THE NATIONAL ACADEMIES
REPORT IN BRIEF

Desalination: A National Perspective

Recent technological advances have made removing salt from seawater and groundwater a realistic option for increasing water supplies in some parts of the U.S., and desalination will likely have a niche in the nation's future water management portfolio. However, the potential of desalination is constrained by financial, social, and environmental factors. Substantial uncertainties remain about its environmental impacts, which have led to costly permitting delays. A coordinated, strategic research effort with steady funding is needed to better understand and minimize desalination's environmental impacts—and to find ways to further lower its costs and energy use.

Although planet Earth stands out as a watery oasis, nearly all of its water is found in the oceans. Only about 2.5 percent is freshwater—with much of this bound up in glaciers and snowpack—leaving only a small fraction to meet the world's domestic, agricultural, and environmental freshwater demands. Growing concern over water scarcity, not only in arid and semi-arid regions but also in some humid regions, has led to heightened interest in desalination. For example, the city of Tampa developed its seawater desalination plant when it became clear that groundwater pumping was draining local wetlands.

Reverse osmosis membrane modules at the Larnaca desalination plant, Cyprus.
Photo courtesy of Thomas Pankratz.

Desalination technology offers the potential to convert the almost inexhaustible supply of seawater and apparently vast quantities of brackish groundwater into a new source of freshwater. Technological advances over the past 40 years have reduced its cost and have led to dramatic increases in its use worldwide (see Figure 1, page 2). However, a host of financial, social, and environmental factors still impede its use. Among these factors are the high costs of dealing with concentrated salt wastes, especially at inland locations, and the considerable uncertainties about potential environmental impacts.

With the support of the U.S. Bureau of Reclamation and the U.S. Environmental Protection Agency, the National Research Council convened a committee to assess the state-of-the-art in desalination technology, address factors such as cost and implementation challenges, and to provide recommendations for action and research. The report concludes that a national strategic research agenda can help make desalination a more practical water supply option for some communities facing water shortages and enable desalination technology to serve a larger role in addressing the nation's water demands.

What is Desalination?

Desalination is the process of removing salts from seawater or brackish waters. The key elements of the water desalination system are: (1) intakes of seawater or brackish water (2) pre-treatment to remove suspended solids and prepare the source water for further processing (3) removal of dissolved solids, primarily salts, from the water (4) post-treatment to prevent corrosion of downstream water pipes, and (5) concentrate management, the handling and disposal or reuse of the salt wastes from the process. Several desalination technologies exist today, but the most common is the process of reverse osmosis. Reverse osmosis uses the driving force of hydraulic pressure to force seawater or brackish water through a semi-permeable membrane, removing a majority of dissolved salts and other contaminants.

Environmental Uncertainties Impede Use

A variety of environmental impacts are possible with desalination. One concern is that pumps

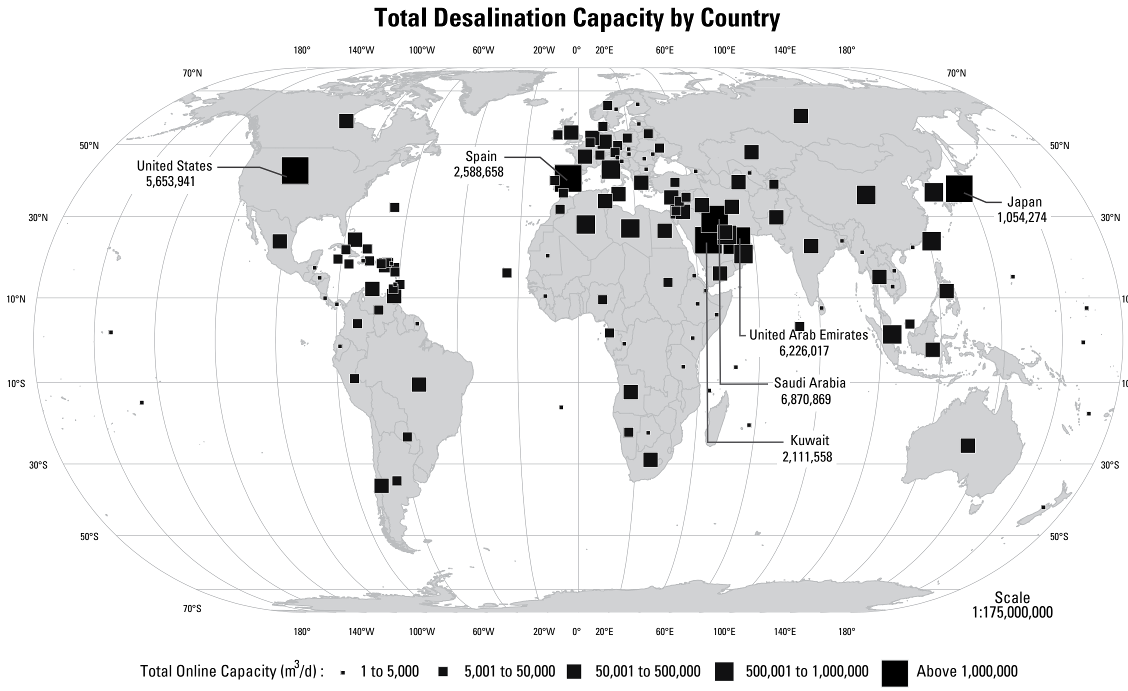

Figure 1. In 2006, worldwide online desalination capacity was roughly 10 billion gallons a day (data from GWI, 2006). From 2000 to 2005, U.S. desalination capacity grew by around 40 percent, but the total accounts for less than 0.4 percent of municipal and industrial water used in the United States. © International Mapping Associates

bringing in large volumes of ocean or estuary water into coastal desalination plants can pin or trap fish and other marine life in the intake structures. Another concern is that the use of inland brackish groundwater sources could deplete the groundwater, create subsidence, or affect water quality and quantity in adjacent lakes, streams, or aquifers. Another concern is the effect of the waste products of desalination, which include salt concentrates (and sometimes cleaning and conditioning agents), on the various surface water ecosystems into which they are discharged. Seawater desalination is also an energy-intensive process that can add to greenhouse gas emissions.

Knowledge of potential environmental impacts is essential to water supply planners when they consider desalination among water supply alternatives. However, there is still considerable uncertainty about the environmental impacts of desalination and, consequently, concern over its potential effects. Public concern has, in some cases, led to costly permitting delays for large seawater desalination plants. Limited studies to date suggest that the environmental impacts *may* be less detrimental than many other ways to supplement water—such as diverting freshwater from sensitive ecosystems—but definitive conclusions cannot be made without further research. The report recommends research to identify and reduce potential environmental impacts. However, the report concludes that desalination efforts do not need to be halted until this research is done and the uncertainties are removed.

The State of Desalination Technology

Industry has made great strides in reducing energy use for desalination with the commercialization of high-efficiency energy recovery devices and improvements in membrane technology. Reverse osmosis technology is relatively mature, and current energy use is near optimal values (within a factor of two of the theoretical thermodynamic minimum value for separating solutes from water) and can likely only be improved by another 15 percent. Therefore, all novel technologies should be assessed against reverse osmosis when energy use is the main consideration.

Nevertheless, opportunities remain to improve current technologies and further reduce cost and energy by small but economically significant amounts. With reverse osmosis desalination, there are ways to reduce the hydraulic pressure while maintaining the throughput of water which include: reducing membrane fouling through improved pretreatment; developing high-permeability, fouling-resistant, high-rejection, oxidant-resistant membranes; and optimizing membrane system design. There are also opportunities to reduce desalination costs by powering thermal or novel desalination processes with low-grade heat energy, left over from other industrial processes that would otherwise go to waste.

Several methods of concentrate management are available, including surface water discharge, deep-well injection, and high-recovery/thermal evaporation systems, and each has its own site-specific costs, regulatory requirements, environmental impacts, and limitations. Brackish groundwater desalination facilities face significant challenges as there are few, if any, cost-effective environmentally sustainable concentrate management technologies available for inland locations.

Costs of Desalination

Historically, the relatively high financial costs of desalination prevented the application of desalination technologies in most areas. The cost "picture" is changing in a number of important ways; improved membrane technologies are less expensive, the desalination process is becoming more energy efficient, and most notably the cost of other alternatives are becoming more expensive. At present, desalination costs are already low enough to make desalination an attractive option for some communities when the benefits of desalination are considered, such as providing a drought resistant supply and providing a means to diversify a large community's water supply portfolio.

However, the costs of desalination, like the costs of water supply alternatives, are locally variable and are influenced by factors such as site conditions and concentrate disposal options. In addition, increasing

Box 1. Priority Research Areas. Following are the priority research areas to help make desalination a competitive option among water supply alternatives. Highest priority topics are shown in bold. Research topics for which the federal government should have an interest—those with widespread benefits but for which no private sector entities are willing to make investments and assume the risks—are marked with asterisks.

GOAL #1: Understand the environmental impacts of desalination and develop approaches to minimize these impacts relative to other water supply alternatives

1. **Assess environmental impacts of desalination intake and concentrate management approaches****
    a. Conduct field studies to assess environmental impacts of seawater intakes**
    b. Conduct field studies to assess environmental impacts of brackish groundwater development**
    c. Develop protocols and conduct field studies to assess the impacts of concentrate management approaches in inland and coastal settings**
    d. Develop laboratory protocols for long-term toxicity testing of whole effluent to assess long-term impacts of concentrate on aquatic life**
    e. Assess the environmental fate and bioaccumulation potential of desalination-related contaminants**
2. **Develop improved intake methods at coastal facilities to minimize impingement of larger organisms and entrainment of smaller ones****
3. Assess the quantity and distribution of brackish water resources nationwide**
4. Analyze the human health impacts of boron to expedite water-quality guidance for desalination process design **

GOAL #2: Develop approaches to lower the financial costs of desalination so that it is an attractive option relative to other alternatives in locations where traditional sources of water are inadequate

5. Improve pretreatment for membrane desalination
    a. Develop more robust, cost-effective pretreatment processes
    b. Reduce chemical requirements for pretreatment
6. Improve membrane system performance
    a. Develop high-permeability, fouling-resistant, high-rejection, oxidant-resistant membranes
    b. Optimize membrane system design
    c. Develop lower cost, corrosion-resistant materials of construction
    d. Develop ion-selective processes for brackish water
    e. Develop hybrid desalination processes to increase recovery
7. Improve existing desalination approaches to reduce primary energy use
    a. Develop improved energy recovery technologies and techniques for desalination
    b. Research configurations and applications for desalination to utilize waste heat**
    c. Understand the impact of energy pricing on desalination technology over time**
    d. Investigate approaches for integrating renewable energy with desalination**
8. Develop novel approaches/processes to desalinate water in a way that reduces primary energy use**

GOAL #1 and 2 Cross Cuts:

9. **Develop cost-effective approaches for concentrate management that minimize environmental impacts****

awareness of potential environmental impacts is raising the costs of permitting and intake and out fall configurations in the United States. Meanwhile, the future costs of energy are uncertain. Conservation and water transfers will usually be less costly than desalination, and conservation of water often comes with associated benefits, such as reduced energy costs.

A Strategic Desalination Research Agenda

In order for desalination to become a more attractive option for communities facing water shortages, two overarching long-term research goals need to be met:

1. Understand the environmental impacts of desalination and develop approaches to minimize these impacts relative to other water supply alternatives, and
2. Develop approaches to lower the financial costs of desalination so that it is an attractive option relative to other alternatives in locations where traditional sources of water are inadequate.

The report recommends that a coordinated, strategic plan be developed to ensure that future federal investments in desalination are integrated and prioritized and address the topics in the federal interest within the two major goals identified in this report (see Box 1). The report also recommends that environmental research be emphasized up front when implementing the research agenda, because this research has the greatest potential for enabling desalination to help meet future U.S. water needs.

The growth in desalination was made possible to a great extent by a major federal investment in desalination research and development from the late 1950s to the early 1980s. Today, however, the private sector appears to be funding the majority of desalination research, with estimated spending more than twice that of other sources of funding. Some states, specifically California, are investing in desalination research, but state funding is generally directed to site-specific or region-specific problems, with a heavy emphasis on pilot and demonstration projects.

Most of the federal funding for desalination R&D comes from Congressional earmarks which limit the ability to develop a steady research program. Furthermore, federal investments in desalination research fell to $10 million in FY 2007, down from $24 million dollars in FY 2005 and 2006, largely due to an absence of earmarks in FY 2007. Among the nine federal agencies and laboratories that currently fund desalination research, there is no integrated or coordinated strategic research plan, and each agency or laboratory has its own research objectives.

Continuation of a federal program of research dominated by congressional earmarks will not serve the nation well. To ensure that future federal investments in desalination research are integrated and prioritized so as to address the two major goals identified in this report, the report recommends that the Office of Science and Technology Policy (OSTP) take the lead in planning and coordinating federal research and development. Initial federal appropriations on the order of recent spending on desalination research (total appropriations of about $25 million annually) should be sufficient to make good progress toward these goals, when complemented by ongoing non federal and private-sector desalination research.

Committee on Advancing Desalination Technology,
Amy K. Zander *(Chair)*, Clarkson University; **Menachem Elimelech,** Yale University; **David H. Furukawa,** Separation Consultants Inc.; **Peter Gleick**, Pacific Institute for Studies in Development, Environment, and Security; **Kenneth Herd**, Southwest Florida Water Management District; **Kimberly L. Jones**, Howard University; **Philip Rolchigo**, Pentair, Inc.; **Sandeep Sethi,** Carollo Engineers; **John Tonner,** Water Consultants International; **Henry J. Vaux**, University of California, Berkeley; **Judith S. Weis**, Rutgers University; **Warren W. Wood**, Michigan State University; **Stephanie E. Johnson** *(Study Director),* **Laura J. Ehlers** *(Interim Study Director (October 2006 to January 2007))*, and **Michael Stoever** *(Sr. Project Assistant)*, National Research Council.

This report brief was prepared by the National Research Council based on the committee's report. For more information or copies, contact the Water Science and Technology Board at (202) 334-3422 or visit http://nationalacademies.org/wstb. Copies of *Desalination: A National Perspective* are available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; www.nap.edu. Support for the study was provided by the U.S. Bureau of Reclamation and the U.S. Environmental Protection Agency.