WATER AND SUSTAINABLE DEVELOPMENT

OPPORTUNITIES FOR THE CHEMICAL SCIENCES

A WORKSHOP

REPORT TO THE

CHEMICAL SCIENCES

ROUNDTABLE

IAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

WATER AND SUSTAINABLE DEVELOPMENT

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Parry Norling, Frankie Wood-Black, and Tina M. Masciangioli, Editors

Chemical Sciences Roundtable

Board on Chemical Sciences and Technology

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Preface

The Chemical Sciences Roundtable (CSR) was established in 1997 by the National Research Council (NRC). It provides a science-oriented, apolitical forum for leaders in the chemical sciences to discuss chemically related issues affecting government, industry, and universities. Organized by the NRC's Board on Chemical Sciences and Technology (BCST), the CSR aims to strengthen the chemical sciences by fostering communication among the people and organizations—spanning industry, government, universities, and professional associations—involved with the chemical enterprise. The CSR does this primarily by organizing workshops addressing issues in chemical science and technology that require national attention.

A workshop was organized by the Chemical Sciences Roundtable of BCST on the topic Water and Sustainable Development: Opportunities for the Chemical Sciences. The workshop brought together top experts in the area of water science and technology and leaders in chemistry and chemical engineering from government, industry, and academia. This interaction was intended to enhance the synergy between these two communities and help engage a broader cross section of the chemical sciences community in this important arena of science and technology. The workshop sessions provided technical background and explored enhanced roles that the chemical sciences R&D community might play in identifying and addressing the issues that make water a critical limiting factor in human economic development and sustainability. The goal of the workshop was to inform the Chemical Sciences Roundtable. In that process, it may also engage the broad chemical sciences community in addressing the question of how to ensure the adequate supply of water that is required for public health, sustainable agriculture and food security, energy generation, and economic growth.

This report is largely an edited transcript of speaker and discussion remarks at the workshop. The discussions were edited and organized around major themes to provide a more readable summary. In accordance with the policies of the CSR, the workshop did not attempt to establish any conclusions or recommendations about needs and future directions, focusing instead on issues identified by the speakers.

Parry Norling and Frankie Wood-Black
Workshop Organizers

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Arthur Daemmrich, Chemical Heritage Foundation
Jean H. Futrell, Pacific Northwest National Laboratories
Raymond Hamelin, Université Pierre et Marie Curie (retired)
David Rea, DuPont Company (retired)
Vernon L. Snoeyink, University of Illinois
Garret P. Westerhoff, Malcolm Pirnie, Inc.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by **Perry L. McCarty**, Silas H. Palmer Professor Emeritus, Stanford University. Appointed by the Division on Earth and Life Studies, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authors and the institution.

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Introduction and Summary

Frankie Wood-Black
ConocoPhillips

Parry Norling
DuPont Company (retired)

At the World Summit on Sustainable Development, held in 2002 in Johannesburg, South Africa, concern for safe water supplies and adequate sanitation was noted as a key issue in the protection and management of natural resources for economic and social development. The report issued from the World Summit indicated a number of commitments that are directly related to water and sustainability—the focus and the topics of discussion at this workshop. Perhaps one of the most challenging of these commitments, outlined in Section IV of the Implementation Plan of the report),[1] is to launch a program of actions to achieve the millennium development goal (outlined in the Millennium Declaration) for safe water. The goal is, by the year 2015, to halve the proportion of people unable to reach or afford safe drinking water and the proportion of people without access to basic sanitation. Meeting this challenge will require the talents of chemists and chemical engineers, in addition to economists, city planners, and engineers in other fields. Greater understanding is needed of the fundamental causes of the problems and how to develop innovative technologies to reduce water scarcity (improved desalination, water conservation, water recycle); purify available water (analysis, treatment, pollution prevention); and manage water resources.

Many of the specific technical challenges and opportunities for the chemical sciences are well understood, but most responses have yet to be formulated and funded. Much of the public debate has focused on the problems and not the solutions, especially where the chemical sciences have answers. This workshop of the Chemical Sciences Roundtable sought to focus on solutions or paths to solutions in three sessions: Context and Overview, Water Quality and Supply, and Business Opportunities and Responsibilities. In the scope and time frame of this workshop it was impossible to cover all aspects of sustainable water supplies.

It should be noted that this meeting occurred at a fortuitous time. On June 2, 2003, the G8 leaders released a Water Action Plan that built on the principles and goals of the $1 billion Water for the Poor Initiative of the United States. That initiative was created to improve sustainable management of freshwater resources and to accelerate and expand international efforts to achieve the United Nations Millennium Declaration Goal. Initiative efforts include improving access to clean water and sanitation services, improving watershed management, and increasing the productivity of water. The G8 plan included two components from the U.S. initiative: (1) point-of-use technologies (chlorine-based solutions and filters used in the household), which are effective in combating disease and saving lives, and (2) revolving funds, which allow communities to finance capital-intensive water infrastructure projects over an affordable period of time at competitive rates.

CONTEXT AND OVERVIEW

To understand the opportunities for the chemical sciences in dealing with water-related problems, it is important to understand various aspects of the issues related to the current global agenda, impacts on water quality, water supplies (quantity and availability), and potential problems raised by water pollution. In this session, presentations were given by **Alan Hecht**, White House Council on Environmental Quality (currently at the U.S. Environmental Protection Agency); **Dennis Hjeresen**, Green Chemistry Institute; and **David Krabbenhoft**, U.S. Geologic Survey. Their talks framed the context of the issues surrounding water and provided a global perspective, appreciation of the role of green chemistry, and a specific challenge from a single contaminant—methylmercury.

[1]The Report of the World Summit on Sustainable Development Johannesburg, South Africa, August 26-September 4, 2002, can be found at *http://www.johannesburgsummit.org/.*

Here, it was pointed out that 80 percent of diseases in the developing world are water related, 4 billion to 7 billion people will face water scarcity in 2050, and water has become a priority issue for economic development throughout the world. The chemical sciences were called upon to address issues such as sanitation (the number-one means of reducing disease), water management (including use of innovative technology), and national water strategies. Other challenges mentioned include the shift of water use from agricultural to industrial applications; accessibility of water supplies; and dilemma of who pays for the treatment, transportation, and infrastructure necessary to deliver water to end users.

There was discussion about getting bright young scientists and engineers more interested in the world's water problems. It was suggested that the water issue lacks a "glamour factor" and that although the world's water concerns are great, there does not appear to be a major driver for attracting the best and brightest toward this fundamental problem that impacts every individual.

It was noted that developing countries currently have the opportunity to avoid the mistakes of the developed world. Instead of following the model of "develop first and clean up later," they might "leapfrog" with current and new technologies. A number of examples in which current technologies are far superior and can minimize the impact on water resources were provided.

Another key point raised involved the water-energy balance. It was pointed out that it takes energy to produce or transport water to the areas that are in need, and that current population densities in the arid and semiarid regions, the water-intensive nature of both agriculture and industry, and the sources and uses of water are all at the crux of this balance.

A number of places where green chemistry will eliminate the use of hazardous reactants (potential water pollutants), conserve water, and increase both the quality and the quantity of pure water were discussed. In one example, a systems approach is being used in industrial water treatment to protect infrastructure from corrosion, scaling, and bacterial growth with the use of more benign chemicals at lower levels. Another example highlighted the use of unique catalysts that are making hydrogen peroxide an economical and viable replacement for chlorine as an oxidant in a number of processes. Praise was also given to closed-loop systems that eliminate the use and contamination of water. It was noted that such systems are now in place for photographic film processing.

This session concluded with a look at mercury, the leading environmental contaminant that often results in consumption advisories for fish in the United States and around the world. Sources of mercury emissions in the environment, biological processes that transform mercury to the more biologically available methylmercury, and chemical conditions that favor such transformations were described. It was suggested that greater understanding of the true toxicological impacts of mercury is needed, and concern was raised about the way in which wetland restoration projects have been carried out. Such efforts, it was noted, can actually increase the presence of methylmercury in the environment.

WATER QUALITY AND SUPPLY: ANALYSIS AND TREATMENT

In this session, technical approaches to analysis and treatment of water problems were discussed by **Thomas E. Hinkebein,** National Desalination Roadmap Program manager and manager of the Geochemistry Department, Sandia National Laboratories; **Richard Luthy,** Silas H. Palmer Professor of Civil and Environmental Engineering Stanford University; and **Elias Greenbaum,** corporate fellow and research group leader, Oak Ridge National Laboratory, and professor of biological physics, University of Tennessee.

The link between population growth and stresses on water supplies was emphasized. It was pointed out that significant growth is taking place in areas with limited water supply. Since 54 percent of the U.S. population lives within 60 miles of the ocean, often in a marginal environment, it was suggested that the opportunity exists for development of viable desalination water sources. However, without a clear plan for the future, it was predicted that water supply issues will limit growth, rely on case-by-case government support, and cause more conflict between states that have water and those that do not.

Challenges of desalination were discussed within the context of the jointly developed Desalination and Water Purification Technology Roadmap of the Bureau of Reclamation and Sandia National Laboratories. This roadmap serves as a strategic research pathway for desalination and water purification technologies to meet future water needs. Near-term and long-term objectives were discussed and included extending existing technologies, requiring technology breakthroughs such as reducing capital costs, increasing energy efficiency, reducing operating costs, and reducing cost of zero liquid discharge processes. It should be noted that in the time since this workshop was held, the National Research Council's Water Science and Technology Board has reviewed the roadmap (see Appendix D).

Detection of organic contaminants (especially compounds that are persistent, bioaccumulative, and toxic [PBTs], such as polychlorinated biphenyls [PCBs]) in water and in sediments was also discussed during this session. Details of work on mitigating the effects of contaminants in sediments and reducing the risk to health by decreasing the bioavailability of the chemicals were described. This work involves adding carbonaceous material to sediments to facilitate binding of contaminants. It was explained that these treatments may be superior to dredging, which is planned for PCBs in the Hudson River.

The types of analytical tools and bioavailability tests now

available to address some of these questions were discussed; however, it was pointed out that no single tool or currently available test will allow these questions to be answered. It was suggested that tools must be used with prudence to avoid misapplication and care must be taken to avoid "short cuts" when dealing with living systems since impacts may not be known until years later. It was noted that partnerships between the disciplines and the regulatory agencies are essential in allowing the scientific community to address, understand, and tackle these complex problems.

The conclusion of the afternoon session centered on a device that uses the natural fluorescence associated with the photosynthesis of algae to detect the health of the drinking water supply. The basic concept behind this technology is that if a chemical agent or other contaminant entered a body of water, the algae would be affected in real time. This would impact its ability to photosynthesize and provide a useful signal for monitoring water quality.

In the evening, workshop participants heard from **Virginia Grebbien,** general manager of the Orange County Water District in California, about the status and challenges faced by the water district, which is considered one of the most innovative in the United States. She outlined some solutions that the district has implemented to address these challenges. Once again, the scientific community was called on to engage in helping to meet the future needs of this water district as well as others around the country. The importance of understanding the impacts of contaminants; how to deal with them; and how to develop fast, reliable, and inexpensive monitoring methods was highlighted.

BUSINESS OPPORTUNITIES AND RESPONSIBILITIES

The final session of the workshop focused on what industry and the scientific community can do to help meet the challenges presented in the first two sessions. This session looked at the market opportunities and responsibilities faced by the regulated industries (i.e., industrial users and suppliers), as well as the regulatory agencies. Presentations were given by **Floyd Wicks,** president and chief executive officer of American States Water Company; **Bhasker Davé,** R&D manager of advanced recycle technology and membrane separations technology at Ondeo Nalco; **Carol Jensen,** vice president of global research and development for performance chemicals, Dow Chemical Company; and **Bruce Macler,** national microbial risk assessment expert in the Water Division of the U.S. Environmental Protection Agency, Region 9.

A number of important issues facing private water supply companies were also outlined during this session. It was pointed out that about half of the 60,000 water systems in the United States are privately owned and that investor-owned water utilities serve approximately one in seven people. It was also suggested that a fundamental challenge to the industry is that there is an increased perception of risk, yet research dollars in this area are declining.

The overall process of managing the costs and risks in industrial water management as a critical component of sustainable development was highlighted. Here, sustainable development was described as development that is socially desirable, ecologically sustainable, and most importantly, economically viable. Solutions in integrated water management that follow this path were presented, such as how industries can minimize their water usage by conserving, recycling, and cascading water. It was pointed out that this involves matching the water purity to the needs of the process and stepping-down water from high-purity-requirement processes to lower-purity-requirement processes. Three areas of industrial waste management in which the chemical sciences can provide the needed innovation—green chemistry, novel equipment (e.g., membrane technology), and smart operations (e.g., use of modeling and sensors to allow automation)—were also discussed.

Another company's effort as a water user and as a supplier of clean water technology was presented. It was reported that a significant amount of fresh water is used by industry each year and that there is heavy investment in annual water acquisition, treatment, and disposal. To reduce the rising expenses, efforts are being made to integrate best practices in water, manage resources and technology, and optimize supplier relationships across the entire company. Success stories and discussion of technologies being developed helped illustrate industry's awareness and commitment to the proactive and intelligent management of water.

The formulation of regulations and current problems facing the regulatory agencies were the final topics of discussion. It was pointed out that regulations are intended to minimize the danger from contamination. They also deal with the public perception of safety and its social, political, and economic implications. In order to continue to improve the regulatory structure for water, several challenges were outlined for the research community. These included the need for robust technology to monitor environmental problems, an understanding of how to control persistent organics, knowing how to minimize disinfection by-products, and continued improvement in membrane technology. It was predicted that in the near term (within the next five years) the need to control pollutants such as arsenate and perchlorate, will continue and tools to monitor these materials will be required. However, the longer term (10 years plus) will require approaches to control a broad spectrum of persistent organics in the environment, as well as improvements in brine and sludge disposal techniques.

KEY QUESTIONS

The presentations and discussions that followed raised some important questions for further consideration:

- What constitutes safe drinking water and who decides what safe is?
- What roles should industry and government play in water management?
- Where do cost-benefit analyses come into play?
- Should all water be treated to the same standards?
- What is the future of desalination, and is it limited?
- How should water be valued more appropriately?

Context and Overview

1

Meeting the Global Water Challenge

Alan D. Hecht
White House Council on Environmental Quality[1]

DEVELOPMENT CHALLENGES

Today, 1.1 billion people worldwide live in poverty without access to safe drinking water and another 2.4 billion have no access to proper sanitation. Water-related diseases are among the most common cause of illness, affecting mainly the poor in developing countries. In 2000, the estimated mortality due to water- and hygiene-associated diarrheas and other diseases was 2.2 million, the majority of whom are children under the age of 5. For the developing world, achieving clean water and improving sanitation are crucial elements of development and poverty alleviation. It is no wonder that access to clean water and sanitation has become a priority international issue.

DEVELOPMENT GOALS FOR WATER

The United Nations Millennium Development Goals and the World Summit on Sustainable Development (WSSD) Action Plan target two key water-related issues: By 2015, halve the proportion both of people without access to safe drinking water and of people without adequate sanitation. Achieving the goal of access to safe drinking water alone requires addressing the needs of approximately 125,000 people every day until 2015.

The United States is aggressively pursuing several programs to address these basic human needs. At the WSSD in September 2003, the United States launched a nearly $1 billion Water for the Poor Initiative aimed at significantly increasing access in the developing world to clean water and sanitation. A major element of the U.S. initiative is the promotion of safe drinking water systems at the household level.

The 2002 World Health Organization (WHO) world health report attributed 2.2 million deaths annually, mainly from infectious diarrhea, to the lack of safe drinking water, sanitation, and hygiene. These constitute the third-highest risk factor for disease and disability in the developing world, after malnourishment and unsafe sexual practices. Meeting the internationally agreed water goal on sanitation requires a frontal attack on eliminating waterborne diseases.

SAFE WATER SYSTEMS

The WHO report has identified the provision of water disinfection capacity at point of use (POU) as the most cost-effective approach to reducing waterborne disease. Regardless of whether or not collected household water is initially of acceptable microbiological quality, it often becomes contaminated with pathogens of fecal origins during transport and storage. Cost-effective technologies already exist to treat water at its POU, including locally produced water disinfectant and dilute chlorine-based solution. A variety of candidate technologies for treatment of household water have been developed and employed in different parts of the world. New technologies are being field-tested. Proctor and Gamble has pioneered the development of a coagulating and water purification tablet called PUR, which has been field-tested in Nicaragua and the Philippines by the U.S. Centers for Disease Control and Prevention (CDC). The product, especially designed for the low-income market, has demonstrated significant reductions in diarrheal disease in test markets. PUR will soon be available to join other products to serve as a tool for point source purification of water.

When these technologies are coupled with education and hygiene programs, field experience shows that a 50 percent or greater reduction in water-related disease can be achieved relatively quickly. According to the WHO (2002) world health report: "There is now conclusive evidence that simple, acceptable, low-cost interventions at the household and com-

[1]Dr. Hecht is now director for sustainable development in the Office of Research and Development at the U.S. Environmental Protection Agency.