts in the early 2000s.

Relatively wet conditions across the upper basin in the early 20th century turned out to have legal implications of great historical importance. The Colorado River Compact—the cornerstone legislation for water-management treaties, acts, allocations, and contracts—was signed in 1922. At that time, based on flow data collected during that wet period by the U.S. Bureau of Reclamation, it was assumed that the mean annual average flow of the Colorado River was 16.4 MAF/yr (Hundley, 1986), and the division of the Colorado's flows between the upper basin states and lower basin states, with 7.5 MAF/yr for each, was based on this assumption.

Over time, and with additional data from both Lees Ferry and reconstructed flow data based on tree-ring analyses, it has become clear that the average annual flow is less than 16.4 MAF/yr. This hydrological reality has sobering implications for areas that plan to base future economic development on water rights, especially areas in the upper basin that do not have high priority rights under the Colorado River Compact and other water-use and sharing agreements. The effects on these areas could be exacerbated if future changes in climate further reduce Colorado River flows (Kenney, 2010).

Options for Augmenting Water Supplies

In considering limited water supplies in the Colorado River basin and possible short- or long-term reductions in water availability, it is natural to consider how water

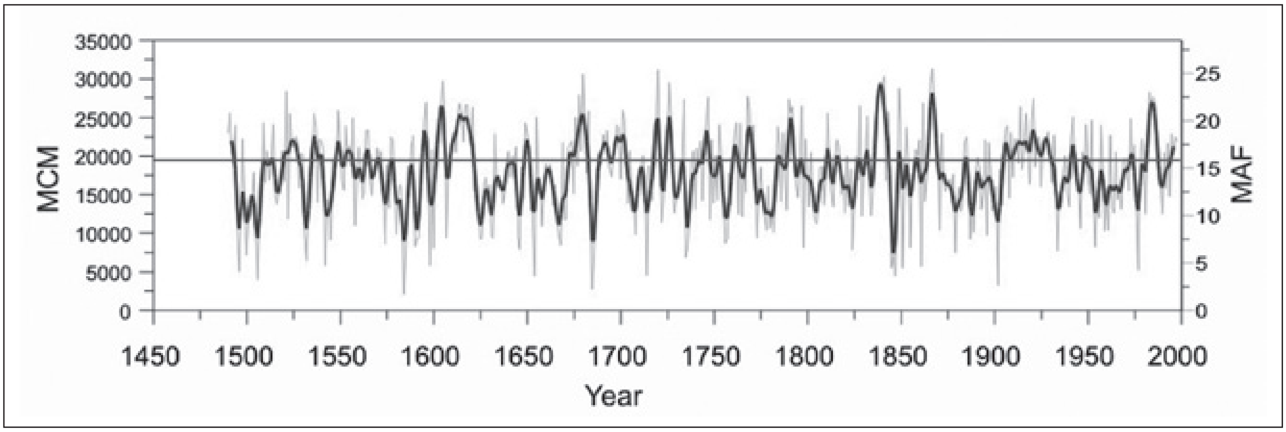


FIGURE 4 Reconstruction of Colorado River flows at Lees Ferry, Arizona, 1450–1997. The lighter line represents annual values; the darker line represents a five-year moving average. Source: Woodhouse et al., 2006. Copyright 2006 American Geophysical Union.

supplies might be augmented. The traditional approach was by constructing multi-purpose dams and storage reservoirs. However, for a number of reasons, including costs and potential environmental impacts, prospects for constructing large-scale water projects today are much less likely than in the past.

As a result, water managers are considering other strategies, some novel and some that have been the subject of experiments for decades. Alternatives include weather modification (i.e., seeding clouds with various agents, such as silver iodine or dry ice, to induce or enhance precipitation), desalination, removal of water-consuming plant species (e.g., tamarisk), agricultural and urban water conservation, changes in water pricing policies and rate structures, wider use of reclaimed wastewater, and off-stream water banking (i.e., storing water underground in aquifers for later use).

The latter option, off-stream water banking, is a promising technique for improving the efficiency of water management. The state of Arizona established the Arizona Water Banking Authority in 1996 to store Colorado River water by recharging groundwater. Arizona, California, and Nevada have also engaged in creative interstate agreements whereby one state banks groundwater in another state for withdrawal at a future date.

Although lessons and results tend to be site-specific, many conservation programs in the region, such as those that emphasize new landscaping techniques and technologies, have resulted in reductions in urban water demand. The U.S. Bureau of Reclamation, state and municipal water agencies, the private sector, and non-governmental entities have all promoted and participated in these efforts, which will surely continue to be refined and improved.

Another means by which urban water supplies might be augmented is via the sale, transfer, or lease of water rights from agricultural users to growing urban areas. Historically, the majority of water diversions have been for the purpose of irrigation, and water diverted to irrigated agriculture in the western United States represents a considerable supply.

Today, agriculture-urban water transfers are taking place throughout the Colorado River basin, including in Denver, Las Vegas, and Phoenix. In strictly monetary terms, these transactions often represent "win-win" situations for buyers and sellers, as water typically shifts from lower value agricultural uses to higher value urban uses.

However, these transactions are not without costs and limitations. For example, the direct effects associated with water rights moving away from agriculture include the reduced capability of domestic food production. In addition, such transfers usually entail "third-party" effects beyond those that accrue to buyers and sellers. Examples include reduced agricultural return flows that support riparian ecosystems and reduced business and sales by merchants in agriculture-related sectors (NRC, 1992).

Third-party effects that harm rural communities and valuable ecosystems may well prevent some transfers of water to western cities. Furthermore, even though the amount of water diverted to irrigated agriculture in and near the Colorado River basin is considerable, the volume of agricultural water is finite, so transfers may not be an option at some point in the future.

In short, none of these options resolves the fundamental tension between limited supplies and steadily growing demand, which will inevitably require costly and controversial trade-offs. In addition, the combination of increases in population and water demand also reduces the region's capacity to cope with droughts and water shortages.

Off-stream water banking is a promising technique for improving the efficiency of water management.

Findings and Conclusions

In the late 20th century, there was a strong trend of rising mean temperature in the region. The preponderance of evidence—both instrumental data and projections based on modeling—strongly suggests that warmer temperatures will reduce future Colorado River stream-flow and water supplies. In addition, tree-ring based reconstructions of Colorado River stream-flow have shown that extended droughts are likely to occur. These droughts could be even more severe than the drought of the early and mid-2000s, which resulted in sharp reductions in inflows into Lake Powell and prompted concerns about meeting water-delivery obligations. These studies of Colorado River flows have called into question traditional assumptions about long-term mean flows and availability.

Today, the Colorado River basin continues to be home to the fastest growing states in the nation adding to the strains on limited water supplies. Measures to extend and conserve water supplies, such as conservation programs, changes in landscaping practices and related technologies, aquifer storage, and desalination, have improved water use efficiencies, and agriculture-urban water transfers have increased water supplies available to urban areas. However, the benefits of all of these options are limited. Rapid population growth has already increased aggregate water demand to the point that it exceeds the available water supply in some years.

Future choices for water use will no doubt unfold in complex, perhaps unanticipated, ways, and future warming and droughts may reduce the availability of water resources even further. Current scientific understanding of the river's historical flows and regional droughts, coupled with the potential for future reductions in flows, raises fundamental questions about the sustainability of current population growth and development. Moreover, some existing paradigms and principles that have governed Colorado River water use in the past will undoubtedly have to be adjusted to fit these realities.

References

Christensen, N., A. Wood, N. Viosin, D. Lettenmaier, and R. Palmer. 2004. The effects of climate change on the hydrology and water resources of the Colorado River Basin. Climatic Change 62(1): 337–363.

Fulp, T. 2005. Response of the System to Various Hydrological and Operational Assumptions: Reclamation Modeling Results. University of Colorado Natural Resources Law Center, Twenty-sixth Annual Conference.

Glennon, R. 2009. Unquenchable: America's Water Crisis and What to do About it. Chicago, Ill.: Island Press.

Hundley, N. Jr. 1975. Water and the West: The Colorado River Compact and the Politics of Water in the American West. Berkeley, Calif.: University of California Press.

Hundley, N. Jr. 1986. The West Against Itself: The Colorado River—An Institutional History. In New Courses for the Colorado River: Major Issues for the Next Century, edited by G. Weatherford and F.L. Brown. Albuquerque, N.M.: University of New Mexico Press.

Jerla, C., K. Morino, R. Bark, and T. Fulp. 2011. The Role of Research and Development in Drought Adaptation on the Colorado River Basin. Pp. 423–438 in Water Resources Planning and Management, edited by R.Q. Grafton and K. Hussey. West Nyack, NY: Cambridge University Press.

Kenney, D. 2010. Rethinking the Future of the Colorado River. Draft Interim Report of the Colorado River Governance Initiative, Boulder, Colo.

NRC (National Research Council). 1992. Water Transfers in the West: Efficiency, Equity, and the Environment. Washington, D.C.: National Academy Press.

NRC. 2007. Colorado River Basin Water Management: Evaluating and Adjusting to Hydroclimatic Variability. Washington, D.C.: National Academies Press.

Rogers, P., and S. Leal. 2010. Running out of Water: The Looming Crisis and Solutions to Conserve our Most Precious Resource. New York: Palgrave Macmillan.

Stegner, W. 1954. Beyond the Hundredth Meridian: John Wesley Powell and the Second Opening of the West. Boston, Mass.: Houghton Mifflin.

Stockton, C., and G. Jacoby. 1976. Long-term surface-water supply and streamflow trends in the Upper Colorado River Basin based on tree-ring analyses. Lake Powell Research Project Bulletin 18: 1–70.

Stockton, C., and W. Boggess. 1979. Geohydrological Implications of Climate Change on Water Resources Development. U.S. Army Coastal Engineering Research Center, Fort Belvoir, Va.

U.S. Bureau of Reclamation. 2011. Colorado River Basin Water Supply and Demand Study: Interim Report No. 1. Available online at *http://www.usbr.gov/lc/region/programs/crbstudy/report1.html*.

Woodhouse, C., S. Gray, and D. Meko. 2006. Updated streamflow reconstructions for the Upper Colorado River Basin. Water Resources Research 42(W05415): 16 pp.

Hypoxic conditions in the Chesapeake Bay and northern Gulf of Mexico are examples of the challenges posed by large-scale nonpoint discharges of nutrients.

Nutrient Control in Large-Scale U.S. Watersheds

The Chesapeake Bay and Northern Gulf of Mexico

David A. Dzombak is Walter J. Blenko Sr. University Professor of Environmental Engineering, Carnegie Mellon University, and an NAE member.

David A. Dzombak

Nutrient contamination of surface waters, especially from nitrogen and phosphorus, has long been a major water-quality problem around the world. In the United States, nutrient contamination has created problems in lakes and coastal waters, including Lake Erie, the Chesapeake Bay, the northern Gulf of Mexico, and many other locations.

Although nutrients are necessary to support aquatic ecosystems, excessive amounts can cause serious damage. Nutrients in runoff from municipal, industrial, and agricultural sources stimulate the growth of algae, which, upon dying, are degraded by bacteria that consume oxygen in the water. This can result hypoxia (i.e., low oxygen conditions sometimes referred to as “dead zones”). Because of the large-scale impacts of nutrient contamination, the National Academy of Engineering has identified management of the nitrogen cycle as one of the 14 grand challenges for engineering in the 21st century (NAE, 2011).

This article provides an overview of the nutrient-control challenge for large-scale watersheds, the impacts of nutrient loadings on water quality in the Chesapeake Bay and northern Gulf of Mexico, and efforts to reduce nutrient inputs in these two prominent bodies of water. The technical and regulatory challenges in addressing diffuse, “nonpoint” sources of nutrients are also discussed.

The Clean Water Act and Nonpoint Source Control

The primary source of nutrients—nitrogen and phosphorus—found in lakes, rivers, and coastal waters of the United States and elsewhere around the world is rainfall-induced runoff from agricultural lands to which nutrient compounds have been added as fertilizer. Control of these and other nonpoint sources, especially over large areas, poses technical and administrative challenges. In the United States, the administrative challenges might be as significant as the technical challenges, due in large part to limitations in the Clean Water Act, the major national law that governs protection of surface water quality.

The Clean Water Act does not include regulations or enforcement mechanisms for nonpoint source control.

Passed in 1972 and amended in 1977 and 1987, the Clean Water Act was a monumental achievement for the United States. The law put into place a combination of regulations, funding for treatment systems, and administrative controls that have resulted in significant reductions in water pollution and the restoration of many polluted bodies of water (ASIWPCA, 2004).

The law was the result of years of development and negotiations weighing the needs of states for flexibility in addressing particular kinds of water systems and water-quality issues against national interests and the need for basic levels of consistency for all states (ASIWPCA, 2004; Craig, 2004; Houck, 2002).

The primary focus of the Clean Water Act is on controlling point source discharges (i.e., discharges from discrete conveyances, such as channels and pipes), and regulatory efforts in the first 25 years after passage of the law were predominantly focused on discharges of municipal and industrial wastewater. In the 1970s and 1980s, the nation invested in the construction of many municipal wastewater treatment plants through a construction-grant program that was part of the Clean Water Act. A system of regulatory permitting of point source discharges was also instituted, and within two decades, tremendous progress was made in bringing pollution from point sources under control.

However, control of nonpoint sources—such as runoff from urban and agricultural land—is a much more complex and difficult challenge. The Clean Water Act provides assistance for states to study nonpoint source pollution and implement programs to mitigate nonpoint discharges. However, the law does not include regulations or enforcement mechanisms for nonpoint source control.

The relatively weak provisions in the law for addressing nonpoint sources of water pollution represent a basic shortcoming. Nevertheless, the existing nonpoint source provisions do provide a framework for understanding the contributions of nonpoint sources to the overall quality of a body of water and for targeting the highest priority sources for action.

Today, provisions in the Clean Water Act for characterizing and mitigating nonpoint sources, for assessing water quality, and for setting goals for contaminant load limits are a starting point for taking on large-scale issues of nonpoint source contamination, such as nutrients in runoff. Hypoxic conditions in the Chesapeake Bay and northern Gulf of Mexico are two high-profile examples of the challenges posed by large-scale nonpoint source discharges of nutrients.

Nutrient Inputs to Surface Waters

The nutrients of most concern for water quality are dissolved species of nitrogen and phosphorus, especially nitrogen, which is more soluble than phosphorus and hence has greater potential for aqueous transport. The primary concern about both nutrients is that they enrich waters and stimulate algal production.

Algae use dissolved inorganic carbon (CO_2) and nutrients in the presence of light to form plant protoplasm, increase algal biomass, and release oxygen.

$$106\,CO_2 + 16\,NO_3^- + HPO_4^{2-} + 122\,H_2O + 18H^+ \xrightarrow{\text{light}} C_{106}H_{263}O_{110}N_{16}P_1 + 138\,O_2$$

In this process (photosynthesis), nutrients are incorporated into the synthesized biomass.

Algal growth impacts water quality when algae die and algal biomass is degraded by bacteria, which consume oxygen in the process. Aerobic biodegradation of organic matter in algal biomass involves conversion of organic carbon back into inorganic carbon, CO_2.

$$\text{biomass} + O_2 \xrightarrow{\text{bacteria}} CO_2 + H_2O$$

The big problem is the consumption of oxygen by bacteria in the conversion process. Thus, as algal biomass is degraded, oxygen dissolved in the water is used up, usually at a much faster rate than it can be resupplied from the atmosphere.

In many respects, the level of dissolved oxygen is the most important chemical parameter in determining the ecological health of waters. The level of dissolved oxygen is a very sensitive water quality parameter in that the solubility of oxygen is low, about 10 milligrams per liter at 20°C. Thus, it does not take much aerobic biodegradation of organic matter to use up most or all of the oxygen, causing hypoxia.

Hypoxia is a condition of a low concentration of dissolved oxygen in water. At concentrations of less than about 4 milligrams per liter, many types of fish and other aquatic organisms cannot be sustained. Thus, decreasing dissolved oxygen changes the nature of an aquatic system dramatically.

Sources of Nutrient Discharges

Nutrient loading in surface waters comes from both point and nonpoint sources. Municipal wastewater treatment plants, which are common point sources, discharge nitrogen and phosphorus species. However, their contribution to overall loading depends on the local conditions, such as the size of the body of water receiving the discharge.

Wastewater treatment facilities may be dominant sources of nutrients in one section of a river or a lake, but for large watersheds, they are often relatively small contributors of nutrients compared to runoff from agricultural lands. In the Mississippi River, for example, about 90 percent of the nitrogen load that reaches the Gulf of Mexico comes from nonpoint sources; the remaining 10 percent comes primarily from industrial and municipal point sources (NRC, 2008). Nutrients in storm-water runoff from urban environments (e.g., nutrients from fertilizers applied to lawns) also contribute to nutrient loading.

Runoff from nonpoint sources, whether in urban or agricultural environments, enters a body of water in a more distributed and diffuse way than discharges from point sources and thus is more difficult to control. In most large watersheds, runoff from agricultural lands, where large amounts of nitrogen and phosphorus are applied regularly to increase crop production, is the major nutrient source.

Another nonpoint source, although much less important than agricultural runoff, is deposition from the atmosphere. Emissions of nitrogen compounds to the atmosphere (e.g., ammonia and nitrogen oxides) can be washed out by rain, deposited in watersheds, and transported to receiving waters.

Hypoxia

Discharge of large amounts of nutrients leads to hypoxia in lakes, streams, estuaries, and coastal waters. In this article, the focus is on coastal waters where nitrogen loadings are the most significant cause of hypoxic conditions.

The production and application of nitrogen- and phosphorus-bearing fertilizers in agriculture has increased dramatically in the last half-century. Thus, as a result of human activity, nitrogen loading to coastal waters is about six times higher than natural loadings (Howarth and Marino, 2006). In some cases it is 10 times higher or more relative to natural background levels (Howarth and Marino, 2006).

High-nutrient loading in coastal waters is a problem along much of the coastline of the United States, and also across the globe (Figure 1). Humans have perturbed the natural cycle of nitrogen by fixing it out of the atmosphere at much higher rates than occurs naturally, primarily for the production of ammonia (NH_3), which is incorporated into fertilizers and eventually ends up in runoff as nitrate (NO_3^-) (NRC, 2000).

In many ways, the level of dissolved oxygen is the most important chemical parameter in determining the ecological health of waters.

Restoration Efforts in the Chesapeake Bay

Hypoxia in the Chesapeake Bay as a result of nutrient inputs is a longstanding problem. Figure 2 shows the extent to which low dissolved-oxygen levels (generally less than 4 to 5 milligrams per liter) existed in the Chesapeake Bay during the summer months from 2007 to 2009. As the figure shows, levels of dissolved oxygen were lower than desired in many of the tributaries as well as in the main body of the bay.

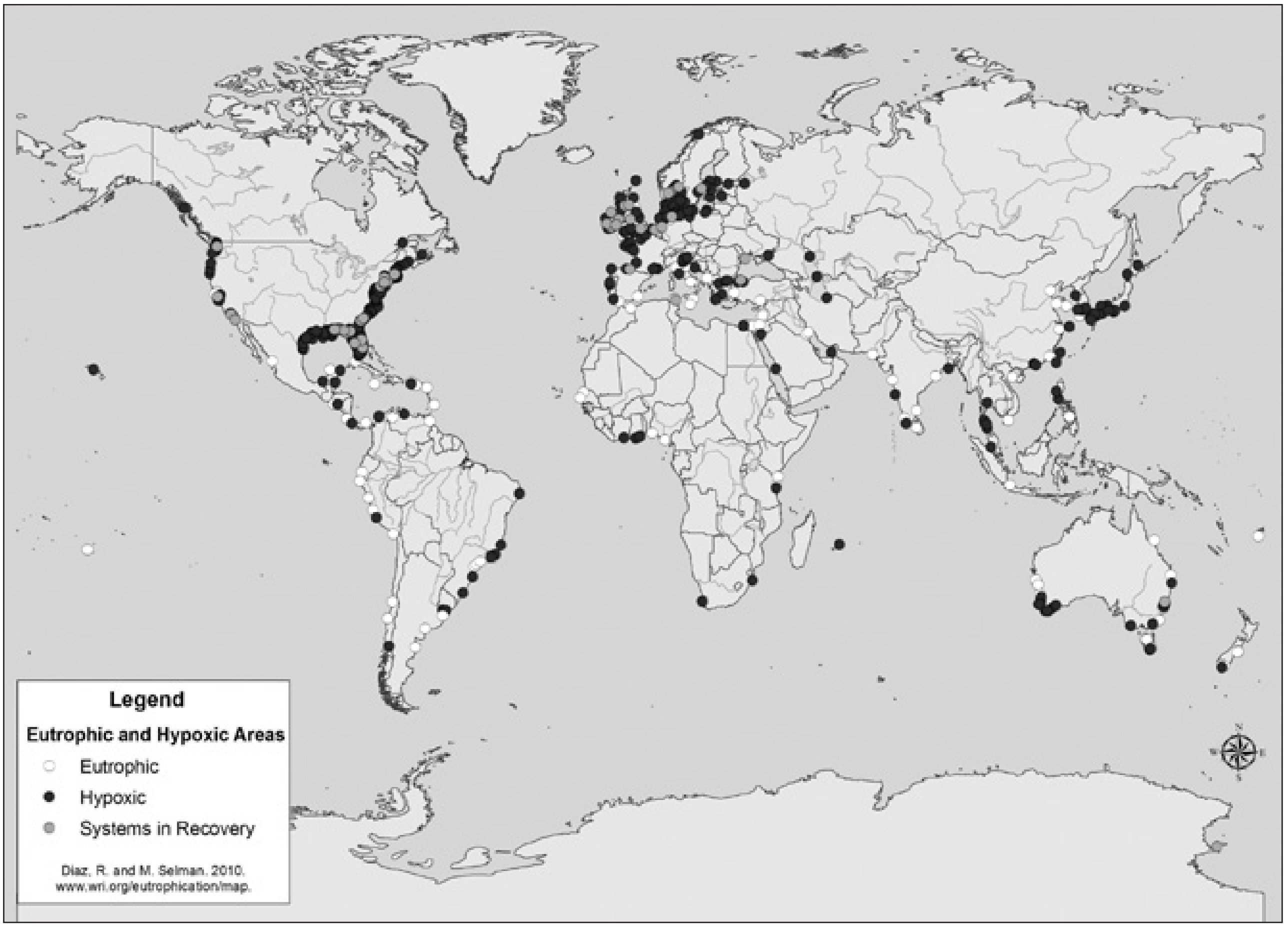


FIGURE 1 Hypoxic and eutrophic coastal areas around the world. Source: *http://www.wri.org/project/eutrophication/map.*

Hypoxia in the Chesapeake Bay has been investigated longer, and more resources have been expended on it, than for any other coastal water in the United States. In 1983, in cooperation with the Environmental Protection Agency (EPA), a multi-state agreement was put in place. Additional states joined later, and the partnership now involves six states, the District of Columbia, and EPA (CBP, 2011).

The partnership has focused on reducing nutrient and sediment loadings in the Chesapeake Bay with the goal of restoring bay grasses, various species of fish, blue crabs, and other aquatic life. This is a basin-wide effort that involves coordinated monitoring throughout the watershed and a central modeling effort to synthesize data and provide a framework for interpretation and informing decisions.

The Chesapeake Bay Program represents a model effort in the United States for addressing the challenge of nutrient pollution in coastal waters. Efforts have been ongoing for more than 25 years and have involved substantial investments of resources from all partners. Progress has been slow, which is frustrating to some, but it will necessarily take a long time to stabilize and reverse this large-scale water-quality problem that developed over a period of more than 200 years of changing land use and population increase in this large watershed.

Progress in the Chesapeake Watershed

The Chesapeake Bay Program has become the test case for the nation for learning how to address watershed-scale nutrient pollution under the Clean Water Act, from both a technical and administrative standpoint. The undertaking has been challenging and very expensive, but much has been learned and progress has been made.

The Chesapeake Bay Program has greatly improved our understanding of the sources of the most significant nutrient loadings to the bay. Figure 3 shows a map of the watershed indicating the relative impact on levels of dissolved oxygen of nutrient loadings from various

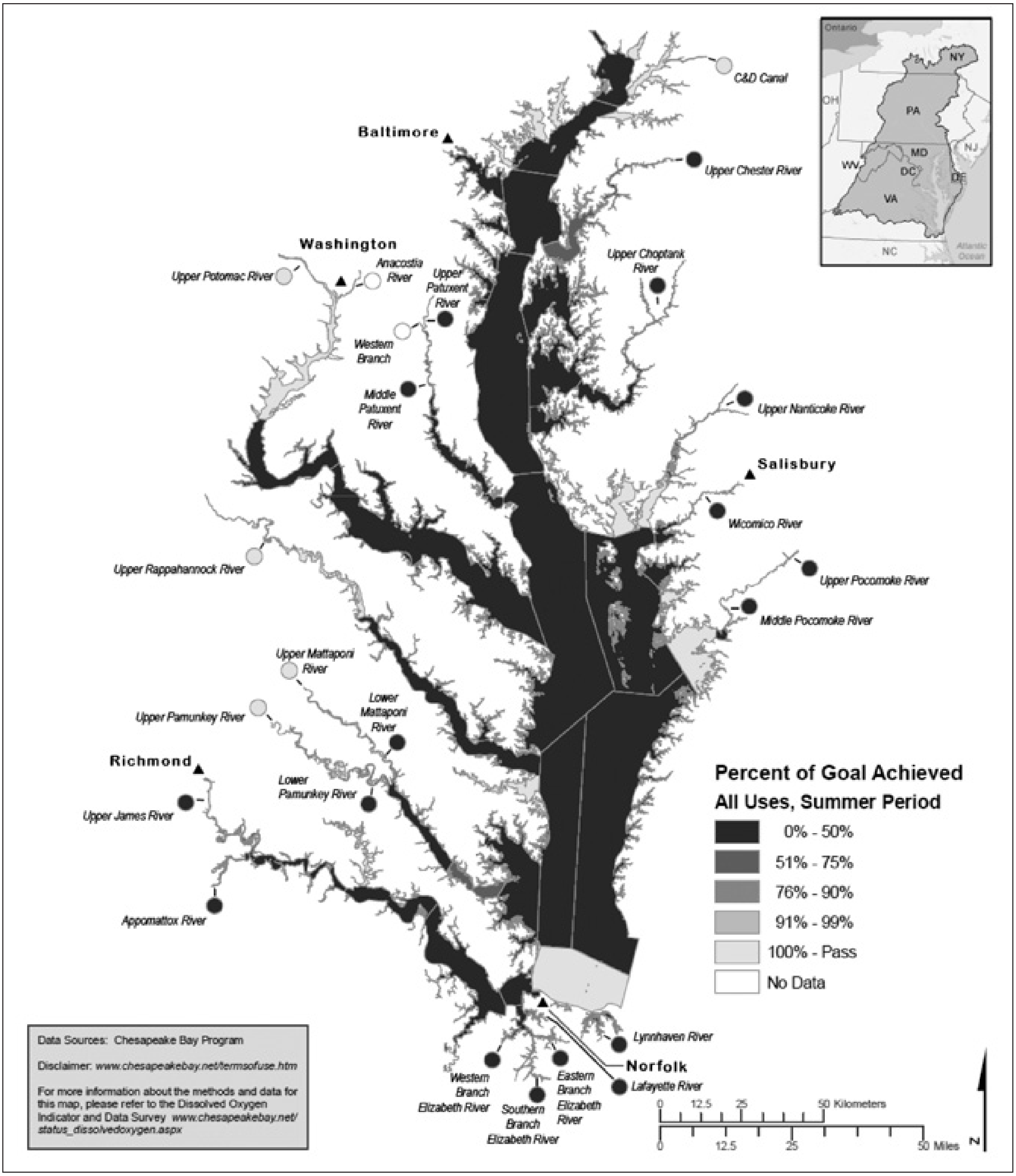


FIGURE 2 Percentage of goals for dissolved oxygen achieved in the Cheseapeake Bay, June–September, 2007–2009. Source: CBP, 2011.

areas. As Figure 3 shows, the Susquehanna River basin, which extends through Maryland, Pennsylvania, and into New York, is the most significant contributor of nutrient loadings, but not the only one.

This information, developed through long-term monitoring and modeling, has provided a basis for setting goals for controlling nutrient levels in sub-watershed areas and establishing caps on the amount of nutrients

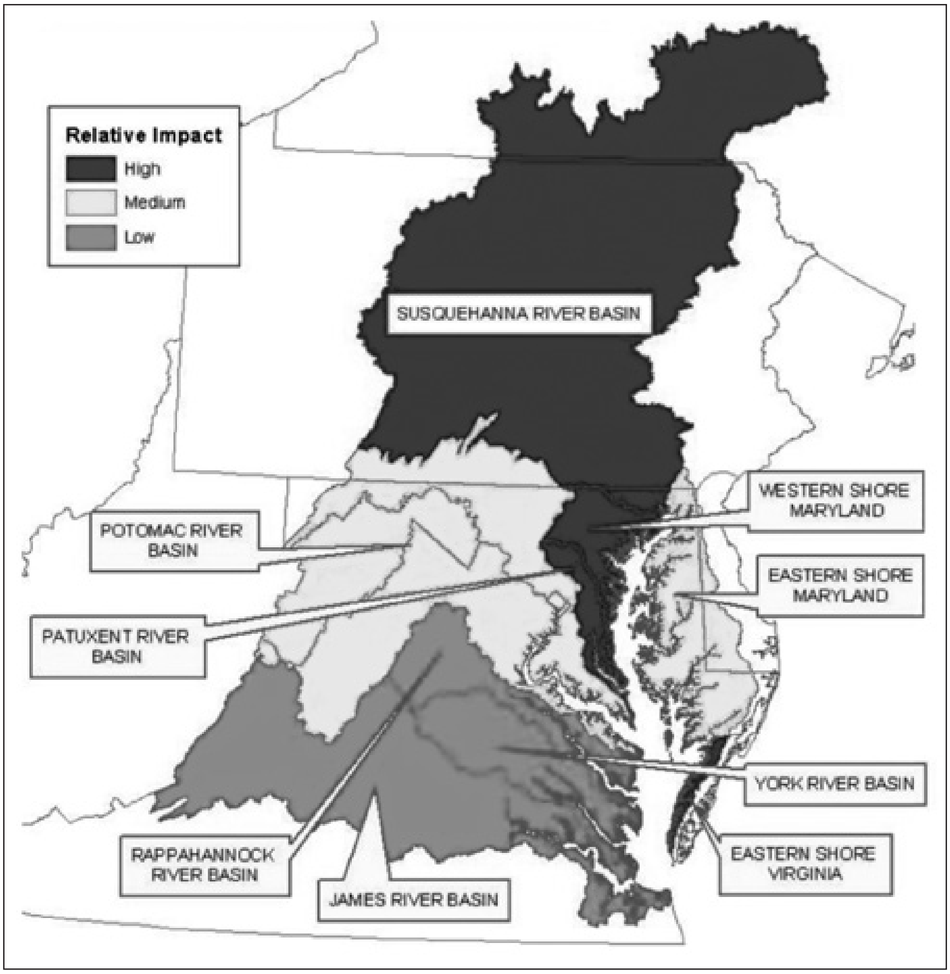


FIGURE 3 Relative impact of contributing sub-watersheds on levels of dissolved oxygen in the Chesapeake Bay. Source: EPA, 2003.

released from different sub-watersheds in the basin. Nutrient control goals have been set for 9 major river basins in the Chesapeake Bay watershed, and related goals have been set for 20 tributary basins. At the state level, goals are further subdivided down to the level of individual farms.

In December 2010, under legal pressure from external groups, an agreement was reached by the partner states and EPA to establish specific total maximum daily loads (TMDLs) of nutrients and sediment (EPA, 2010). A TMDL is a tool established in the Clean Water Act for specifying maximum allowable discharge loads to achieve water quality goals and for assessing sources of loadings in a watershed for the purpose of reducing them and prioritizing the allocation of resources. Establishing TMDLs for nutrients and sediments in the bay provided a basis for determining maximum allowable (or cap) loads for various jurisdictions in the Chesapeake Bay watershed.

In fact, the Clean Water Act *requires* the establishment of TMDLs once water quality impairment has been demonstrated. However, TMDLs are not the same as enforceable limits under a discharge permit. Instead, they are meant to provide a basis for establishing watershed implementation plans to achieve water quality goals, including load caps for all sub-watersheds.

The TMDL concept and process were included in the original Clean Water Act passed in 1972, but they have only been put to use in earnest since the late 1990s as a result of legal actions requiring EPA and states to do so (Houck, 2002).

The Chesapeake Bay TMDL of December 2010 has led to a great deal of scientific and regulatory progress, as well as lawsuits among the partners, and it will take some time for the nature and effectiveness of the responses to become clear. What is clear, however, is that the implementation of the TMDL for the Chesapeake Bay is a formative experience for learning how large-scale nonpoint source pollution can be addressed under the Clean Water Act.

Hypoxia in the Northern Gulf of Mexico

The northern Gulf of Mexico has large areas of hypoxia as a result of nitrogen from the Mississippi River basin. Figure 4 shows the extent of hypoxia in the northern Gulf of Mexico in summer 2010 (EPA, 2011). Although the area of low dissolved oxygen has been expanding consistently since monitoring began, to date, no coordinated effort to remediate the hypoxia problem in the northern Gulf of Mexico has been initiated. Nevertheless, the need for taking action is clear, and various groups have put forward ideas for doing so (NRC, 2008).

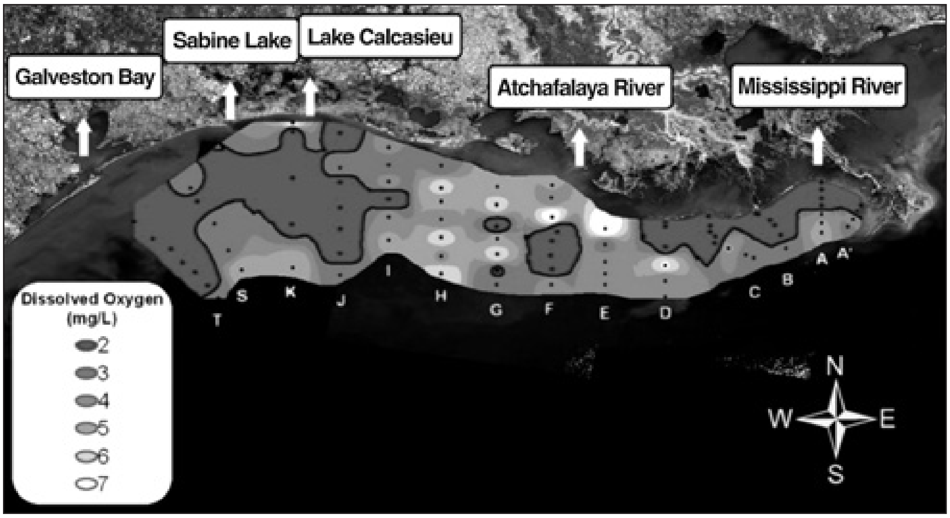


FIGURE 4 Hypoxic zones in the northern Gulf of Mexico, 2010. Source: EPA, 2011.

Gaining control of nutrient and sediment inputs in the northern Gulf of Mexico is a more complex problem than for the Chesapeake Bay because of the enormous size of the Mississippi River basin, which covers more than half of the continental United States. In addition, like the Chesapeake Bay basin, the Mississippi River basin has undergone extensive modifications, including the development of large cities on the main stem Mississippi River and its tributaries and, more distinctively, massive clearing of land and intensive agriculture in the basin.

The U.S. Geological Survey has compiled water-quality data on nutrients in the Mississippi River and its tributaries and developed a spatial regression model to estimate loadings from sub-watersheds that contribute to the tributary and main stem sections of the river. Figure 5 shows the estimated nitrogen delivery to the Gulf of Mexico from land areas throughout the Mississippi River basin; these estimates are based on analyses of water-quality data by the SPARROW (spatially referenced regressions on watershed attributes) model (Alexander et al., 2008).

The shading in Figure 5 indicates areas with relatively high and relatively low loadings, in terms of estimated total nitrogen yields in kilograms per square kilometer delivered to the Gulf of Mexico. A similar analysis was performed for phosphorus loadings (Alexander et al., 2008).

Figure 6 shows how nutrient loading to the Gulf of Mexico from the Mississippi River has increased over time. The graph shows nitrate (NO_3^-) loading in millions of metric tons per year based on measurements of nitrate concentration, and volumetric flow rates at a particular sampling location along the Mississippi River in southern Louisiana.

Flow measurements, also shown on the graph, illustrate that annual flows vary around an average value. In contrast, nitrogen loading has increased steadily over time, which is reflected in the rising levels of nitrate concentrations.

Clearly, the amount of nitrogen discharged to the Mississippi River and the northern Gulf of Mexico has been increasing. To shrink the size of the hypoxic region will require stopping and reversing this trend, an enormous challenge considering that this is the largest watershed in the nation.

Charting a Path Forward

The National Research Council has conducted three studies and issued three reports on water quality in the Mississippi River and the nutrient-control issue (NRC, 2008, 2009, 2010). The first study (NRC, 2008) focused on Mississippi River water quality issues in general and how well the Clean Water Act is protecting

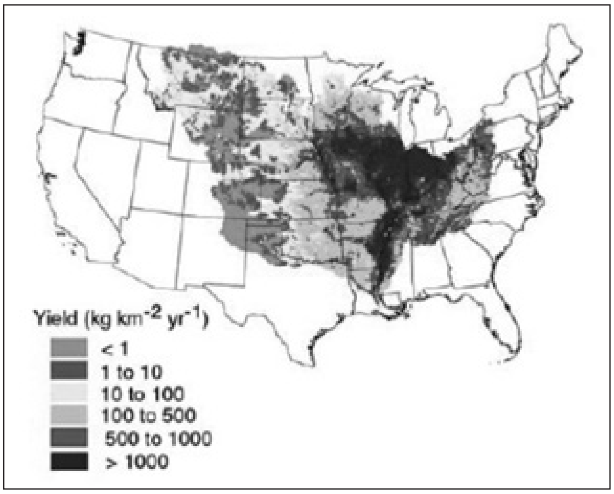


Figure 5 Estimated total nitrogen incremememtal yields (kg/km^2/yr) delivered from sub-watersheds in the Mississippi River basin to the Gulf of Mexico, from modeling with SPARROW. Source: Alexander et al., 2008. Reprinted with permission from Figure S6. Copyright 2008 American Chemical Society.

and restoring water quality in the river. The two subsequent studies (NRC, 2009, 2010) focused on particular science, engineering, and institutional challenges to reducing nutrient pollutant loads throughout the Mississippi River basin. The challenge of controlling water pollution largely from nonpoint sources in a large watershed is magnified for the Mississippi River basin because of its size and because of the large number of states that must participate in coordinated action to address the problem effectively.

As discussed above, the primary mechanism in the Clean Water Act for addressing nonpoint sources is through the TMDL process, which involves studying, on a watershed scale, the sources of loads of specific contaminants or contaminant groups. Such an integrative framework is critical to developing a system-wide view of the location and magnitude of sources, a plan for prioritizing the sources, and plans to reduce inputs from the most significant ones.

The data on water quality and hydrology from across the watershed can be used to develop and calibrate watershed-scale water-quality models for interpreting monitoring data and making projections of the effects of implementing various control options. System-scale modeling has been a critical tool for evaluating data and forecasting water quality for the Chesapeake Bay watershed (NRC, 2011).

Lack of Coordination

In contrast to the coordinated monitoring and modeling efforts for the Chesapeake Bay, no coordinated monitoring efforts among states in the Mississippi River basin or system-wide modeling has been initiated. In addition, although several federal agencies maintain programs that include some monitoring of water quality in the Mississippi River watershed and the northern Gulf of Mexico, no single federal program is monitoring water quality and collecting data for the river as a whole.

The National Oceanic and Atmospheric Administration 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 U.S. Geological Survey has collected water-quality data for many years at specific Mississippi River locations under various monitoring programs. Thus, the monitoring and management of water quality in the Mississippi River is fragmented, with different agencies conducting programs with a variety of goals (NRC, 2008).

A Strategy for Coordinated Efforts

The NRC (2008) committee that evaluated the monitoring and management of water quality in the Mississippi River from a system-level perspective concluded that "there is a clear need for federal leadership in system-wide monitoring of the Mississippi River" and that "the EPA should take the lead in establishing a water quality data sharing system." The committee argued that EPA is best positioned, and indeed obligated by the Clean Water Act, to facilitate better interstate collaboration and improve delivery of Clean Water Act programs, such as permitting, monitoring, and conducting water-quality assessments.

To advance nutrient control in the Mississippi River basin, NRC (2008) recommended that EPA develop water-quality criteria for nutrients in the Mississippi

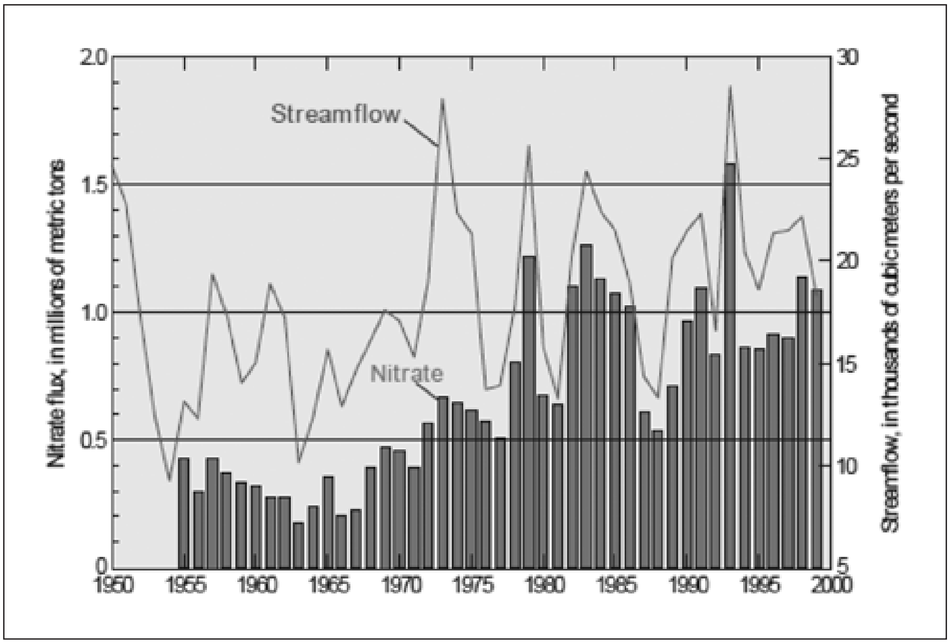


Figure 6 Annual flux of nitrate from the Mississippi River basin to the Gulf of Mexico, 1955–1999, and mean annual streamflow, 1950–1999. Source: Goolsby and Battaglin, 2000.

River and northern Gulf of Mexico and ensure that states in the basin also establish water-quality standards (i.e., designated uses and water quality criteria) as well as TMDLs to protect against excessive nutrient pollution. The NRC (2008) committee also recommended that EPA ultimately develop a federal TMDL, or the functional equivalent, for the Mississippi River and northern Gulf of Mexico through a process similar to the one developed for the Chesapeake Bay.

Because runoff from agricultural lands is the main contributor of nutrient loadings to the Mississippi River, reducing those inputs will be a critical goal that will require implementing effective management practices. Existing U.S. Department of Agriculture (USDA) programs already provide technological and financial support for implementing nonpoint source control in agriculture. However, these programs will have to be coordinated with efforts by EPA and state water-quality agencies to realize their potential for improving water quality. Examples of relevant USDA programs include the Conservation Reserve Program (CRP), Environmental Quality Improvement Program (EQIP), and Conservation Security Program (CSP).

In the first two NRC reports (2008, 2009), the authoring committees recommended that (1) USDA conservation programs be focused aggressively on runoff from areas with high nutrient input and (2) that EPA and USDA combine their efforts to reduce impacts from agriculture on water quality in the Mississippi River and northern Gulf of Mexico.

NRC (2009) outlined a number of specific actions that could be undertaken jointly and separately by USDA and EPA to make a start on the large-scale challenge of reducing nutrient discharges into the waters of the Mississippi River basin. Some of these activities have been initiated, notably a USDA program (described below) focused on the highest priority watersheds in the basin in terms of nutrient loadings.

The Mississippi River Basin Healthy Watersheds Initiative

The USDA Mississippi River Basin Healthy Watersheds Initiative (MRBI), established in 2009, is a four-year, $320 million program that targets 41 watersheds in the Mississippi River basin. The program is designed to promote improvements in nutrient management and water quality. Considering the provisions of the Clean Water Act and the responsibilities of EPA, close collaboration between USDA and EPA will be essential to the success of this program.

The authoring committee of the third NRC report (2010) noted that EPA support for MRBI could promote research and learning important for informing future management decisions. Thus MRBI could be an important first step toward an action-oriented, basin-wide, adaptive strategy for improving nutrient control in the vast Mississippi River basin.

To improve water quality, the U.S. Department of Agriculture, Environmental Protection Agency, and state water-quality agencies must coordinate their efforts.

Conclusions

Excess nutrient loading of nitrogen and phosphorus is a problem in surface and coastal waters of the United States and around the world. The primary impact is low levels of dissolved oxygen, or hypoxia, which has harmful effects on aquatic ecosystems and commercial fisheries. Hypoxic conditions in large areas of the Chesapeake Bay and the northern Gulf of Mexico from riverine loadings of nutrients are two prominent examples in the United States. Nonpoint sources, primarily runoff from agricultural lands, are the primary contributors to nutrient loadings.

The Chesapeake Bay Program, established in 1983, is a partnership of six basin states, the District of Columbia, and EPA that has become the model effort in the United States for addressing the challenge of nutrient pollution in coastal waters in the framework of the Clean Water Act. Despite substantial investments of resources by all partners, progress has been frustratingly slow. However, it must be recognized that it will take a long time to stabilize and reverse this large-scale problem that developed over the course of more than 200 years of changes in land use in this large watershed.

The challenge of controlling nonpoint sources of nutrients is magnified for the Mississippi River watershed because of its very large size and the large number of states that must coordinate their efforts. In several recent reports, the NRC concluded: (1) there is a clear need for federal leadership in system-wide monitoring of the Mississippi River and system-wide modeling and (2) EPA is the government entity best positioned to facilitate interstate collaboration and provide basin-wide coordination.

In addition, considering that runoff from agricultural lands is the dominant contributor to nutrient loading, USDA will be a vital participant in efforts to improve nutrient control in the Mississippi River basin. The Mississippi River Basin Healthy Watersheds Initiative, a USDA program, could represent an important first step toward an action-oriented, basin-wide, adaptive strategy for reaching that goal.

References

Alexander, R.B., R.A. Smith, G.E. Schwarz, E.W. Boyer, J.V. Nolan, and J.W. Brakebill. 2008. Differences in phosphorous and nitrogen delivery to the Gulf of Mexico from the Mississippi River Basin. Environmental Science and Technology 42: 822–830.

ASIWPCA (Association of State and Interstate Water Pollution Control Administrators). 2004. Clean Water Act Thirty-Year Retrospective. Washington, D.C.: ASIWPCA.

CBP (Chesapeake Bay Program). 2011. Chesapeake Bay Program: A Watershed Partnership. Available online at *http://www.chesapeakebay.net/*.

Craig, R.K. 2004. The Clean Water Act and the Constitution. Washington, D.C.: Environmental Law Institute.

EPA (U.S. Environmental Protection Agency). 2003. Setting and Allocating the Chesapeake Bay Basin Nutrient and Sediment Loads: The Collaborative Process, Technical Tools, and Innovative Approaches. Principal authors R. Koroncai, L. Linker, J. Sweeney, and R. Baiuk. U.S. Environmental Protection Agency, Region III, Chesapeake Bay Program Office, Annapolis, MD. Available online at *http://www.chesapeakebay.net/content/publications/cbp_19713.pdf*.

EPA. 2010. Fact Sheet: Chesapeake Bay Total Maximum Daily Load (TMDL): Driving Actions to Clean Local Waters and the Chesapeake Bay. Available online at *http://www.epa.gov/reg3wapd/pdf/pdf_chesbay/BayTMDLFactSheet8_6.pdf*.

EPA. 2011. Hypoxia 101. U.S. Environmental Protection Agency, Mississippi River–Gulf of Mexico Watershed Nutrient Task Force. Available online at *http://water.epa.gov/type/watersheds/named/msbasin/hypoxia101.cfm*.

Goolsby, D.A., and W.A. Battaglin. 2000. Nitrogen in the Mississippi River Basin—Estimating Sources and Predicting Flux to the Gulf of Mexico. Fact Sheet 135-00. USGS Kansas Water Science Center. Available online at *http://ks.water.usgs.gov/pubs/fact-sheets/fs.135-00.html*

Houck, O.A. 2002. The Clean Water Act TMDL Program: Law, Policy, and Implementation. Washington, D.C.: Environmental Law Institute.

Howarth, R.W., and R. Marino. 2006. Nitrogen as the limiting nutrient for eutrophication in coastal marine ecosystems: evolving views over three decades. Limnology and Oceanography 51(1): 364–376.

NAE (National Academy of Engineering). 2011. Grand Challenges for Engineering. Available online at *http://www.engineeringchallenges.org/*.

NRC (National Research Council). 2000. Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution. Washington, D.C.: National Academies Press.

NRC. 2008. Mississippi River Water Quality and the Clean Water Act: Progress, Challenges, and Opportunities. Washington, D.C.: National Academies Press.

NRC. 2009. Nutrient Control Actions for Improving Water Quality in the Mississippi River Basin and Northern Gulf of Mexico. Washington, D.C.: National Academies Press.

NRC. 2010. Improving Water Quality in the Mississippi River Basin and Northern Gulf of Mexico: Strategies and Priorities. Washington, D.C.: National Academies Press.

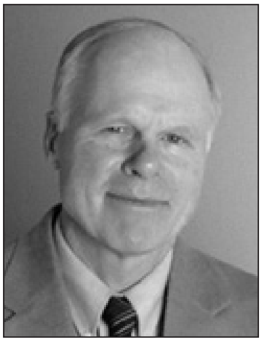
NRC. 2011. Achieving Nutrient and Sediment Reduction Goals in the Chesapeake Bay: An Evaluation of Program Strategies and Implementation. Washington, D.C.: National Academies Press.

New York City and metropolitan Boston have been pioneers in protecting their source waters through effective watershed management.

Managing Sustainable Water Supplies

The New York City and Metropolitan Boston Experience[1]

Rutherford H. Platt



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In the mid-19th century, New York City (only Manhattan Island at the time) and Boston, Massachusetts, faced crises of water quality and quantity due to their locations on saltwater estuaries, their population growth, the pollution of local water sources, frequent fires, and waterborne epidemics. To bring water to urban users, both cities began to develop hinterland facilities to deliver pure fresh water by gravity through a system of impoundments and aqueducts. Both projects were directed by the noted civil engineer John Jervis. New York's original Croton River Reservoir and its 41-mile aqueduct (including the famous High Bridge over the Harlem River) first delivered fresh water to the city in 1842. Boston's Lake Cochituate system, a smaller version of the Croton River project, was completed six years later.

To meet the needs of rapid population growth, rising industrial demand, and the proliferation of household toilets and other plumbing devices, both systems had to be substantially enlarged with the addition of new and more distant water sources. For New York, this meant water from sources across

[1] This article is based partly on the author's participation as a member of the study committee that prepared the National Research Council report, *Watershed Management for Potable Water Supply: Assessing New York City's Approach* (NRC, 2000) and on meetings with city officials during the study. The Boston material is largely based on his experience as a member of the Water Supply Citizens Advisory Committee in the 1980s and the Massachusetts Water Resources Authority website (*http://www.mwra.state.ma.us/*).

the Hudson River in the Catskill Mountains and Upper Delaware River basin (Figure 1). Meanwhile, by the 1890s Boston was drawing water from a series of small impoundments in the nearby Sudbury River watershed along with its Lake Cochituate supply. Under a series of metropolitan-level agencies, the Boston system was further enlarged with the completion of Wachusett Reservoir near Worcester in 1905, followed by the much larger Quabbin Reservoir 65 miles west of Boston in 1946 (Figure 2). Quabbin today provides most of the water supply for metropolitan Boston.

Today, the New York City Department of Environmental Protection (NYDEP) administers the city's sprawling water system, which serves 8 million city residents and another 1 million in nearby suburbs. The Metropolitan Boston system, now administered by the Massachusetts Water Resources Authority (MWRA), a regional agency established in 1985, serves 2.2 million people in 45 cities and towns in eastern Massachusetts.

By the 1990s, both systems faced dual challenges: (1) controlling rising water demand to remain within their respective safe yields; and (2) protecting and improving the purity of water delivered to users. To address the former challenge, both system managers took steps to reduce per capita demand, such as repairing system leaks and instituting household and commercial plumbing codes and retrofit programs, improving metering, and imposing higher water and sewer fees. As a result, both the New York and MWRA systems have dramatically reduced system and per capita demand levels (discussed below).

Regarding water quality, both systems have long relied on the purity of their sources in rural watersheds to ensure the healthiness of their raw water. For many years, the water was disinfected with chlorine but was not filtered. However, changing land uses in the source watersheds, as well as new concerns about chlorine by-products and other newly recognized health threats, raised doubts about continued reliance on unfiltered source water.

In 1989, the Environmental Protection Agency (EPA) mandated filtration for drinking water from surface sources. However, a filtration waiver was authorized for large systems that could demonstrate that

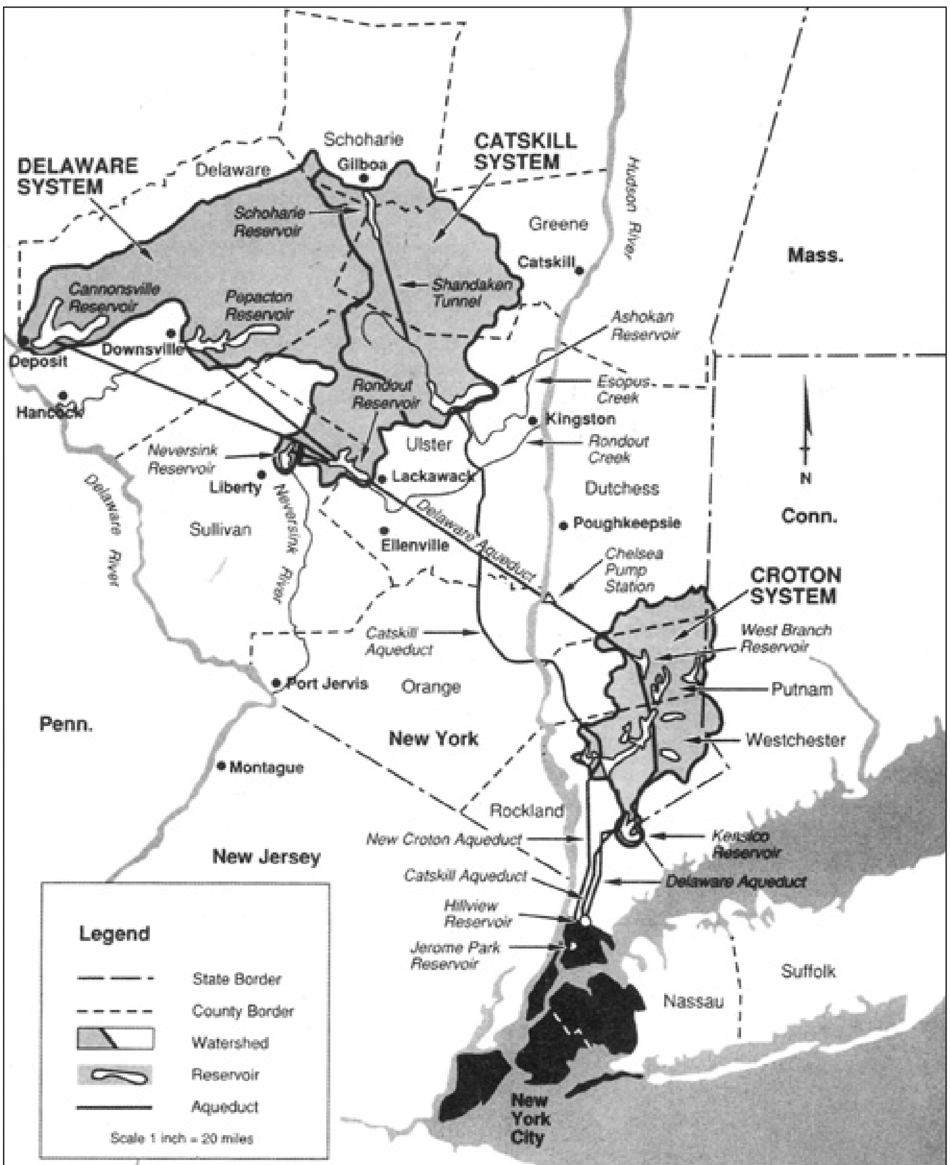

FIGURE 1 Map of the New York City Water System. Source: New York Department of Environmental Protection.

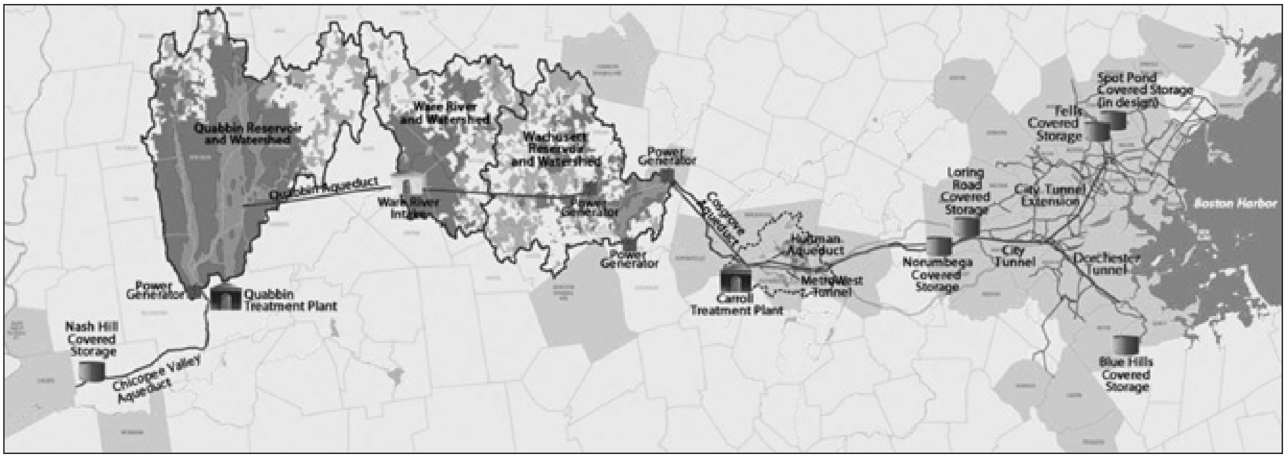

FIGURE 2 Map of the Metropolitan Boston Water System. Source: Massachusetts Water Resources Authority.

they could maintain and improve water quality through nonstructural watershed management. Both the New York City and Metropolitan Boston systems have been pioneers in protecting their sources with watershed management and have qualified for filtration waivers.

Today, a new technology, "hydrofracking," poses a potential threat to the purity of New York's water supply. As of 2011, New York City opposes the extraction by "hydrofracking" of natural gas from the Marcellus Shale, an area that underlies the city's trans-Hudson source watersheds. As of this writing, the state has issued a ban on hydrofracking pending studies by the New York Department of Environmental Conservation and EPA.

The New York City Water Systems

On July 4, 1842, New York City celebrated the opening of the world's first long-distance urban water supply aqueduct since the Roman Empire. Since 1800, New York's population had quadrupled, from 60,000 to 250,000, and the city was wracked by chronic water shortages, outbreaks of cholera, and recurrent fires. Surrounded by brackish estuaries and with local wells polluted, the growing city turned in desperation to its rural hinterland in search of a reliable source of pure water.

Following the advice of engineer DeWitt Clinton Jr., the city selected a tributary of the Hudson River, the Croton River, which could be dammed at sufficient elevation for water to flow to the city by gravity without pumping. The Croton project, designed by John Jervis, involved a series of engineering marvels for the time: impoundment of a 600-million-gallon reservoir; a 40-mile aqueduct; the "High Bridge" spanning the Harlem River; and distributing reservoirs in Manhattan. The Croton system was enlarged with the construction of a larger dam and expanded impoundment capacity in the 1890s.

With the consolidation of Greater New York City in 1898 to form a five-borough metropolis of 3.5 million people—second only to London at the time—it was imperative that the city develop new water sources to augment the fully developed Croton system before it was tapped out. In addition, suburban development in the Croton watershed was rapidly increasing. Once state authority was granted in 1905, the city began looking farther afield, and in the 1920s it turned to distant upland watersheds across the Hudson River in the Catskill Mountains and the upper Delaware River (the Cat-Del reservoirs) watershed.

By the mid-1960s, most of the city's water was supplied from six major reservoirs in the Catskills and upper Delaware River watershed via two high-pressure aqueducts that plunge beneath the Hudson. East of the Hudson, the 93-mile Catskill Aqueduct and the 110-mile Delaware Aqueduct converge at Kensico Reservoir about 20 miles north of the city in Westchester County. At Kensico, the combined flows are chlorinated, then conducted into the city's two main water tunnels for distribution to the five boroughs. (A third water tunnel has been under construction since the 1970s.)

Today, the Cat-Del reservoirs meet about 90 percent of the water needs of 8 million city residents and another 1 million suburbanites; the other 10 percent is provided by the Croton system. Cat-Del water, which is unfiltered, originates in pure upland sources, a condition that gave rise to the watershed management initiatives described below.

The Boston Metropolitan Water System

In the 1840s, the city of Boston followed New York's lead and hired Jervis to design and construct its Lake Cochituate Reservoir and a 14-mile aqueduct to deliver pure water. This early source was augmented in the 1870s by a series of small impoundments and transfer facilities in the Sudbury River watershed just northwest of the city. All of these sources were later closed with the development of much larger and more distant sources in central Massachusetts.

In 1893, the Boston system was transferred to a new Metropolitan Water District (later merged into the Metropolitan District Commission along with counterpart sewer and park districts in 1919). The state legislature authorized the MWD to provide water to towns within 10 miles of the State House in Boston (later expanded to 15 miles). This regionalization of the system was motivated in part by the reluctance of suburban towns to being annexed to Boston in order to connect to its water system.

Under the MWD and its successors, the metropolitan water system was greatly enlarged with the completion of Wachusett Reservoir near Worcester in 1908. The much larger Quabbin Reservoir in the Chicopee River Valley (a tributary of the Connecticut River) 60 miles west of Boston was completed in 1939. As shown in Figure 2, water originating in Quabbin flows by tunnel to Wachusett and then through a series of tunnels and pipes to metropolitan Boston.

Today, Quabbin supplies at least 90 percent of the water used by 2.2 million residents and 5,500 businesses in eastern Massachusetts. Like New York's Cat-Del sources, water from Quabbin and Wachusett is not filtered.

Demand Management

By the 1960s, like other urban water providers, the New York and Metropolitan Boston water systems faced rising demand for water. The safe yield of the New York City system of about 1,400 million gallons per day (mgd) was exceeded regularly, and further increases in demand from population growth, higher per capita usage, and system leakage were likely. In Boston, the safe yield of 300 mgd was also facing shortfalls as additional communities were added to the system, per capita usage rose, and system leakage worsened.

In 1986, New York announced a Universal Water Metering Program to address the city's notorious absence of water meters and the consequent inability to relate water costs to usage. More than 600,000 meters were installed at a cost of $350 million, enabling the city to monitor the use of water and use pricing as a strategy to limit waste and meet increasing demand.

Concurrently, the city embarked on a long-range program of leak detection and repair. In 1990, it launched a pilot water conservation program that offered free leak detection and installation of water-saving plumbing devices, such as water-saving showerheads, faucets, aerators, toilet tank displacement bags, and low-flow toilets. The end result of these measures has been a decrease in the average system demand from about 1.5 billion gallons per day (bgd) in 1980 to about 1.0 bgd in 2009, a decrease in per capita use from 187 gallons per day (gpd) in 1980 to 125 gpd in 2009 (*http://www.nyc.gov/html/dep/html/drinkingwater/droughthist.shtml*).

Meanwhile, MWRA has reduced water demand from 330 millions gallons per day (mgd) in 1985 to about 220 mgd in 2009 (Figure 3). Both systems have thus effectively applied water conservation strategies to live within their available supplies and avert the need to find new sources in the face of economic and environmental constraints.

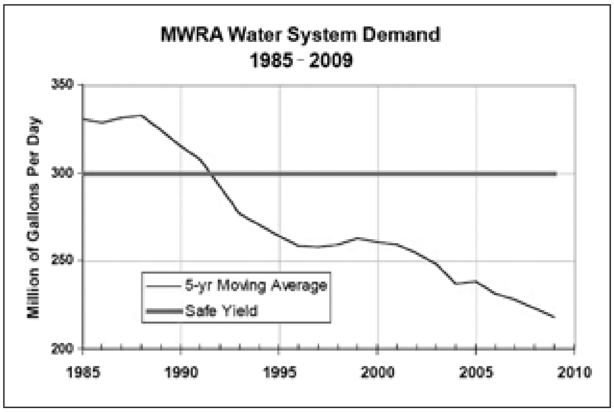

FIGURE 3 Water demand on the Metropolitan Boston Water System, 1985–2009. Source: Massachusetts Water Resources Authority. Available online at *http://www.mwra.state.ma.us/monthly/wsupdat/demand-1985-2010-640.jpg*.

Watershed Management

The next priority—sustainable watershed management—has put New York City and MWRA in a class by themselves. Since the days of John Jervis, who designed the first stages of both systems, New York and Boston have relied on the natural purity of their hinterland sources, disinfected with chlorine, to provide high-quality water without filtration. In the 1970s and

1980s, public health concerns arose about "disinfection by-products" from the heavy use of chlorine and about *Cryptosporidium* and *Giardia*, waterborne pathogens that might survive chlorination.

In 1986, EPA issued the "Surface Water Treatment Rule," pursuant to the Safe Drinking Water Act (SWDA) of 1974, requiring that public water supplies drawn from reservoirs be micro-filtered to meet higher drinking water criteria and to reduce dependence on chlorination. The rule, however, offered the possibility of a filtration avoidance determination (FAD) for systems that could demonstrate the capacity to protect their source waters from listed microbial agents and chemical pollutants through watershed management. Given extremely high estimated costs of building filtration plants, both New York City and MWRA decided to pursue the watershed management option to qualify for a FAD.

Unlike standard engineering practices, nonstructural watershed management requires the development of a market basket of innovative technical, economic, and legal strategies of unproven effectiveness. EPA required that each system pursue a "dual track" approach, taking preliminary steps in the design process to provide filtration just in case the watershed management track failed.

The challenge was more daunting politically for New York than for Boston. Whereas MWRA was a new regional authority established by the state in 1985 with no history of confrontation with the source watershed region, New York City was viewed by the rural towns in the 1,800 square-mile Cat-Del watersheds as an alien and threatening outsider. Furthermore, anything involving New York City is likely to be contentious!

To explore ways of protecting the city's water supplies with the cooperation, rather than hostility, of local governments in the watersheds, the city in 1995 entered into a complex negotiation process launched with the encouragement of then-governor George Pataki and Robert F. Kennedy Jr. and his organization, Hudson Riverkeeper. After more than two years, the negotiations finally yielded the 1997 Watershed Memorandum of Agreement (1997 MOA), one of the most extraordinary legal agreements in the history of American water resource management. With more than 1,000 pages of text and appendices, the document was signed by representatives of EPA, the state, the city, 46 watershed towns, and 6 environmental organizations, including Hudson Riverkeeper.

The 1997 MOA committed the city to spending more than $1 billion over the next decade on a variety of projects to remediate sources of pollution and promote sustainable economic growth and resource management in the Cat-Del watersheds. (The Croton system was not part of the MOA, and the city is currently building a long-delayed Croton filtration plant pursuant to a court order.)

The MOA addressed a wide range of watershed-protection strategies: (1) land acquisition in the trans-Hudson watersheds; (2) wetlands and buffer protection; (3) wildfowl control; (4) agricultural best-management practices; and (5) upgrades of local sewage treatment plants and septic systems that drain into the reservoirs. Under the MOA's provisions, the city has purchased about 108,000 acres of critical riparian habitat. The Watershed Agricultural Council, established under the MOA, promotes best farming practices to prevent the runoff of chemicals or livestock wastes into local streams. The Catskill Watershed Corporation provides small grants and technical assistance to watershed businesses. Finally, the Watershed Forestry Program promotes sensible management of public and private timberlands.

The 1997 Watershed Memorandum of Agreement is one of the most extraordinary legal agreements in the history of American water resource management.

In the first decade, the city committed about $1 billion dollars to implementing the terms of the MOA. In 1977, pursuant to this commitment, EPA awarded the city a preliminary FAD, subject to exhaustive monitoring and oversight by the New York Department of Environmental Conservation. Based on the results, the FAD was extended for another 10 years beginning in 2007.

MWRA pursued a similar program under a different legal framework. In place of an intergovernmental agreement like New York's MOA, MWRA relied primarily on new state watershed management laws regulating wetlands and buffer zones along rivers in the state. The Quabbin watershed was already substantially publicly owned, but certain parcels of private land there and in the Wachusett watershed have been acquired in fee or easement.

EPA Region 1 initially challenged the efficacy of MWRA's watershed management program and demanded in federal court that, under SDWA, all water from the Quabbin/Wachusett system be filtered. This claim was based in part on occasional surges in fecal coliform, which MWRA resolved by sending young employees in boats to chase away waterfowl near reservoir outlets by making loud noises.

MWRA withstood EPA's legal challenge in 2001 and was awarded a filtration waiver, which remains in effect at this writing. In response to concerns about chlorine by-products, MWRA now uses ozone disinfection at its new Carroll Water Treatment Plant in Marlborough, Massachusetts. In addition, several open storage reservoirs have been covered to eliminate contamination from airborne pollutants.

Hydrofracking

In 2010, a new threat to New York's water supply arose in the form of proposals from energy companies that want to exploit natural gas deposits under portions of the watershed region. According to an article in *Scientific American* of July 2010: "A single vast shale deposit—the Marcellus Formation, stretching from Tennessee to New York—might contain enough natural gas to supply the U.S. for more than 30 years at today's consumption rates" (Fischetti, 2010).

The technology preferred by the industry, known as "fracking," involves extracting natural gas from deep rock strata by injecting high-pressure water mixed with chemicals to fracture the gas-bearing layers. The use of fracking to date in Pennsylvania, Ohio, and elsewhere has contaminated groundwater supplies in some areas and posed serious issues of recovery and safe disposal of the toxic chemicals used in the process.

The potential use of fracking has led to a bitter controversy in New York state, especially in the Cat-Del watersheds. Local citizens yearn for the jobs the industry would create in a depressed economy, while environmentalists and water managers decry the technology's evident risks. *The New York Times* (Sept. 28, 2010) warned editorially that "…carefully regulated drilling in the Marcellus Shale might be feasible, but the state should put the city's watershed permanently off limits. . . . There are simply too many points in the drilling process where toxic chemicals could escape."

On December 11, 2010, outgoing Governor David A. Patterson issued an executive order delaying any permit for fracking in the state until at least July 1, 2011, pending a review of the environmental impacts of the process. As of October 2011, Governor Andrew Cuomo has continued to defer state permits for hydrofracking until the state review has been completed. Meanwhile EPA is conducting its own environmental review.

Conclusion

Putting aside the ruckus over fracking, the management process established by the 1997 MOA has been remarkably smooth. Issues concerning particular provisions of the MOA have been raised, sometimes emphatically, by the Coalition of Watershed Towns, and the city has tried to promote both environmental and economic progress in the rural watershed region. At the same time, the results have been to restrain water demand and avoid any public health incidents for the past 13 years. Perhaps it is not premature to suggest that "the jury is in"—the New York City watershed management program, and its Metro Boston counterpart, may be declared successful experiments in sustainable urban drinking water management.

References

Fischetti, M. 2010. The drillers are coming: debate over hydraulic fracturing heats up. Scientific American 303(1): 82–85.

NRC (National Research Council). 2000. Watershed Management for Potable Water Supply: Assessing New York City's Approach. Washington, D.C.: National Academies Press.

Water-wastewater utilities face critical issues in every aspect of their operation.

Critical Issues and Sustainability Challenges for a Large Metropolitan Water-Wastewater Utility

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Water and wastewater (W-WW) utilities and the people who operate them are public servants dedicated to protecting public health and the environment by providing safe drinking water and managing wastewater in an environmentally sound way at reasonable cost and with limited resources and authority. W-WW utilities, in keeping with the goals put forth by the United Nations in 1987, strive to "meet present needs without compromising the ability of future generations to meet their needs" (UN, 1987). This article provides an overview of the challenges W-WW utilities face based on the experiences of the author and his colleagues during 29 years of service at the Washington Suburban Sanitary Commission (WSSC).[1]

Washington Suburban Sanitary Commission: Historical Performance

WSSC is a progressive, not-for-profit W-WW utility that has been in business for 93 years. It serves about 1.8 million people in two suburban communities, Montgomery County and Prince George's County, Maryland, adjacent to Washington, D.C.

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[1] The views expressed in this article are those of the author and his colleagues. They are not intended to represent the official views of the Washington Suburban Sanitary Commission.

FIGURE 1 a. Drinking water quality. b. Treated wastewater effluent quality for calendar year 2010. TTHMs = total trihalomethanes. BOD = biological oxygen demand. Source: WSSC.

To protect public health as well as the ecosystem, WSSC conducts about 500,000 laboratory analyses per year related to water quality and cleaned wastewater. Throughout its history, WSSC has met all water-quality standards for potable water, including the latest requirements of the Safe Drinking Water Act (SDWA) for turbidity, lead, and disinfection by-products (Figure 1a). In addition, treated wastewater has almost always been below the levels allowed by the Clean Water Act (CWA) for biological oxygen demand, suspended solids, phosphorus, nitrogen, and other regulated parameters (Figure 1b).

Despite its good record, WSSC, like many other large W-WW utilities, faces major challenges related to infrastructure, emerging contaminants, and other critical issues. Providing safe drinking water and disposing of wastewater in a sustainable way is a complex undertaking that requires a multi-step cycle that faces major challenges at every step: ensuring the availability and quality of source water; properly treating water and wastewater; maintaining infrastructure; and returning clean water to the environment. Examples of these challenges are described below.

The Availability of Source Water

WSSC has been fortunate to have enough source water to provide safe drinking water to its customers. However, water utilities in other parts of the country (e.g., California, Georgia, and Texas) have experienced source water shortages. It is believed that by 2050 water shortages will become more widespread in the United States as a result of significant increases in population, water demand, and food production (IWMI, 2006) (Figure 2). In all likelihood, this will signal the end of the era of free source water and exacerbate funding and other challenges for W-WW utilities.

The Quality of Source Water

Historical Perspective

Today's safe drinking water practices for ensuring high-quality water are the result of thousands of years of experience. About 3,000 years ago, driven by the limited availability of surface water, groundwater was discovered in the Middle East as a source of clean water (Issar, 2008). One thousand years later, the Romans developed aqueducts to convey surface water to large cities, supply potable water, and maintain sanitary conditions.

More recently, significant improvements in water quality were achieved by introducing filtration and disinfection in treatment systems. Filtration, which was first implemented in this country in 1906, improved the physical removal of contaminants and, at the time, reduced the incidence of typhoid by as much as 86 percent to fewer than 100 cases per 100,000 people. Further treatment with chlorine disinfectant to inactivate microorganisms practically eradicated the disease by the 1930s.

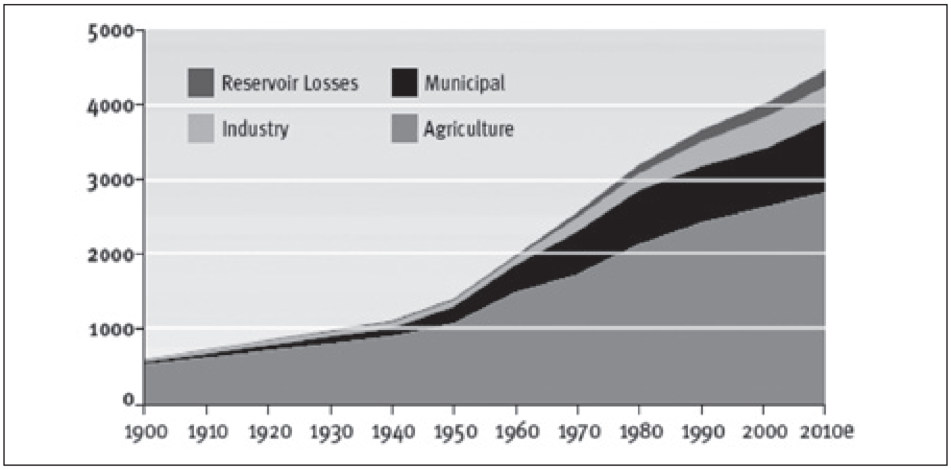

FIGURE 2 Water demand from different sectors from 1900 to 2010. Source: Knight and Miller-Bakewell, 2007.

Unfortunately, this achievement created a false sense of security on the part of water practitioners and the public that all contaminants in water could be eliminated by available treatment practices. This resulted in less focus on source water quality.

Concerns about the quality of source water on a national scale reappeared in the mid/late decades of the 20th century with the development of new technologies for detecting contaminants at trace levels and advances in health sciences that provided a better understanding of the health implications of such contaminants. As a result, the treatment-based framework for providing safe water was gradually replaced by a multi-barrier approach that requires protective action at every point in the water cycle, beginning with the protection of source water.

Limitations of the Clean Water Act

Significant improvements in water quality were achieved in many U.S. rivers following the implementation of the Clean Water Act (CWA), which was enacted in 1971 to ensure that U.S. waters were swimmable and fishable. As an example, no more fires occurred on the Cuyahoga River, which had at least 13 fires due to oil pollution prior to 1971. Unfortunately, these improvements were not adequate for protecting source water, largely because the CWA does not include regulatory control over nonpoint sources of pollution.

Chromium Pollution

Chromium contamination is another, probably less noted, example of a CWA shortcoming in terms of protecting drinking water sources. A carcinogen in the hexavalent form (Cr^{6+} or Cr^{-6}) (Kimbrough et al., 1999), chromium occurs naturally in the environment but is also released into the environment by a number of industries. About 44.3 million pounds of chromium were disposed of by U.S. industries in 2009, including 10.6 million pounds from electric utilities (Evans et al., 2011).

Assuming a U.S. population of 300 million, the chromium from electric utilities alone is equivalent to 44 milligrams (mg) per person per day. By comparison, the amount of chromium currently allowable in drinking water is 0.1 mg/liter. Assuming that 2 liters of water are consumed per person per day, exposure to chromium via drinking water is 220 times lower than the chromium released by just this one industry. If ongoing discussions of regulation of Cr^{-6} result in even lower allowable levels of chromium in drinking water, the ratio will be even larger.

Upgrading water treatment plants to achieve these extremely low levels of Cr^{-6} in drinking water would be very expensive and would substantially increase energy use and greenhouse gas emissions. Therefore, we believe it would be more economical and prudent to control chromium disposal and its release to the environment at the source by tightening controls in the CWA or Resource Conservation and Recovery Act, rather than controlling it "downstream" at water treatment plants by very stringent regulations that would require very costly plant upgrades.

The Safe Drinking Water Act

Like the CWA, SDWA provisions are not adequate for protecting source water. SDWA requires that states conduct a source water assessment (SWA) for each water intake to determine its susceptibility to pollution. However, the SDWA lacks any provision for controlling sources of pollution identified by SWAs. Control is left to voluntary partnerships at the local level, which rarely work unless utilities pay for controlling pollution by upstream dischargers.

Controlling Potential Oil Pollution

Another challenge to protecting source water is oil pollution caused by failures of oil pipelines that cross watersheds. These pipelines are loosely regulated by the federal government, but state and local agencies have no control over them.

In 1993, for example, about 477,000 gallons of petroleum products, which can contain harmful chemicals such as benzene and toluene, spilled into a tributary of the Potomac River upstream of the Fairfax County Water Authority Corbalis Water Treatment Plant. The plant, which provides potable water to about 1.5 million people close to the nation's capital, was forced to shut down completely for 13 days (EPA, 1999).

Extreme hydrological events and rapid variations in source water quality are expected to become more frequent and more intense as a result of climate change.

Fortunately, a combination of water-conservation efforts by the community and the availability of alternative sources of drinking water enabled Fairfax Water to offset the loss of water production at Corbalis. If those water sources had not been available, however, the community would have been without a safe supply of potable water for two weeks.

Pollution from Natural Events

Natural hydrological events also affect source waters. In 1938, a catastrophic hurricane hit the Quabbin Reservoir, Boston's primary water supply. Heavy rain and winds caused severe uprooting and stem breaks of approximately 75 percent of the trees in the Quabbin watershed (Ottenheimer, 1992). As a result, tree roots could no longer hold sediment and nutrients in place, and significant amounts of both washed into the reservoir, promoting the growth of algae (and the potential formation of algal toxins dangerous to humans), depleting oxygen from the water, and suffocating fish and other aquatic wildlife.

Treatment plants are also impacted by severe hydrobiological events, such as intense rain and major algal blooms. Treatment plants are designed to operate optimally in terms of performance and costs within a certain range of conditions, and large, rapid variations can negatively impact their operation. During one such event, WSSC Potomac WFP faced a 40-fold increase in raw water turbidity (an increase of 21 nephelometric turbidity units [NTU] to 900 NTU in just 2 hours).

In the future, extreme hydrological events and rapid variations in source water quality are expected to become more frequent and more intense as a result of climate change. These events could greatly increase strains on drinking water treatment facilities.

Emerging Contaminants: A Major Challenge for Water Treatment Facilities

Emerging contaminants present serious challenges for water utilities. The European Union estimates that approximately 140,000 products, including pharmaceuticals and personal care products (PPCP), on the market contain compounds considered emerging contaminants (ChemSec, 2011). Our understanding of potential human health impacts and persistence in the environment of these compounds, as well as our capability of detecting them, are still limited. Moreover, no regulations or guidelines have been put in place for managing the vast majority of these compounds.

Potential impacts on aquatic organisms, as demonstrated by intersex fish (female characteristics observed in males or vice versa) have been widely reported. The media and the public consider the occurrence of intersex fish "the canary in the coal mine" of potential effects of emerging contaminants in drinking water on human health. Concerns include mixture effects (from the presence of multiple compounds), effects on vulnerable individuals (e.g., infants and very young children), and intergenerational effects.

However, because of significant differences between fish and human exposure, using intersex fish as the canary in the coal mine may not be appropriate. Fish are exposed to water that may contain low levels of contaminants continuously—24 hours a day, 7 days a week—whereas human exposure to water is dramatically lower. Each person drinks only about 2 liters of water a day and has limited dermal exposure.

More important, fish are exposed to much higher levels of contaminants in water as a result of bioaccumulation-biomagnification of contaminants via the aquatic food chain. Studies have shown that biomagnification can amplify very low aqueous concentrations in a river to high concentrations in aquatic organisms much higher on the food chain (Kelly et al., 2007). For example, DDT has been increased by 7 orders of magnitude, from 0.000003 parts per million (ppm) in a river to 20.00 ppm in birds that ingest fish exposed to contaminated water.

Although the canary in the coal mine image may be questionable for assessing human health implications from drinking water exposures, it may be appropriate for total exposure to contaminants. Based on the limited data currently available, we do not have reliable knowledge about the level of human exposure to these chemicals, but it is likely to be many times higher via food and chemicals than via drinking water.

What we do know is that removing trace levels of contaminants during the water treatment process would be extremely expensive and energy intensive. In addition, sometimes changes can have unintended consequences. For example, switching from chlorine to chloramine disinfection to reduce the formation of disinfection by-products (DBP) in tap water increased lead in water due to corrosion in lead pipes (e.g., Giammar, 2009). In other instances, the removal of organic matter in drinking water to reduce DBPs is believed to have caused pinhole leaks in copper pipes, requiring homeowners to spend millions of dollars collectively for repairs (Edwards and Sprague, 2001; Edwards et al., 2003).

Overall, using intersex fish as the canary in the coal mine not only seems unwarranted for water supply, at least for now, but it also diverts attention from a holistic approach to protecting public health, the ecosystem, and source waters. In addition, it puts the financial burden on water utilities and leaves the producers of emergent contaminants and upstream dischargers with no incentives to reduce pollution (e.g., by green chemistry or control at the source).

We believe that requiring water utilities to treat water to very low contaminant detection limits without considering pollution reduction/elimination at the source or from other exposure pathways would not only be a huge financial challenge to water utilities (as well as a moral dilemma about redirecting limited financial resources), but also might not achieve meaningful reductions in total exposures. Nevertheless, we recognize that water utilities must continue to monitor research; advocate/participate in relevant investigations; educate customers, the media, and others; and advocate a holistic approach in lieu of an inefficient, "silo-based" strategy.

Infrastructure Challenges

A major problem plaguing many W-WW utilities is pipe breaks and service interruptions caused by aging infrastructure. The American Society of Civil Engineers (ASCE) assigned water and wastewater infrastructure in the United States a grade of D– and cited a five-year funding shortfall of about $109 billion for the nation, above and beyond the $146 billion that will be spent by W-WW utilities (i.e., $255 billion total is required) (ASCE, 2010). Disruptions caused by pipe breaks can interfere with the distribution of potable water, adversely impact firefighters, damage roadways and other infrastructure, and potentially expose water to external contaminants.

Water Distribution Systems

In the late 1960s and early 1970s, WSSC installed approximately 350 miles of pre-stressed concrete cylinder pipe (PCCP), ranging from 18 to 96 inches in diameter. PCCP is a composite of concrete and pre-stressed steel cylinders. However, from 1975 on, numerous catastrophic PCCP failures occurred in the WSSC district (see example in Figure 3) arousing public outrage and causing tremendous damage to roads and adjacent

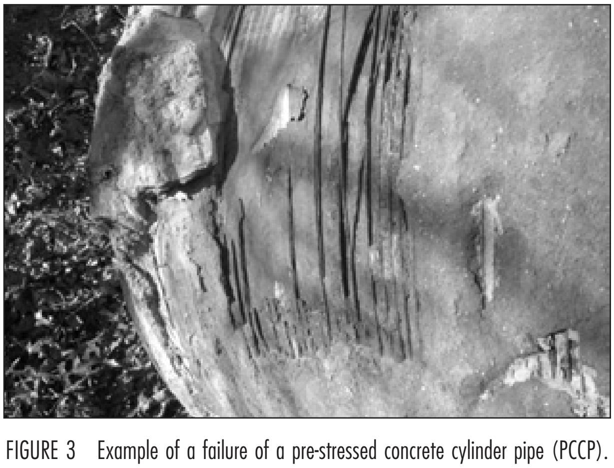

FIGURE 3 Example of a failure of a pre-stressed concrete cylinder pipe (PCCP). Source: WSSC.

infrastructure. The price tag for replacing all of the PCCP as a preventive measure, as the public desired, would have been about $2.9 billion. WSSC adopted a more economical approach of using nondestructive testing, monitoring, and inspection and replacing the segments at high risk of failure.

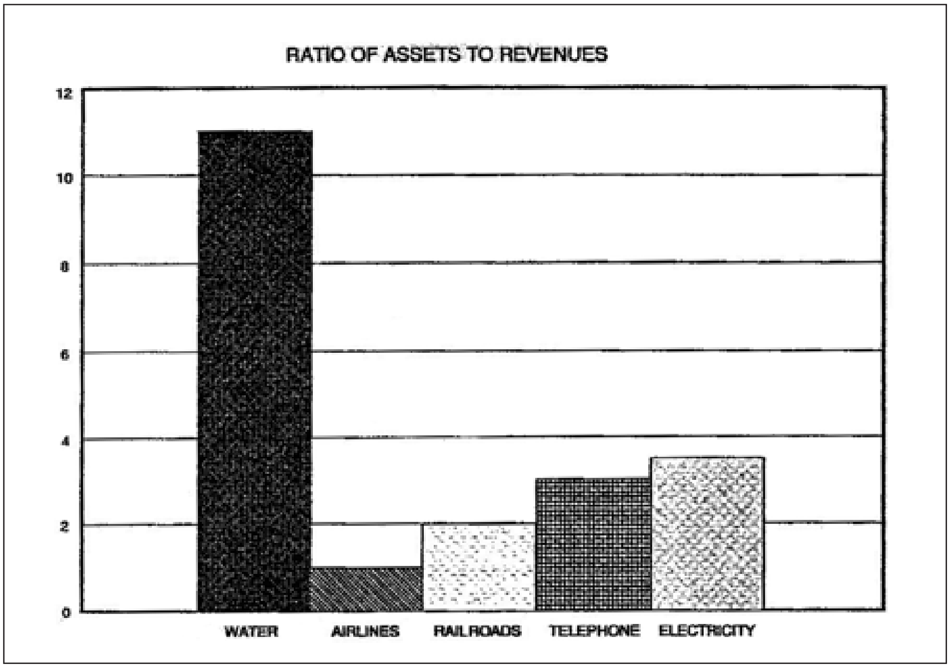

FIGURE 4 Comparisons of the capital intensity by industry. Source: EPRI, 1998.

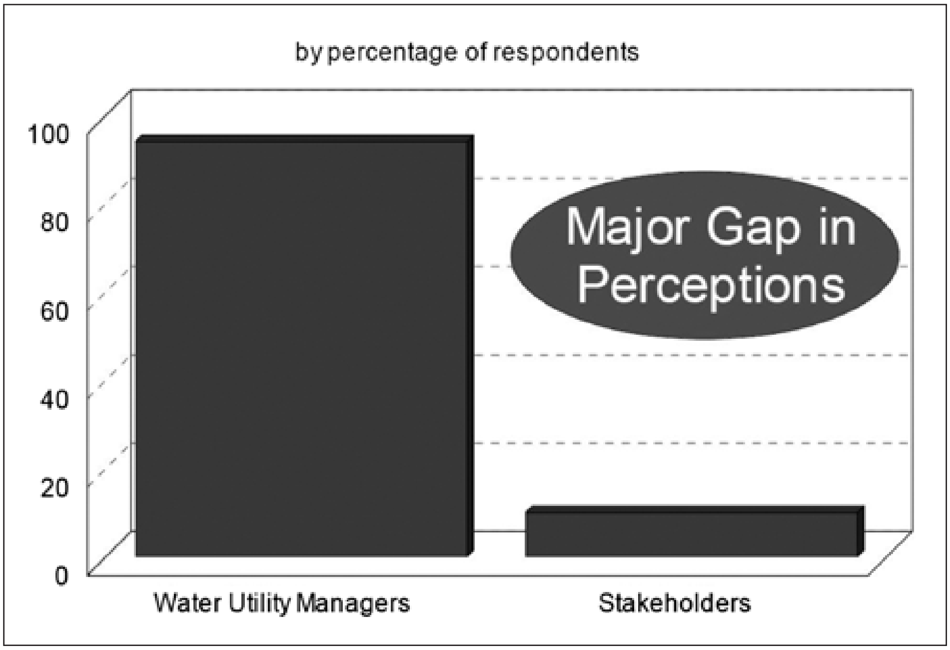

FIGURE 5 Differences in perceptions of environmental leadership by water utilities and stakeholders. Source: Tatham et al., 2006.

Wastewater Collection Systems

Similarly, W-WW utilities face major challenges related to sanitary sewer overflows (SSO). Houston, for example, conducted a study to monitor and model occurrences of fecal coliform upstream and downstream of SSO discharge points. The study revealed that because of highly polluted runoff from nonpoint sources, fecal coliform levels above and below the SSO discharge point differed by only about 1 percent. Thus, the benefit of SSO control was almost nil.

Nevertheless, the utility was required to allocate $1.2 billion for SSO control, funds that could have been used for extensive holistic actions in the watershed to achieve a much bigger improvement in water quality. Many other utilities face similar challenges.

Funding Issues

W-WW utility service is a capital-intensive undertaking, and many W-WW utilities face funding issues. Their asset/revenue ratio (11) is far higher than for other types of utility services, such as electric utilities (3.5) (Figure 4). In addition, some components of water and wastewater infrastructure (e.g., pipelines, tank structures) have 50 to 100 years of service life but generally must be paid for with 20- to 25-year loans. We urgently need to address this issue in particular to ensure the sustainability of water and wastewater services.

Communication Challenges

Until a few decades ago, W-WW utilities worked primarily with federal and state agencies and did not have much interaction with customers. This resulted in significant misunderstandings between utilities and their customers (Figure 5).

Times have changed, however. Today W-WW utilities are confronted not only by more stringent, sometimes conflicting, regulatory requirements, but they also receive inputs/questions on a daily basis from a growing number of other stakeholders. Computer-savvy groups and individuals often use social networking tools to pursue their objectives and ideas, which may or may not be based on sound science and may or may not lead to holistic solutions. In these situations, W-WW utilities may be pressured to make short-sighted decisions that do not take into account the larger context of sustainability.

Unfortunately, sensational reporting during crises makes communication particularly difficult, and fear mongering by advocacy groups addressing the contaminant *du jour* is often spread by the media. Educating customers and stakeholders on actual risks and persuading them to take a holistic, rational approach may be the most difficult challenge of all, especially during a crisis.

To address the communication challenge, W-WW utilities must establish a proactive relationship with stakeholders based on credibility and trust. Although it might take years to establish such a relationship, especially if public perceptions have been negative, only when utilities are considered credible and trustworthy will their arguments for addressing issues in a holistic sustainable way be heard above the noise.

Conclusions

W-WW utilities face critical issues in every aspect of their operation, including source water availability and quality, treatment for controlling emerging contaminants at trace levels, major rehabilitation and replacement of aging water distribution and wastewater collection infrastructure, serious funding issues, and communication challenges. To address these issues, we must educate our customers and the media and work collectively with legislative and regulatory agencies to expedite the transition from the current silo-based approach to addressing problems to a more efficient and long-term holistic approach.

Acknowledgment

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References

ASCE (American Society of Civil Engineers). 2010. Report Card for America's Drinking Water Infrastructure for 2009. Available online at *http://www.infrastructurereportcard.org/fact-sheet/drinking-water*. (Accessed September 16, 2011).

ChemSec (International Chemical Secretariat). 2011. "The EU regulation on chemicals." Available online at *http://www.chemsec.org/get-informed/eu-chemicals/reach*.

Edwards, M., and N. Sprague. 2001. Organic matter and copper corrosion by-product release: a mechanistic study. Corrosion Science 43(1): 1–18.

Edwards, M., D. Bosch, G.V. Loganathan, and A.M. Dietrich. 2003. The Future Challenge of Controlling Distribution System Water Quality and Protecting Plumbing Infrastructure: Focusing on Consumers. In Proceedings of the IWA Leading Edge Conference. Noordwijk; Netherlands.

EPA (Environmental Protection Agency). 1999. Response to Oil Spills. Chapter 8. EPA: Washington, D.C.

EPRI (Electric Power Research Institute). 1998. Competition in the Water and Wastewater Industries. Industrial and Agricultural Technologies and Services, Report CR-110244.

Evans, L., B. Gottlieb, L. Widawsky, J. Stant, A. Russ, and J. Dawes. 2011. EPA' s Blind Spot: Hexavalent Chromium in Coal Ash. Available online at *http://www.psr.org/assets/pdfs/epas-blind-spot.pdf*.

Giammar, D. 2009. Influence of Water Chemistry on the Dissolution Rates of Lead Corrosion Products. In Proceedings of the American Water Works Association Water Quality and Technology Conference. Seattle, Wash.: American Water Works Association.

Issar, A.S. 2008. The impact of global warming on the water resources of the Middle East: past, present, and future. Pp. 145–164 in Climatic Changes and Water Resources in the Middle East and North Africa. New York: Springer.

IWMI (International Water Management Institute). 2006. Water for Food, Water for Life: Insights from the Comprehensive Assessment of Water Management in Agriculture. Battaramulla, Sri Lanka: IWMI.

Kelly, B.C., M.G. Ikonomou, J.D. Blair, A.E. Morin, and F.A.P.C. Gobas. 2007. Food web-specific biomagnification of persistent organic pollutants. Science 317(5835): 236–239.

Kimbrough, D.E., Y. Cohen, A. Winer, L. Creelman, and C. Mabuni. 1999. A critical assessment of chromium in the environment. Critical Reviews in Environmental Science and Technology 29(1): 1–46.

Knight, Z., and R. Miller-Bakewell. 2007. Water Scarcity: A Bigger Problem than Assumed. New York: Merrill Lynch Equity Strategy. Available online at *http://www.ml.com/media/86941.pdf*.

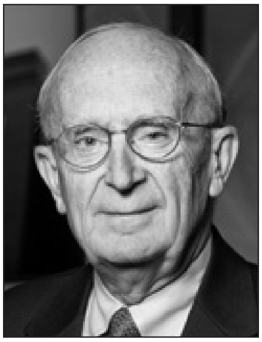
Ottenheimer, D.G. 1992. Hurricane susceptibility and water quality at Quabbin Forest, Massachusetts. Master's Thesis. SUNY College of Environmental Science and Forestry.

Tatham, C., R. Cicerone, and E. Tatham. 2006. Stakeholder Perceptions of Utility Role in Environmental Leadership. Denver, Colo.: Water Research Foundation, American Water Works Association, IWA Publishing.

UN (United Nations). 1987. *Report of the World Commission on Environment and Development*. A/RES/42/187, 96th Plenary Meeting, December 11, 1987.

The United States has no national policies or institutions in place to deal with the major water challenges that lie ahead.

A Plea for a Coordinated National Water Policy



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U.S. scientists chartered by Congress through the National Academies have affirmed that climate change is occurring, identified its potential impacts, and concluded that it is very likely related to human activity (NRC, 2011a). As Working Group II of the Intergovernmental Panel on Climate Change (IPCC) has reported, the direct impacts of climate change on world water resources will be to reduce available water supplies in some regions, raise sea level, and increase the probability of significant water-related disasters such as floods and hurricanes (Bates et al., 2008).

The world is enmeshed in climate-related change, and the United States is in the thick of it. The U.S. population is growing faster than in most other developed countries, and the U.S. Census Bureau expects it will increase by as many as 150 million by 2050; this will also increase the demand for water as well as for food and fiber. This rapid growth, coupled with a continuing shift in population to areas near water and/or with warm climates, is also likely to result in unplanned growth in areas subject to natural disasters.

All of these changes are occurring amidst volatile, complex, and ambiguous changes in many nations around the world. Until recently, when planners looked to the future, they envisioned a world very much like the present. Future climate could be judged by past climate, and societal needs and demands could be expected to remain within a narrow range (Figure 1a). However, a bounded future can no longer be expected.

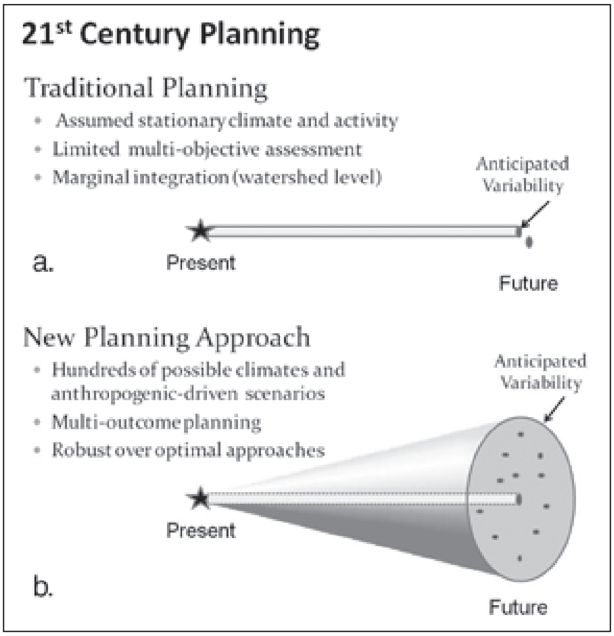


FIGURE 1 (a) Planning under current paradigms, which have undergone limited change over time. (b) New paradigm with a broad range of potential futures. Source: Adapted from Mark Waage, Denver Water (2010) with permission.

Planners and decision makers must now consider numerous alternative scenarios characterized by a high degree of variability and uncertainty (Figure 1b).

The hydroclimatic changes underway have been held responsible for the end of "stationarity—"the idea that natural systems fluctuate within an unchanging envelope of variability" (Milly et al., 2008). Previously predictable hydrologic futures have become considerably more uncertain, making water-related planning and decision making much more difficult.

Like other countries, the United States faces a long list of water challenges:

- More frequent and more severe droughts and increased water demand. In 2002, 49 percent of the country was experiencing moderate to severe drought. Since then, drought has become commonplace in many more places across the country. At the same time, population growth, especially in urban areas of the West, is increasing pressures on limited water supplies (NDMC, 2011).
- Degraded water quality. The 1970s goal of providing fishable, swimmable, and drinkable water throughout the nation has not been realized. Control over point-source pollution has resulted in significant improvement in water quality. However, we have yet to effectively address nonpoint-source pollution and its impact on our nation's rivers and groundwater (EPA, 2011a).
- Increasing flood damage. Over the last five decades, average annual flood damage has increased in spite of significant federal investment in structural and nonstructural programs to reduce flood risks and lessen the impact of flooding when it occurs. Flood damage connected with Hurricane Katrina and major floods in 2008 and 2011 resulted in losses higher than the annual average of $6 billion. Stormwater flooding is also a growing problem in urban areas (NWS, 2011).
- Aging and inadequate maritime infrastructure. Although ports, harbors, and inland waterways are critical to the success of national and international commerce, much of the U.S. inland waterway infrastructure is outdated and appreciably slows barge traffic. In addition, many ports, harbors, and channels are not competitive in today's deep-draft shipping environment (ASCE, 2009a; USACE, 2011).
- Inadequate protection of the environment. Riverine and coastal ecosystems remain at risk as floodplains and wetlands are subject to increasing pressure by developers or are disappearing as a result of anthropogenic activities that have undermined their stability. More than 1,300 species of animals and plants are on the federal threatened or endangered species lists (USFWS, 2011).
- Legacy environmental damage. Human activities over the last century have severely damaged ecosystems in many places in the United States, including the Everglades, coastal Louisiana, the Chesapeake Bay, the upper Mississippi and Missouri Rivers, and the California Bay Delta. Only in the last two decades have efforts begun to restore the natural functions of these areas. The resources needed for restorations far exceed the amount that has been, or is likely to be, committed to those efforts (EPA, 2011b).
- Lack of understanding of the water-energy nexus. The availability of water is critical to the extraction of a variety of energy resources, the safe operation of nuclear and conventional power plants, and the production of renewable energy resources. The deep pumping of groundwater resources and the diversion of ground and surface waters for irrigation has placed heavy demands on energy supplies. Trade-offs are being made on a daily basis among water uses in an essentially zero-sum game.

- Inadequate protection of groundwater. Groundwater provides 18 percent of the nation's urban water supply, yet we are a long way from fully understanding the locations and conditions of groundwater resources. Contamination is a continuing challenge, and only a few communities have taken steps to protect the source areas of their groundwater (Kenny et al., 2009; USGS, 2011).
- Inadequate or nonexistent watershed planning. At the federal level, authorization and appropriation of funds for water resources are linked to specific projects rather than to needs identified on a watershed or basin level. Management by earmark rather than by national priorities and watershed needs inhibits comprehensive planning and ignores upstream-downstream interrelationships (AWRA, 2007).
- Dealing with interstate conflicts. States are responsible for managing waters entirely within their boundaries. However, management of interstate waters is problematic, and decisions on the use of shared waters are frequently made by courts or the federal government instead of by collective action of the states involved. For example, the states in the Missouri River basin have been arguing for more than two decades about the operation of the six large federal dams on the main stem of the Missouri. In another example, Florida, Alabama, and Georgia, to which Congress delegated authority to develop an accord on the use of the waters of the Apalachicola, Chattahoochee, and Flint Rivers, have been unable to come to an agreement in spite of more than two decades of negotiating. In both cases, the courts have been called upon to adjudicate specific issues that should have been addressed by multistate agreements (NRC, 2009, 2011b).
- Crumbling, outdated water infrastructure. The American Society of Civil Engineers (ASCE), in its biennial report on the condition of the nation's built environment, continues to give the five water infrastructure sectors grades of D or D– and has identified multibillion dollar funding shortages and deficient conditions in water and wastewater systems, dams, navigation, and levees (ASCE, 2009a).
- Lack of knowledge of current conditions. The United States has not undertaken a comprehensive water assessment since 1976. Although the U.S. Geological Survey (USGS) produces periodic reports on aspects of water availability and use, no effort has been made to fully understand 21st century challenges. On the contrary, resources for monitoring current conditions are being reduced every year (Schiffries and Gropp, 2009).

Managing Our Water Resources

So what are the guidelines for U.S. water policy as we enter the second decade of the 21st century? Good water management, any management for that matter, is predicated on a vision based on goals and objectives for realizing that vision. Together the vision, goals, and objectives shape the policies that define responsibilities and authorities of organizations and individuals and describe how they will bring us closer to achieving the vision and how they will be coordinated with activities in other sectors.

> *Since the 1970s, we have become increasingly confused about fundamental management of U.S. water resources.*

The Policy Framework

The National Environmental Policy Act of 1969 clearly stated the goals, objectives, and policies that have guided our treatment of the environment. The Water Pollution Control Act Amendments of 1972 provided a vision for the future condition of water—fishable, swimmable, and drinkable—and established policies and procedures that have led to improvements in water quality. The Endangered Species Act of 1974 defined the treatment of flora and fauna and the habitats on which they rely. However, since the 1970s we have made little progress and have become increasingly confused about fundamental management of the nation's water resources.

Following the great Mississippi flood of 1993, a White House study committee reported that the nation's approach to dealing with floods was uncoordinated and lacked clear direction. In its report, *Sharing the Challenge: Floodplain Management into the 21st Century*, the committee recommended enactment of legislation based on a vision for management of floodplains and a description of the responsibilities of federal, state, and local governments (IFRMC, 1994). Although legislation was considered in 1994, political changes in Congress that year tabled all action.[1]

Wrangling over Flood Management in the Missouri River Basin

Use and control of the waters in the Missouri River basin have long been of interest to the federal government. Early in the 20th century, dams in support of power and reclamation were built, and in 1933, construction began on Fort Peck Dam in Montana to support downstream flood control and navigation.

In the 1940s, concern about the water resources of the Missouri River basin led to congressional approval of the Pick-Sloan Plan in the 1944 Flood Control Act. The plan was developed by the U.S. Army Corps of Engineers (USACE) and the Bureau of Reclamation (Bureau) to address the need for flood control, navigation, fish and wildlife protection, hydroelectric power, public water, recreation, irrigation, and water quality.

An NRC report concluded that the ecosystem in the Missouri River basin was in danger of collapse.

In the 1950s and 1960s, five additional large dams were built on the main stem of the Missouri River, and numerous others were built by USACE and the Bureau on tributaries to carry out this mandate. Subsequent environmental legislation, such as the Endangered Species Act, added additional purposes to the use of the Missouri River basin, and congressional committee guidance "informed" decisions on operating matters.

When a major drought hit the Midwest in 1988 and drew down water in the Mississippi River, concerns arose that Missouri River water might be used to "help out" the Mississippi at the expense of Missouri River navigation and several threatened and endangered species. Following the drought, USACE began a detailed review of its operation of the main stem dams.

In spite of efforts by all parties, no resolution had been reached as the 21st century began. The 10 states in the basin have not agreed among themselves even about what would constitute appropriate operation. In 1999, USACE and EPA asked the National Research Council (NRC) to examine threats to the Missouri River ecosystem. The NRC report concluded that unless immediate actions were taken to address the needs of endangered and other species, the ecosystem was in danger of collapse (NRC, 2002):

> Current management protocols for operating the Missouri River system represent an accretion of federal laws, congressional committee language, appropriations instructions, and organizational interpretations that have been enacted or developed over the past century. This guidance has generally not been updated to reflect changing economic and social conditions, scientific knowledge, economies, and social preferences which have clearly changed across the Missouri River basin since the mainstem dams were planned and constructed. However, the institutional and policymaking framework for Missouri River management has not changed accordingly. The decision-making context for the Missouri and its tributaries is characterized by prolonged disputes, disaffected stakeholders, and degrading ecological conditions. Barriers to resolving this policy gridlock on the Missouri River include a lack of clearly stated, consensus-based, measurable management objectives, powerful stakeholders' expectations of a steady delivery of entitlements, and sharply differing opinions and perspectives among some Missouri River basin states.

Even as the NRC study was under way, various basin states were bringing suit in federal court against USACE to force modifications of its operating rules. The states came down on all sides of the disputes, but the U.S. Department of Justice consolidated them into one case that was heard by a federal judge in Minnesota. His ruling, in 2004, acknowledged the conflicting guidelines under which USACE was operating and, in essence, seconded the comments of the NRC committee. In 2006, USACE made the decision to implement new operating procedures. In the FY 2009 Omnibus Appropriations Act, Congress finally acted, directing that a study be initiated to determine if changes to the authorized purposes of the project and existing federal water resources infrastructure might be warranted (MoRAST, 2009).

[1] The 1994 report was a subject of discussion during Senate hearings in 2008 and 2011 following major Midwest floods in those years. In both cases, the administration was directed to report on actions taken in response to the 1994 report.

Confusion and Failed Efforts

In 1992, in response to concerns about future challenges to water use in the western United States, Congress directed the formation of a federal-state-public commission to "review present and anticipated water resource problems affecting the nineteen Western States." Members of Congress were concerned about overlapping and conflicting jurisdictions and the large number of cabinet departments, independent agencies, and White House offices dealing with national water policy. The situation, according to then-Senator Mark Hatfield, "created considerable confusion among the ranks of water policy makers and water policy implementers" (WWPRAC, 1998).

In 1998, the commission issued its report, *Water in the West: Challenge for the Next Century*, in which it concluded that addressing water challenges would require "fundamental changes in institutional structure and government process." It confirmed the congressional belief that "federal water policy suffers from unclear and conflicting goals implemented by a maze of agencies and programs." Although the report received considerable notice, little action resulted. Other NRC studies during those same years also highlighted the absence of a national approach to water resources development and the need for coordinated water-related legislation.

Even in the absence of legislation on a watershed level, effective management could be facilitated by a clear definition of the objectives of water projects. In 1965, Congress passed the Water Resources Planning Act, which, among other things, directed the administration to develop principles and standards for water resources project development.

The first Principles and Standards, produced by the Water Resources Council in 1973 and revised in 1977, called for projects to be judged on the basis of their contributions to a combination of national economic development, regional economic development, environmental quality, and other social effects (WRC, 1973a,b).

In 1983, the Reagan administration replaced the Principles and Standards with Principles and Guidelines, which established national economic development as the sole objective of development and paid lip service to the other objectives (WRC, 1983). Criticism of this revision was consistent over the next two decades, and several NRC reports pointed out its shortcomings. (NRC, 1999, 2004a,b).

The Beat Goes On

Given the absence of a unifying national approach, many have expressed concerns about conflicts among sectors (agriculture, navigation, hydropower, recreation, etc.) over uses of water and continuing interstate discord. In 2001, several federal agencies asked the American Water Resources Association (AWRA) to bring together water experts from around the nation to discuss policies for guiding water resources activities of the United States. By the time the first dialogue was held in Washington in 2002, 10 federal sponsors were fiscally supporting the dialogue.

Many have expressed concerns about conflicts among economic sectors over uses of water and continuing interstate discord.

More than 20 nongovernmental organizations agreed to cosponsor the dialogue, which brought together more than 250 people for two-and-one-half days. The result was a letter to the president and congressional leaders highlighting the general consensus of the participants. Unfortunately, little attention was paid to the letter either on Capitol Hill or in the White House.

A year after the first dialogue and the submission of the letter, the same federal agencies asked AWRA to conduct a second dialogue in 2005 in Tucson, Arizona, to ensure that western views were incorporated into the conversation. The issues raised in the second dialogue paralleled those in the first, and a letter similar in content to the first was sent to the president. Unfortunately, the reaction from leaders was also similar.

In 2006, the same federal agencies, in hopes of transforming the results of the first two dialogues into action, asked AWRA to bring together experts in Washington, this time with the goal of identifying actions to be taken. Following this meeting, letters were sent to the president, senior congressional leaders, and all state governors, noting that "Stewardship of the Nation's water resources is being neglected and the manner in which we deal with water issues is dysfunctional." All three letters stressed the same general needs (AWRA, 2007):

- The Administration and Congress should work with governors and tribal leaders to establish broad principles for water management—in essence, a national vision. In turn the vision must be translated into water policies that clearly define the roles and responsibilities of federal, state and local governments and the public with respect to water and the goals and objectives that would establish a blueprint for future actions.

The House Transportation and Infrastructure Committee is responsible for preparing a biennial Water Resources Development Act.

- The Administration and Congress should better coordinate water resources activities. The efforts of federal agencies can overlap and at times conflict, and there is no body within the Administration to provide substantive coordination or adjudication of disagreements among agencies and to ensure needed collaboration. Furthermore, the Congress should work to eliminate the frequently uncoordinated actions of the numerous Congressional committees that deal with water.
- The Administration, Congress, and the governors must encourage policies that promote watershed planning and change policies that do not. Federal agency operations and programs need to be more watershed-oriented rather than tied to political boundaries and project-level authorizations and appropriations that often create more problems than they solve. Much should be learned from the successful efforts of some states and tribal organizations to operate in this manner.
- The Administration, Congress, and the governors must ensure that the Nation's vast scientific knowledge about water is available to all, clearly presented, and fully considered in making decisions on key water issues. Critical data about water resources must be collected.

The 2007 letter did receive some attention from both the administration and Congress. Senior staff members in both groups requested briefings on the results of the dialogue, and later that year, in the 2007 Water Resource Development Act, Congress established a National Water Resources Planning Policy and directed the Secretary of the Army to revise the current Principles and Guidelines to reflect those policies within two years.

Since the Principles and Guidelines had resulted from a presidential directive and applied to four federal agencies, the administration assumed responsibility for the formulation of a new principles and guidelines document that would apply to all federal agencies. In 2010, the White House circulated an initial draft of the new document for comment by the public and the National Academies. In late 2010, an NRC committee submitted its comments (NRC, 2011a) to the White House indicating that, although the thrust of the document seemed responsive to the congressional direction, the document itself was confusing and in need of substantial revision. A new document has yet to be issued.

In 2009, Congressman James L. Oberstar, then chairman of the House of Representatives Transportation and Infrastructure Committee, which is responsible for preparing the biennial Water Resources Development Act, reported to a group of water experts assembled in Washington, D.C. (USACE, 2010):

> Today, the diverse water resources challenges throughout the United States are often studied, planned and managed in individual silos, independently of other water areas and projects. Generally, this has resulted in local and narrowly focused project objectives with little consideration of the broader watersheds that surround the project. There are 24 Federal agencies with water responsibilities and this does not count the land management agencies with related responsibilities. Policy is ad hoc, implementation is decentralized, coordination is fragmented, and communication is non-existent or fails to connect. We need a national water policy and unifying vision and guiding principles.

Glimmers of Hope

In 2008 and 2009, USACE, in coordination with several other federal agencies, conducted listening sessions around the country to explore how collaborative efforts to deal with water resources challenges could be improved. The group concluded its efforts with a two-day National Conference in Washington that brought together "water actors" on the federal, state, and local levels.

Participants in the conference supported the development of "a national water vision, especially one that unifies the focus and policies regarding water resources across levels of government, and especially across the federal agencies." For some, the ongoing review of Principles and Guidelines would offer an opportunity to begin the development of the elements of a vision (USACE, 2010).

Following the disastrous 2008 floods in the Midwest, the president of the Mississippi River Commission brought together senior representatives of federal agencies operating in the flood-affected areas to develop a long-term vision that included the following goals for people living in the Mississippi River basin (MRC, 2011):

- They would enjoy a quality of life unmatched in the world.
- They would lead secure lives along any river or tributary in the basin.
- They would enjoy fresh air and the surrounding fauna, flora, and forests while hunting, fishing, and recreating along any river or tributary in the basin.
- They could travel easily, safely, and affordably to various destinations in the watershed.
- They could drink from and use the abundant waters of any river, stream, or aquifer in the basin.
- They could choose from an abundance of affordable basic goods and essential supplies grown, manufactured, and transported along the river to local and world markets.

In April 2011, the White House issued a water framework, *Clean Water: Foundation of Healthy Communities and a Healthy Environment,* which, although titled *Clean Water,* describes coordinated actions being taken by the Obama administration to deal with an array of pressing water issues and the overarching concepts that will guide the development of solutions to those issues. The framework focused on the following principles (EOP, 2011):

- Promoting Innovative Partnerships . . . to restore urban waters, promote sustainable water supplies, and develop new incentives for farmers to protect clean water.
- Enhancing Communities and Economies by Restoring Important Water Bodies…including restoring iconic places like the Chesapeake Bay, California Bay-Delta, Great Lakes, Gulf of Mexico and Everglades.[2]
- Innovating for More Water-Efficient Communities.
- Ensuring Clean Water to Protect Public Health.[3]
- Enhancing Use and Enjoyment of our Waters [by] . . . expanding access to waterways for recreation, protecting rural landscapes, and promoting public access to private lands for hunting, fishing and other recreational activities.
- Updating the Nation's Water Policies includ[ing] action to modernize water resources guidelines, and update Federal guidance on where the Clean Water Act applies nationwide.
- Supporting Science to Solve Water Problems.

The European Union has put in place directives for standards for clean water, sustainable practices, marine environmental policy, and managing flood risks for all 27 member countries.

Example of a Successful Collaborative Approach

In light of the disappointing history of water policy described above, we might ask if it is even possible in this dynamic and politically focused world to develop a formal collaborative framework dealing with water issues that cross boundaries and include differing conditions.

The answer is yes! It is possible. In Europe, a Water Framework Directive was developed by the European Commission and approved by the European Parliament. The directive "governs" some water activities of the 27 countries that are part of the European Union (EU), and it "establishes a legal framework to protect and restore clean water across Europe and ensure its long-term and sustainable use." Although the primary focus

[2] See the article in this issue by David Dzombak, "Nutrient Control in Large-Scale U.S. Watersheds." which discusses some recent successes in the Chesapeake Bay and the challenges ahead.

[3] The article by Rutherford Platt in this issue describes how New York City and Boston, working collaboratively with the federal government, have brought clean water to their residents by carefully managing the watersheds in which the water was collected and obviating the need for expensive water filtration.

is on cleaner EU waters and increasing citizen participation in water decisions, the directive does require the development of basin-level plans to address water use in each basin, as well as floods, hydropower, and navigation (European Commission, 2000).

The Framework Directive has been followed by directives on the quality of water intended for human consumption, the assessment and management of flood risks, and frameworks for community action in marine environmental policy. Under the flood directive, every country must make flood maps—flood-risk maps that include the boundaries of the largest floods that have occurred on each river—and other data. Each directive requires EU countries to pass implementing legislation or face economic sanctions.

So, yes, it is possible to face difficult problems in a collaborative way when the leadership understands the necessity of doing so.

The Need for Effective Communication

So why can't we adopt a similar approach in the United States and take action on key issues? Is this a problem of communication?

> Leaders in the water sector… have long been aware that water is essential to sustainable development, but they do not make the decisions on development objectives and the allocation of human and financial resources to meet them. These decisions are made or influenced by leaders in government, the private sector and civil society, who must learn to recognize water's role in obtaining their objectives (WWAP, 2009).

Even if an agreement is reached in the water community on the need for policy, the challenge will be to communicate this need to those who must make it happen. This is the water box challenge (Figure 2). Every three years, the World Water Assessment Program (WWAP), a United Nations activity, publishes a report on the status of the world's water and the challenges to managing this precious resource.

In the *Third World Water Development Report* (WWAP, 2009), WWAP addressed issues in management of water resources, beginning with a description of the management structure for world water systems. According to WWAP, the governance mechanism for water is divided into two sections.

In the bottom section, the so-called "water box," are water-resources professionals who plan, operate, and maintain world water systems. This group deals with myriad problems of managing this fragile, scarce resource and the technical challenges in dealing with water infrastructure, droughts, floods, and other water issues. The people and groups in the water box focus on the specific issues of the day and meeting the needs of the sectors in which they operate. However, their ability to meet these challenges is heavily influenced by the actions of the actors outside the water box—the political and business sectors and the public at large, who may be, but most likely are not, educated in the specifics of water resource issues.

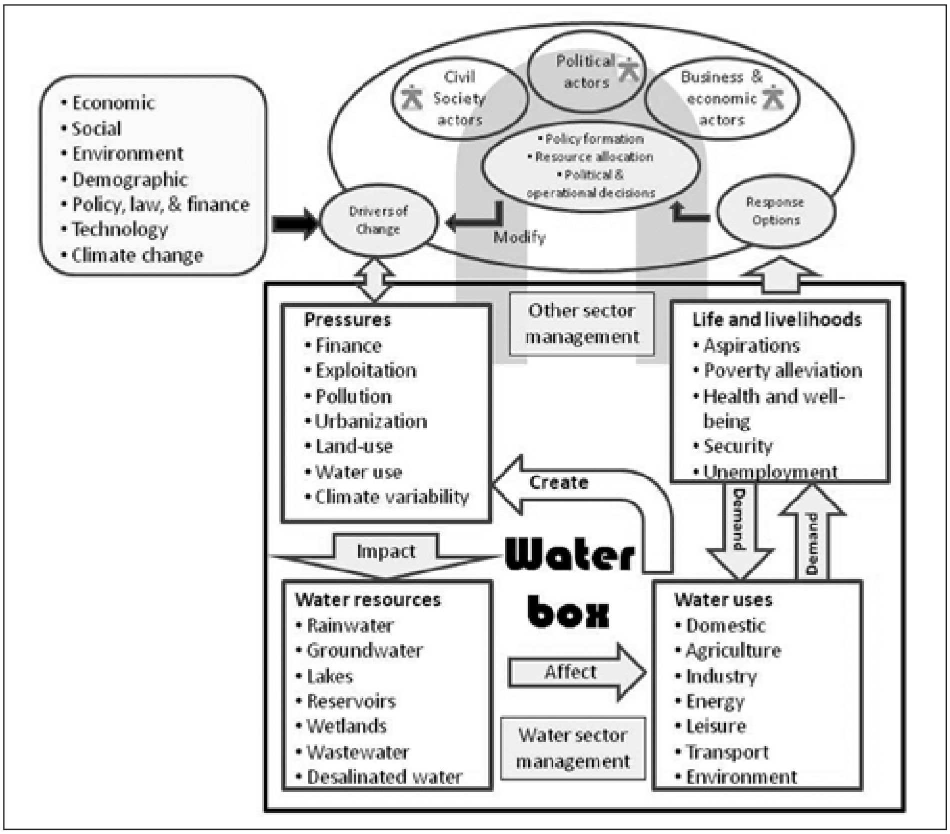


FIGURE 2 The Water Box. Source: WWAP, 2009.

It is not unusual for significant national decisions with water implications to be made without a comprehensive discussion of the implications on the affected resources. For example, recent U.S. actions in support of ethanol production and energy extraction were made outside the water box with only marginal analysis of the long-term implications for water resources.

For those outside the water box to make sustainable decisions, communication between those in the box and external actors must be dramatically improved. Water professionals must do a better job of getting their messages to principal decision makers and insisting that they understand the full story before they make sometimes irreversible commitments.

In *Vision 2025*, ASCE argues that civil engineers must learn to lead and become motivated to initiate, communicate, negotiate, and participate in cross-professional efforts to envision societal changes that shape the quality of life (ASCE, 2007). In a follow-on document, *Achieving the Vision for Civil Engineering 2025: A Roadmap for the Profession*, ASCE continues the argument that engineers "have to raise their visibility, becoming proactive within public policy forums and promoting an awareness that their unique background and skills are crucial…engineers cannot just provide engineered solutions; they must define the problems that affect quality-of-life improvements" (ASCE, 2009b).

That statement translates into increased participation in local meetings, working with legislatures, delivering testimony, and providing knowledge and expertise when and where it is needed through lobbying and other activities. Those tasks are also crucial to the water community.

Conclusion

The time has come for the water community to step up to the challenge and begin to educate and influence those outside the water box about the challenges facing the nation to the efficient, effective, and sustainable management of water resources and what must be done to navigate the uncertainties of the future. No doubt, this mission will make some people uncomfortable—communication is not what we normally do—but it needs to be done, and it needs to be done now!

References

ASCE (American Society of Civil Engineers). 2007. Vision for Civil Engineering 2025. Reston, Va.: ASCE.

ASCE. 2009a. Report Card for America's Infrastructure. Reston, Va.: ASCE.

ASCE. 2009b. Achieving the Vision for Civil Engineering 2025: A Roadmap for the Profession. Reston, Va.: ASCE.

AWRA (American Water Resources Association). 2007. Letter to the President of the United States: National Water Policy Dialogue. Middleburg, Va.: AWRA.

Bates, B.C., Z.W. Kundzewicz, S. Wu, and J.P. Palutikof, eds. 2008. Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp.

EOP (U.S. Executive Office of the President). 2011. Clean Water: Foundation of Healthy Communities and a Healthy Environment. Washington, D.C.: The White House. April 27, 2011.

EPA (U.S. Environmental Protection Agency). 2011a. Monitoring and Assessing Water Quality. Available online at *http://water.epa.gov/type/watersheds/monitoring/monitoring_index.cfm*. Accessed October 1, 2011.

EPA. 2011b. America's Wetlands. Available online at *http://water.epa.gov/type/wetlands/toc.cfm*. Accessed October 1, 2011.

European Commission. 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy. Official Journal of the European Communities (22.12.2000): L 327/1–L 372/72. Brussels: European Commission. Available online at *http://bit.ly/oJPYKH*.

IFRMC (Interagency Floodplain Management Review Committee). 1994. Sharing the Challenge: Floodplain Management into the 21st Century. Washington, D.C.: U.S. Government Printing Office.

Kenny, J.F., N.L., Barber, S.S. Hutson, K.S. Linsey, J.K. Lovelace, and M.A. Maupin. 2009. Estimated Use of Water in the United States in 2005. U.S. Geological Survey Circular 1344. 52 pp. Available online at *http://pubs.usgs.gov/circ/1344/*.

Milly, P.C., D.J. Betancourt, M. Falkenmark, R.M. Hirsch, Z.W. Kundzewicz, D.P. Lettenmaier, and R.J. Stouffer. 2008. Stationarity is dead—whither water management? Science 319(5863): 573–574.

MoRAST (Missouri River Association of States and Tribes). 2009. Section 108 study, 1944 Flood Control Act: Potential questions and issues to be studied. Lawrence, Kan.: MoRAST. Available online at *http://www.dnr.ne.gov/MissouriRiverActivities/Section_108_Questions_0709.pdf*.

MRC (Mississippi River Commission). 2011. America's Watershed: A 200-year vision: An Intergenerational Commitment. Available at *http://www.mvd.usace.army.*

mil/mrc/pdf/MRC_200_Yr_working_Vision_Aug_2011.pdf. Accessed October 1, 2011.

NDMC (National Drought Mitigation Center). 2011. U.S. Drought Monitor. Available on line at *http://droughtmonitor.unl.edu/*. Accessed October 1, 2011.

NEPA (National Environmental Policy Act). The National Environmental Policy Act of 1969. 42 U.S.C. §4332. Available online at *http://ceq.hss.doe.gov/nepa/regs/nepa/nepaeqia.htm*.

NRC (National Research Council). 1999. New Directions in Water Resources Planning for the U.S. Army Corps of Engineers. Washington, D.C.: National Academy Press.

NRC. 2002. The Missouri River Ecosystem: Exploring the Prospects for Recovery. Washington, D.C.: National Academies Press.

NRC. 2004a. U.S. Army Corps of Engineers Water Resources Planning: A New Opportunity for Service. Washington, D.C.: National Academies Press.

NRC. 2004b. Review of the U.S. Army Corps of Engineers Restructured Upper Mississippi River-Illinois Waterway Feasibility Study. Washington, D.C.: National Academies Press.

NRC. 2004c. Analytical Methods and Approaches for Water Resources Project Planning. Washington, D.C.: National Academies Press.

NRC. 2009. Summary of a Workshop on Water Issues in the Apalachicola-Chattahoochee-Flint and Alabama-Coosa-Tallapoosa (ACF-ACT) River Basins. Washington, D.C.: National Academies Press.

NRC. 2011a. America's Climate Choices. Washington, D.C.: National Academies Press.

NRC. 2011b. Challenges Facing the U.S. Army Corps of Engineers. Washington, D.C.: National Academies Press.

NRC. 2011c. Missouri River Planning: Recognizing and Incorporating Sediment Management. Washington, D.C.: National Academies Press.

NRC. 2011d. A Review of the Proposed Revisions to the Federal Principles and Guidelines Water Resources Planning Document. Washington, D.C.: National Academies Press.

NWS (National Weather Service). 2011. Hydrologic Information Center - Flood Loss Data. Available online at *http://www.nws.noaa.gov/hic/flood_stats/Flood_loss_time_series.shtml*. Accessed October 1, 2011.

Schiffries, C., and R. Gropp. 2009. Testimony of the USGS Coalition Regarding the U.S. Geological Survey FY 2010 Budget Request. United States Senate Committee on Appropriations Subcommittee on Interior, Environment, and Related Agencies, May 2009. Available online at *http://usgscoalition.org/FY10_Senate_Testimony.pdf*.

USACE (U.S. Army Corps of Engineers). 2010. National Report: Responding to National Water Resources Challenges. Washington, D.C.: USACE Civil Works Directorate. Available online at *http://www.building-collaboration-for-water.org/Documents/nationalreport_final.pdf*.

USFWS (U.S. Fish and Wildlife Service). 2011. Summary of Listed Species Listed Populations and Recovery Plans. Available at *http://ecos.fws.gov/tess_public/pub/Boxscore.do*. Accessed October 1, 2011.

USGS (U.S. Geological Survey). 2011. USGS Water-Quality Information. Available online at *http://water.usgs.gov/owq/*. Accessed October 1, 2011

Waage, M. 2010. Nonstationarity Water Planning Methods. In Workshop on Nonstationarity, Hydrologic Frequency Analysis, and Water Management, edited by J.R. Olsen, J, Kiang, and R. Waskom. Colorado Water Institute Information Series No. 109. Available online at *www.cwi.colostate.edu*.

WRC (Water Resources Council). 1973a. Establishment of Principles and Standards. Federal Register 8(174): 24778–24869.

WRC. 1973b. Water and Related Land Resources: Establishment of Principles and Standards for Planning. Federal Register 38: 24784, 248222–248223.

WRC. 1983. Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies. Washington, D.C.: U.S. Government Printing Office.

WRDA (Water Resources Development Act of 2007). 2007. Water Resources Development Act of 2007. Public Law 110-114, 121 STAT. 1041.

WWAP (World Water Assessment Programme). 2009. The 3rd United Nations World Water Development Report: Water in a Changing World. Available online at *http://www.unesco.org/water/wwap/wwdr/wwdr3/*.

WWPRAC (Western Water Policy Review Advisory Commission). 1998. Water in the West: Challenge for the Next Century. Available online at *http://wwa.colorado.edu/western_water_law/docs/WaterintheWest_WPPRAC.pdf*. Accessed October 1, 2011.

NAE News and Notes

NAE Members Receive Two National Medals of Science and Three National Medals of Technology and Innovation

Shu Chien, 2010 National Medal of Science Laureate

Richard A. Tapia, 2010 National Medal of Science Laureate

Rakesh Agrawal, National Medal of Technology and Innovation Laureate

On October 21, 2011, at a ceremony in the East Room of the White House, President Barack Obama presented the 2010 National Medals of Science and National Medals of Technology and Innovation. In his remarks, President Obama said: "Each of these extraordinary scientists, engineers, and inventors is guided by a passion for innovation, a fearlessness even as they explore the very frontiers of human knowledge, and a desire to make the world a better place. Their ingenuity inspires us all to reach higher and try harder, no matter how difficult the challenges we face." Five NAE members were among the recipients of these prestigious awards.

National Medals of Science were awarded to two NAE members, **Shu Chien**, and **Richard A. Tapia**.

Shu Chien, University Professor of Bioengineering and Medicine, Y.C. Fung Professor of Bioengineering, and director, Institute of Engineering in Medicine, University of California, San Diego, was honored "For pioneering work in cardiovascular physiology and bioengineering, which has had tremendous impact in the fields of microcirculation, blood rheology, and mechanotransduction in human health and disease."

Richard A. Tapia, University Professor and Maxfield-Oshman Professor in Engineering, Rice University, was cited "For his pioneering and fundamental contributions in optimization theory and numerical analysis and for his dedication and sustained efforts in fostering

B. Jayan Baliga, National Medals of Technology and Innovation Laureate

All photos by Ryan K Morris, National Science & Technology Medals Foundation.

Yvonne C. Brill, National Medals of Technology and Innovation Laureate

diversity and excellence in mathematics and science education."

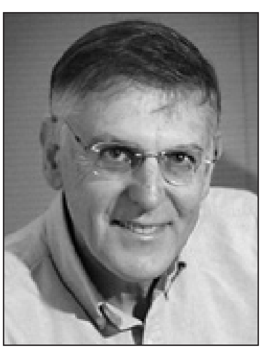
National Medals of Technology and Innovation were presented to three NAE members, **Rakesh Agrawal**, **B. Jayant Baliga,** and **Yvonne C. Brill**.

Rakesh Agrawal, Winthrop E. Stone Distinguished Professor, School of Chemical Engineering, Purdue University, received the award "For an extraordinary record of innovations in improving the energy efficiency and reducing the cost of gas liquefaction and separation. These innovations have had significant positive impacts on electronic device manufacturing, liquefied gas production, and the supply of industrial gases for diverse industries."

B. Jayant Baliga, director, Power Semiconductor Research Center, North Carolina State University, was honored "For development and commercialization of the Insulated Gate Bipolar Transistor and other power semiconductor devices that are extensively used in transportation, lighting, medicine, defense, and renewable energy generation systems."

Yvonne C. Brill, aerospace consultant, was cited "For innovation in rocket propulsion systems for geosynchronous and low earth orbit communication satellites, which greatly improved the effectiveness of space propulsion systems."

NAE Member Wins Nobel Prize for Chemistry



Dan Shechtman. Photo courtesy Technion-Israel Institute of Technology.

Dan Shechtman, professor of materials science, Technion-Israel Institute of Technology, professor of chemistry, Iowa State University, and researcher, U.S. Department of Energy, Ames Laboratory, won the **2011 Nobel Prize in Chemistry** for his discovery of quasicrystals—an entirely new form of matter. This discovery has important implications for the development of high-strength, low-friction surfaces and thin quasicrystalline film with unique thermal and electrical transport properties. In the wake of Shechtman's discovery, the International Society of Crystallographers has changed its basic definition of a crystal. Dr. Shechtman accepted the award in Stockholm on December 10 from the Royal Swedish Academy of Sciences.

NAE Newsmakers

Zdenek P. Bazant, McCormick Institute Professor and W.P. Murphy Professor of Civil Engineering and Materials Science, Northwestern University, has been awarded the 2011 **Maurice A. Biot Medal** from the American Society of Civil Engineers. Established to honor the lifetime achievement of Dr. Maurice A. Biot, the medal is awarded to an individual who has made outstanding research contributions to the mechanics of porous materials. In addition, the **Czech Society for Mechanics**, Prague, has instituted the **Z.P. Bazant Prize for Engineering Mechanics**, which will be given annually and will include a monetary award of $1,200. Members of the selection committee are drawn from the ranks of the Czech Academy of Sciences and the Czech Technical University in Prague.

Arden L. Bement Jr., director, Global Policy Research Institute, Purdue University, received the insignia of **Chevalier dans l'Ordre Legion d'Honneur** (Knight of the French Legion of Honor) on March 24 from Ambassador Francois Delattre, current French ambassador to the United States. Bement was honored for bringing together scientists and engineers and facilitating cooperation in international research. The award was established by Napoleon in 1802 and is the highest civilian decoration in France.

Alan N. Gent, Dr. Harold A. Morton Professor Emeritus of Polymer Physics and Polymer Engineering, Institute of Polymer Science, University of Akron, was awarded the **Tan Sri Dr. B.C. Sekhar Gold Medal** for his significant contributions to the world rubber industry. The industry magazine, *Rubber Asia*, instituted the award to honor the late world-renowned polymer scientist Tan Sri Dr. B.C. Sekhar.

Susan L. Graham, Pehong Chen Distinguished Professor Emerita and professor in the Graduate School, Computer Science Division—EECS, University of California, Berkeley, received the Association for Computing Machinery and IEEE Computer Society **Ken Kennedy Award** for contributions to computer programming tools that have significantly advanced software development. Dr. Graham's collaborative research has led to the construction of several interactive tools to enhance programmer productivity and programming language implementation methods that improve performance and software quality. Dr. Graham received the Kennedy award on November 15 in Seattle at SC11, the International Conference on High-Performance Computing.

BioMed SA, a nonprofit corporation in San Antonio, Texas, that promotes the health care and bioscience sector, will award its sixth annual **Julio Palmaz Award for Innovation in Healthcare and the Biosciences** to **Leroy Hood**, president and co-founder of the Institute for Systems Biology, in Seattle, Washington. The award, named after Julio Palmaz, M.D., the inventor of the Palmaz® stent, is awarded to individuals who have made significant contributions that have advanced health care and bioscience. Dr. Hood accepted the award at BioMed SA's annual Palmaz Award Dinner in San Antonio on September 20, 2011.

Tony Hoare, principle researcher, Microsoft, received the **2011 IEEE John von Neumann Medal** for his pioneering work, which has had a large impact on database management and safety in the medical, transport, and nuclear power sectors. His contributions, many of which bear his name (e.g., the Hoare Axiom, Hoare Logic, and Hoare Triple) have advanced computer science research on algorithms, data types, and programming.

Martin Klein, president, Martin Klein Consultants, received the **Arnold O. Beckman Founder Award** from the International Society of Automation at the society's Honors and Awards Gala on October 17. The award is given in recognition of a significant technological contribution to the conception and implementation of a new principle of instrument design, development, or application. Mr. Klein was recognized for the invention and development of dual-channel side-scan sonar instrumentation, which opened the world's oceans to exploration, safe navigation, and underwater recovery.

The National Academy of Television Arts & Sciences (NATAS) has named **Shuji Nakamura**, professor, Materials Department, University of California, Santa Barbara, winner of an Emmy. The **63rd Annual Technology and Engineering Emmy Awards** will be presented during the International Consumer Electronics Show in Las Vegas in January. The Emmys are given to individuals, companies, and scientific or technical organizations for developments in engineering technology that have significantly impacted broadcast television. Professor Nakamura was selected for his pioneering development of large-venue, large-screen direct-view color displays.

Roderic Pettigrew, director, National Institute of Biomedical Imaging and Bioengineering (NIBIB), was awarded the **2011 Distinguished Achievement Award** from the Biomedical Engineering Society (BMES) at the BMES Annual Scientific Conference in Hartford, Connecticut, on October 14. This prestigious award is conferred on a non-academic institution for contributions of preeminent importance to the field of biomedical engineering.

Simon Ramo, co-founder of TRW Inc., has received the **Robert H. Goddard Trophy**, the preeminent award of the National Space Club, for his contributions to U.S. leadership in rocketry and astronautics.

Linda S. Sanford, senior vice president, Enterprise Transformation, IBM, and past chair and co-chair of the Business Council, is the recipient of the **2011 Corning Award for Excellence,** the most prestigious award presented by the Business Council of New York State Inc. Ms. Sanford received the award on September 22 at the Business Council's Annual Meeting in Bolton Landing, New York. The award is given annually to a New Yorker with outstanding accomplishments to his or her credit and a demonstrated, sustained commitment to the people of New York.

Henry Samueli, co-founder and CTO, Broadcom Corporation, has been awarded the **Dr. Morris Chang Exemplary Leadership Award** by the Global Semiconductor Alliance (GSA). Dr. Samueli was honored for his exceptional contributions and leadership that have "transformed and elevated the semiconductor industry." He received this award for lifetime achievement on December 8 during the GSA Awards Dinner in Santa Clara, California.

David W. Thompson, chairman and chief executive officer, Orbital Sciences Corporation, has been awarded the **2011 International Von Karman Wings Award** by the Aerospace Historical Society and the Graduate Aerospace Laboratories of the California Institute of Technology. The award was presented to Mr. Thompson for three decades of leadership of Orbital, which has pioneered new classes of rockets and satellites that have helped to make space applications more affordable and accessible to people and enterprises around the world. Each year, the von Karman Wings Award is bestowed upon an individual who has made outstanding contributions to the aerospace community over a sustained period of time as a pioneer, innovator, and leader.

Highlights of the 2011 NAE Annual Meeting

NAE Class of 2011

NAE members, foreign associates, and guests gathered in Washington, D.C., on October 15–17 for the 2011 NAE Annual Meeting. The meeting began on Saturday afternoon, October 15, with an orientation session for new members. That evening, the NAE Council held a dinner in the ballroom of the Willard Hotel in honor of the 68 new members and 9 new foreign associates.

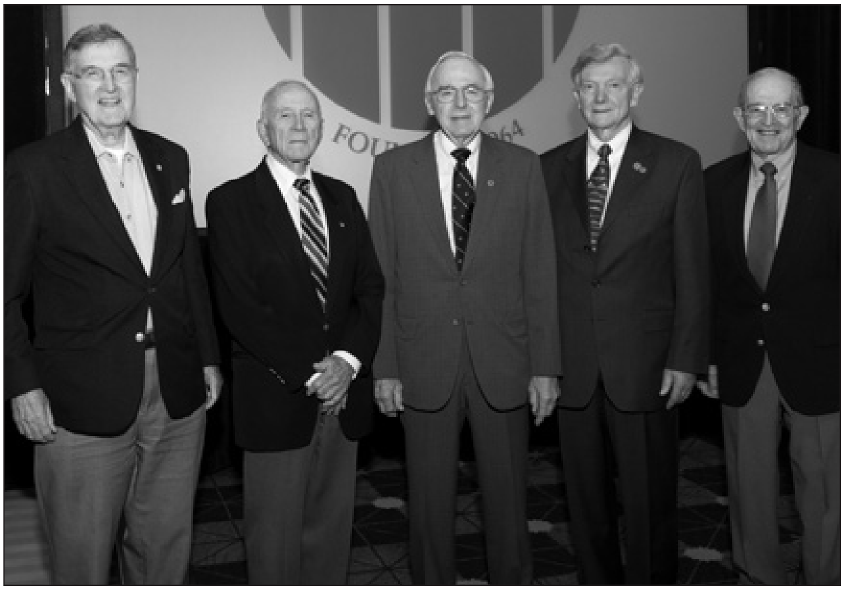
NAE chair **Irwin M. Jacobs** opened the public session on Sunday, October 16, with brief remarks welcoming the new members and their families (see p. 54). President **Charles M. Vest** then delivered his annual address, "Engineers: The Next Generation: Do We Need More? Who Will They Be? What Will They Do?" Dr. Vest talked about the urgent need to improve engineering education and the engineering challenges ahead (see p. 56). The induction of the NAE Class of 2011 followed, with introductions by NAE Executive Officer **Lance Davis**.

The program continued with the presentation of the 2011 Founders Award and Arthur M. Bueche Award. The recipient of the 2011 Founders Award, **David Atlas**, Distinguished Visiting Scientist, NASA Goddard Space Flight Center, was honored for "five decades of research, innovation and development, leading to operational weather radar systems that have improved aviation safety and weather-related safety for millions worldwide" (see p. 61).

Charles Elachi, director, Jet Propulsion Laboratory, was presented with the 2011 Arthur M. Bueche Award. Dr. Elachi was cited for "innovations in planetary remote sensing science and technology, and distinguished leadership in creating government, university and industry partnerships and space technology policies" (see p. 63).

The awards ceremony was followed by the Bernard M. Gordon Prize Lecture, delivered by the winner of the 2011 Gordon Prize, Dr. **Edward F. Crawley**, Ford Professor of Engineering and professor of aeronautics and astronautics and of engineering systems, Massachusetts Institute of Technology (MIT). Dr. Crawley established the Conceive-Design-Implement-Operate (CDIO) Initiative at MIT.

After the awards ceremony, Dr. Vest introduced the two Armstrong



Anniversary members (l to r): Daniel Berg, Norman Abramson, Jerome Rivard, John W. Fisher, and David Atlas.

Forum panelists and moderator

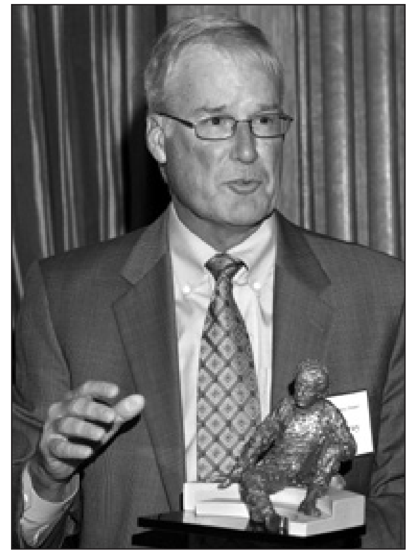
Endowment for Young Engineers–Gilbreth Lecturers, chosen for their outstanding presentations at the 2010 U.S. NAE Frontiers of Engineering Symposium. The first lecture, "Water Infrastructure in a Digital Age," was by Jeanne M. VanBriesen, professor of civil and environmental engineering and director, Center for Water Quality in Urban Environmental Systems, Carnegie Mellon University. The second lecturer was Armando Fox, adjunct associate professor and co-founder of the Reliable Adaptive Distributed Systems Laboratory, University of California, Berkeley. He spoke on "The Potential for Cloud Computing: Opportunities and Challenges."

The guest lecturer for this year, Dr. Arunava Majumdar, director, Advanced Research Projects Agency–Energy, was the next speaker. His lecture was on "ARPA-E: Catalyzing Energy Breakthroughs for a Secure American Future." The day ended with a reception for members and guests.

On Monday morning at the Annual Business Session, Dr. Vest provided a brief update on NAE finances, membership, and program activities. The business session was followed by the Annual Forum, "Making Things: 21st Century Manufacturing and Design," moderated by Ali Velshi, anchor and chief business correspondent for CNN. The speakers explored economic, political, educational, and technical issues related to how and where products will be produced in the future. The panelists were: **Craig R. Barrett**, former chair and CEO of Intel Corporation; **Rodney A. Brooks**, founder, chair, and CTO, Heartland Robotics, and Professor Emeritus, Massachusetts Institute of Technology; **Lawrence D. Burns**, former vice president for R&D, General Motors Corporation; Ursula M. Burns, chair and CEO, Xerox Corporation; Regina E. Dugan, director, Defense Advanced Research Projects Agency (DARPA); Brett P. Giroir, vice chancellor for strategic initiatives, The Texas A&M University System, and executive director, National Center for Therapeutics Manufacturing; and **David M. Kelley**, founder and chair of IDEO and professor of mechanical engineering at Stanford University. A video of the Forum is available at *http://fednet.net/nas101711/*.

On Monday afternoon, members and foreign associates participated in NAE section meetings at the Keck Center and the J.W. Marriott. The Annual Meeting concluded with a reception and dinner dance that evening at the J.W. Marriott with dance music by the Odyssey Band.

Associate Justice O'Connor and NAE President Charles Vest during dinner.



Dr. Paul R. Gray accepting his Einstein Statuette.

Special Event: Golden Bridge Society Dinner at U.S. Supreme Court

On Sunday, October 16, Associate Justice Sandra Day O'Connor (retired) hosted 50 NAE donors at the Supreme Court for the annual Golden Bridge Society Dinner to thank members of NAE's cumulative giving societies—the Golden Bridge, Einstein, and Heritage societies. Justice O'Connor opened the festivities by welcoming guests in the impressive main courtroom; she briefly described its architecture and then opened the floor to questions, most of which involved proceedings of the Court.

During dinner, Dr. **Charles M. Vest** presented Dr. **Paul R. Gray**, a member of the NAE Council, with his newly earned Einstein statuette for cumulative contributions of more than $100,000 to NAE. In his remarks, Dr. Gray emphasized the importance of philanthropy to NAE and encouraged other donors to continue their support of the institution.

News of this year's dinner raised the profile of the Golden Bridge Society at the Annual Meeting and inspired one NAE member to contribute more than $10,000 to bring his contributions to Golden Bridge status.

For more information on giving to NAE and to learn how to become a member of an NAE cumulative giving society, please visit *www.nae.edu/giving*.

The next annual meeting is scheduled for September 30–October 1, 2012, in Washington, D.C.

Remarks by NAE Chair Irwin Jacobs

Irwin Jacobs

It is a pleasure to see all of our new members and associates and to add my congratulations to those of the NAE councillors in welcoming you to NAE. Every year, I review the list of new initiates and read the citations, just to get a feel for the range of activities in which you've been involved. The contributions you have made are truly amazing!

For one new member today, **Terry Sejnowski,** this is the third of the National Academies to which he has been inducted. He is now a member of the National Academy of Sciences, Institute of Medicine, and now NAE. I think only 8 or 10 people have had the very special privilege of being elected to all three.

In the past year, there have also been other significant honors for NAE members. As you know, there is no Nobel Prize in engineering, but Professor **Daniel Shechtman** was awarded the Nobel Prize for chemistry. And we have some very special prizes we award ourselves, two of which, the Founders Award and Arthur M. Bueche Award, will be given out later today.

A number of other honors have been received by our members. Five NAE members were awarded either a National Medal of Science or National Medal of Technology and Innovation. These are very special accomplishments.

Unfortunately, there were also a number of deaths in our group. One that has received a lot of attention is **Steve Jobs**, with whom I am sure all of you are familiar. As a former CEO, I was always impressed by his strategic thinking, his ability to plan and make things happen, his fantastic marketing skills, and also his attention to detail. For a CEO, there is always a question of finding the right balance: how much should you be doing that is strategic, and how much should you get into details. I have always been a great believer that managing a company well requires paying attention to details, not to all of them but to a number of them. Steve certainly was able to do that.

One of Steve Jobs' latest and perhaps best-known products is the iPhone, which was followed by the iPad. Both of them made a tremendous impact. For a long time, we had been talking in the industry about smart phones, a single device that could be carried around that was not just a telephone but could also perform many other functions. For many years skeptics thought it would be too complicated and confusing for most people to handle such a phone. However, Steve Jobs and Apple came up with a very nice user interface that allows people to make many uses of the cell phones they carry around with them. Actually, these days, they may use them more for some data functions and applications than for telephoning.

The smart phone has made a major change because of Apple's focus on how humans interact with it. One of our inductees today, Don Norman, also specializes in the design of intuitive human/device interfaces, an area that is becoming increasingly important as our devices become more and more capable.

My background is in the wireless industry. It is interesting to note the increasing impact of wireless on how we live and work, particularly on engineering and engineering education. Today there are 5.5 billion subscribers to wireless phones, which is amazing because there are only 7 billion people in the world. Of course, this includes some double counting of people who have more than one device or more than one subscription. In the United States, we now have more than 100 percent penetration—that is, more phones and devices than people. The penetration will increase well beyond 100 percent, as person-to-person communication increases, and more machines talk to other machines. eBooks, for example, talk to servers to download books, and we are moving rapidly to smart power grids that communicate with meters and generators. Soon even automobiles will talk to one another.

All of these changes have had a growing impact on how we educate students. It takes people in many disciplines working together to design a communication system and to make a cell phone. You need communication theory, information theory, network theory, antenna and electromagnetic theory, and semiconductor technology just to support what is called the physical layer, the means of connecting phones efficiently.

Smart phones incorporate much more than the physical layer. They are also very powerful computers. One measure of computing power is DMIPS. Some of you might remember the excitement when DEC introduced the VAX 11/780 minicomputer in 1977, hardware that occupied one or two racks of equipment. The Vax 11/780 achieved one DMIPS. Today, a computer core on part of one digital chip in your phone achieves 10,000 DMIPS, giving your phone the computing power of 10,000 DEC 11/780s. And the chip in your phone will soon have two or more cores, all running on a battery.

Many capabilities are included on that chip, such as a GPS receiver, camera and camcorder, graphics processing, TV receivers, and more. Making all of these requires that engineers with different backgrounds work together.

Another area of considerable interest is sensors, in particular MEMS (micro-electro-mechanical systems) sensors, tiny devices used in airbags, for example, to detect a collision. Now MEMS devices are also being used with phones for gyroscopes for sensing orientation and digital compasses for sensing aspects of the environment around the phone. For example, a sensor might be able to tell if there are pathogens or other contaminants in the air and send the information to a data-gathering center, along with the location determined by the GPS receiver.

With 5.5 billion of these devices in all parts of the world, many with appropriate sensors and adequate privacy protection, we will be able to sample and understand more and more of the world around us. These are very powerful devices.

I believe a major use of phones and sensors will be in telemedicine. Smart bandages, for example, are becoming available that can measure cardiac function, blood pressure, pulse, etc. These measurements, which are often noisy, can be communicated a short distance to a phone that has the computing power and downloaded algorithms to extract a meaningful signal. When necessary, the phone can alert you, a family member, or your doctor to take action.

I might mention another of our inductees today, Dr. **Yulun Wang**, who has a robotic approach to handling certain medical functions. Together with Qualcomm, he conducted demonstrations with a cell phone in one city and a robot in a hospital in another city. Using the phone, he and the patient and a local nurse were able to communicate via audio and video links. He could control the robot, and the patient could see and speak directly to the doctor. Telemedicine is rapidly advancing, and I believe it will greatly improve medical care and reduce costs.

Now let's turn to another area. For about 30 years, we've been talking about the effective use of technology in education. I think we will see a positive impact on education in this decade as a result of powerful new mobile devices that are available to students 24/7. In early demonstration projects, students are already using such devices to provide effective peer-to-peer support outside of the classroom, and the FCC has set aside funding to support mobile Internet access outside of the classroom for a number of projects. NAE, of course, has focused on improving engineering education in K–12, as well as at the university level.

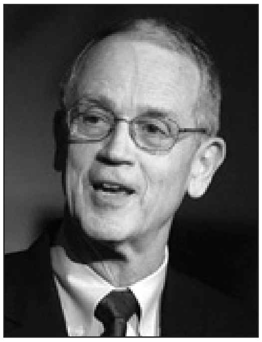
One exciting development has been the spread of what one might call "$100K competitions," in which students get together, come up with an idea and a business plan, and then compete with other such groups. These competitions are growing rapidly and are fun to watch and support. I have tracked, and indeed invested in, a few companies that have come out of these types of competitions. If you look at the composition of the competing groups, you will find an engineer, often a bioengineer or someone associated with a medical school, and someone from a business school—in other words students in a variety of disciplines working together to form a successful company. We can all participate in such activities—by being judges and encouraging students to participate.

There is clearly a great deal of excitement in engineering these days. But we must do a better job of communicating that excitement to youngsters and encouraging more of them to enter engineering.

Again, I congratulate all of you on your election to NAE, and I urge you to look for ways to support the Academy, the profession, and the country.

Thank you all very much.

Engineers: The Next Generation
Do We Need More? Who Will They Be? What Will They Do?
Annual Address by NAE President Charles M. Vest



Charles M. Vest

Do We Need More?

The distinguished National Academies volunteers who wrote the influential report *Rising Above the Gathering Storm* concluded that we need to increase the number of engineers graduating in this country. Not everyone agrees with that assessment, and I am frequently asked if we really need more engineers. I think the answer is "Yes," for at least four reasons:

1. U.S. industry, including the national security industry, is facing a wave of retirements in the the next decade or two.
2. It is not crystal clear that we will be able to continue to fill the engineering gap with the best and brightest from other countries.
3. Many high-tech companies report that they cannot find qualified U.S. citizens to fill critically important engineering and technology jobs, including in manufacturing.
4. Most important of all, we need a new generation of brilliant engineers, researchers, and entrepreneurs to create a vibrant future, just as preceding generations did.

So, yes, I think we need more engineers and better engineers.

Thank goodness we live in a democracy where we have the personal freedom to choose what we study and how we plan to spend our lives. In the current unhappy economic times we have brought on ourselves, no doubt young people feel more constrained than I did at their age. But they still will have a lot of choice over time about what to make of themselves.

On the one hand, the last thing I want is for government or some other group to dictate fields of study or how many people we should have in each professional field. On the other hand, leaders in our society, including leaders in the private sector, which actually provides career opportunities, need to think clearly about current trends and what they imply about the future. This is necessary to provide broad guidance to our educational system, our culture, and our incentive systems.

Who Will They Be?

So what are some of the trends we might consider? First, we should think globally. How do we stack up in the *education* of engineers? Thirty years ago the United States, Japan, and for that matter, China, all educated the same number of engineers each year, about 70,000. But over time, the number of U.S. students graduating with bachelor's degrees in engineering has declined, slowly but more or less continuously, to about 60,000.

In the meantime, Japan and even South Korea now exceed our engineering graduation rates. And of course, as you have heard many times, the number of first engineering degrees in China has reached the astounding number of almost 600,000! India apparently has followed similar trends, but data are very hard to find.

Yes, I know there is a huge range of quality in China's higher education system. But the best of their universities are getting pretty darn good in engineering and science, and we can safely assume that the overall quality trend is upward. I also know that China's population is more than 1.3 billion people, they are climbing the economic ladder rapidly, at least in the eastern part of their country, and they have a huge infrastructure to plan, design, and build. So of course, they need vastly more engineers than we do.

So it would be rational to ask what *percentage* of college and university graduates around the world are earning degrees in engineering and science. The answer is very interesting. Whether we look to Asia or Europe or the United States, roughly 10 to 13 percent of college and university students graduate with degrees in one of the natural sciences.

What about engineering? In Asia more than 21 percent of students who graduate are engineers. In Europe, just under 12 percent of recent graduates are engineers. In the United States, the number is only 4.5 percent. We are at the bottom of the list in this metric.

Does this make any difference? I think it does. I will come back to this, but for the moment, let's ask whether the small fraction of U.S. students graduating in engineering is a new phenomenon. Actually, it has been this small for almost 50 years.

While the total number of bachelor's degrees in *all* fields increased by 220 percent, from 500,000 in 1966 to 1.6 million today, the number of engineers graduated has increased at half that rate, from about 33,000 to just under 70,000. And the number of engineering graduates has pretty much remained stagnant since the mid-1980s—for the past three decades.

Who have we been educating, and who will we educate in the future? Now the plot thickens. Let's start with gender, because therein lies much of the reason for our small fraction of B.S. degrees in engineering.

Remember all that growth over the years in the number of bachelor's degrees? Women have been dominant in it. Their numbers grew by 350 percent during this period, from 200,000 in 1966 to 900,000 today. The number of men graduating increased by only one-third this rate. So today almost 60 percent of our university graduates are women.

But when we look at U.S. *engineering* graduates, we see a world-class flip-flop of this situation. (The flip-flop is so glaring it makes politicians look like amateurs.) Women in America today earn fewer than 20 percent of engineering degrees. That means only 1.3 percent of the women graduating from U.S. colleges and universities are engineers!

There are many historical and cultural reasons for this—some of which we understand and some of which we may not understand. But the fact remains that engineering attracts a very small share of the fastest growing segment of college students. This is a huge waste of talent. We can do something about this. No, we must do something about it!

Here is another piece to the puzzle. It turns out that when students arrive at universities for their freshman year, move into dorms, and begin their college adventure, almost 10 percent of them plan to study engineering. Wait a minute! I just said that only 4.5 percent of our graduates are engineers. Yes, indeed, we lose half of them on their way through college. We lose 50 percent of the women, and we lose 50 percent of the men.

So there must be something about science and engineering education that drives students away. Right? Think again. Less than a third of the women students leave *science* before graduation. That is not good, but it's not as bad as the loss of 50 percent of the women who enter engineering. And the ranks of male scientists actually grow by 15 percent on the way through college. I can guess where the 15 percent growth comes from. It most likely includes many of the engineers we lost along the way. In other words, the problem is an engineering problem.

The bottom line is that half of engineering students leave the field during their university years. If we could stop that loss, we would instantly double our national output of engineers.

Why do they leave? Surely there are as many specific reasons as there are students, and surely the situation varies from school to school. But across the entire system, we are failing in some combination of inspiration, motivation, and learning.

That is one reason the National Academy of Engineering promotes and encourages innovation and change in the quality of experience and learning of our undergraduates. I think change is imperative, and I know that many people sitting in this room are effectively bringing about such change in their institutions. But far more needs to be done. We have to consider the possibility that we are our own worst enemies.

I am worried that I am throwing too many numbers at you, not always a good idea in a speech. Sorry, but I have a few more. Because we have been looking in the rearview mirror and at the present situation, you might say, "So what? It's the future that counts. More women are coming into engineering now. This is an exciting time in technology, and engineers will be needed to address many of the grand challenges facing humankind in the years ahead. Maybe everything will be OK." Maybe, but I doubt it.

Looking ahead, one needs to think about the generation of Americans who are 18–23 years old. In 1985, 10 percent of these "college age" kids were Hispanic American. Today 17 percent are. Hispanics are on a very steep growth curve. College-age African Americans are also growing as a fraction of the population. The growth rate of young Asian Americans is higher still.

The point is that, taken together, our two largest racial minority groups comprise about one-third of the college-age kids in our country, and that fraction is growing steadily. Nevertheless, they earn less than 13 percent of engineering degrees. Let me repeat that. The fastest growing segment of our young population earns less than 13 percent of our engineering degrees. Projecting forward, this is a workforce train wreck in the making, and we must take action now to avoid it.

So why hasn't the United States already been steamrolled? The answer is clear. We have addressed the engineering gap by attracting remarkable talent from around the world to study in the United States, and we have been fortunate that many have stayed and become leaders in industry, academia, and entrepreneurship. Large numbers of these individuals still aspire to stay and contribute to the United States, but our visa policies are making their path increasingly difficult. We must fix this *post haste*.

Furthermore, the gravy train is slowing down. More and more engineers and entrepreneurs are returning to China, India, and elsewhere. Vivek Wadwha's surveys indicate that their primary reasons for returning are that their professional careers or the companies they wish to found can be built much faster back in China or India.

For many decades, we have followed a truly bizarre federal policy of (1) making it hard for brilliant, accomplished foreigners to enter the United States to work, and (2) pushing immigrants who have earned advanced degrees in our universities out of the United States. This is simply wrongheaded, and it has gotten worse since 9/11.

And by the way, it is not only wrongheaded, it is bipartisan. Leaders from Silicon Valley come to town saying, "For heavens sake, staple a green card to every engineering and science graduate degree." No matter which party controls what, the politicians say, "We understand, and we are going to fix it, but it must be part of a comprehensive immigration bill." Then they return to partisan gridlock, being careful not to arrive at a comprehensive solution. The nation suffers the consequences.

To repeat, we are still considered a wonderful destination for engineers from around the world, but we go out of our way to make it difficult for them to get here or stay here. So, nonsensical immigration policy is *cause number two* for worrying about a possible workforce train wreck. On top of that, many recent immigrant engineers and entrepreneurs choose to return home or go to yet another country, part of a growing "brain circulation" around the globe. And, of course, many of our own young Americans are joining this great circulation. We need to press even harder to get this problem fixed.

But more important, we have to get serious about improving K–12 education in America. To that end, we must enlist everyone who understands the issue to work to change the conversation, to get kids to understand that "Dreams need doing," and that "Engineering is essential to our health, happiness, and safety." And we must help them to understand that most of the Grand Challenges facing humankind can only be solved if engineers are at the center of the effort.

Finally, we need to work creatively to improve engineering education across the country. We cannot rest on our laurels. Having been the best in the world for the last 50 years guarantees nothing as we move forward.

What Will They Do?

Yes, I am worried about the quantity and quality of the future engineering workforce, *but what will they do*? Suppose I had been asked this question when I graduated from engineering school in 1963. I probably would not have answered, "Why, they'll work in the IT industry." I wouldn't have given this answer because the IT industry did not exist. Yet a huge fraction of the engineers in my generation indeed ended up working in the IT industry.

The IT industry exists because engineers innovated. They figured out how to do new things, and some of those things, like IT, turned out to be game changers and major job creators. Indeed, the IT revolution created 22 million U.S. jobs in just one decade.

Do I know what the next game-changing innovation will be? Of course not. But historical precedents lead me to be extremely optimistic that there will be one…*if* we invest in education and research, build a great environment for entrepreneurship, and put sound economic policies in place. We'd better do this, because we will increasingly need to be first out of the box and first to market with new products, processes, and services.

Come to think of it, if I had listened more carefully to the emerging language of engineering in 1963, I would have had at least an inkling that something called IT might blossom and grow. I didn't have the necessary prescience. But if we listen to the language of engineering today, we will hear the same words I have heard throughout my career—terms like:

Force	Speed
Size	Tolerance
Modulus	Voltage
Temperature	Precision

This is the language of basic engineering, and it is as relevant today as it was when I started out.

But I also hear terms like:

Scale	Scope
State	Complexity
Integration	Architecture
Resilience	Evolution
Affordability	Social Context

This is the language of engineering systems. It is about how things are interconnected and interactive. And it is about the *integration* of what engineers know and can do with what social scientists, management experts, policy makers, citizens groups, lawyers, and politicians know and can do. Integration is essential for a vibrant future.

Last week, *New York Times* columnist David Brooks wrote this about Steve Jobs: "*The roots of great innovation are never just in the technology itself. They are always in the wider historical context. They require new ways of seeing.*" Our universities need to prepare engineering students accordingly.

Let me tell you what else I hear. Increasingly, I hear terms like:

Cellular Circuitry
Adaptive Immunity
Reprogramming Bacteria
Synthetic Biology
Natural Adhesives
Bacteria-Laced Concrete
Integrated Cancer Research
Neuroprosthetics

This is the language of a new biological engineering, of the convergence of life sciences with engineering and physical science that is beginning to range far beyond medical applications. The life sciences, as well as biomimetics, are new foundations for engineering. Biological engineering today is more or less where computers were in 1963.

And there is another strand of language I hear. I hope you hear it too, because we at the National Academy of Engineering are making a concerted effort to propagate it:

- Engineers are creative problem solvers.
- Engineers make a world of difference.
- Engineers help shape the future.
- Engineering is essential to our health, happiness, and safety.
- Engineers can meet the Grand Challenges of the 21st century.

This language is intended to change the public perception of engineering, especially among bright young people who aspire to make the world a better place by driving sustainability, helping advance the cause of better health, making the world more secure, and expanding humankind's capabilities to enable people to live more joyful, productive lives.

I am not worried about what engineers in this country will do in the future, and I do believe we will need more good engineers, because I also believe they will continue to innovate, produce new industries, and drive economic and social vitality, just as they have for the last two centuries. To be more accurate, they will accomplish these things *if* we make the proper investment and, put in place appropriate policies and corporate and political leadership to build a vibrant future.

But one very important aspect of future jobs and engineering work in the United States is particularly puzzling. That is the future of manufacturing.

Twenty years ago, an MIT commission conducted a study that was published as an influential book, *Made in America*. The primary finding was that "*To live well, a nation must produce well.*" Is this still true today, in 2011? The answer to this question has a major bearing on what engineers will be doing in the coming decades and where they will be doing it. It also has major ramifications for the nature of the U.S. economy and workforce. And it has a lot to do with jobs and education.

Although by some metrics, the United States is doing well in manufacturing right now, there are some very disturbing trends. For example, consider the manufacturing of solar photovoltaics. In the mid-1990s, the United States had almost half of the world's market share. Today, our share is about 5 percent. Well, this isn't a huge industry, so maybe we shouldn't care. However, this segment of green energy products and infrastructure may be a leading indicator, a harbinger of things to come. So maybe we should care.

Or maybe we shouldn't care because we are well on our way to becoming a service economy. Things change. In 1800, a full 90 percent of American workers lived and worked on farms. American farmers grew crops and raised animals to feed their families, and as time rolled on they fed their communities, and eventually they fed the nation and large parts of the world.

But their numbers have continually decreased, and today only 2–3 percent of U.S. workers are farmers. Why did this happen? It happened because farm productivity has increased astoundingly as scientific knowledge, sophisticated technology, and business organization were applied.

Then the industrial age came along, and most jobs displaced from farms reappeared in factories where workers produced increasingly numerous and complex products. They made things. By 1950, about 60 percent of U.S. workers were making physical goods in factories. As industrial productivity improved, factory jobs declined, and today less than one-third of the workforce is making physical things.

These were tectonic shifts. The old order has changed. As one telling example, in 1970 the Big Three automobile manufacturers employed more than 450,000 workers in the state of Michigan. Today, they employ fewer than 100,000.

We all know what happened. It's not just about increasing productivity. Our society became more complex and demanding. Then the IT revolution came along, and globalization spread operations all over the world.

Now the action and jobs have moved to the service sector. Today, around 70 percent of U.S. jobs are in the service sector—ranging from flipping hamburgers to conducting sophisticated global operations using supercomputers, the Internet, and the World Wide Web.

So what happened to manufacturing? A lot of it moved offshore. In a typical scenario, a product may initially be manufactured here in the United States; then its production is moved to Korea or Taiwan; later it goes to China; and then it migrates to, say, Vietnam.

The common wisdom is that this happens because wages are much lower in those countries. But it is not that simple. Germany's manufacturing sector, for example, is booming and is responsible for 21 percent of its GDP. Yet the all-in wage rate for German factory workers is 40 percent *higher* than in the United States.

It is not simply about producing something "here or there." Today all large corporations are global entities. They have to be in today's economy. The end result is that we are generating enormous wealth in the United States, but the traditional manufacturing jobs, and increasingly, a big chunk of engineering functions, have gone to other countries.

Looked at from the perspective of the developing world, this is described as the "U Curve Theory." People in developing countries see the United States retaining many of the high-quality jobs in front offices, R&D facilities, and design centers, while shipping low-wage manufacturing jobs to them. They see the big financial returns from these manufactured goods going back to the United States along with higher paying marketing and sales jobs. There is some truth to this theory.

And remember in 1990 when Robert Reich famously asked, "Who is us?" He was asking whether the interests of U.S. companies and the interests of the U.S. economy were diverging. We still haven't answered his question. Today, in this bad economic climate, it is being asked again, including by protesters on Wall Street.

I think we need some serious introspection about "Who is us?" and whose interests are being served. No matter the answer, globalization has been the dominant reality for several decades, and it is here to stay. Because the world is totally interconnected, both manufacturing and service functions are being distributed far and wide. As a consequence, corporate interests and national interests have become the Yin and Yang of global enterprise. Indeed, in today's world, nations must simultaneously compete to drive excellence and wealth and cooperate to improve efficiency and expand markets.

In my view, Robert Reich's question has no simple answer. But we should expect our leaders in both corporations and government to explicitly think through this issue and move toward a balance that favors our nation to the extent that is reasonable. Exactly how we define "reasonable" in this complex, interconnected, open, transforming world of competition and cooperation is not clear. But it must continually be on the minds of our leaders.

Above all, they should lead by explaining the modern world better and investing the resources necessary for the next generation to succeed. But time is running out. I fear our politics have become a circus in the face of serious challenges and global transformations. It should not be our destiny to stand around and observe as a new *New World* in the East moves on.

Our leaders must lead by implementing the agenda the National Academies laid out in *Rising Above the Gathering Storm*. That means investing big-time in long-term R&D. It means enabling us to attract the best and brightest from the United States and throughout the world to engineering and science. It means reinvigorating the environment for innovation and entrepreneurship. Above all, it means building an America that provides a world-class education and training for all of our young people.

Franklin D. Roosevelt once said, "We may not be able to prepare the future for our children, but we can at least prepare our children for the future."

Thank you.

2011 Founders Award: Acceptance Remarks by David Atlas

The 2011 Founders Award was presented to ***David Atlas****, Distinguished Visiting Scientist, NASA Goddard Space Flight Center, for "five decades of research, innovation, and development, leading to operational weather radar systems that have improved aviation safety and weather-related safety for millions worldwide."*

NAE chairman Irwin M. Jacobs, Founders Award recipient David Atlas, NAE president Charles M. Vest, and Arun Majumdar, 2011 NAE Awards Committee chair and director, ARPA-E

Early in my career, I realized I was a big fish in a small pond. Suddenly, I find myself a small fish in a rather big pond wondering what I am doing here. If this isn't a mistake, I want to thank everyone who made it possible.

Today I thought you might be interested in the ingredients in my recipe for successful innovation. Surely most of you have found similar formulas; but let's see how general these recipes are. First, I list interdisciplinary training. Next comes symbiotic relations with creative colleagues. And then comes a flexible and supporting organization. Part of the mix is being able to seize the day when serendipitous events occur.

One may place these ingredients in a different order. For example, the mathematician Poincaré noted "an unsuspected kinship between facts, long known, but wrongly believed to be strangers to one another." This observation was mirrored by a modern author who reported that discovery comprised making connections between matrices of knowledge previously thought to be unrelated.

In my case, I was trained in both meteorology and radar during WW II. Weather radar itself was an accident resulting from the discovery of the magnetron and the move to short microwave wavelengths that made it possible to detect rain and snow. The Army Air Corps trained some 10,000 weather officers during the war, but it was Captain Joe Fletcher who had the foresight to convince the Air Corps to train 100 of us in radar. When the war ended, only a handful of us continued to work in the field—so I had unprecedented opportunities—with stimulation mainly from the MIT Weather Radar Project and the Stormy Weather Group at McGill University.

By the end of the war, I had the good fortune to be assigned to the All Weather Flying Division at Wright-Patterson Air Force Base. The division's goal was to exploit wartime advanced technologies to improve flight safety.

The first task I undertook was to devise a scheme for measuring and displaying the intensity of storms by contouring the strength of radar echoes. Nowadays this is done in color as you see regularly on television. Only a few years later, this method was adopted by the airlines; and then RCA, Collins Radio, and Bendix started to build weather radars. Today airborne radar is a must on every transport plane, and the nation is covered with a network of sophisticated ground-based weather radars.

In 1945, the academic and airline communities initiated the two-year Thunderstorm Project to understand such storms and improve flight safety, the first year in Florida and the second in Ohio. I was assigned to visit the Radar Test Facility in Boca Raton to select the radars for the project. Serendipity played a role when a hurricane occurred and I seized the opportunity to take photos of the radar scopes for 36 hours, thus providing the first observations of much of the lifetime of a hurricane. My excitement was indescribable, so much so that I never thought of the possibility that the radar, without a radome, would be destroyed by the raging winds. That was "Carpe diem" at its best, although I did not think of it that way at all.

Let's move ahead to 1957 at the Air Force Cambridge Research Labs at Hanscom Field, Massachusetts. We were only a stone's throw from MIT Lincoln Labs where they had a Doppler radar on the roof. Evidently they never bothered to use that radar in bad weather. So Roger Lhermitte, a brilliant scientist from France, and I joined forces to add an audio amplifier to the radar output and listen to the signal as we rotated the antenna 360°. What a thrill it was to hear the wind singing to us as we rotated the antenna full circle. Except for some earlier work at Cornell Aeronautical Labs, these were evidently the first Doppler wind measurements.

In 1959 I received an NSF postdoctoral fellowship to work with Professor Frank Ludlam at Imperial College in England. Our goal was to study the structure and dynamics of intense storms. Now why would one go to England where such storms are very rare? But serendipity favored us once more when the Wokingham storm occurred on July 9, 1959. **Keith Browning** (an NAE Foreign Associate) and Ludlam published an iconic paper on the dynamics of that storm.

But what did we do in the six weeks while we were waiting for a storm? Since little was known about the backscatter from hailstones larger than the wavelength, we made artificial stones frozen in tennis balls and suspended them below a tethered balloon. We then compared their cross sections to the cross section of a metal sphere, and lo and behold, the results matched those computed theoretically by Battan and Herman only a few weeks later in Arizona. The thrill of that discovery resounded across the ocean years before the Internet. Louis Battan was my WW II roommate and the best man at our wedding.

A few years later the Air Force turned its attention to detecting turbulence. We had just completed a paper on the possibility of detecting clear air turbulence by sensitive radar. By sheer coincidence, MIT Lincoln Labs had just given up the use of the giant radars at Wallops Island, Virginia. With a bit of maneuvering, we convinced the Air Force to provide major funding to take over these radars for a number of years. What a find! Suddenly we were able to see an entirely new world of atmospheric phenomena, including waves, inversions, the tropopause, convective clouds, birds, and insects.

Later, while I was at the University of Chicago, Jurgen Richter at the Naval Electronics Laboratory (NEL) on Point Loma, San Diego, had built an ultra-sensitive and extremely high-resolution FM-CW radar. Richter invited me and Jim Metcalf, a doctoral student there, to explore its capabilities. We were also fortunate to have access to the Buffalo aircraft, which was equipped with a remarkable set of instruments from the National Center for Atmospheric Research.

The NEL radar was ultra-sensitive and with very high resolution so that we saw many previously unseen structures of the atmosphere, such as thin inversions, waves, and insects riding the waves. We also directed the airplane to fly porpoise transits through the waves, because otherwise it would have been impossible for the pilot to fly through a thin inversion with sufficient precision to detect it. In this way, we were able to measure the temperature and flow in and around the phenomena seen by the radar. On various occasions the waves would grow and break, thus giving us a breathtaking picture of the birth of clear air turbulence.

In 1972, I became the director of the Atmospheric Technology Division at the National Center for Atmospheric Research in Boulder, Colorado There we developed sophisticated ground-based radars, a host of novel airborne instruments, and a surface-based portable network of meteorological sensors.

In 1977, when I became director of the NASA Goddard Laboratory for Atmospheric Sciences, we developed sensors for space-borne remote sensing of the atmosphere and oceans. Perhaps my greatest contribution, however, was my excitement and enthusiasm for each advance and making sure that the responsible scientists and engineers were properly acknowledged.

My colleagues, students, and I have shared many Eureka moments over more than six decades. I gratefully acknowledge their creativity and passion, and the institutions that were so supportive and flexible.

Most of all, I pay tribute to my wife, Lucille, whom I met serendipitously 63 years ago. Her unfailing love and support have been vital. Together we have shared this fulfilling experience, and we are tremendously grateful to NAE for acknowledging our life's work in this exciting career.

2011 Arthur M. Bueche Award: Acceptance Remarks by Charles Elachi

The 2011 Arthur M. Bueche Award was presented to ***Charles Elachi****, director, Jet Propulsion Laboratory, for "innovations in planetary remote sensing science and technology, and distinguished leadership in creating government, university, and industry partnerships and space technology policies."*

Irwin M. Jacobs, Bueche Award recipient Charles Elachi, Charles M. Vest, and Arun Majumdar

I am extremely honored to be the recipient of the Arthur M. Bueche Award, which I accept on behalf of all my colleagues at NASA, JPL, and Caltech who have supported me over the years. As a team, we have accomplished amazing things in space exploration and made advances in almost every field of engineering.

We live in a truly golden age of space exploration and the utilization of space assets. As we stand here today, JPL alone has 22 spacecraft across the solar system, including two famous Voyagers at the very edge of our solar system that will soon be the first human-made machines to reach interstellar space. In addition, Cassini is orbiting majestic Saturn, and the rover, Opportunity, continues to roam the surface of Mars on a 90-day mission now in its eighth year. The space telescope Kepler is discovering planets around other stars. And a suite of Earth-orbiting spacecraft is helping us understand changes on our own planet.

Becoming a space-faring nation, which once was only a goal, has come true in less than a lifetime. Today, our presence in space is not only far reaching, it is also continuous. For more than a decade, there has been a human presence in Earth orbit on the Space Station. And for more than 13 years we have been monitoring Mars without a single day off.

These achievements are the results of amazing engineering advances in every discipline. Amazing and *precise*! For instance, landing the rovers on Mars required pinpoint accuracy. We had to hit the top of the atmosphere to within 100 meters! That's after traveling 400 million miles. And remember, Mars is a moving target. And don't forget, the Earth is moving too!

The Voyagers are more than 16 light hours away from us now. The signal we detect from them is so weak that we would have to store up its energy for tens of billions of years to light a single flash bulb. Yet both Voyagers continue to provide new science.

The public and scientists alike are sometimes left speechless by the beauty of the images our machines send us. Today we can see the universe through eyes that span the entire electromagnetic spectrum. The results are as dazzling as they are significant as we peer through galactic clouds to see stars in the process of coming into being.

The way *Star Trek*'s USS Enterprise traveled through the galaxy was once the stuff of science fiction. We now have spacecraft that use ion propulsion to reach their destinations. One of them, *Dawn*, is orbiting a large asteroid named Vesta.

We don't make enough of the fact that these technological advances are critical to the competitiveness of our nation. And we take it for granted, with hardly a thought, that space engineering has become part of our day-to-day lives. Weather prediction, GPS navigation, satellite TV, cell phones, digital cameras. The list is almost endless.

So our field of engineering, each section of our academy, and every one of you, has at one time or another either contributed to the great quest for space exploration or has benefitted from it. We should all be proud of what our generation has accomplished. We have truly followed the advice of the poet Ralph Waldo Emerson, who once said, "Do not go where the path may lead, go instead where there is no path and leave a trail."

Thank you for this great honor. You all deserve a part of it.

NAE Welcomes Kate S. Whitefoot


Kate S. Whitefoot

NAE is pleased to welcome Dr. Kate S. Whitefoot, Senior Program Officer for the new Design, Manufacturing, and Competitiveness Initiative. She began working with the Program Office on Monday, August 15.

Dr. Whitefoot earned a B.S. and M.S. in mechanical engineering and a Ph.D. in design science, with a focus on engineering design and economics, all from the University of Michigan. The major focus of her research was on the impact of environmental and technology policies on engineering design and technological development. As part of her research, she developed methods of evaluating the effects of proposed automotive policies on optimal vehicle designs, consumer demand, and manufacturing capabilities. As a student at Michigan, she also taught seven semesters of a team-taught senior and graduate student course on engineering design and manufacturing.

Dr. Whitefoot held a core position on the Ford Motor Company–University of Michigan Sustainability Alliance for three years, where she proposed and evaluated sustainable design and service strategies, designed surveys on customer perceptions, and developed methods of evaluating demand for vehicle designs. She also has conducted research on science and technology policy at Resources for the Future, where she studied how to use competitive prizes as a mechanism for encouraging innovation, and was a consultant at ICF International for the EPA SmartWay Partnership, for which she developed tools for tracking carbon-dioxide emissions for freight-transportation companies.

At NAE, Dr. Whitefoot will lead the development of a portfolio of activities to explore the future of manufacturing and design in terms of implications for innovation, employment, and economic growth in the United States and abroad and their relevance to workforce education, engineering research and practice, and public policy.

Mirzayan Fellows Join NAE Program Office

Candice "Sachi" Gerbin

Victoria (Vickie) Gunderson

Pria Young

Candice Sachi Gerbin received her Ph.D. in biological chemistry from UCLA, where her work was focused on the regulation of receptor proteins involved in cancers and the development of fluorescence-based assays for finding targeted cancer drugs. She earned her B.S. in biology from Harvey Mudd College. Sachi has enjoyed teaching science to a wide audience, both as a high school biology teacher in Japan through the JET Program and as a writer for the Nature Publishing Group's education website. Her ultimate goal is to improve public health and safety by increasing public awareness.

Through the Mirzayan Fellowship, Sachi hopes to learn more about communicating information effectively to the public, promoting science and engineering, and gaining a better understanding of how the policy world works. In her free time, she enjoys traveling and good food.

Victoria "Vickie" Gunderson recently defended her Ph.D. thesis in chemistry at Northwestern University. Her doctoral research focused on understanding basic design requirements for the practical conversion of solar energy to electricity and fuels. Prior to graduate school, Vickie received a bachelor's degree in chemistry from Carleton College and then worked as a chemist at UOP (Honeywell). Her professional interests are concentrated at the intersection of science, technology, and policy, with an emphasis on energy and diversity in education.

As a Mirzayan Fellow, Vickie is using both her academic and industrial scientific expertise to support NAE's program on diversity in engineering. She works closely with Catherine Didion in the Diversity in the Engineering Workforce (DEW) Program to support the Committee on Capitalizing on the Diversity of the Science & Engineering Workforce in Industry. Her experience teaching monthly science lessons to third and fourth graders and volunteering with Big Brothers/Big Sisters has given her useful insights for improving the content and publicity for the *EngineerGirl!* website and essay contest. Vickie is also working with a National Research Council (NRC) program promoting women in science, engineering, and medicine. She provides support for the Committee for Women in Science, Engineering and Medicine, which is exploring ways of advancing minority women in academia through institutional transformation.

Passionate about finding ways to impact society directly, Vickie is looking forward to taking the next steps toward a career in science and technology policy. She is also an avid traveler, an aspiring wine connoisseur, and a die-hard Cubs fan.

Pria Young is a fourth year Ph.D. candidate in the Chemical and Biological Engineering Department at Northwestern University where she is designing new solid catalysts for the conversion of carbon dioxide into desirable compounds, such as liquid fuels and chemical feedstocks. In addition to working on her degree, Pria has held several campus leadership positions. As co-chair of the McCormick Graduate Leadership Council, she organized a panel series, "Preparing Future Professionals," for science and technology graduate students; as chair of the Northwestern Graduate Leadership Council, she was a strong advocate on issues like conflict resolution and child care for graduate students throughout the university. Before arriving at Northwestern, Pria was a student athlete at Hobart and William Smith Colleges (HWS) where she received a B.A. in English and a B.S. in chemistry with high honors. After HWS she took time off to indulge her love of the outdoors, mostly snowboarding and hiking in the mountains of Colorado and New Hampshire.

Pria is passionate about the responsible and thoughtful integration of alternative energy resources and sustainable technology into our complex socio-technical infrastructure. She hopes her Mirzayan Fellowship will provide opportunities for her to explore the complexities of this undertaking from a policy perspective. Ultimately, Pria would like to merge her engineering background with her growing interest in business to drive innovation from the private sector. At NAE, she is working with Rachelle Hollander, head of the Center for Engineering, Ethics, and Society (CEES), on the Energy Ethics in Science and Engineering Education project.

2011 U.S. Frontiers of Engineering Symposium

Speakers in the Additive Manufacturing Session—Brett Lyons (Boeing), Brent Stucker (University of Louisville), Hod Lipson (Cornell University), and Andrew Christensen (Medical Modeling, Inc.)—take questions from the audience following their presentations at the 2011 US FOE meeting. Photo courtesy of Google.

On September 19–21, 112 early-to-middle-career engineers attended the 2011 U.S. Frontiers of Engineering (US FOE) Symposium hosted by Google at its headquarters in Mountain View, California. NAE member **Andrew M. Weiner**, Scifres Family Distinguished Professor of Electrical and Computer Engineering at Purdue University, chaired the organizing committee and the symposium. The presentation topics this year were additive manufacturing, semantic processing, engineering sustainable buildings, and neuroprosthetics.

In the first session, on additive manufacturing, researchers described how cutting-edge technologies enable layer-wise fabrication of complex objects directly from computer-aided design (CAD) files, without part-specific tooling. Examples of these technologies include stereolithography, fused-deposition modeling, 3D printing, selective laser melting, laser-engineered net-shape processes, ultrasonic consolidation, and selective laser sintering. The presentations included an overview of additive manufacturing processes and their impact on industrial practices and academic research, descriptions of applications in the fields of aerospace and medicine, and a discussion of the potential challenges and implications of additive manufacturing.

The explosion of content on the Internet and its impact as a source of information requires a deep understanding of Web content. Semantic processing, the topic of the second session, refers to high-level information-understanding tasks, such as inferring author sentiment from a blog or review; searching through collections of documents, images, and videos; and translating text from one language to another. Because natural languages and images constitute the majority of data on the Internet, presenters described semantic processing algorithms that advance the understanding of the meaning of words and sentences, relationships, and sentiments; use collaboratively generated content to represent the semantics of natural language; and improve searches for images and video, as well as plots, graphs, and diagrams.

According to the U.S. Energy Information Administration, buildings account for one-third of primary energy usage and two-thirds of all electricity consumption. The session on engineering sustainable buildings focused on the emerging integration and transformation of the architecture, engineering, and construction industries to increase social, economic, and environmental benefits via sustainable buildings. The four speakers focused on cutting-edge benchmarking for building performance and life-cycle cost assessment, tools that execute more efficient and effective design processes, multi-scale modeling for designing new and renovating old buildings with sustainability in mind, and the use of location-based services and social networks to drive market transformation for sustainable building.

The last session, on neuroprosthetics, focused on engineering technologies that can interface with the nervous system—for example, by stimulating the nervous system to restore sensory function or capturing motor intention from the brain to control prostheses. Talks covered the recent clinical development of retinal implants to restore sight and the emerging field of optogenetics, the use of neural recording devices to extract motor-command signals as communication aids and brain-machine interfaces for disabled populations, and new paradigms of "neuromorphic" processing, that is, applying lessons based on the brain's processing properties to next-generation applications, such as cochlear implants.

On the first afternoon of the meeting, participants gathered in small groups for "get-acquainted" sessions, where each of them presented and answered questions about a slide describing his/her research or technical work. This event gave everyone an opportunity to meet and learn about each other's work early in the program. On the second afternoon, Google staff presented "lightning talks" on current work on translation, speech recognition, optical character recognition, machine perception, and audio signal processing. The talks were followed by a lively question and answer period.

The dinner speaker for this year's symposium was **Alfred Spector**, vice president of research and special initiatives at Google. He described how computer science has been changing, its influence on the world, and how it can help us manage the grand challenges that lie ahead. Specifically, he noted that computer science can have a major impact on health care by improving the collection and interpretation of data and on education by facilitating individualized instruction. Although obstacles to achieving these goals will have to be overcome and security remains a key issue, he is optimistic that great progress will be made in this time of tremendous opportunity.

A new initiative for US FOE participants—The Grainger Foundation Frontiers of Engineering Grants—was announced at the 2011 meeting. The grants will provide seed funding for US FOE participants working at U.S.-based institutions to enable further pursuit of important interdisciplinary research and projects stimulated by US FOE symposia.

Funding for the 2011 US FOE Symposium was provided by Google, The Grainger Foundation, the Air Force Office of Scientific Research, the U.S. Department of Defense (ASDR&E), the National Science Foundation, Microsoft Research, and Cummins Inc.

The 2012 US FOE Symposium, scheduled for September 13–15, will be hosted by General Motors at the GM Tech Center in Warren, Michigan. Topics for 2012 will be: engineering materials for the biological interface, serious games, climate engineering, and vehicle electrification. **Kristi Anseth**, Distinguished Professor and professor of surgery, University of Colorado, Boulder, will chair the symposium. She succeeds Andrew Weiner, who has served a three-year term as chair of the US FOE Symposium.

For more information about the symposium series or to nominate an outstanding engineer to participate in a future event, contact Janet Hunziker at the NAE Program Office at (202) 334-1571 or by e-mail (*jhunziker@nae.edu*).

New Volume of *Memorial Tributes* Available

The fifteenth volume in the *Memorial Tributes* series in remembrance of recently deceased NAE members and foreign associates is available. Each volume includes personal remembrances of their lives and outstanding achievements that will stand as an enduring record of their contributions to engineering and to humankind. The tributes are written mostly by contemporaries and colleagues with personal knowledge of the interests and engineering accomplishments of the deceased.

This volume includes tributes to the following individuals:

William D. Alexander
Lew Allen Jr.
Neal R. Amundson
John H. Argyris
Holt Ashley
Kermit Earl Brown
Praveen Chaudhari
Aaron Cohen
Charles Concordia
Alfred John Eggers Jr.
Leopold B. Felsen
Iain Finnie
John A. Focht Jr.
George A. Fox
Ferdinand Freudenstein
Robert A. Fuhrman
Haren S. Gandhi
Joseph G. Gavin Jr.
Leslie A. Geddes
Paul Germain
Robert R. Gilruth
Lawrence R. Glosten
Wallace D. Hayes
Ira Grant Hedrick
David R. Heebner
Allan F. Henry
George Herrmann
Walter Herrmann
Walter R. Hibbard Jr
John Hill
David Clarence Hogg
George W. Housner
W.J. "Jack" Howard
Frederick Jelinek
Amos E. Joel Jr.
Roy G. Johnston
James C. Keck
Edwin E. Kintner
Herbert J.C. Kouts
Thomas R. Kuesel
Joseph Talbot Kummer
(Michael) James Lighthill
Henry R. Linden
A. L. London
John (Jack) P. Longwell
Fred E. Luborsky
Alan G. Macdiarmid
John H. McElroy
Henry L. Michel
Walter Shepard Owen
William H. Phillips
Thomas H. Pigford
Brian H. Rowe
Rustum Roy
George S. Schairer
Manfred Robert Schroeder
Glenn A. Schurman
L. E. (Skip) Scriven
Joanne Simpson
Robert J. Spinrad
H. Guyford Stever
Martin Summerfield
Milton D. Van Dyke
William L. Wearly
John V. Wehausen
Max T. Weiss
Richard T. Whitcomb
Maurice V. Wilkes

Calendar of Upcoming Meetings and Events

December 12	Meeting of the Roundtable on Technology, Science, and Peacebuilding
December 30– January 30, 2012	Election of new NAE Members and Foreign Associates

2012

January 3– April 2	Call for nominations for the 2013 Draper, Gordon, and Russ Prizes and the 2012 Founders and Bueche Awards
January 10–12	Meeting of the Committee on Integrated STEM Education
January 12	Meeting of the NRC Governing Board Executive Committee
January 15	Deadline for submission of petition candidates for NAE officers and councillors
February 2–3	Meeting of the Membership Policy Committee Irvine, California
February 6	Meeting of the National Academies Corporation Irvine, California
February 6–7	Meeting of the NRC Governing Board Irvine, California
February 8–9	Meeting of the NAE Council Irvine, California
February 9	Press Release: Announcement of the NAE Class of 2012
February 9	NAE National Meeting Irvine, California
February 19–25	National Engineers Week
February 21	NAE Awards Forum and Awards Dinner/Ceremony (by invitation only)
February 28	NAE Regional Meeting Houston, Texas
February 15	Meeting of the NRC Governing Board Executive Committee
March 1–3	Indo-America Frontiers of Engineering Symposium Bethesda, Maryland
March 1–31	Election of NAE officers and councillors
March 14	Meeting of the NRC Governing Board Executive Committee
March 22	NAE Regional Meeting Santa Barbara, California
March 29–31	German-American Frontiers of Engineering Symposium Potsdam, Germany
April 11	Meeting of the NRC Governing Board Executive Committee

All events are held in Washington, D.C., unless otherwise noted. For information about regional meetings, please contact Sonja Atkinson at *satkinso@nae.edu* or (202) 334-3677.

In Memoriam

S. GEORGE BANKOFF, 89, Walter P. Murphy Professor of Chemical and Mechanical Engineering, Emeritus, Northwestern University, died on July 14, 2011. Dr. Bankoff was elected to NAE in 1996 "for contributions to the field of two-phase flow and heat transfer and its application to nuclear-reactor thermohydraulics."

JORDAN J. BARUCH, 88, president, Jordan Baruch Associates, died on October 26, 2011. Dr. Baruch was elected to NAE in 1974 "for contributions to technology transfer to industry, noise control systems, and application of computer technology."

SETH BONDER, 79, The Bonder Group, died on October 29, 2011. Dr. Bonder was elected to NAE in 2000 "for technical and organizational leadership in military and civilian operations research."

Y. AUSTIN CHANG, 78, Wisconsin Distinguished Professor Emeritus, Department of Materials Science and Engineering, University of Wisconsin, died on August 2, 2011. Dr. Chang was elected to NAE in 1996 "for applications of thermodynamics, phase diagrams, and kinetics to the understanding of modern materials of technological significance."

ROBERT A. CHARPIE, 86, chairman, Ampersand Ventures, died on October 13, 2011. Dr. Charpie was elected to NAE in 1975 "for contributions to nuclear, electronic, photographic, and energy related enterprises."

LEE L. DAVENPORT, 95, retired vice president and chief scientist, GTE, died on September 30, 2011. Dr. Davenport was elected to NAE in 1973 "for original contributions to the development of radar, infrared analytical instrumentation, and leadership in development of communications technology."

RICHARD E. DEVOR, 67, College of Engineering Distinguished Professor of Manufacturing, Department of Mechanical Science and Engineering, University of Illinois, died on July 26, 2011. Dr. DeVor was elected to NAE in 2000 "for contributions to the field of manufacturing research and its applications."

ROBERT C. EARLOUGHER JR., 70, retired vice president, International Production, Marathon Oil Company, died on August 19, 2011. Dr. Earlougher was elected to NAE in 1996 "for contributions to pressure transient analysis of petroleum reservoirs and for technological management."

ROBERT W. GALVIN, 89, Chairman Emeritus, Motorola Inc., died on October 11, 2011. Mr. Galvin was elected to NAE in 2002 "for leadership in the commercialization of innovative electronics technologies, and for advancing the principles of Total Quality Management."

WILSON GREATBATCH, 92, president, Wilson Energy LLC, died on September 27, 2011. Mr. Greatbatch was elected to NAE in 1988 "for the invention and relentless improvement of the life-saving implantable cardiac pacemaker and the long-life lithium-iodine battery."

WILLIAM R. HAWTHORNE, 98, Senior Lecturer Emeritus, Massachusetts Institute of Technology, died on September 16, 2011. Sir Hawthorne was elected Foreign Associate of NAE in 1976 "for pioneering contributions in the understanding of fluid dynamics and thermodynamics and their applications in mechanical engineering, particularly jet engines."

STEPHEN P. JOBS, 56, CEO, Apple Inc., died on October 5, 2011. Mr. Jobs was elected to NAE in 1997 "for contributions to the creation and development of the personal computer industry."

EDWARD R. KANE, 93, former president, E.I. du Pont de Nemours & Company, died on September 16, 2011. Dr. Kane was elected to NAE in 1979 "for contributions to the development of synthetic fiber processing and leadership in the chemical industry."

YAO TZU LI, 97, Professor Emeritus of Aeronautics and Astronautics, Massachusetts Institute of Technology, died on August 14, 2011. Dr. Li was elected to NAE in 1987 "for contributions to innovation in instrumentation, control, and to engineering education."

JOHN MCCARTHY, 84, Professor Emeritus, Stanford University, died on October 24, 2011. Dr. McCarthy was elected to NAE in 1987 "for innovation, leadership, and education contributions in computer science and technology, including programming languages, artificial intelligence, and theory of computation."

DADE W. MOELLER, 84, chairman of the board, Dade Moeller & Associates Inc., died on September 26, 2011. Dr. Moeller was elected to NAE in 1978 "for leadership in education and research and services to governmental agencies in the control of radiation in the environment."

WESLEY L. NYBORG, 94, Professor Emeritus, Department of Physics, University of Vermont, died on September 24, 2011. Dr. Nyborg was elected to NAE in 1996 "for the applications of acoustic physical theory to the safety of medical ultrasound."

HENRY J. ONGERTH, 98, retired sanitary engineer, California Department of Health, died on August 18, 2011. Mr. Ongerth was elected to NAE in 1976 "for leadership in water supply field, particularly in maintaining drinking water standards and criteria."

JOSEPH PENZIEN, 86, Professor Emeritus of Structural Engineering, University of California, Berkeley, died on September 19, 2011. Dr. Penzien was elected to NAE in 1977 "for pioneering research on probabilistic methods in earthquake engineering, with emphasis on linear and non-linear structural response analysis."

MAX S. PETERS, 90, Professor Emeritus of Chemical Engineering, University of Colorado, died on June 20, 2011. Dr. Peters was elected to NAE in 1969 "for contributions to the study of kinetics and mechanisms of chemical reactions."

JAMES W. POIROT, 79, Chairman Emeritus, CH2M Hill Inc., died on August 4, 2011. Mr. Poirot was elected to NAE in 1993 "for providing leadership in the development of quality management systems for engineering organizations."

ROBERT A. PRITZKER, 85, president and CEO, Colson Associates Inc., died on October 27, 2011.

Mr. Pritzker was elected to NAE in 1991 “for innovative use of industrial engineering and management principles in the growth and development of diversified product-based manufacturing operations.”

JOSEPH B. REAGAN, 76, retired vice president and general manager, Lockheed Martin Missiles & Space Company, died on August 14, 2011. Dr. Reagan was elected to NAE in 1998 “for contributions to space science and instrumentation and their application to national space programs.”

DENNIS M. RITCHIE, 70, Member of the Technical Staff, Bell Laboratories, Lucent Technologies, died on October 12, 2011. Dr. Ritchie was elected to NAE in 1988 “for development of the ‘C’ programming language and for co-development of the UNIX operating system.”

KLAUS SCHOENERT, 84, professor of mineral engineering, retired, Technical University of Clausthal, died on September 24, 2011. Dr. Schoenert was elected Foreign Associate of NAE in 1991 “for contributions to fracture physics and fragmentation fundamentals leading to innovative technology for size reductions in ore processing.”

MAURICE M. SEVIK, 88, retired senior research scientist, Naval Surface Warfare Center, died on October 20, 2011. Dr. Sevik was elected to NAE in 1994 “for leadership and contributions leading to quiet U.S. Navy ships and nuclear submarines.”

REUEL SHINNAR, 87, Distinguished Professor of Chemical Engineering, The City College of the City University of New York, died on August 19, 2011. Professor Shinnar was elected to NAE in 1985 “for the breadth and quality of his research in reactor design, control theory, chemical kinetics, statistical analysis and process economics.”

ANTHONY E. SIEGMAN, 79, McMurtry Professor of Engineering Emeritus, Stanford University, died on October 7, 2011. Dr. Siegman was elected to NAE in 1973 “for contributions to maser and laser technology and to education in this field.”

JOHN W. TOWNSEND JR., 87, retired director, NASA Goddard Space Flight Center, died on October 29, 2011. Dr. Townsend was elected to NAE in 1975 “for leadership in developing sounding rockets and earth environment satellites and advanced technology environmental studies.”

MILTON H. WARD, 79, retired president, Ward Resources Inc., died on October 13, 2011. Mr. Ward was elected to NAE in 1994 “for leadership in developing, building, and operating major mineral production facilities in remote and challenging environments.”

ROBERT H. WIDMER, 95, retired vice president, General Dynamics Corporation, died on June 20, 2011. Mr. Widmer was elected to NAE in 1977 “for leadership and technical skill in applying innovations and improvement to aircraft and weapon system design.”

Publications of Interest

The following reports have been published recently by the National Academy of Engineering or the National Research Council. Unless otherwise noted, all publications are for sale (prepaid) from the National Academies Press (NAP), 500 Fifth Street, N.W., Lockbox 285, Washington, DC 20055. In addition, all reports can be downloaded, in pdf format, for free. For more information or to place an order, contact NAP online at *http://www.nap.edu* or by phone at (888) 624-8373. *(Note: Prices quoted are subject to change without notice. Online orders receive a 20 percent discount. Please add $4.50 for shipping and handling for the first book and $0.95 for each additional book. Add applicable sales tax or GST if you live in CA, DC, FL, MD, MO, TX, or Canada.)*

Chemistry in Primetime and Online: Communicating Chemistry in Informal Environments. For the United States to maintain its competitive edge in the global economy, the public must have a much better understanding of science and technology issues than it has today. This can be achieved through both formal and informal learning. Considering that most Americans learn about science outside of school, chemistry content on television, on the Internet, in museums, and in other informal educational settings may be effective ways of transmitting information and stimulating interest in chemistry. In May 2010, the National Academies Chemical Sciences Roundtable held a workshop to look into how most people get scientific information informally and discuss how chemists can improve the way they approach a general, nontechnical audience. Workshop participants included chemical practitioners (e.g., graduate students, postdoctoral students, professors, and administrators); experts on informal learning; representatives of public and private funding organizations; science writers, bloggers, publishers, and university communications officers; and producers of television and Internet content. This volume provides a summary of the workshop and examples of chemistry-related content in informal educational settings. It also includes a discussion of the development of measures for gauging recognition and retention of information presented in various media formats and settings. No conclusions or recommendations are included, but participants largely agreed that chemists should work more with professional writers, artists, and videographers with experience in communicating with general audiences. In addition, there was general agreement that formal education sets the stage for informal interactions with chemists and chemistry content.

NAE member **Mark A. Barteau**, senior vice provost for research and strategic initiatives, University of Delaware, co-chaired the roundtable. Paper, $30.00.

Health Care Comes Home: The Human Factors. Health care devices, technologies, and practices are increasingly being found in the home. The factors behind this migration include rising costs of health care, growing numbers of older adults, the prevalence, and improved survival rates, of people with chronic conditions and diseases, and a wide range of technological innovations. The quality of care that results varies considerably in terms of safety, effectiveness, and efficiency, as well as in cost. This report by a committee of experts provides a review of current knowledge and practice of health care in residential settings and discussions of short- and long-term effects of emerging trends and technologies. The committee also identifies design flaws and imbalances between the requirements for the proper use of technological systems and the capabilities of users. Recommendations for improving health care in the home cover the regulation of health care technologies, training and preparation of in-home care providers, and modifications of existing housing and the design of new accessible housing. In addition, the committee identifies gaps in knowledge and suggests how they can be addressed through research and development and how the Agency for Healthcare Research and Quality, the Food and Drug Administration, and federal housing agencies can collaborate to improve the quality of health care in the home.

NAE member **P. Hunter Peckham**, Donnell Institute Professor of Biomedical Engineering & Orthopaedics, Case Western Reserve University, and director, Functional Electrical Stimulation Center, Cleveland Louis Stokes Veterans Affairs Medical Center, was a member of the study committee. Paper, $35.00.

Assessment of Marine and Hydrokinetic Energy Technology: Interim Letter Report. Power in ocean waves originates as wind that is transferred to the sea surface when it blows over large areas of the ocean. The resulting wave field consists of a collection of waves at different frequencies traveling in various directions and delivering their power to near-shore areas. In comparison, ocean tides are a response to gravitational forces exerted by the Moon and Sun.

Marine and hydrokinetic resources are increasingly becoming part of energy regulatory, planning, and marketing in the United States, and assessments are being conducted for future development. State-based renewable portfolio standards and federal production and investment tax credits have increased interest in the possible deployment of marine and hydrokinetic technologies. This interim report provides an evaluation of detailed appraisals for the U.S. Department of Energy estimating the amount of extractable energy in U.S. marine and hydrokinetic resources. In addition, the report includes evaluations of methodologies, technologies, and assumptions associated with resource assessments of wave and tidal energy.

NAE members on the study committee were **Paul G. Gaffney II** (chair), president, Monmouth University, and **Bhakta B. Rath**, head, Materials Science and Component Technology, Directorate and Associate Director of Research, Naval Research Laboratory. Free PDF.

Learning What Works: Infrastructure Required for Comparative Effectiveness Research: Workshop Summary. To improve the effectiveness and value of health care, the United States must increase its capacity for the ongoing study and monitoring of the relative effectiveness of different clinical interventions. This will require more and bigger trials and studies, systematic reviews, innovative research strategies, and clinical registries, as well as improvements, through the translation of information and decision support, in how the results are applied. As part of the Learning Health System series of workshops, the Institute of Medicine Roundtable on Value and Science-Driven Health Care hosted a workshop to discuss capacity priorities for building an evidence base for more effective care and higher value for patients. This volume provides a summary of the proceedings of the seventh workshop in the series, which was focused on infrastructural needs—including methods, coordination capacities, data resources and linkages, and workforce—for developing an expanded, efficient national capacity for comparative-effectiveness research. In addition, it provides assessments of current capacity and identifies priorities for next steps.

NAE member **Cato T. Laurencin**, University Professor; Albert and Wilda Van Dusen Distinguished Professor of Orthopaedic Surgery; Professor of Chemical, Materials, and Biomolecular Engineering; CEO, Connecticut Institute for Clinical and Translational Science; and director, Institute for Regenerative Engineering, University of Connecticut, was a member of the roundtable. Paper, $63.00.

Opportunities in Protection Materials Science and Technology for Future Army Applications. Despite advances in materials, reducing the weight of armor that can protect against increasingly destructive threats presents a huge challenge. This report explores the current theoretical and experimental understanding of key issues surrounding protection materials, identifies major challenges and technical gaps for the development of future lightweight protection materials, and recommends steps toward their development. The study committee reviews multi-scale shockwave energy-transfer mechanisms and experimental approaches for characterizing them over short time scales, as well as multiscale modeling techniques for predicting mechanisms of dissipating energy. The report also considers exemplary threats and a design philosophy for the three key applications of armor systems: (1) personnel protection, including body armor and helmets, (2) vehicle armor, and (3) transparent armor. The committee recommends that the U.S. Department of Defense establish a defense initiative for protection materials by design (PMD), along with funding lines for basic and applied research by government, industry, and academia. The PMD initiative should include a combination of research on computational, experimental, and materials testing, characterization, and processing.

NAE members on the study committee were **Edwin L. Thomas** (chair), William and Stephanie Sick Dean of Engineering, professor of mechanical engineering and materials science, and professor of chemical and biomolecular engineering, Rice University; **John W. Hutchinson**, Abbott and James Lawrence Professor of Engineering, Harvard University; and **Robert M. McMeeking**, professor of mechanical engineering and professor of materials, Department of Mechanical Engineering, University of California, Santa Barbara. Paper, $40.50.

Waste Forms Technology and Performance: Final Report. The U.S. Department of Energy Office of Environmental Management (DOE-EM) is responsible for cleaning up radioactive waste and environmental contamination resulting from five decades of nuclear weapons production and testing. A major focus of this program involves the retrieval, processing, and immobilization of waste into stable, solid waste forms for disposal. This report, requested by DOE-EM, examines requirements for waste-form technology and performance in the cleanup program. The report provides information to support improvements in methods of processing waste and selecting and fabricating waste forms. The study committee focuses particularly on processing technologies for high-level radioactive waste, DOE's most expensive and arguably most difficult challenge. The key messages are presented in 10 findings and one recommendation.

NAE members on the study committee were **Milton Levenson** (chair), consultant and retired vice president, Bechtel International, and **David W. Johnson Jr.**, editor, *Journal of the American Ceramic Society*. Paper, $57.00.

Building the 21st Century: U.S. China Cooperation on Science, Technology, and Innovations. The global economy is characterized by increasing competition to attract the resources necessary to develop leading-edge technologies that can stimulate regional and national growth. One way to facilitate growth and improve national competitiveness is to improve the national "innovation system." This will require national technology development and innovation programs designed to support research on new technologies, enhance commercial returns on the national research investment, and facilitate the production of globally competitive products. Understanding the policies that other nations are pursuing and their effectiveness is essential to understanding changes in the nature and terms of economic competition. This report reviews selected foreign innovation programs and compares them with major U.S. programs. The analysis includes a review of the goals, concepts, structures, operation, funding levels, and evaluations of foreign programs designed to advance the innovation capacity of national economies and improve their international competitiveness. The analysis focuses on key areas of future growth (e.g., renewable energy) to generate case-specific recommendations where appropriate.

NAE member **Mary L. Good**, Donaghey University Professor and Dean Emeritus, Donaghey College of Engineering and Information Technology, University of Arkansas at Little Rock, and former under secretary for technology, U.S. Department of Commerce, was a member of the study committee. Paper, $47.75.

Report of a Workshop on Pedagogical Aspects of Computational Thinking. In 2008, the Computer and Information Science and Engineering Directorate of the National Science Foundation asked the National Research Council to conduct two workshops to explore the nature of computational thinking and its cognitive and educational implications. The first workshop focused on the scope and nature of computational thinking and on articulating what "computational thinking for everyone" might mean. Drawing in part on the proceedings of that workshop, this report summarizes the second workshop, held February 4–5, 2010, which focused on pedagogical considerations for computational thinking. Structured to gather pedagogical insights from educators with a variety of perspectives who have worked with K–12 teachers and students, the workshop highlighted different approaches to computational thinking and explored lessons learned and best practices. Because the workshop was not intended to result in a consensus on the scope and nature of computational thinking, no findings or recommendations are included.

NAE member **Alfred V. Aho**, Lawrence Gussman Professor of Computer Science, Columbia University, was a member of the study committee. Paper, $42.00.

The Future of Photovoltaic Manufacturing in the United States. One of the major projects of the National Research Council Board on Science Technology and Economic Policy (STEP) is to examine state and local investment programs for attracting and supporting knowledge-based industries. STEP also analyzes state and regional innovation initiatives to gain a better understanding of the challenges associated with the transition of research results into products, the characteristics of successful state and regional programs, and their interactions with federal programs and private initiatives.

In April and July 2009, STEP convened two meetings to assess the future of the U.S. photovoltaics industry and the practical steps taken by the federal government and some state and regional governments to develop U.S. capacity to manufacture photovoltaics competitively. This report includes the presentations and discussions from these meetings and explores prospects for cooperative R&D, standards, and road-mapping that could accelerate the growth of a U.S. photovoltaics industry. The discussion covers strengthening existing industries, as well as specific new technology focus areas, such as nanotechnology, stem cells, and energy.

NAE member **Mary L. Good**, Donaghey University Professor and Dean Emeritus, Donaghey College of Engineering and Information Technology, University of Arkansas at Little Rock, and former under secretary for technology, U.S. Department of Commerce, chaired the study committee. Hardcover, $60.24.

A Review of the Use of Science and Adaptive Management in California's Draft Bay Delta Conservation Plan. The San Francisco Bay Delta estuary is a large, complex ecosystem in California that has been substantially altered by dikes, levees, channelization, pumps, human development, introduced species, dams on its tributary streams, and contaminants. The Delta supplies water from the state's wetter northern regions to drier southern regions, as well as providing habitat for many species, some of which are threatened and endangered. The restoration of water in recent years has exacerbated tensions over water allocations, and various comprehensive plans have been developed to ensure that reliable water supplies are available and to protect the ecosystem. One of these plans is the Bay Delta Conservation Plan (BDCP). This review of the draft BDCP concludes that the plan is incomplete in a number of important areas and identifies key scientific and structural gaps. The plan is missing the type of structure usually associated with current planning methods in which goals and objectives are specified, alternative measures for achieving the objectives are introduced and analyzed, and a course of action is identified based on analytical optimization of economic, social, and environmental factors. The panel underscores the importance of a credible, robust BDCP in addressing water management problems that beset the Delta and concludes that a stronger, more complete, and more scientifically credible plan that effectively integrates available science could pave the way for the next generation of solutions to California's chronic water problems.

NAE member **Jerome B. Gilbert**, consulting engineer, Orinda, California, was a member of the study committee. Paper, $26.00.

Summary of the Workshop to Identify Gaps and Possible Directions for NASA's Micrometeoroid and Orbital Debris Programs. This report summarizes a two-day workshop held on March 9–10, 2011, that brought together stakeholders with various perspectives on matters concerning NASA Micrometeoroid and Orbital Debris (MMOD) programs, NASA mission operators, the role and relationships of NASA MMOD programs to other federal agencies, MMOD and the commercial industry, and orbital debris retrieval and removal. The summary includes assessments of NASA's existing efforts, policies, and organizations for retrieving and removing orbital debris and dealing with micrometeoroids and creates an "advisory dialogue" on potential opportunities for improving program and maintenance practices.

NAE members on the study committee were **Kyle T. Alfriend**, TEES Distinguished Research Chair, and professor of aerospace engineering, Texas A&M University, and **George J. Gleghorn**, retired vice president and chief engineer, TRW Space and Technology Group. Paper, $15.00.

Structural Integrity of Offshore Wind Turbines: Oversight of Design, Fabrication, and Installation: Special Report 305. This Special Report by the Transportation Research Board (TRB) explores the approach of the U.S. Department of the Interior Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE) to overseeing the development and safe operation of wind turbines on the outer continental shelf, with a focus on structural safety. To ensure the orderly development of offshore wind energy and support the stable economic development of this nascent industry, the committee that developed the report recommends that the United States establish clearly defined requirements that can accommodate future design changes. The report committee recommends that BOEMRE develop requirements that establish goals and objectives for structural integrity, environmental performance, and energy generation. The committee argues that, because offshore wind farms are primarily unmanned and involve minimal quantities of hazardous substances, risks to human life and the environment associated with them are substantially lower than for other industries, such as offshore oil and gas. Thus significantly less regulatory oversight may be necessary, which would mean the industry would be responsible for proposing standards, guidelines, and recommended practices to meet the performance requirements established by BOEMRE. The domestic industry could build on standards, guidelines, and practices developed in Europe, where offshore wind energy is more fully developed, but will have to fill in gaps, such as addressing wave and wind loadings encountered in hurricanes. The report also includes findings and recommendations on the role of certified verification agents (third-party evaluators) in reviewing standards and project-specific proposals.

NAE member **Bruce R. Ellingwood**, professor, School of Civil and Environmental Engineering, Georgia Institute of Technology, was a member of the study committee. Free PDF.

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