



Protecting Public Health in Small Water Systems

**May 9 - 12, 2004
Bozeman, Montana
USA**



**Report of an
International
Colloquium**

January 2005

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Compiled by

Tim Ford, Gretchen Rupp, Phillip Butterfield
and Anne Camper

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Montana Water Center
101 Huffman Building
Montana State University
Bozeman, Montana 59717 - 2690
406.994.6690 (phone) • 406.994.1774 (fax)
E-mail: water@montana.edu

NOTICE

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PREFACE

Drinking water quality and human health have always been closely linked. In the past few decades, many nations have developed regulations to protect public health from contaminants in drinking water. Yet regulations are difficult to enforce and health risks are still very real. In the more developed nations, where incidents of cholera and typhoid have virtually disappeared, outbreaks of cryptosporidiosis, *Escherichia coli* O157, campylobacteriosis and other protozoan and bacterial diseases continue to confound the regulators. Viruses, although seldom diagnosed, are today thought to exceed all other causes of waterborne disease outbreaks.

Drinking water in major cities of the more developed nations is usually maintained at potable quality. Major investments in source water protection, treatment, monitoring, maintenance of a disinfection residual and sufficient water pressure to prevent backflow, provide multiple barriers to contamination (although outbreaks do still occur). The small water system, however, does not always have the economic base of a large system, nor do personnel have the training to properly maintain these multiple barriers. In addition, medical personnel in rural communities may lack the skills to recognize disease outbreaks related to water.

Montana State University brought researchers, regulators and utility professionals from around the world to the Museum of the Rockies in Bozeman, Montana, U.S. for an intense three-day meeting to highlight the risks and challenges faced by small water systems. This report is a step forward in identifying not only the risks faced by these smaller communities, but also ideas for solutions and future research needs from a truly global perspective. Representatives from many different countries provided often-differing perspectives on protection of water quality. However, the goal of protecting human health was a unifying theme throughout the deliberations. Perhaps the most important message to emerge was the critical need for education and training at all levels, from utility workers to the regulatory community.

Much still remains to be achieved in the field of public health and protection of drinking water supplies. However, the truly international and multidisciplinary approach represented at this colloquium is an important step forward in recognizing risks that we can no longer afford to neglect.



Ismail Serageldin
Librarian of Alexandria
Director of the Bibliotheca Alexandrina

EXECUTIVE SUMMARY

Small water systems support human communities worldwide, in broadly diverse regions that lack larger systems due to economic, political, or geographic causes. Small systems characteristically struggle to produce and monitor continuous and safe water supplies. They suffer serious funding, personnel, and training limitations and face many obstacles not shared by larger utilities. Many urgently need up-to-date technical guidance on their entire scope of activities, from safeguarding source waters to preventing microbial and chemical contaminants. In May 2004, a group of international experts convened to share observations and recommendations on which small-system approaches successfully supply water in a sustainable way within developed countries around the world.

Water system specialists from 15 nations, various U.S. public agencies, and a number of water-related professional organizations met in Bozeman, Montana, U.S. to consider a detailed set of questions and issues facing small water systems throughout the developed world. Among the issues discussed were potential threats to public health, system management and operation, personnel training and public education, regulatory challenges, and models of system consolidation. Colloquium attendees agreed upon four principal problems affecting small systems: incomplete understanding of public health risks; lack of crucial expertise on regulating, managing, monitoring and operating small systems; insufficient training and education at all levels of operator and user; and a regulatory climate overly focused on compliance rather than public health protection.

Public health risks associated with small water systems can be incurred at any point in the water treatment and transmission process, encompassing both acute and chronic diseases due to microbial or chemical contamination. Small systems most commonly function in areas underserved by health care systems, often supply transient populations shaped by tourism or agriculture, and remain more susceptible to system failures and animal-borne contaminants. Colloquium participants concurred that system stakeholders must become far more aware of these potential health risks. Recommendations included a more proactive approach to system operations with risk management in mind, local access to up-to-date health literature, use of detailed checklists to assess system vulnerabilities, mandatory risk assessment/management training for operators and regulators, and improved surveillance protocols for water-borne disease.

Failures in small water system management/operation reflect shortages in financial and technical resources, incomplete understanding of system function, and additional shortcomings that could be alleviated through better planning and communication. For example, colloquium participants noted that small systems frequently have limited capabilities to adopt cutting-edge protocols and technologies or to respond to unexpected events such as flooding. Widespread complacency, poor communication, and lackluster oversight exacerbate problems. Actions that were recommended to preclude these conditions emphasize greater reliance on planning and on clearly-explained procedures and responsibilities, developed with expert advice from technical-assistance personnel or from larger water systems. Solid knowledge of the local system is crucial. Management and operation would be improved in many nations if they were based on detailed Water Safety Plans and on the Hazard Analysis

and Critical Control Point (HACCP) approach to identifying system vulnerabilities. System-specific procedures should rely on thorough, up-to-date sanitary surveys, followed by annual self-audits to assess and possibly revise procedures. Each system needs a clear, current emergency plan, which must be provided to the pertinent individuals in all affected agencies. Frequent, comprehensive monitoring is necessary to verify that protective measures are working, with less focus on compliance and more on performance control.

Human error accounts for many of the disease outbreaks linked to small water systems. Poorly trained operators can jeopardize public health, and colloquium participants identified personnel training as the single greatest need in any effort to enhance system capability. The rapid turnover of personnel common to small water systems inevitably results in the loss of so-called institutional memory. To eliminate this information gap, recommendations incorporated a range of on-site training or teaching tools that include sanitary surveys, plus seminars and distance-learning programs for system personnel, regulators and technical-assistance providers. Those educated should include members of local water boards and public health commissions. Education resources should emphasize risk awareness, and include disease outbreak case histories. Technical advisors should be available for on-site consultation. Professional societies and universities were urged to develop and disseminate training programs specific to managing and operating small water systems.

An ever-changing regulatory environment is very difficult for small water systems, which generally are not well-represented in the regulatory process. Changed rules may be enforced before small systems have the technical expertise or financial capacity to implement them. Colloquium participants agreed that the same health standards must apply to both large and small systems, but cautioned that regulators should be aware of challenges unique to systems with limited resources. Regulations need to be achievable at reasonable cost, and smaller systems may require subsidies to comply. The regulatory process should place more emphasis on quality assurance and risk management and less emphasis on catching systems out of regulatory compliance.

Small water systems need considerable help in water source protection, treatment, and distribution, from basic research to community-wide education. Scientists present at the colloquium, for example, identified research needs for lower-cost monitoring, better treatment methods, public perception of water utilities, and more. Consolidation with larger systems can improve both economies of scale and access to technical expertise. Yet it is clear that better funding or expert advice cannot remove all small-system barriers to safe water delivery. The locally-achievable goals of improved communication, science-based education, and thorough planning by all involved still remain key components of small system success.

ACKNOWLEDGMENTS

The colloquium organizers would like to express their gratitude to the event's participants. Considerable preparation was required of them. When the meeting took place, some labored under jet lag and for some the language of the discussions was their second or third language. Yet all worked hard to convey the experience of their nations, and to arrive at a common understanding of problems and solutions in the small-water-system world. Abby Aiken, Nik Bouskil, Stewart Clarke, Henriette Geier, Anne O'Neill and Karen Sanchez acted as rapporteurs for the discussion groups. Several participants made time to review draft versions of this report and contribute detailed comments or case histories. In this regard, the organizers owe special thanks to Geoff Aitkenhead, Harvey Minnigh, Tim Hooten, Darragh Page, Jay Rutherford, David Smith, and Del Haylock and colleagues in British Columbia. Technical editor Diane Edwards accepted the task of bringing order to a comprehensive but chaotic manuscript, for which the organizers are profoundly grateful. Publication layout was by Molly Boucher.

COLLOQUIUM PARTICIPANTS

- | | |
|---|---|
| Randy Adams
Rural Community Assistance Partnerships,
Inc
USA | Stephen Carty
Ontario Ministry of the Environment
Canada |
| Abby Aiken
Montana State University
USA | David Clapham
City of Bradford Metropolitan District Council
England |
| Geoff Aitkenhead
Scottish Water
Scotland | Stewart Clarke
Montana State University
USA |
| Fredrik Alfer
Swedish Ministry of Agriculture
Sweden | Eugene Cloete
University of Pretoria
South Africa |
| Nicholas Ashbolt
University of New South Wales
Australia | Ana-Maria de Roda Husman
RIVM, Holland
Netherlands |
| Risto Aurola
Ministry of Social Affairs & Health
Finland | Glendon Deal
U.S. Department of Agriculture Rural Utilities
Services
USA |
| Hartmut Bartel
WaBoLu, German Umweltbundesamt
Germany | Hermann Dieter
WaBoLu, German Umweltbundesamt
Germany |
| Jon Bender
U.S. Environmental Protection Agency
USA | Ron Duffell
British Columbia Ministry of Health Services
Canada |
| Jerry Biberstine
National Rural Water Association
USA | Andrey Egorov
Tufts University
USA/Russia |
| Nik Bouskil
Montana State University
USA | Hans-Curt Flemming
Universität Duisburg-Essen
Germany |
| Phillip Butterfield
University of Washington
USA | Bruce Florquist
National Drinking Water Advisory Council
USA |
| Paul Byleveld
New South Wales Department of Health
Australia | Jon Fogarty
US Indian Health Service
USA |
| Anne Camper
Montana State University
USA | Tim Ford
Montana State University
USA |

Janne Forslund
Myljöstyrlsen
Denmark

Dan Fraser
Cadmus Group
USA

Bill French
Rural Community Assistance Corporation
USA

Henriette Geier
Montana State University
USA

Del Haylock
British Columbia Water & Waste Association
Canada

Tim Hooton
Drinking Water Quality Regulator for Scotland
Scotland

Jane Horton
Centers for Disease Control
USA

Steve Hrudey
University of Alberta
Canada

Paul Hunter
University of East Anglia
England

Claus Jørgensen
DHI – Institute of Water and Environment
Denmark

Bill Keevil
University of Southampton
England

Harvey Minnigh
RCAP Solutions, Inc.
Puerto Rico, USA

Christine Moe
Emory University
USA

Lance Nielsen
Idaho Department of Environmental
Quality
USA

Anne O'Neill
Montana State University
USA

Darragh Page
Environmental Protection Agency
Ireland

Gary Patterson
Northland District Health Board
New Zealand

Tiia Pedusaar
Tallinn Water Ltd
Estonia

Graciela Ramirez
Interamerican University of Puerto Rico
Puerto Rico, USA

Joan Rose
Michigan State University
USA

Gretchen Rupp
Montana State University
USA

Jay Rutherford
Vermont Department of Environmental
Conservation
USA

Karen Sanchez
U.S. Department of Agriculture Rural
Utilities Services
USA

Ismail Serageldin
Library of Alexandria
Egypt

Dave Siburg
AWWA Small Systems Committee
USA

David Smith
Environmental Protection Agency
Ireland

Michael Taylor
Ministry of Health
New Zealand

Gary Toranzos
Universidad de Puerto Rico
Puerto Rico, USA



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1. INTRODUCTION

Background

This report documents the findings and recommendations from a colloquium of experts convened in Bozeman, Montana, US, May 9-12, 2004. The colloquium was funded by a grant from the US Environmental Protection Agency to the Montana Water Center. The colloquium organizers, all from Montana State University-Bozeman, were:

- Tim Ford, Head, Department of Microbiology (meeting chair),
- Gretchen Rupp, Director, Montana Water Center,
- Phil Butterfield, formerly Assistant Research Professor, MSU Center for Biofilm Engineering, currently Research Scientist, Department of Environmental and Occupational Health Sciences, University of Washington, and
- Anne Camper, Associate Dean, College of Engineering.

The impetus for the colloquium was the understanding that small public water systems face challenges not experienced by larger systems, and in many regards are poorly served by the materials and methods used by those larger systems. The organizers, each with extensive small-system experience, designed the colloquium as a forum to share observations on 'what works and what doesn't work' in small systems in different developed nations. There was no expectation that every practice that is successful anywhere can be applied everywhere – legal, fiscal and social situations differ too much. Nonetheless, many practices developed in individual nations should prove useful elsewhere.

Problems faced by public water systems in developing countries were not considered at this meeting, as that would



have required much longer deliberation and a great number of participants. Many of the colloquium findings, however, apply to small water systems in the developing world.

Forty-six people from 15 nations participated in the colloquium; attendance was by invitation. There was broad-based representation from the pertinent professional disciplines – drinking-water microbiology, system operation, management, and regulation. Participants came from academia, regulatory agencies, public water utilities, and technical assistance organizations. They were briefed *a priori* with key technical papers and given a detailed list of suggested topics for discussion. Following plenary sessions, the participants split into three groups, where they deliberated for two days. Co-leaders facilitated each group discussion; student assistants recorded the proceedings. At the end of the colloquium, all participants re-convened and shared their observations.

Box 1. USEPA definitions

- The USEPA defines public water systems as systems that provide water for human consumption to at least 15 service connections or serve an average of at least 25 people for at least 60 days a year. Systems are classified as very small water systems that serve 25-500 people; small water systems that serve 501-3,300 people; medium water systems that serve 3,301-10,000 people; large water systems that serve 10,001-100,000 people and very large water systems that serve 100,001+ people.
- 84% of community water systems (CWS) in the US, or systems that supply water to the same population year-round, are small or very small, representing about 9% of the population served.
- 99.4% of non-transient non-community water systems (NTNCWS), or public water systems that regularly supply water to the same population at least six months per year (e.g., schools), are small or very small, representing 81% of the population served by these systems.
- 99.8% of transient non-community water systems (TNCWS), i.e., public water systems that supply transient populations (e.g., campgrounds), are small or very small, representing 43% of the population served by these systems.
- Overall, small and very small water systems account for 94.5% of all public water systems, but serve only 13.3% of the population served by these systems.

The Colloquium report

The colloquium organizing committee prepared this report, with several specific case studies contributed by participants. All participants had the opportunity to review the draft report, and some provided detailed comments.

The report follows the sequence of deliberations during the colloquium. After defining a small water system, it deals with health risks, system management and operation, monitoring, training, regulations, and funding. Each section includes both observations and recommendations, as well as pertinent research needs. Where the colloquium participants could not agree on a recommendation, alternative possibilities are highlighted.

Small water systems - definition

The term “small water systems” has different meanings in different parts of the world. The United States Environmental Protection Agency (USEPA) (Box 1) defines a small system as one that serves a population of fewer than 3,300 people, The Irish EPA defines any system that supplies fewer than 5,000 people as a small system and any system serving below 15 people as a very small system. In Russia, system size is not specifically defined but affects frequency of sampling, with the lowest frequency prescribed for systems serving fewer than 10,000 people. In Denmark, many of the small water groups are run as cooperatives and are not considered to be small systems under a set definition. The Province of British Columbia, Canada, has a tiered classification for small water systems based on the number of connections, as follows:

WS4 - 1 connection, semi-public; i.e., restaurant/
resort/gas station
WS3 - 2 - 15 connections
WS2 - 16 - 300 connections
WS1a - 301 - 10,000 connections
WS1b - 10,001 - 20,000 connections
WS1c - more than 20,000 connections.

Within certain countries, definitions may differ depending on the federal agency involved. For example, the US Geological Survey (USGS) defines a small system as one that serves fewer than 10,000 people.

For the purposes of this report, we adopt a functional definition for a small water system. In effect, the issues under discussion relate more to the availability of resources to the operators and managers than to the actual size of the system. Therefore a small system may be defined as one that has pressing limitations in terms of resources (capital, personnel, training) available to produce and monitor for “safe” water. Systems small in size are those that most often fall under this definition.

The definition of a small water system includes the capacity to provide potable water to the community. However, small water systems, or systems with limited resources, not only range considerably in population served, but also with respect to their water sources (Box 2).

Using USEPA definitions of size, medium and even large water systems may face the same issues as small systems, particularly in poorer communities. One example presented in this report is the waterborne disease outbreak in Walkerton, Ontario, Canada (by EPA definition, a

Box 2. Small systems classified by water source

- Groundwater systems: those supplied from confined or unconfined aquifers, or from springs
 - » Critical considerations for groundwater systems are the nature of the soil/aquifer matrix, the potential for surface water interaction (in the US, 'Ground Water Under the Direct Influence of Surface Water' is regulated by different criteria than groundwater alone), the age, depth and recharge rates of the aquifer.
 - » Groundwater may or may not require some level of treatment, including disinfection.
- Surface water systems: rivers, lakes or reservoirs
 - » Generally disinfected (always disinfected in the US).
 - » Unless source water protection is of the highest quality, usually require filtration.
- Roof water: rainwater collection
 - » Collected and distributed to customers in some areas (e.g., in Australia, Virgin Islands, Guam).
 - » Collected and stored in tanks for individual household use (e.g., Bermuda).
 - » May be disinfected with bleach (or sodium hypochloride).
 - » May be treated using filtration and disinfection.
- Desalinated seawater or brackish water
 - » On Kangaroo Island and Hamilton Island, Australia, small scale desalination is used to supply potable water during the tourist season.
 - » Examples in the US include systems in St. Thomas, Hawaii and Florida.
- Purified wastewater
 - » In Singapore, wastewater is treated and added to raw water reservoirs and treated again for potable uses.
 - » In Namibia, wastewater undergoes treatment and is directly utilized.
 - » In the US, wastewater reuse is gaining in popularity for non-potable uses such as irrigation and toilet flushing.

“medium” water system). In addition, many of the recommendations presented in this report could have applied in the early 1990s to the Milwaukee, Wisconsin, US, outbreak of cryptosporidiosis.

Among the many challenges facing a water system with limited resources, four areas are highlighted and discussed in greater detail in this report:

- Consumers, purveyors and policymakers lack understanding of public health risks.
- Many small systems worldwide need assistance in tailoring their operational and management practices to safeguard public health.
- Training and education of operators, managers, regulators and consumers are crucial to the delivery of safe water, and can be improved nearly everywhere.
- Regulatory schemes in many jurisdictions focus on compliance rather than on health risk management.

2. PUBLIC HEALTH RISKS

Drinking water systems play a key role in protecting the health of the public, but this role is many times misunderstood or not appreciated by the public. Operators and managers of small systems may also not fully understand the importance of their role in protecting the public from the many risks associated with drinking water. This section presents a discussion of the risks and associated issues facing small drinking water systems.

Pathogens

Health problems are more likely to arise from exposure to “disinfectable pathogens” in smaller systems with limited resources than in larger systems.

Typical waterborne disease outbreaks involve pathogens such as *Escherichia coli* O157:H7 and *Campylobacter* sp. These outbreaks tend to occur either in systems with no treatment or when there has been an interruption in treatment. In many cases, as in larger systems (including major municipalities), outbreaks go unnoticed unless there is severe illness.

There are many examples of outbreaks caused by limited treatment capabilities of small systems:

- A cyanobacteria problem in Australia resulted from lack of an effective treatment for toxin-producing species – routine chlorination does not kill these organisms.
- Difficulties with maintaining a chlorine residual may have caused 20 deaths from *Naegleria fowleri* in Port Augusta, Australia, although it was inconclusive that drinking water was the problem because recreational sources were thought to be the predominant source.
- Treatment failures led to outbreaks of giardiasis at 100 Mile House and Revelstoke in British Columbia, Canada.



- Untreated ground water from a shallow well led to a reported 921 cases of diarrhea and possibly two deaths from *Escherichia coli* O157:H7 at the Washington County Fair, New York, US (MMWR 1999).

In rural areas in particular, health risks may be exacerbated by a number of factors:

- There may be an enhanced risk of waterborne zoonoses because of wild or domestic animals in the environment.
- Limited access to health care may result in greater consequences from infection.
- Health care providers in isolated areas may not be familiar with some unusual pathogens or realize that the infection may be waterborne.
- Health care providers may not collect stool specimens from cases, making it difficult to properly diagnose and recognize a waterborne outbreak.
- Rural areas are often tourist sites with numerous transient visitors. In agricultural areas harvest time brings an influx of transient workers. Transient visitors may not only be at greater risk of waterborne infections because they lack immunity to local patho-

gens (demonstrated among foreigners in Nepal, e.g., Shlim *et al.* 1999), but they may also introduce new pathogens into isolated communities, increasing risks to local residents.

- The combination of high variability of rural water supplies, low degree of resilience in the system, and high cost of mitigation may make it difficult for small systems to meet requirements for monitoring.
- Small systems many times lack control of activities within their watersheds, sharing the watershed with uses such as forestry, agriculture and recreation.
- In rural communities, farmers using animal antibiotics may promote antibiotic resistance in manure bacteria that are washed into water supplies or percolate to the ground water aquifer (the presence of antibiotic resistance has been identified in Danish and German

drinking water systems) (Heberer, Mechlinski *et al.* 2004; Stolker, Niesing *et al.* 2004; Walia, Kaiser *et al.* 2004).

Conversely, outbreaks in small systems may be more likely to be recognized, because a single health care provider seeing many cases would alert health authorities (e.g., the 1987 *Cryptosporidium* outbreak in Carrollton, Georgia, US). In areas without a regular health care provider, however, it is likely an outbreak could go unnoticed and unreported.

Cryptosporidium is considered one of the “emerging pathogens.” These can be defined as pathogens that have only recently been recognized as important causes of human disease. Box 3 provides a discussion of this group of pathogens, which have become an increasing focus for USEPA research programs.

Box 3. Emerging pathogens

How relevant to small systems are the “emerging” pathogens of concern to the USEPA, e.g., *Cryptosporidium parvum*, calciviruses, *Aeromonas*, *Legionella pneumophila*, environmental mycobacteria, *Helicobacter pylori*, and *Toxoplasma gondii*?

- All pathogens are important no matter the size of the system.
- A lack of testing in small systems may miss a number of emerging pathogens. Treatment may be removing pathogens present in the system but if the pathogens are not identified and the treatment fails, health risks may emerge, e.g., toxoplasmosis.
- The awareness of pathogen sources is vital (e.g., housecats in the case of *Toxoplasma*). A range of other unanticipated hosts may exist in the watershed area. Guidelines for small water supplies should include information about the significance of specific animals present in the watershed – this should be an important component of training.

Different pathogens will be of concern in different geographic regions. The key questions are: what is the water source, and which pathogens are likely to be present in that source?

C. parvum is a good example: Cryptosporidiosis seems to be an important cause of diarrheal illness in Russia. In a recent study, approximately 7 % of children hospitalized with non-specific gastroenteritis tested positive for *C. parvum*. This parasite had been largely unknown to water supply specialists in Russia until a new standard requiring zero concentration of *Cryptosporidium* oocysts in treated water was introduced in 2003. However, the standard Russian method for *Cryptosporidium* monitoring is rather basic (membrane filtration of a 50 L sample, elution, centrifugation, separation of oocysts in density gradient, chemical staining of sample, microscopic examination in transmitted light). The use of this basic method probably results in very low recovery rates in most laboratories. Thus, system “compliance” may simply be the result of poor detection sensitivity. A more modern monitoring method (such as the USEPA method 1623 that includes immunomagnetic separation of oocysts and detection using fluorescent antibodies) is not used because of the difficulties in equipping a sufficient number of laboratories with appropriate epifluorescence-capable microscopes and with antibody-based separation and detection kits not produced in Russia.

In contrast, Denmark has not had any *C. parvum* problems in drinking water. This is thought to be primarily because most of the water comes from wells. Well water can, however, become contaminated with surface water. In Germany, the spore-forming bacterium *Clostridium perfringens* is being used as a surrogate marker for *C. parvum*. If *C. perfringens* concentrations exceed a trigger value, a filtration step activates and *C. parvum* monitoring begins.

Chemical risks

It is important to distinguish between acute and chronic health risks because they may have different monitoring needs. Unlike most microbial pathogens that cause acute gastrointestinal disease, many chemicals represent chronic health risks through long term exposure. These health risks can be related to site-specific characteristics (pesticide use, hazardous waste dumps, geologic characteristics such as arsenic and radon), as well as distribution system materials and household plumbing (lead, copper).

In the United States, the US Geological Survey has completed a number of groundwater surveys and found sites contaminated with arsenic, nitrates, pesticides, and other chemicals (Hamilton, Miller *et al.* 2004). Nitrate concentrations in shallow groundwater are more likely to be higher near farming communities due to the use of nitrogen fertilizers. Some specific concerns for chemical contamination are listed in Box 4.

Population susceptibility factors

Certain populations are at increased risk from waterborne diseases. A population's response to exposure to waterborne pathogens depends on a variety of factors including:

- Immune status – the young, elderly, pregnant and immune-compromised (through chemotherapy, HIV, etc.) are particularly susceptible to disease;
- Community awareness of the importance of basic hygiene and sanitation and of heeding specific health warnings (e.g., boil water orders);
- Access to health care in rural communities;

- The primarily rural status of indigenous populations, where mortality rates may be higher and diseases underreported because of embarrassment and social stigma; and
- Ease of travel between rural communities and cities, between cities and between countries, making it difficult to identify and report sources of waterborne diseases.

An important ethical question for regulators is 'who is being protected?' As demographics shift to older populations in the developed countries, and numbers of HIV/AIDS patients overwhelm less-developed countries, the majority may no longer be represented by the "healthy individual." In the United States, for instance, small water systems tend to serve rural areas, where there is an increasing proportion of older people (USDA 2002). It is important to consider at what point "safe" drinking water is not safe enough for an aging population. On the other hand, is it possible that we could compromise the development of innate defenses in the young as we strive to protect those most susceptible to disease?

The question of risk

An important question for small water systems is how risks are being managed (see Box 5 for definitions used in risk management). Most health risks from drinking water can be ascribed to inappropriate/insufficient treatment, inadequately trained staff, and infrequent or poor-quality testing. These in turn may stem from inadequate financial investment in the system or lack of understanding of health risks by managers, operators and customers. Small systems, by their nature, are more likely to use source water at

Box 4. Chemical contamination concerns for small systems

- Are disinfection by-products (DBPs) a significant health concern for small water systems compared to other health risks?
- In Australia and elsewhere rural water sources have been shown to be vulnerable to pesticides. The spraying of pesticides by planes can directly introduce chemicals into source waters.
- Copper contamination from pipe degradation poses an acute health risk; this has been documented in small water systems in Australia, the UK, the United States, Germany and Denmark.
- In some systems, local geology results in high levels of chemical constituents such as arsenic, fluoride and radon (+ daughter products). It is difficult for small systems to treat for these elements. In Ireland, high levels of uranium were detected in water supplies in 2002; 300 supplies were monitored and higher levels of uranium were found in the smaller supplies, with highest levels in a system serving 600 people. Four water supplies were shut down because of uranium.
- Uranium in water supplies is a problem in some locations in the western and southwestern United States.
- Intense agriculture in the Fraser Valley of British Columbia, Canada has caused high nitrate concentrations in some groundwater.

Box 5. Definitions (Nadebaum *et al.* 2004)

- A **hazard** is a biological, chemical, physical or radiological agent that has the potential to cause harm;
- A **hazardous event** is an incident or situation that can lead to the presence of a hazard;
- **Risk** is the likelihood of identified hazards causing harm in exposed populations during a specified time frame, including the magnitude of that harm and/or the consequences;
- **Risk assessment** is the systematic process of using available information to predict how often identified hazards or specified events may occur (likelihood) and the magnitude of their consequences. Risk should be assessed at two levels: maximum risk in the absence of preventive measures, and residual risk after consideration of existing preventive measures;
- **Risk management** refers to the overall process of evaluating the water supply system; identifying hazards, sources and hazardous events; assessing and prioritizing risks; and developing and implementing effective preventive measures and strategies to manage the risks.

higher risk of contamination due to multiple, uncontrolled activities within the watershed. The small system may lack the resources to respond to problems as they arise, making them more at risk for potential public health problems.

Small systems can be more at risk for a variety of reasons:

- As distribution systems age and deteriorate, the burden of replacement is far greater for small systems and the per-household costs are very high. Preventive maintenance is often neglected or misunderstood by small systems, leading to equipment failures or pipe breaks with the increased potential for contamination.
- Financial limitations and relative lack of access to laboratories and technical expertise may lead to inadequate monitoring and poorly trained personnel.
- Cumulative risks may be greater for customers of small systems. Stressors can make people more susceptible to certain chemicals. Rural, aging populations and indigenous people may be more susceptible to chemical toxicity as well as infection, as described previously. There would appear to be a link between nutritional status and the health affects of arsenic, for example (Mitra *et al.* 2002). An additional stressor can be lack of adequate health care.
- A question of current political interest is whether small systems are more susceptible to acts of terrorism. Certainly, the smaller the system the easier it is to intentionally contaminate. In comparison with a large system, it is easier to reach a toxic concentration or infectious dose due to lower water flow and less dilution of the contaminant. In Idaho, US, water customers are routinely advised to be prepared for contamination by disgruntled employees and natural disasters.
- There has been an alarming rise of *Escherichia coli* O157:H7 contamination over the past 30 years, probably stemming from the spread of intensive animal husbandry (Lawson 2004).

- Increasing links between heavy rainfall and waterborne disease outbreaks have been documented (Curriero, Patz *et al.* 2001). Coupled with the agricultural application of animal and human wastes as fertilizer, heavy rainfall can become a factor in increased risk of microbial contamination.

Overall risk management is the goal of New Zealand's "Public Health Risk Management Guides" to be used by water systems to develop their own Public Health Risk Management Plans (MOH 2001), as outlined in Box 6. Utilizing the "Framework for Management of Drinking Water Quality" (NHMRC 2004), the guides are designed to help a water system identify causes of a particular problem, establish preventive measures, determine how to check preventive measures, and find possible corrective actions.

Communication of risks

Customers of small water systems need more information on their community sources of drinking water, how human activity affects water quality, and how proper treatment and distribution can reduce health risks. This will require coordinated efforts at federal, state (provincial) and community levels. Water customers are willing to pay higher rates for their water if they understand potential risks and why they need to be addressed. However, it is important to communicate risks without unduly frightening people. Training at the school level may be an appropriate strategy and is currently practiced by some utilities. Water quality education is probably best addressed as part of a broader environmental education curriculum. After all, keeping the environment clean is an important component of source water protection. Alternative education programs should be targeted to adult audiences such as elderly persons and other at-risk populations. Some important educational points could include:

Box 6. Elements of the New Zealand/Australia Framework for Management of Drinking Water Quality (NHMRC 2004)

1. Commitment to Drinking Water Quality
Drinking water quality policy
Requirements
Partnership agencies
2. Assessment of the Drinking Water Supply System
Water supply system analysis
Review of water quality data
Hazard identification and risk assessment
3. Planning – Preventive Strategies for Drinking Water Quality Management
Multiple barriers
Critical control points
4. Implementation – Operational Procedures and Process Control
Operational procedures
Equipment capability
Materials and chemicals
Operational monitoring
Operational preventive and corrective action
5. Verification of Drinking Water Quality
Drinking water quality monitoring
Consumer satisfaction
Short-term evaluation of results
Corrective action
6. Incident and Emergency Response
Communication
Incident and emergency response protocols
7. Employee Awareness and Training
Employee awareness and involvement
Employee training
8. Community Involvement and Awareness
Community consultation
Communication
9. Research and Development
Investigative studies and research monitoring
Validation of processes
Design of equipment
10. Documentation and Reporting
Documentation and records management
Reporting
11. Evaluation and Audit
Long-term evaluation of results
Drinking water quality management audit
12. Review and Continual Improvement
Senior executive review
Drinking water quality improvement plan

- Vulnerability of systems – small systems are more vulnerable and at risk for a variety of pathogens and chemicals.
- Economic realities – small systems have limited financial resources in terms of the number of customers available to pay the costs.
- Hygiene and sanitation – general education about infectious diseases and the importance of hygiene and sanitation may be lacking.
- Importance of water source – protection of the source from contamination is paramount whether the source is groundwater or surface water. In some areas the public perceives the water supply as “pristine,” making it difficult to demonstrate the importance of source protection.
- Risks of mismanagement – consumers must understand the risks of mismanagement of their local water source. Mismanagement can include actions such as lack of preventive maintenance, poorly designed and constructed facilities, or improper operation and monitoring.
- Chain of communication – operators, managers, health professionals and regulators are there to protect public health. A timely and appropriate chain of communication is essential among these individuals

and with the public. The public must realize that operators and managers are there to maintain barriers to water contamination. The public also must understand its role as responsible stewards (e.g., report illegal dumping of chemicals in the water source area).

Unfortunately, most people may be unaware of where their water comes from and how it is treated, stored and distributed. It is essential that water consumers know and understand their water supply and how their taxes and/or water fees are used in protecting, treating, distributing and monitoring the resource. In addition, the local health community should know the risks and vulnerabilities of the water supply. In the United States, the EPA has mandated that utilities produce annual Consumer Confidence Reports (Box 7). As with any communication of risk, people are far more likely to comply with watershed regulations, boil-water orders, etc., if they actually understand why regulations are necessary and how contaminants can affect them.

An annual Consumer Confidence Report (CCR) is certainly not enough on its own and its effectiveness at communicating water quality issues is not proven. Depending upon the state, small water systems may only be required to publish

Box 7. Consumer Confidence Reports

An important outcome from the 1996 amendment of the U.S. Safe Drinking Water Act has been the requirement for utilities to provide Consumer Confidence Reports. The requirement was finalized in 1998 and is designed to “enable Americans to make practical, knowledgeable decisions about their health and their environment.” The key components of the final rule are described on the USEPA website at <http://www.epa.gov/safewater/ccr/ccrfact.html>:

“While water systems are free to enhance their reports in any useful way, each report must provide consumers with the following fundamental information about their drinking water:

- the lake, river, aquifer, or other source of the drinking water;
- a brief summary of the susceptibility to contamination of the local drinking water source, based on the source water assessments that states are completing over the next five years;
- how to get a copy of the water system’s complete source water assessment, if it is available;
- the level (or range of levels) of any contaminant found in local drinking water, as well as EPA’s health-based standard (maximum contaminant level) for comparison;
- the likely source of that contaminant in the local drinking water supply;
- the potential health effects of any contaminant detected in violation of an EPA health standard, and an accounting of the system’s actions to restore safe drinking water;
- the water system’s compliance with other drinking water-related rules;
- an educational statement for vulnerable populations about avoiding *Cryptosporidium*;
- educational information on nitrate, arsenic, or lead in areas where these contaminants are detected above 50% of EPA’s standard; and
- telephone numbers of additional sources of information, including the water system and EPA’s Safe Drinking Water Hotline (800-426-4791).

This information will supplement public notification that water systems must provide to their customers upon discovering any violation of a contaminant standard. This annual report should not be the primary notification of potential health risks posed by drinking water, but will provide customers with a snapshot of their drinking water supply.”

their CCR once in a local newspaper and make it available upon request. Systems serving fewer than 500 persons need only notify customers that the report is available.

Surveillance for waterborne disease

Unfortunately, a disease outbreak may be the first indication of system failure. In fact, medical surveillance has been suggested as a better indicator of water quality problems than routine monitoring, since infrequent monitoring in small systems may allow a short-term problem to go undetected. In the United States, the state of Florida is currently creating a database through which it can more rapidly analyze medical information for outbreaks. If a public health authority makes it mandatory to report a particular disease, more cases will be reported. As in most US states, cryptosporidiosis is now a medically reportable disease in Ireland, and as a result, more outbreaks are being detected. However, if there is reliance on medical surveillance only, certain protective components of a water system may fail or be ignored (Box 8).

Current surveillance systems are generally ineffective, as most cases of gastrointestinal illness go unreported. Smaller systems, in particular, are often in more isolated areas with less access to medical facilities. For the entire United States, the Centers for Disease Control and Prevention (CDC) estimates that underreporting of waterborne diseases is about 10-fold. In other words, for every 10 people who go to the doctor, 100 more are also infected. This discrepancy is even greater in less-developed countries where access to health care is less available. In general, surveillance only results in system investigation when large numbers of people seek medical attention and/or people die.

Some experts have suggested that surveillance could be achieved through monitoring drug sales. For example, pharmacies could be required to report increases in sales of anti-diarrheal drugs. The ESSENCE II Biosurveillance System in Montgomery County, Maryland, US, has shown good correlation between sales of anti-diarrheal drugs and reported gastrointestinal illnesses (Hurt-Mullen *et al.* 2004). Yet the feasibility and applicability of using a syndromic surveillance system for rural areas has not been tested, and the costs may be prohibitive.

Box 8. Walkerton, Ontario, Canada; *E. coli* O157 outbreak in 2000 - Chronology of events

Preamble: The town of Walkerton, Ontario, was drawing part of its source water from a well adjacent to a local farming operation.

- May 12: Heavy rains over several days are thought to have caused pathogens in cattle manure to either infiltrate the well-head or contaminate the aquifer through seepage.
- May 17: Tests of the drinking water indicate the presence of coliforms and *E. coli*, in samples taken on May 15. However, the general manager of the Public Utilities Commission fails to notify appropriate health officials.
- May 18: Walkerton residents begin to report symptoms of gastrointestinal illness; two children with bloody diarrhea are admitted to hospital.
- May 19: Health officials contact the Public Utilities Commission and are assured that the water is safe
- May 20-21: Number of illnesses continues to rise. The government health officer orders a boil water advisory despite continued assurances from utility personnel.
- May 22: First person dies.
- May 23: Independent tests show that *E. coli* O157:H7 is present in the drinking water. Hundreds of people complain of symptoms, more than 150 people seek hospital treatment, and a two-year-old girl dies.
- May 24: Two more deaths.
- May 25: Fifth death and four children listed as critical.
- May 29: Sixth death.
- May 30: Seventh death.
- May 31: Public inquiry ordered.

Outcome: The utility had been falsifying records for some time and the chlorination system had not been working properly. The utility operator “did not like the taste of chlorine.” Class action suits and criminal investigations have followed, but the real outcome of this tragedy is the implementation of far stricter regulations for Ontario’s drinking water -- and the realization that proper operator training is critical.

Box 9. The 2004 Australian Drinking Water Guidelines (NHMRC 2004)

The guidelines are based on six fundamental principles:

- The greatest risks to consumers of drinking water are pathogenic microorganisms. Protection of water sources and treatment are of paramount importance and must never be compromised.
- The drinking water system must have, and continuously maintain, robust multiple barriers appropriate to the level of potential contamination facing the raw water supply.
- Any sudden or extreme change in water quality, flow or environmental conditions (e.g., extreme rainfall or flooding) should arouse suspicion that drinking water might become contaminated.
- System operators must be able to respond quickly and effectively to adverse monitoring signals.
- System operators must maintain a personal sense of responsibility and dedication to providing consumers with safe water, and should never ignore a consumer complaint about water quality.
- Ensuring drinking water safety and quality requires the application of a considered risk management approach.

Observation of these principles:

- protects public health by assuring safer drinking water, and increases trust and confidence by demonstrating commitment to quality management;
- provides for a systematic, in-depth and holistic evaluation of water supply systems enabling the identification of hazards and assessment of risks;
- places emphasis on prevention rather than corrective action;
- introduces a common and standard protocol throughout the industry which establishes due diligence and credibility;
- increases communication and defines responsibilities of various agencies and stakeholders; and
- provides an effective framework for communication.

Despite the potential of such systems, there are always uncertainties involved:

- In community-based surveillance, some of the questions asked may diagnose people who are not really ill with waterborne disease (e.g., effects of alcohol abuse).
- People may not seek conventional treatment, but may instead turn to non-traditional medicines or plant remedies.
- People may be exposed to waterborne pathogens during recreation or through contaminated food, person-to-person transmission, or drinking water from other sources. Improving their drinking water might not prevent a specific outbreak.

It should be noted that surveillance systems are only one aspect in protection of public health. The disease outbreak has already occurred when it is detected through surveillance. Minimizing and preventing the risks in the first place is of primary importance. Box 9 highlights Australia's approach to protecting the safety of drinking water with emphasis on risk from pathogenic microorganisms.

Recommendations and research needs

Develop risk awareness programs

Support agencies should develop a program of risk awareness that can be used by small water systems. This includes simple brochures for the public and more detailed technical documentation for operators and health professionals. Information should be adapted to the particular system or system types. Community-based surveillance could be more effective if all health services personnel are fully educated not only on the risks of infectious disease and chemical toxicity, but also on how to properly recognize a potential outbreak of waterborne disease, collect and analyze specimens and then report the suspected outbreak. Risk-related information should be easily accessible via journals, trade magazines, the Internet, and technical notes. Information should be freely available to as much of the served community as possible, with consumers given the opportunity to provide input. Funding and expertise are required to develop and maintain such materials, raising questions of who will fund and provide the services.

Develop risk management tools that can be used by the small system

Colloquium participants recommended distribution of checklists to the operators of small systems, to help them

develop their own lists of vulnerabilities. It is important that any checklists be accompanied by explanations of how or why a particular component of a water system can represent a risk to public health. Sanitary surveys (Box 10) can provide a small system with a list of potential vulnerabilities, but such tools require assessment by regulators, thus sometimes limiting the water system's or operator's ownership of the outcomes.

Regulators should provide tools to assist small systems in risk management (see Box 11 as an example). Regional teams of experts including social scientists would be very valuable both as advisors and as advocates.

Educate the community

In most nations, small water utilities and the agencies that regulate them should work to build better local awareness and promote responsible land use. Emphasis should be on those geographic areas tributary to a surface water source or overlying the zone of contribution for a groundwater source. This is particularly important for management of animal waste and hazardous chemicals. It includes educating farm operators and others (e.g., owners of chemical or pesticide storage sites) about the potential dangers of their activities and the best techniques to minimize risks. Focus groups could be developed to help in understanding the population's viewpoints.

It would be desirable for each community to have readily accessible sources for information, including Internet sources and knowledgeable experts reachable by phone or email. However, this may present social barriers to those with limited access. Communities need to develop their own most-effective and culturally acceptable system of communication. Adequate funding is an important consideration when determining the best communication strategies.

Improve surveillance systems

Developing improved systems of disease surveillance for small communities is recommended (Box 12). There is a need for a stronger connection between water quality and medical tracking. This could include: 1) increased vigilance by the health care community to recognize symptoms of waterborne disease and disease clusters; 2) use of barcode systems to track the sales of anti-diarrheal drugs and determine consumption trends; and 3) a system to track absenteeism from schools and work that is above a baseline. In turn, these surveillance systems must be linked back to the water supply via the regulatory community.

Box 10. The Sanitary Survey

In the US, there is an important tool called a “sanitary survey.” This is a complete evaluation of facilities, operations, maintenance, compliance, qualifications of operators, etc., that is conducted by a regulator for each system at least every five years. All water utility personnel want to deliver safe water. However, they don’t always know what the regulations are and they may not understand the risks to their particular systems. Sanitary surveys are designed to provide the water system with information on how it can provide a safe supply of water. The survey process can also serve to educate and train operators. The properly conducted sanitary survey is an excellent way to address many potential risks within a system.

Box 11. Toolbox to Assess Potential Microbial Contamination Risks in Small Water Systems

Individual and small water systems account for the majority of waterborne disease outbreaks recorded in the United States each year. To help address this problem, a comprehensive self-assessment toolbox was developed, to be used by small water system personnel to determine where their system has the greatest potential for microbial contamination. The toolbox components consist of 1) a survey that asks specific questions, 2) a ranking tool that computes numerical scores for water system components based on survey answers, 3) comments and results from the ranking tool, 4) a guidance document to help the user understand why certain conditions may represent a risk, and 5) instructions for using the toolbox. Each component of a water system, e.g., a well or storage tank, is evaluated and relative scores are computed. The results of the toolbox can be used to identify those components of a water system that may be most at risk, thus providing one indicator for setting priorities and a tool for establishing a risk-based approach to system operation and management. The toolbox was developed as a cooperative effort between the Montana Water Center and the Center for Biofilm Engineering at Montana State University.

Box 12. Research needs, surveillance and risk

- *Surveillance*: Design better surveillance systems to understand the prevalence of waterborne diseases and differences between geographic regions. Research is needed to develop better ways to track community health and to determine how a tracking system could be effectively implemented in low population regions. Currently in the United States, clustering of state investigations tends to occur around the Atlanta-based CDC or state capitals.
- *Health linkage*: Conduct further scientific studies of the correlation between the risk of exposure and the incidence of disease linked to water systems.
- *Baselines*: Develop methods to establish baseline health in communities, to better track changes and establish trends.
- *Culture*: Determine the influence of local cultures on the use of water and the operation and maintenance of the systems. Routes of exposure will vary depending on cultural practices. The cultural practices of indigenous communities in developed countries are frequently ignored in risk assessment. Establish an interdisciplinary group researching cultural, psychological and religious influence on the education, communication and acceptance of basic operational rules for small water systems.
- *Sociology*: Research what small-system customers expect from their water systems, their level of education, and the existing knowledge base regarding the drinking water supply. Some communities will not collaborate and therefore attempts to consolidate systems would be a misuse of resources. Other research questions include: 1) What are the social and behavioral factors that lead people to allow failure of water systems, and 2) How can operators be empowered to stand up to supervisors on controversial issues with public health and economic implications?
- *Communication*: Promote research into how information on risk is communicated most effectively and best applied by the people involved.
- *New areas*: Identify key targets in need of change or improvement. Many research needs of small systems are not necessarily known or well understood.

3. SYSTEM MANAGEMENT AND OPERATION

The organization, management and operation of a small water system are central to minimizing public health risks (Box 13 discusses management models). Involvement in these issues by the regulatory community is crucial, because small systems frequently rely upon regulators for assistance. This section outlines the many challenges faced by water system operators and managers and provides recommendations to help build the foundation for facing those challenges.

Specific challenges

A number of challenges faced by small-system operators are common to the developed countries:

- There is a multiplicity of regulations, which can be confusing. It is not always obvious to the operator responsible for compliance why the regulations exist or whether they apply to all systems.
- Older operators may have difficulty understanding new technologies, in part due to insufficient training opportunities or poor reading skills.
- When older operators retire there is limited ability or opportunity to pass on historical operation knowledge to new operators.
- Operators may be part-time employees or even volunteers, with limited knowledge of health risks related to water quality or how to troubleshoot, solve problems and maintain proper records.
- Very often there is a lack of available training or few incentives for operators to take whatever training is offered.
- The ability to attend training sessions is many times limited by the lack of backup operators. On-line courses can help, but this assumes the operator is computer literate and there is access to the Internet.
- There is a shortage of new people to replace retiring operators, a situation exacerbated by the poor pay and sometimes low status given small-system operators.
- Operators may not have the influence to take measures that would be protective of health, but in conflict with other financial demands on the system or the community.



System managers (who may also be the operators) also face a number of challenges:

- Economic pressures range from the ability of a rural system to afford a trained operator in the first place to sufficient funding for system maintenance and monitoring.
- Developing a long-term investment plan that balances cost, performance and risks can be complicated.
- Risk management plans for system failure, e.g., after a major flooding event, may be nonexistent or inadequate.
- Balancing other system needs with the costs to meet new regulations can be difficult in resource-poor systems.
- The logistics of a changing regulatory environment can be daunting. An example is augmenting a simple

chlorinator with a complex ion exchange system to remove arsenic, mandated by new, lower arsenic standards. Managers may not have enough scientific and technical support to manage these changing technologies appropriately. Regulatory changes are often made before the technical capacity to implement the change is in place.

Finally, those who oversee water system operation have responsibilities that are not always fulfilled:

- Water board members and elected officials may not always recognize good practice or thoroughly understand the importance of consistent operations.
- Board members and elected officials may be reluctant to raise rates, or may have conflicting priorities when it comes to distributing funds.
- Board members need to realize that serving on the water board is more than a public honor; it entails real responsibility and potential liability.

All levels of management must be committed to operating a quality water system. This includes operators, managers, boards, and elected officials such as mayors and council members. An important step is for all stakeholders to periodically review the entire water system and then optimize processes. For small systems, external expert assistance may be needed for the review and optimization. Before considering an upgrade, the water supplier should ask whether the existing system could be better operated and if the proposed upgrade reduces a perceived risk. It is therefore important that all persons involved in the water system understand the benefits and costs of obtaining outside assistance.

The larger system

One approach to overcoming many operation and management difficulties has been the consolidation of a group of small water systems, allowing a better economy of scale. Where geographically feasible, small systems have formed joint agreements to build and finance a single treatment facility. In other cases, a larger water system has agreed to take over the operation and maintenance of a nearby small system.

System consolidation

An operator's time may be thinly stretched among cooperatives. In Scotland, consolidation has involved many older systems that are not able to deliver water at current standards (Box 14). With one operator for 10 plants, they are ill equipped to deal with crisis events such as flooding. Nonetheless, Scotland's efforts at consolidation represent one approach to management of many smaller systems.

The consolidation of management can help tie systems together without physical connection. An advantage of this approach is that the technical person who understands the data is independent of the specific utility. A disadvantage is that technical staff members are not on site and there may be delays in dealing with problems. In the UK, small systems are linked into a computer control system, so problems are identified rapidly. Systems in the United States are run by many different entities and integration is difficult. If management were consolidated, savings could be used to improve operations. However, small towns

Box 13. Management models

- In Ireland, group water schemes (systems) are encouraged to collaborate to develop common water treatment facilities or a series of improved facilities. The group issues design-build-operate (DBO) contracts for developing the facilities over a 20-year period. The contractor must guarantee meeting all Irish EPA Drinking Water Standards, as well as other performance items. Bundling of schemes in this manner has provided up to 20% savings in operation and maintenance costs.
- In Denmark, four or five cooperatives sometimes pool together to hire one operator and one administrator. Centralized management of decentralized systems can be a challenge, particularly in places separated by long distances.
- In countries like Estonia, the cost of providing trained operators is a serious challenge. This is in contrast to the US, where it is assumed that costs of service can increasingly be passed on to the consumer.
- In Russia, the federal government mandates extensive monitoring. However, enforcement is typically limited to several basic parameters. Some resource-poor systems may be in chronic non-compliance without serious consequences.
- In British Columbia, the provincial government discourages creation of new improvement (water) districts. The trend is for larger Regional Districts (RD) to replace smaller systems. Issues include liability for the RD, cost to bring small systems up to RD standards, and loss of independence by small systems.

Box 14. Case Study – Institutional reform in Scotland

Rapid economic development in Scotland during the 1960s made clear that the existing 234 local water systems needed extensive restructuring. During the next four decades, a number of institutional changes towards centralization addressed increasing demand on water supplies, rising costs, and new water quality regulations.

In 1968, the first major reform established seven water boards to manage residential and industrial water supplies. The boards included representatives from the local water authorities and were funded by local taxation, but they operated independently of both central and local governments. Also established was a bulk supply authority, the Central Scotland Water Development Board (CSWDB), responsible for resource development in the main population centers of Scotland.

Subsequent evaluation and reorganization in 1975 of the 234 local systems resulted in a two-tier structure, with twelve Regional and Islands Councils in the upper tier overseeing the local systems. The CSWDB continued to operate, but the seven original water boards were disbanded and their responsibilities transferred to the newly created councils, now fully part of local government.

In 1980, the European Union mandated its first Drinking Water Directive, to be implemented in 1985. Scotland initially chose to impose the new regulations solely through administrative means, rather than through passage of new legislation. Administrators were to enforce the regulations under laws making it a criminal offense to supply water unfit for human consumption. The European Union quickly challenged this approach, and by 1990 Scottish lawmakers passed detailed statutory regulations to ensure reporting and subsequent correction of any noncompliance with the EU Directive.

The Regional and Islands Councils struggled somewhat to adjust to the new sampling and reporting requirements, delaying until January 1993 the first detailed report on system performance during 1991. The report revealed an unacceptable situation: while most of the larger towns and cities in Scotland benefited from high quality water, around 600 water systems serving small communities did not meet the required standards. It soon became clear that new facilities were needed in most cases, a daunting task well beyond the capabilities of the Regional and Islands Councils. In 1989, England and Wales had successfully privatized their water industries, but Scotland opposed privatization and sought a different solution.

A unique experiment in public ownership emerged, with the creation in 1996 of three administrative entities to provide water and sewerage services throughout Scotland. A massive program of improvements followed, but by 2001 the improvement costs in the sparsely populated highlands and islands meant exorbitant water charges for many. The three authorities merged in 2002 to form Scottish Water, which in the first two years of operation reduced annual operating costs by 20 percent. Under this single operating entity, Scottish water system operations, capital investment planning and risk management techniques have improved for large and small supplies alike. The capital expenditure program required to meet the revised EU Drinking Water Directive, in effect as of 2001, will be largely complete by 2007.

or communities may not wish to consolidate, as initial set-up costs put pressure on communities already under high financial burdens. Additionally, communities may be reluctant to collaborate with each other to this extent, especially since rates for some customers can increase due to consolidation with a system that is in poor condition and in need of investment for improvements. In the United States, consolidation generally requires long-term commitment and work on the part of a local community activist (i.e., a “local champion”).

Application of large-system practices

Small systems can benefit from following a number of practices used by larger systems. In particular, asset management plans are applicable to all sizes of systems. Vulnerability assessments and emergency plans also are appropriate. Standard operating procedures (SOPs) should be written down, even if there is only one operator. It is important for outside investigators to see written SOPs, particularly in the case of a waterborne disease outbreak. For small

systems it will most likely be necessary to enlist outside assistance to prepare SOPs, vulnerability assessments, emergency plans, and so forth.

Large utilities are adopting the “multiple barrier approach,” and it is recommended as a risk management tool for smaller systems as well (O’Connor 2002). Essentially, the approach is to select a clean water source, protect the source from contamination, provide adequate treatment and disinfection, upgrade distribution networks, and provide adequate monitoring and operator training (Ford 1999). Each component (barrier) is managed to optimize protection of public health, and if one fails, the others should be able to prevent contamination. Many small systems cannot fully implement the multiple barrier approach, and sometimes their single line of defense is compromised. The critical question becomes which barriers can be used and maintained in a cost-effective and sustainable manner.

Large systems in Germany, the United States and elsewhere are utilizing new water treatment technologies as they are being developed, for waters that cannot be economically treated by other means. Ozone is becoming increasingly used as a disinfectant. Estonia is utilizing ozone, Ireland is piloting its implementation, and many US cities have initiated its use. Ultraviolet (UV) light is also gaining in popularity as a primary means of disinfection. Its advantages include very good inactivation of protozoa like *Cryptosporidium* that are difficult to kill using chlorine, and it does not add chemicals to the water. Disadvantages are that the water must be very clean and an added residual disinfectant may be required to provide adequate protection in the distribution system. Another new technology (also being used by small systems) is synthetic membranes to remove pollutants and microbes from the water, taking the place of the traditional coagulation, settling and filtration. In large water treatment plants, where resources are available to test and evaluate these newer technologies, decisions for implementation can be made based on data collected for that particular site. Since all of these methods have limitations and must be integrated with the entire treatment and distribution system, this testing is important to ensure that proper choices are made.

For small systems, newer technologies may present problems. Small systems rarely have the financial resources to perform extensive testing of alternative treatment methods. There may be the need for skilled operators, specialized maintenance, and additional financial resources to operate and maintain the technology. A case in point is a small water system in Montana (US), where the community was told that ozonation would be the best solution to its disinfection requirements. Since installation, there has been no support of the system and operation is less than optimal. In many rural areas around the world, energy

supply may be limited, not reliable, or too expensive, which will preclude the use of many newer technologies.

Source water protection

For any size water system, source water protection is important, representing one barrier to contamination in the multiple barrier process. For the small system, source water protection is critical, since resources may not be available for extensive treatment. Because small systems also typically lack financial and other resources to find and develop alternative water sources, protection of the existing sources appears even more imperative than for large systems. The quality of source water can change over the years and the change may go unnoticed if there is inadequate monitoring by the water system. It is important for all water systems to regularly examine potential sources of contaminants in the watershed area. Protection zones (Box 15) should be clearly displayed, enforced and inspected at least annually.

However, source water protection by a small system can be very difficult if the system lacks ownership or management control for land in the watershed, aquifer recharge area or even the immediate protection zone around a well. In British Columbia, the Drinking Water Officer can seek an injunction for activities that threaten drinking water quality or require someone to take action, providing a means of enforcing source water protection. In the US and some other countries, water utilities and public agencies may not have authority to preclude threatening activities within the watershed area. For example, land-disturbing activities that transport sediment to streams are only beginning to be regulated. This is a huge impediment to protecting water sources. In the absence of regulatory powers, the only ways to protect sources may be to buy the land, purchase easements, or enter into complex agreements with landowners.

A successful source water protection program requires finding and educating the proper stakeholders. Once stakeholders recognize both the personal health and economic benefits of protected water sources, it is probable that they will be more willing to comply. The situation is more difficult when the user of the water supply is significantly downstream from the source and there are no apparent benefits to the landowner. In fact, source protection may cause economic loss to owners, making monetary compensation the most effective way to protect the water.

All colloquium participants acknowledged the importance and benefits of source water protection. However there remain two divergent points of view regarding protection of the source. The first and possibly more dominant viewpoint

is that source water protection is an important step in protecting public health and should be part of a small water system's operational or risk management program. The second viewpoint is that many small systems truly lack the management and other resources necessary to effectively protect their sources, and should therefore focus their resources on those barriers that they can best control, e.g., treatment. This does not mean the system should disregard the quality of its source. Source water quality monitoring becomes more important in those cases where no active source water protection program is in place.

Monitoring

Water suppliers use monitoring to verify that the quality of the water meets standards for its intended use (Box 16

compares monitoring approaches). Use of appropriate technology and monitoring methods presents one of the greatest challenges for the small water system with limited financial and human resources. With infrequent monitoring and, in some cases, volunteer operators, record-keeping may be poor. Consequently, these systems may be unaware of potential or actual contamination events.

Key monitoring questions for small systems include:

- Is the major potential contaminant problem microbial, chemical or both?
- How can the problem be abated?
- What are the appropriate responses (actions to be taken by the operator) in case of contamination?
- How should the equipment be monitored to ensure that it is functioning properly?
- Where should water be sampled?

Box 15. Groundwater Protection Zones (WHO 1997)

I: The area surrounding the source most at risk from pathogen contamination. This is often the 50 day zone¹ - water takes 50 days to reach the well. This of course depends on the hydrogeology, which can create problems for systems where geology is not mapped. Some soils and geological conditions facilitate rapid transport of microorganisms from fecal sources (i.e., septic tank effluent, animal manure spreading onto fields) through soil into groundwater sources. Karst, fractured limestone, porous volcanic soils, and sandy soils are aquifer media that pose increased risk. Saturated soils also facilitate rapid movement of microorganisms in the subsurface.

II: The area surrounding the source most at risk from chemical contamination. This will vary greatly and will depend on aquifer type and abstraction rate as well as on industrial and agricultural activity in the area.

III: The total watershed area – the area that contributes water to the groundwater aquifer.

¹Ireland uses a 100 day zone. During the planning process, documents are prepared that note underground storage, septic tanks, gas tanks, and manure spreading. Manure spreading is specifically controlled by codes of practice.

Box 16. Monitoring approaches compared

- In Russia, a high frequency of sampling is required for small systems. The monitoring regimen is typically too burdensome, leading to fewer analyses being performed than the number legislated. There is also independent monitoring done by a state agency (Sanitary and Epidemiological Control) that collects compliance samples of treated water at a lower frequency. This agency also investigates potential waterborne disease outbreaks.
- In Ireland, local authorities must have documented procedures for dealing with contaminant levels exceeding the standards, to ensure that each incident is investigated and that appropriate corrective action is taken. Sampling procedures are standardized throughout Ireland and approximately 60-70 laboratories do the monitoring for the entire country.
- In Denmark, both the analysis and the sampling techniques must be accredited. There are no problems with distance and sample holding time.
- In contrast, in Idaho (US), the population density is so low and the distances so great that the microbiological samples must be shipped in a cooler on a bus to an accredited lab. Some small utilities have problems with sample collection, and false negatives and positives may result.

- Where should samples be analyzed?
- How often should samples be taken?
- Who pays?
- How do monitoring data help reduce risks and protect public health?

One of the fundamental roadblocks to effective monitoring in small systems is getting samples from the field to the laboratory within 24 hours, which can be difficult in remote areas. There are examples of laboratories that arrange to collect samples from small systems, analyze them and act as a “phantom operator.” There are clearly opportunities for the private sector to sample and evaluate water. However, in a number of cases, sample collection by a private laboratory can be too expensive because of the distances involved in transporting them. Bacteriological tests that can be performed by operators could help resolve this problem.

The frequency of sampling and choice of sampling sites are also important. On-line, real-time monitoring throughout the system would be ideal (Rose and Grimes 2001), but in the absence of reliable, affordable technologies to achieve this, government guidelines determine choice of sampling site, frequency of sampling and sample size. For example, under European directives, systems must sample twice a year in different seasons at sites that are representative of potential exposure risk. In the United States, sampling frequency typically is related to the population served by the system. It is more likely that pathogens will be detected using large samples or more frequent small samples. However, there are logistical constraints as to the volumes and numbers of samples that can be collected and analyzed.

An important component of monitoring is the reaction to an exceedence. This was a fundamental failure in the Walkerton *E. coli* outbreak (see Box 8). There have been other examples with small supplies in the United Kingdom, where operators have falsely stated that water quality is fine, despite exceedences in routine samples. If there is a positive sample, there must be an immediate response – resample, review potential contamination routes, flush pipes, hyperchlorinate, or issue boil-water orders if the samples continue to be positive. Obviously, there needs to be a relationship among the operators, managers, health department and regulators that creates a climate of cooperation.

Microbial methods have long been cornerstones to assessing water quality. The presence of total coliforms in the finished water can indicate a problem in the treatment process. Total coliforms detected in the distribution system may indicate intrusion, cross-connections or regrowth. Other bacterial indicators, such as high heterotrophic plate counts (HPCs), may also indicate treatment inefficiencies or regrowth. *E. coli*, coliphage, and *Clostridium perfringens*

are useful indicators of fecal contamination, especially in groundwater sources. *C. perfringens* is a relatively good surrogate for protozoa and there are simple, standardized, inexpensive detection methods for this organism. There are also relatively simple and inexpensive methods for coliphages that are not widely used. Although coliphages are a useful indicator of fecal contamination, there is currently insufficient quantitative data to use them as indicators of pathogenic viruses. The presence of animals in the vicinity of source waters can create harmful levels of viruses which pose public health risks (e.g., hepatitis E); there is still a need to develop more effective indicators for these pathogens.

There are a number of useful indicators of process efficacy and system integrity, such as turbidity and chlorine residual. These indicators are relatively easy to measure and should be assessed at greater frequency than microbial or chemical indicators of source contamination. Turbidity and chlorine residual can be measured continuously using automated monitoring systems. For example, if there is no detectable chlorine residual, then the operator needs to check the chlorination process and measure the chlorine demand of the raw water. In turn, high chlorine demand could indicate source water contamination that could then be managed. Measuring turbidity after rainfall is perhaps the easiest and quickest means of monitoring source water quality. Turbidity in itself does not mean that pathogens are present in source water, but it provides an initial trigger to monitor for pathogens and/or change procedures.

Monitoring is not a preventive measure in itself, unless it is integrated into parameters for operation, such as monthly or weekly sampling. Unfortunately, many small systems monitor for compliance only, and the data are underutilized when examining system operation, variation and vulnerability. A risk management approach to monitoring would seem to be far more protective of public health than simple compliance monitoring (Box 17). Monitoring can establish variations in water quality through time, generating data that can subsequently be used to schedule routine flushing or to adjust treatment or disinfection. Risk management requires sampling after high-risk events such as severe weather, source water changes, shifts in management practices, or repair of a water main break. Rainfall, in particular, can affect the quality of surface water and groundwater sources. Heavy storms increase contaminant runoff into surface water sources and increase flow rates (Curriero *et al.* 2001). Rainfall can also cause pathogens in soil to infiltrate a shallow aquifer (e.g., Walkerton outbreak). Contamination during these events can easily be missed by strict compliance to a fixed sampling schedule. One precaution is that generation of too many water samples may overwhelm laboratory facilities and inaccuracies may result.

Box 17. The HACCP Framework Approach

Hazard analysis critical control point (HACCP) approaches, long used by the food industry to protect public health, are gaining interest within the water industry (Deere *et al.* 2001). The standard protocol is:

1. Conduct a sanitary survey to identify potential hazards and hazardous events (including microbial and chemical)
 - Should be revised on regular basis to capture changes in the watershed or aquifer and recharge area
2. Identify key monitoring points and times for small systems
 - There will be different monitoring points for surface vs. groundwater systems.
 - Always monitor treated water at multiple points (operational and management points).
 - Increase “supplemental” monitoring and additional indicators during hazardous events (rainfall, main breaks, repairs, back flush periods, low pressure or pressure interruption). This type of monitoring could be done on a periodic basis to understand what happens to final water quality during these circumstances. Once the operator has sufficient information on how to effectively run the system to manage those situations, then this type of supplemental monitoring does not need to occur during every event.
3. Set response levels (target and trigger levels)
 - Tracking indicator levels over time should be used to create control charts to examine trends and deviations. This information can be used to identify target and trigger levels.
 - Set trigger levels at which the response is to notify appropriate authorities.
4. Take action (operator and/or manager or health authority)
 - When is no action needed?
 - When is it appropriate to take corrective action (i.e. adjust treatment, add further treatment, change treatment, flush distribution system, etc.)?
 - When is it appropriate to issue a boil-water advisory?
 - When is it necessary to provide water from an alternate source?

Contingency planning

Contingency or emergency plans are common in large water systems, defining the response a system operator should take under certain emergency or changing water quality conditions. Contingency plans are approached differently in different countries:

- The World Health Organization has issued guidance about how to document contingency plans. It is recommended there be a written plan supplied to the authorities who conduct a regulatory audit of large systems (WHO 1997).
- German regulations are relatively inflexible. The operators must make contingency plans for emergencies, which can include backup water supply systems, backup electricity lines, etc. Every water supplier in Germany is expected to have a contingency plan. Unfortunately, the small systems are not audited.
- Systems in British Columbia must have an Emergency Response Plan; however, compliance with this requirement has historically been low.
- In Denmark, the municipalities must also prepare contingency plans. There must also be a plan at the County level, as they are responsible for implementing

a boil-water advisory. These plans affect small water suppliers as well, but are not in place everywhere and many of the operators are not aware of appropriate procedures.

- Estonian water systems also have contingency plans for potential problems, which list the chain of command and steps to be taken in an emergency.
- In Puerto Rico not all of the plans are written. However, some contingencies are included in bylaws.

Contingency planning for small water systems raises several questions:

- How often and by whom should contingency plans be reviewed and revised?
- How often should operators practice their responses to emergencies/contingencies?
- What happens when new operators replace old operators?
- Who is the backup operator and is that person aware of the contingency plan?
- Are there adequate budget and expertise resources to prepare a contingency plan?

Recommendations and research needs

Small system organization and operations

Document protocols

For each small water system, operating procedures should be clear and well documented with delegated responsibilities. Procedures should include active, consistent management and maintenance of the small water system. All monitoring test results should be sent to both the small system operator and to management (or someone with oversight responsibility who is not directly operating the system). A formal mechanism should be in place which obliges the water supplier to notify other agencies of any change in the water system or an event that could compromise public health. Communication protocols should be defined in the water system's Emergency Response Plan or similar document.

Prepare guidance documents

Water system professionals should develop a realistic guidance manual on technology for small systems. Guidelines should include evaluation of the physical units, as well as monitoring protocols. These protocols exist in the United States, but they lack adequate funding and can be too complex for most operators to effectively utilize. Funding should be increased where they do exist and initiated where they do not.

A checklist of procedures for operators is useful, listing daily, weekly and monthly tasks. Key operational parameters such as turbidity, chlorine if used, pH, and temperature should be monitored regularly. The operator must review operational data on a routine basis and interpret this knowledgeably (or pass it on to someone who can). There must be an

appropriate response to data, e.g., increased finished-water monitoring if turbidity increases in surface water supplying the plants. Compliance data from periodic sampling must be reported to health officials, inspectors as well as system operators.

Develop emergency response plans

Small systems should have a clear, current, documented multi-agency emergency plan that is distributed among the necessary individuals. This plan needs to be exercised and practiced cooperatively with all stakeholders. Keeping these plans up-to-date and available is a problem for very small systems. Small system representatives, advocates and advisors should be identified to provide expertise during non-compliance, extreme weather or other potential contamination events and/or system failure. Small water systems should self-audit yearly, following guidelines for conducting a sanitary survey. Also, trained professionals and regulators experienced in small systems should conduct a formal audit and review of the system on a regular basis.

Facilitate consolidation and mutual assistance

Small systems need considerable help in identifying opportunities for mutual aid and consolidation of resources and operation (Box 18 details some of these needs). It is recommended that regulatory policies favor those systems that adopt existing, successful models of system consolidation (e.g., State of Victoria, Australia). Partnerships between small and large systems for monitoring are needed and should be encouraged. This may reduce the economic impact of future requirements for pathogen monitoring. As monitoring expands for larger systems (e.g., testing for new pathogens such as viruses and protozoa), small systems should partner with these utilities to be included in the monitoring.

Box 18. Research needs, organizational

- *Current support systems:* Research the current support network. Are there defined roles and responsibilities? Determine how the network needs to be changed or create a new support network that integrates technical regulations and small-system administration with clearly defined roles and responsibilities. Provide sufficient funding to be effective.
- *Centralized operations:* Research remote monitoring and centralizing operations. In the US, broadband connectivity is making it easier to share information and rapidly transmit large amounts of data and images. How can this technology be more effectively used to protect small water systems? A comparison could be made here with rural clinicians transmitting medical information to centralized health services. Capability to automatically alert authorities and, in certain cases, to automatically shut down small systems without full time operators is also important. Supervisory control and data acquisition (SCADA) could provide automated control of plants that are networked to a centralized supervisor.

Make monitoring part of risk management

Standard procedures, training and certification are important for those involved in monitoring. With monitoring costs high, especially on a per-household basis, the monitoring scheme should be flexible and tailored for each system, by using risk-based approaches to identify the most important aspects of the monitoring program. Monitoring should be based more on identified risks (as in the HACCP approach), providing more flexibility than that available using current regulations.

Develop simplified and improved monitoring systems

Because of cost constraints, there is a lack of monitoring data from many small water systems. There should be better use of existing cost-effective methods and more effort to identify additional simple, fast, and practical methods. Improved methods for bacteriological testing that can be performed by operators would greatly assist small systems. Operators should be able to perform all routine laboratory tests on site and use the results to guide decisions about operation. Given current technology, many types of microbiological tests still require the services of a certified laboratory. Small water systems need to be able to send water samples to a certified lab within the recommended time for sample storage (often within 24-48 hours is required). Policy should also encourage use of additional microbial indicators other than just coliforms, to indicate

presence of protozoan pathogens or contamination of groundwater with surface water (e.g., *C. parvum* and the enterococci).

Other options for improved monitoring include continuous monitoring for turbidity and residual chlorine, motion detectors to warn of intrusion by unauthorized persons, and monitors for reservoir overflow, water levels and pump function. Most small water systems currently do not employ many of these technologies due to initial cost and subsequent maintenance requirements. However, as technology improves, the cost of monitoring equipment typically declines and equipment becomes more reliable. Continuous monitoring would allow operators to respond more rapidly to a potential breakdown in one of the barriers of protection, such as disinfection. Regulatory policy should encourage, and possibly fund, affordable online monitoring, e.g. turbidity, redox potential, biofilms and residual chlorine (Box 19).

An important but often overlooked component of monitoring is to create a water quality baseline that can be used to establish trends. Data must therefore be collected and reported in a form that can be easily read and understood, so that trends are clearly visible. It is important to understand the type of information obtained from a positive sample. For example, there are critical numbers of samples that must be collected before the information is statistically valuable. However, too many samples will waste resources and will not provide additional, relevant information.

Box 19. Research needs, monitoring

- *Methods:* Research simple, rapid detection methods. This includes improving existing methods and making them more reliable and user-friendly. In addition, operators need to understand both the method and the background of the method. Other needed technological improvements include automated sensing devices for chlorine residuals and cheaper particle counters for those using filtration barriers. Technological improvements need to be cost effective and reliable, and must be coupled to operator training on maintenance and calibration of instruments.
- *Indicators:* Investigate with scientific studies the actual public health risk posed by the presence of water quality indicators, particularly for small systems where resources for monitoring are more limited. Small systems should be included in research projects addressing this issue.
- *Robotics:* Develop new remote sensing and automated systems. However, for small water systems, the focus still needs to be on low cost solutions.
- *Integration:* Design tools for operators and managers to integrate information and understand the system as a whole, e.g., simple software that can gather information on system parameters and provide an assessment of failure risk.
- *Turbidity:* Review the use and benefits of turbidity in monitoring water quality.
- *Biofilms:* Develop reliable, simple monitors for deposition of biofilm on pipe material.
- *TOC:* Design rapid tests for TOC, its effects in distribution system regrowth and as an indicator of changes in water quality.

Box 20. Cooperation in Puerto Rico

Like most of the United States, Puerto Rico has many water systems that are simply too small to operate in a manner compliant with water quality regulations, unless significant investments bring system units up to acceptable standards. This is, in part, due to economics, but there also are other factors at least as important that are often ignored. Among these are education, sense of community, and technical, managerial and administrative skills and abilities. In southeastern Puerto Rico, a new collaborative effort to address these factors may prove to be a model for not only the island but elsewhere in the United States and the world. Partners in this unique project include the Patillas Water Systems Cooperative (CAP); the Puerto Rico Corporation for Rural Development; Resources for Communities and People, Inc.; the Interamerican Environmental Studies Institute, or CECIA (Interamerican University of Puerto Rico); the EPA; Rural Utility Services of the U.S. Department of Agriculture; and the Puerto Rico Department of Education and the Municipality of Patillas.

The ground-breaking Patillas water cooperative begins the “professionalizing” of potable water systems in rural Puerto Rico. What has been missing both here and elsewhere is the understanding that successful programs must not only provide projects or plans but also skills – skills that go beyond system operation to user understanding of the techniques needed to plan effectively. While users do not need to know how to perform a specific laboratory test, they do need to know what it is, how it can be done and why it should be considered. Local users obviously are those most interested in seeing that possible contaminants are addressed and corrected or managed.

Drawing on these principles, the intent of the Patillas model is to demonstrate how an in-depth and multi-faceted community effort can build high-quality local water systems. The project includes:

- Unification of the 10 member systems (and eventually others) into an administrative, managerial and operational unit. The first 10 systems serve about 1,000 households. The CAP manages all user fees and operations.
- Education of system users, including post-secondary certificates in either operation or administration of small water systems. The certificate program, which requires about 600 hours of practical work, will improve system capabilities and provide the basis for long-term management.
- Preparation of needs assessments, maps and alternative improvement scenarios for CAP consideration, in order to set priorities necessary to reach regulatory compliance. System users will be involved throughout this process. Those in the operator and administrator certificate programs will assist in the collection and compilation of required data, including GPS for GIS mapping and both formal and informal census data.
- Inclusion of CAP partners in applications for system funding and in priority-setting assessment processes.
- Eventual coordination of the potable water needs of these communities with a planned formalization of State Forest Reserves to preserve water source areas.

Protection of source waters

Educate stakeholders

Agencies and communities should recognize that source water protection is the first step in minimizing risks to public health, and the first and perhaps the most crucial barrier in the multi-barrier approach to safe drinking water. Policies and actions should promote local awareness of the immediate environment and watershed protection zones in a relevant social context that promotes social responsibility. An innovative example is underway in Puerto Rico, where emphasis on public education and stakeholder cooperation recognizes the critical role of community effort in overcoming small-system obstacles (Box 20).

Assist small systems in assessment of aquifers

Local hydrogeology in the watershed basins should be mapped and regulated as necessary (Box 21). Public geological surveys or water centers should be charged with conducting regional geological investigations and providing a centralized information repository for each state or province. More stringent technical standards may need to be applied for drilling wells within the watershed area.

Technologies for optimal infrastructure and operation

A multi-barrier approach should be encouraged, encompassing source protection, treatment and distribution. Specific recommendations regarding treatment technologies are shown in Box 22.

Box 21. Research needs, source waters

- *Source protection:* A thorough understanding of watershed geology is vital to source protection, as is the development of better tracers for finding where water is coming from or where wastewater is flowing.
- *Wastewater treatment:* The impact that wastewater treatment has on groundwater needs to be addressed. The effectiveness of drain fields from on-site disposal systems, e.g., septic systems, needs to be carefully evaluated together with the efficacy of protection zones.

Box 22. Research needs, technologies

- *Cheaper technologies:* Develop cheaper technologies for treatment. (Currently, research is being conducted on solar desalination in Australia to identify cheaper options.) However, it should also be recognized that research in treatment technologies may be a lower priority in small systems; improvements in operation may provide greater gain.
- *Membrane technologies:* Further investigate membrane technology to replace traditional coagulation-sedimentation-filtration systems. Review current knowledge on the safe use of membranes in drinking water and applications for small systems.
- *Chlorine disinfection alternatives:* Review current knowledge on the safe use of UV, ozone and chlorine dioxide as primary disinfectants.
- *Use of chemicals:* Improve sustainable, natural, and chemical-free treatments.
- *Piping materials:* Develop better piping materials and research both prevention of leakage and repair methods for existing distribution system pipes. Tests of system piping materials should include assessment of biofilm regrowth potential. This should eventually include household materials such as o-rings and valves.
- *Algal toxins:* Research methods for detection and treatment for algal toxins in small water systems using surface waters.
- *Open research areas:* Study the generation of bad taste, odor or color in water and methods to mitigate these problems. Bacteria (e.g., sulfate reducing bacteria), fungi, algae and decaying plant material all contribute to these parameters, but because the health effects are not obvious, the funding is limited.
- *Remote control:* Develop technologies for reliable, remote controlled water works and remote monitoring technologies.

4. TRAINING

Appropriate training of small water system personnel was the single factor identified by colloquium participants as most vital to achieving a safe drinking water supply. Training must not be limited to operators, but must include system managers, regulators, and technical personnel.

Operators and Managers

Poorly trained operators and managers of small water systems can jeopardize public health. Small system operators may only work part-time or as volunteers while holding down a full-time job elsewhere. There is a considerable range in abilities of small system operators worldwide; different levels of training are required, unlike the more standardized training of large system operators. "Small system manager" is a term that must be used carefully since many small systems do not have a true manager. Instead, that person is a member of the (voluntary) board, one of the elected councilpersons, or an interested volunteer from the community. The education of water system staff is therefore of paramount importance.

Several key points should be considered when training small system operators and managers:

- A large proportion of outbreaks in small water systems are the result of human error. The operators themselves are rarely at fault, as they are usually at the tail-end of a system that is in need of updating.
- Operators do not always recognize when they are overwhelmed and require help. Small system operators may not know where they can obtain advice or assistance. Small system managers or administrators may not be supportive when an operator requests outside or additional help.
- Operators do not necessarily possess the data interpretation skills necessary to make use of process control



and certain monitoring data, which are particularly needed to render risk management programs effective.

- The training that many operators receive is not necessarily specific to small systems, and some operators have trouble applying classroom concepts to their own sites.
- Currently, the perceived low social status of water operators may dissuade people from entering the profession. The position of water operator should be elevated to public health professional standing. This could bolster enthusiasm and job interest, creating a better work environment for the operator. Incentives are needed to convince trained operators to work with small systems.
- In some circumstances, a small system operator may have multiple roles. For example, a trailer park owner will have the commercial venture to consider as well as being both the manager and operator of the water system. Financial interests could impinge on the importance of public health issues. These individuals must be educated about the risks and consequences of their roles as public health protector.

- Managers also face a multitude of serious issues. Often volunteers, they are not always skilled and educated sufficiently to understand and preempt the major problems that may occur within their systems. They may not fully understand their responsibilities and liabilities as public health professionals.

Training opportunities for small systems operators are clearly inadequate, particularly as new technologies and delivery systems are introduced. The complexity of regulations in the United States and the trend towards risk management mean the average volunteer or part-time operator rarely has enough information to guarantee a reliable, safe drinking water supply. This raises the question as to whether operators of water systems should be “professional,” i.e., a person whose full-time job is operation of one or more water systems. However, the economic reality is that volunteers, part-time operators and business owners are a necessity and it is incumbent on the regulators to provide training that can be fully understood by the average high school graduate. .

Common problems regarding the training and certification of operators are as follows:

- The institutional systems to provide training usually are available, but individual utilities may lack the funding or operators may simply decide not to take the training because they do not fully understand the importance of their role.

- In many jurisdictions there is no adequate mechanism to monitor the content of training and refresher courses.
- Water utilities may not know what level of training is appropriate. Should they train personnel how to do everything/ know everything, or simply to know the basics and how to find the answers for anything else?
- Within the United States, operators who move from one state to another cannot automatically transfer their certifications; training requirements are not uniform among states.

Regulators and technical assistance personnel

To be an effective regulator or technical assistance provider requires a high level of training and, just as important, personal experience at the level of the operator (Box 23). The regulator many times needs to be an educator. This is important in creating the relationships with the community, as regulations are written to protect the public health but are not always understood. Community members need to know that the job of the regulator is to protect them and not to punish mistakes or non-compliance. When state and local government resources are inadequate to the demands on them, it is difficult for regulators to have the

Box 23. Who trains the regulator?

There is considerable variation in the regulatory process, and in certain cases it is very unclear who trains regulators and how they are trained:

- The UK has separated regulators into a number of areas - health and safety, environment, and more. It is difficult to determine which regulations should be met first, due to conflicting or confusing messages from separate regulators.
- Individual US states must do considerable additional training to understand and implement regulations. The USEPA now recognizes this fact and is providing more training opportunities than in the past. Appropriate training opportunities and funding should remain a priority.
- In Germany, the Water and Gas Association has written all of the regulatory standards. This has proven very effective and is well known to most of the operators. However, it is very inflexible and it is difficult to amend as situations change.
- In Denmark the regulations are set by the Ministry of Environment. Approval of the facilities is on the county level, inspection is carried out by the municipalities, and in some cases they are inspecting themselves (a situation that is currently changing). At present, training is conducted by the Danish Water and Waste Water Association. The waterworks must pay to attend these courses and people in the communities do not feel the training is adequate. Not all operators or regulators attend the training.
- Mississippi (US) has mandated that elected members of local water system boards have at least eight hours of training per term of office.

time and resources necessary for developing relationships and trust. It is also challenging for regulatory agencies to hire experienced individuals and keep them on staff.

In the United States there are state or EPA-funded non-governmental organizations and water centers that provide technical assistance to small water systems, and training for new regulators. In some states water system personnel know whom they can call for help; however, there is considerable variation in the help that is available.

Recommendations and research needs

Develop practice-based training specific to small systems

Training materials and programs must be tailored to small system operation and management; generic programs may miss key elements unique to small water systems. At the same time, training needs to be standardized. Abilities of operators differ widely, in part due to current differences in the quality of training programs and trainers.

Training design must recognize the practical needs and key deficiencies often found in small systems, such as relatively poor technical skills. Basic math and data interpretation skills are crucial, as are the abilities to troubleshoot equipment and understand a system's vulnerabilities. On-site field experience should be a central component of training, as operators may need help applying classroom lessons to their own systems. The use of outbreak case studies as teaching tools also illustrates the real-world aspects of technical training. Training sessions should be limited in length, as there may not be trained personnel to replace operators attending courses. (In Australia, trainers may travel to a system and teach operators on site.)

Provide accessible off-site information, up-to-date expertise

Mentoring, training, and literature sources need to be readily accessible to system personnel in isolated areas or

with limited resources. The development and promotion of Internet-based training services, as well as databases of information on all aspects of small-system management, are recommended. Experts should be reachable by phone or e-mail. It should be possible to bring in a technical advisor on an as-needed basis.

Consider small-system needs in regulatory decisions

Regulatory agencies must mandate a realistic level of system-dependent training requirements for small water system operators and managers. For each position, needed skills and competencies should be defined by the agency and addressed by appropriate training tools, taking into account the fact that some operator trainees may have poor reading skills. More government resources must be available to train both managers and operators to ensure proper certification. Guidelines for small systems should include a requirement for documented plans within each system for the education of operators, managers, and board members.

Emphasize the importance of public health protection

Many operators and system managers have insufficient contact with training materials concerning the public health aspects of providing drinking water; these should be developed and made available. They should include a discussion of the fecal transmission pathways for pathogens and how piped water systems can become efficient vehicles for disease transmission. Training should include basic information about disinfection, laboratory testing, and possible environmental contaminants.

Reinforce the critical importance and usefulness of the sanitary survey or its equivalent. Some authorities believe there is insufficient funding for these surveys, which often are used as compliance lists rather than as public health necessities. When surveys are performed, the focus is too often on the quantity of the reports, not the quality – a way of thinking that can be changed through better education.

5. REGULATIONS

Regulations help ensure that water systems supply safe drinking water to the public, but they differ widely around the world. Colloquium members explored how current regulatory structures in various nations help or hinder the protection of public health by small water systems.

Differences in approach internationally

There are clear differences in regulatory approach among nations (Box 24). Philosophies of regulation range from reliance on utility knowledge and competence to detailed, rigorously enforced standards for all aspects of system operation. From these differences, it is apparent that specific conditions in a given area and the source of the water used should be considered when writing regulations. An important question is whether current regulations are appropriate for the extreme diversity in small water systems. When unattainable goals are set, rules and standards tend to be undermined. Therefore, whatever the rules and requirements are, they need to be achievable and understood.

Compliance

Different systems use different methods to facilitate and measure compliance. Scotland and many other countries focus on the end result, i.e., meeting water quality standards as demonstrated by finished-water monitoring results. This approach may not always be the best for protecting public health. It is important to continuously examine the entire treatment train for potential failure (as suggested by most risk-based approaches). This is a key role for the sanitary survey in the United States. As an approach to improving compliance, British Columbia provides Best Management Practices for water systems with specific recommendations for small water systems. The documents are posted on a web site and include additional resources and contacts for answers to questions.

Compliance can depend on the economic resources available to the community or water system. For example,



in Idaho (US), the new arsenic rule requires 135 water systems to install treatment to remove arsenic at a cost of approximately \$40 million. The regulation has been passed, but many small utilities will not be able to comply without significant financial help.

Some key issues with regulations and regulators:

- If something is regulated, a plan must be in place for systems to meet the regulations.
- People treat the regulators as experts (and sometimes they present themselves as experts) when that may not necessarily be the case.
- Water suppliers/operators know a great deal about their particular water system; therefore it is important for regulators to listen to and understand the concerns

Box 24. Regulations: a range of approaches

- In Ireland, there is considerable variation both in water sources and in delivery systems. Both surface and groundwater are used and treatment plants must be tailored to fit the source of the water with the ultimate goal of meeting the drinking water standards. The government provides the financial resources for the treatment and carefully scrutinizes the plans.
- In Denmark, community water systems are based more on tradition rather than legislation. Communities have drilled wells in the past and systems are in fact all very similar.
- In Russia, the Law on Drinking Water and Water Supply specifies the minimum treatment requirements for water sources of different quality. Treated water has to be in compliance with the same standards regardless of the quality of source water.
- In Scotland, regulation is focused on the end result, not on how that result is obtained. This allows flexibility in treatment methodologies that is appropriate for different water sources. It is incumbent on the operator/manager to demonstrate that regulations are being met, rather than regulation enforcing specific treatment technology.
- In Estonia, most small water systems use groundwater as their source. The utilities are focused on the end result, i.e., meeting European Union standards for drinking water. How the water supplier decides to meet the EU standards is not an issue for regulators; the end results are the concern.
- In the United States, there is enormous variability in system size, financial viability and source water quality. All systems must meet the same standards for the quality of the water they distribute, but small systems have more time to come into compliance with the regulations.
- In Canada, standards for public water systems are established by the individual provinces. In the province of British Columbia health inspectors and Drinking Water Officers (health officials employed by regional authorities) can place conditions on a water supplier's operating permit, in order to enhance water quality and protection. The province continues to work on clearer definitions of small water systems and the applicability of regulations to systems of particular size.

of the operator as well as provide added insight based on the regulator's experience and training.

- The role of the regulator should be in providing assurances that regulations are in place to prevent contamination and preserve public health.
- A challenge for US regulators is that the regulations are not always financially achievable or sufficiently flexible for small systems.

Representation of small systems in the regulatory process

In general, small systems are not well represented in the regulatory process (Box 25). However, there are also cases where it can be argued that small systems are over-represented. For example, farmers in the United Kingdom, Ireland and Germany have a major influence on the regulatory process; this is probably true for most areas dependent on water for agriculture. In contrast, the average urban person has little influence on regulations. In the United States, agriculture can dominate rural development and therefore water use practices. There is little or no representation in the regulatory process for rural communities that are not primarily agricultural.

A related question is whether small system customers are represented in the regulatory process. Small system managers may ask for a relaxation of regulations, but it is rare that someone asks the customers whether they want standards relaxed. Possibly the more important issue is whether customers should have the choice to assume risks to order to lower costs.

Different regulatory standards for small water systems

Should there be different standards and requirements for drinking water systems because of their size (Box 26)? This question has been debated extensively by others (Gordon 1999) and at this colloquium. The primary issue becomes the cost to the customer. If cost were not an issue, standards or guidelines should be the same regardless of system size. Universal standards to protect public health are critical, but there are different levels of risk and responses to failure that are unique to small systems. For example, the requirement for zero fecal coliforms is and should be identical for all water sources. In contrast, it can be argued that standards that apply to large cities served by surface water are completely inappropriate for small systems served by

Box 25. Regulatory experiences of small systems

- The New Zealand approach requires regulators to explain risks. If the risks cannot be clearly explained then the customers do not understand the need for a regulation.
- In Denmark, the EU Directive is detailed in its requirements and the small water system (and its customers) have very little input in this process.
- In Russia, small communities are not well represented, primarily for economic reasons.
- Germany published two brochures for operators and for the authorities which detail the responsibilities in a language that the audience can understand.
- In Ireland, small suppliers are represented by a federation (National Federation of Group Water Schemes) that has direct input to government policy and is actively involved in representing its members in the legislative process.

deep well water. Different standards should not imply lower standards; however, they should be realistic and achievable regardless of the water source.

Failure to meet regulatory requirements for systems of different sizes may have different outcomes. Small systems may be able to deliver safe water via tanker trucks, bottled water, or other mechanisms, whereas large systems would face major logistical obstacles to similar efforts. Small systems are more likely to have experience dealing with power outages or equipment failure. In contrast, due to their size, large systems may have failures that go unnoticed (backsiphoning, cross-connections, etc.).

Regulation to protect water sources

Control over the watershed is a critical regulatory matter that can be very controversial. It is important that people know about the health risks from source water contamination, so that activities in the watershed can be linked to the safety of their water and to their personal health. In the United States, source water assessments are performed to examine the water source area and identify potential sources of contamination, such as transportation corridors, recreational activities, farming, landfills, manufacturing, petroleum and chemical storage, etc. At present this information is provided to individual water systems and is important to communities trying to protect their sources.

Box 26. Regulatory exceptions for small systems

- Germany sets different standards for iron and manganese in small water systems versus larger systems.
- In Russia, enforcement is problematic since many small systems require financial assistance to address problems caused by pipe deterioration and leakage, lack of power, or inadequate treatment technology. Since shutting down systems for violation is not practicable, some small rural systems are in chronic non-compliance.
- The USEPA generally requires all water systems to meet the same quality standards; the major difference between large and small systems is that the time afforded to the small systems to come into compliance is greater than for large systems. Small systems are eligible for waivers of certain monitoring requirements based on the type of source and past history of compliance. For example, in Vermont waivers are provided to small systems for three years for VOC monitoring and up to nine years for SOC monitoring, provided they meet certain requirements such as having an up-to-date source water protection plan.
- In British Columbia, the Drinking Water Officer has a certain degree of flexibility in applying regulations to small water systems.

Participants in the colloquium agreed that regulation of agricultural activities is essential in preventing contamination of source waters. Pesticide and fertilizer use, manure spreading, flood irrigation, concentrated animal feeding operations, and other activities have the potential for major impacts on a watershed. Regulations and economic incentives could assist in changing those agricultural practices that pose the greatest risk to drinking water sources. However, funding for source water protection, coupled with the political power of agricultural interests, poses a major challenge for small water systems and regulatory agencies.

Recommendations

Focus on risk management

Current regulatory schemes worldwide should be reviewed to determine how regulations can be revised to include a risk management strategy. The United States has shifted its regulatory structure to one that is more compliance-based

than risk-based, to the point that it is no longer asked “How did you prevent or respond to a waterborne outbreak?” but rather “How well did you comply with the regulations?” The compliance approach is not always the best way to protect public health.

Continued use of the sanitary survey as a formal audit tool is recommended. However, the survey should be redefined to focus more on risk management and training rather than on regulatory compliance. Regulators, who ideally have an audit function while enforcing regulations, should receive formal training and accreditation in public health risk management from approved trainers.

Create more flexible regulations for small systems

Regulators need to review the applicability of current technical standards to small systems, while preserving equal water-quality standards regardless of system size. It may be possible to apply a more flexible regulatory program to small systems, one that targets certain high risk parameters previously selected in a risk management assessment. This customized approach would save costs

while focusing sampling resources on critical health aspects. These regulatory parameters could be set after careful evaluation of sanitary surveys, source protection plans, and water quality data. As is, waivers to compliance may exist but there may not be a logical process in place to determine what requirements should be waived. One aspect of tailored monitoring used in Vermont (US) is the requirement to have an updated source water protection plan before a waiver is issued. Waivers allow the water system to monitor certain parameters less frequently, but there may still be a need to increase monitoring in an area where there is a perceived contamination risk.

Improve communication and cooperative interactions

Provide opportunities for collaborative interactions among operators, managers, regulators, and customers, in order to generate mutual understanding and sense of ownership. Appoint small water system advocates to represent the needs of small community systems, to serve on regulatory councils and committees. Educate the public on the specific regulations that safeguard their health.

6. FUNDING

Successful implementation of many of the colloquium recommendations and research needs is directly tied to adequate funding. Funding is a critical challenge for small water systems, since their per-household or user costs can be quite high due to the lack of an economy of scale. Those attending the colloquium shared funding strategies and priorities from their respective experiences (Box 27).

The roles of government at all levels

How is funding raised when small communities need to construct or reconstruct water system infrastructure? Possibilities are many and include user fees, taxes based on land value or other denominators, federal or state grants, or loans from banks, businesses or governments.

A fundamental question is: who is responsible for paying the costs for provision of clean water? A related question is this: are people entitled to clean, safe drinking water no matter where they live and no matter the cost?

Drinking water is clearly a valuable and necessary resource. There is a strong argument that small communities should pay for their water treatment and consumption, though there will always need to be exceptions for very isolated or poor communities. If the end-user pays for a service, rational water use is encouraged. Managers, operators and citizens of the community are more likely to be aware of amounts of water being used and possibly wasted. Decisions on funding must be based on an assessment of needs and consultation with and participation of community members.

Box 27. Funding approaches around the world

- In the US, funding programs have evolved from Federal grant programs to programs in which funding is given in trust to the states and then loaned at low interest to the communities. The former system provides disincentives to improvement. If the water system gains poor ratings, more funding is available from the federal government for improvements. There is therefore a strong argument for the latter process, as funding acquired by loans may result in better care for a facility.
- In Australia, local and county councils are the primary source for funding infrastructure.
- In the UK, water is privatized and there is joint government–utility control over rates.
- With the exception of Ireland, consumers in Europe pay for their water service. The European Union provides some financial assistance to low income countries to enable them to meet regulations.
- In Ireland, the government both purchases and builds the facilities. The funds are paid by the government to the local authority responsible for the plant. In turn, community systems get money from the government via the local authority and many of these upgraded plants are being built and operated by contractors using a Design Build Operate (DBO) approach. Government funds go towards upgrading the plants, connecting private supplies to public supplies, and protecting sources. Commercial users are required to pay for water, while households are subsidized by the government.
- State drinking water programs in the US can provide money for operators of small systems to obtain the training necessary to obtain certification and for continuing education. The Expense Reimbursement Grant (ERG) is funded by the USEPA and administered by each state.

Mechanisms to address funding shortfalls

Low interest loans, generally guaranteed by a governmental agency, are a good solution to funding shortfalls, particularly for capital investments. However, sometimes there is simply no capital available. In other cases, small systems may know that money is available, but they don't have the capacity to comply with all of the loan requirements. This is particularly true in the United States when revenue- or property-based bonds are considered.

Water conservation is one important way of reducing costs and maintaining standards. However, conservation only seems to work when people are forced to conserve, or pay realistic prices for the resource. Water consumption in the United States is particularly high and this can be especially true for systems that are not metered. If each connection is metered and the customer pays according to how much is used, they become aware of the economic realities of a clean water supply and use water more frugally. At present, people in some US communities pay more for television than for water. Although advances have been made (low flush toilets, low flow showerheads), there is still considerable room for development of water-saving devices in the home, as there is in industry and agriculture (e.g., micro- or drip-irrigation). Since a large amount of US water use is for lawns, landscaping and gardens, it is important to encourage alternatives that use less water.

Increased funding and public health

Probably the greatest benefit to public health would be increased funding for management of risk. This sounds obvious, but there are still many deficiencies. It should be noted, for example, that in the United States, the Safe Drinking Water Act prohibits federal funding of monitoring costs. These costs must be borne by the water system customers. As another example, the inclusion of chronic health risks in risk management varies dramatically depending on geographical location and access to technology. Such management requires active source water protection.

More resources should support programs that educate the public on the benefits of source water protection. When a community knows, or is made aware, of indiscriminate pesticide application in the watershed zone, then resources can be used to monitor water quality for these chemicals and to work with the applicators to properly manage pesticide use. A successful source water protection program requires more than an initial infusion of money; it is an ongoing process and must be funded on an ongoing basis. However, some colloquium participants believe that for many small water systems there are no opportunities to protect their

source due to a lack of control over land use activities. In these cases greater emphasis on monitoring and more reliable treatment may be the best approach.

A final and important point is that funding alone will not solve public health issues. Funding must be targeted to those areas that can most influence public health. In many cases those areas are not simply capital improvements, but encompass less tangible but very important items such as developing increased expertise and improving institutional capacity.

Recommendations and research needs

Ensure adequate access to funding

The aspiration to improve public health must be matched by adequate access to funding by loans, grants, or an increase in consumer rates. Small water systems must be aware of all their possible funding sources, perhaps through Internet-based information libraries. Preparation of application packets can be very complicated and generally requires outside help. User communities should understand clearly the costs of providing safe water and the identity of their specific funding sources.

When setting priorities for funding, lending or granting institutions should give priority to risk-based approaches and provide more support to expenditures that will demonstrably improve the management of risk.

Promote water conservation and source protection as cost-effective

Programs that encourage water conservation and wise water use, including metering to ascertain actual use, are important in reducing overall costs for many small systems. Funding that is focused on source water protection not only can save resources, but it is one way of improving the protection of public health.

Research optimal funding and cost-saving practices

A multitude of funding and cost-saving approaches are practiced worldwide. To best advise small water systems, it is important to conduct scientific research comparing these practices. It is important also to demonstrate that cost saving does not necessarily result in diminished performance and consumer safety. Country-to-country comparisons would provide valuable insight to possible alternatives for resource-poor small water systems.

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USEFUL WEB SITES

British Geological Survey -- Arsenic contamination of groundwater

<http://www.bgs.ac.uk/arsenic/>

EPA -- Ground Water and Drinking Water Page

<http://www.epa.gov/safewater/>

EPA -- List of Contaminants & their MCLs

<http://www.epa.gov/safewater/mcl.html#mcls>

EPA -- Safe Drinking Water Act Page

<http://www.epa.gov/safewater/sdwa/sdwa.html>

EPA -- Terms of the Environment

<http://www.epa.gov/OCEPAterms/>

TACnet -- Network of EPA-funded Small Water System Technology Assistance Centers

<http://www.tacnet.info/>

USGS -- National Water Quality Assessment Program

<http://water.usgs.gov/nawqa/>

World Health Organization -- Water, Sanitation and Health Page

http://www.who.int/water_sanitation_health/en/

World Health Organization -- World Health Report

<http://www.who.int/whr/en/>

Woods Hole Oceanographic Research Institution -- Harmful Algae Page

<http://www.whoi.edu/redtide/>



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