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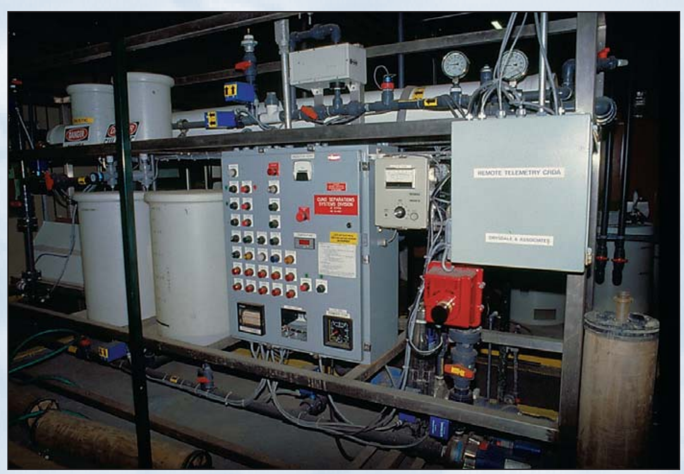
# Small Drinking Water Systems:

# State of the Industry and Treatment Technologies to Meet the Safe Drinking Water Act Requirements



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# Small Drinking Water Systems: State of the Industry and Treatment Technologies to Meet the Safe Drinking Water Act Requirements

by

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## *Notice*

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# *Abstract*

This document summarizes the current national statistics for small drinking water systems (serving less than ten thousand people). It describes the current status of regulations, treatment technologies, source water issues, distribution system characteristics, waste residual issues, security/emergency response, and monitoring as these issues pertain to small systems. This objective of this document is to provide researchers in the Water Supply and Water Resources Division in the National Risk Management Research Laboratory with a basis to design and implement future research projects that will focus on the most pressing needs of small systems. The majority of this report includes data and information acquired between June 1, 2004 and October 1, 2005, and most of the work was completed on November 1, 2005. Section 5.6, related to small systems treatment option "affordability" and definition of "unreasonable risk to health," presents more recent updates (performed in August 2006) based on reviewer comments.

## *Foreword*

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Sally Gutierrez, Director
National Risk Management Research Laboratory

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## *Acronyms and Abbreviations*

| | |
|---|---|
| AA | Activated Alumina |
| ABPA | American Backflow Prevention Association |
| ANSI | American National Standards Institute |
| AOP | Advanced Oxidation Processes |
| APG | Annual Performance Goal |
| APM | Annual Performance Measure |
| ASCE | American Society of Civil Engineers |
| ASDWA | Association of State Drinking Water Administrators |
| AWQC | Ambient Water Quality Criteria |
| AWWA | American Water Works Association |
| BAT | Best Available Technology |
| BMP | Best Management Practices |
| CCL | Contaminant Candidate List |
| CESQG | Conditionally Exempt Small Quantity Generator |
| CFR | Coliform Rule |
| CSO | Combined Sewer Overflows |
| CT | Contact Time |
| CWA | Clean Water Act |
| CWS | Community Water System |
| DBP | Disinfection By-Product |
| DBPR | Disinfection By-Product Rule |
| DE | Diatomaceous Earth |
| DHS | Department of Homeland Security |
| DWSRF | Drinking Water State Revolving Fund |
| EBCT | Empty Bed Contact Time |
| ED | Electrodialysis |
| EPA | Environmental Protection Agency |
| EPCRA | Emergency Planning and Community Right-to-Know Act |
| EPTDS | Entry Point to the Distribution System |
| ERP | Emergency Response Plan |
| ETV | Environmental Technology Verification |
| FBRR | Filter Backwash Recycle Rule |
| GAC | Granular Activated Carbon |
| GFH | Granular Ferric Hydroxide |
| GPM | Gallons per Minute |
| GWUDI | Ground Water Under Direct Influence |
| HAA5 | Haloacetic Acids |
| HFGP | Horizontal Flow Gravel Prefilter |
| HSPD | Homeland Security Presidential Directive |
| IT | Information Technology |
| IUP | Intended Use Plan |
| IX | Ion Exchange |
| LEPC | Local Emergency Planning Committee |
| LGR | Local Government Reimbursements |
| LLRW | Low-level Radioactive Waste |
| LT1ESWTR | Long Term 1 Enhanced Surface Water Treatment Rule |
| LT2ESWTR | Long Term 2 Enhanced Surface Water Treatment Rule |
| M/R | Monitoring and Reporting |
| MCL | Maximum Contaminant Level |
| MCLG | Maximum Contaminant Level Goal |
| MF | Microfiltration |
| MGD | Million Gallons per Day |
| MHI | Median Home Income |
| MOU | Memorandum of Understanding |
| MRDLG | Maximum Residual Disinfectant Level Goal |
| MTBE | Methyl Tertiary Butyl Ether |
| MWCO | Molecular Weight Cut-off |
| NAS | National Academy of Science |
| NDWAC | National Drinking Water Advisory Council |
| NDWC | National Drinking Water Clearinghouse |
| NRMRL | National Risk Management Research Laboratory |
| NF | Nanofiltration |
| NHSRC | National Homeland Security Research Center |
| NIPDWR | National Interim Primary Drinking Water Regulations |
| NOM | Natural Organic Matter |
| NPDES | National Pollution Discharge Elimination System |
| NPDWR | National Primary Drinking Water Regulations |
| NRC | National Research Council (also used for Nuclear Regulatory Commission in Chapter ) |
| NRWA | National Rural Water Association |

| | |
|---|---|
| NSDWR | National Secondary Drinking Water Regulation |
| NSF | National Sanitation Foundation |
| NTNCWS | Non-Transient Non-Cmmunity Water System |
| NTU | Nephelometric Turbidity Units |
| O3 | Ozone |
| O&M | Operation and Maintenance |
| OCMS | Online Contaminant Monitoring System |
| OEM | Office of Emergency Management |
| ORD | Office of Research and Development |
| PAC | Powdered Activated Carbon |
| PDCO | Pore Diameter Cut-off |
| PDD | Presidential Decision Directive |
| POE | Point-of-Entry |
| POTW | Publicly Owned Treatment Works |
| POU | Point-of-Use |
| ppb | Parts per billion |
| PTA | Packed Tower Aeration |
| PVC | Polyvinyl Chloride |
| PWS | Public Water System |
| RCRA | Resource Conservation and Recovery Act |
| RfD | Reference Dose |
| RMCL | Recommended Maximum Contaminant Level |
| RO | Reverse Osmosis |
| RPTB | Response Protocol Toolbox |
| SAB | Science Advisory Board |
| SBA | Strong Base Anion |
| SCADA | Supervisory Control and Data Acquisition |
| SDWA | Safe Drinking Water Act |
| SDWIS | State Drinking Water Information System |
| SEMS | Security Emergency Management Systems |
| SEMS/ICS | Standardized Emergency Management System/Incident Command System |
| SSCT | Small System Compliance Technology |
| SSF | Slow Sand Filter |
| SWAP | Source Water Assessment Plan |
| SWP | Source Water Protection |
| SWR | Solid Waste Residuals |
| SWTR | Surface Water Treatment Rule |
| TCLP | Toxicity Characteristic Leaching Procedure |
| TCR | Total Coliform Rule |
| T&E | Test and Evaluation |
| TENORM | Technologically Enhanced Naturally Occurring Radioactive Material |
| THM | Trihalomethane |
| TMDL | Total Maximum Daily Load |
| TNCWS | Transient Community Water System |
| TOC | Total Organic Carbon |
| TT | Treatment Technique |
| TTHM | Total Trihalomethanes |
| UCMR | Unregulated Contaminants Monitoring Rule |
| UF | Ultrafiltration |
| USACE | United States Army Corps of Engineers |
| UV | Ultraviolet light |
| VA | Vulnerability Assessment |
| VOC | Volatile organic compound |
| WBA | Weak Base Anion |
| WHP | Well Head Protection |
| WHPA | Well Head Protection Area |
| WHPP | Well Head Protection Plan |
| WSD | Water Security Division |
| WSWRD | Water Supply and Water Resources Division |

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# Chapter 1 Introduction

## 1.1 Goals and Objectives of this Document

The objective of this document is to summarize the existing status of drinking water supply in the United States (U.S.) with particular emphasis on small systems (i.e., systems serving less that 10,000 people). This document will then form the backdrop to craft a research plan that will serve as a roadmap for researchers in the U.S. Environmental Protection Agency's (EPA's), Office of Research and Development (ORD), Water Supply and Water Resources Division (WSWRD) by providing focus and direction to the WSWRD's research efforts. Specifically, the Strategy for Small Systems Research aims to:

- Provide timely and appropriate research that will contribute to small system management schemes for reducing Safe Drinking Water Act (SDWA) violations and public health risks.
- Chart a research course that will drive new technologies and improve existing technologies with emphasis on costs/benefits (reduce costs and increase simplicity).

This strategy document focuses on the current state of the following items as they pertain to small systems and on the direction of future research activities for these items:

- Source water issues
- Monitoring/Reporting
- Treatment processes
- Distribution systems
- Residuals Management
- Homeland Security
- Overall Utility Management

All research planning in the document should be in the context of the six-year review of National Primary Drinking Water Regulations (NPDWR) and the five-year update of the Contaminant Candidate List (CCL). Note that the last NPDWR review was in August 2002 and the last CCL update was in February 2005.

## 1.2 Document Organization

This document is organized into the following sections:

Chapter 1 – Introduction – This section presents a brief introduction to this report

Chapter 2 – Current Status and Issues of Small Drinking Water Systems

Chapter 3 – Regulatory Background – This section presents a brief background of the regulations impacting operators of small drinking water systems

Chapter 4 – Source Water Issues

Chapter 5 – Treatment Processes

Chapter 6 – Distribution Systems

Chapter 7 – Waste Residuals

Chapter 8 – Homeland Security/Emergency Response

Chapter 9 – Remote Telemetry

Chapter 10 – Summary

# Chapter 2
# Current Status and Issues of Small Drinking Water Systems

## 2.1 Introduction

This Chapter provides an introduction to the current status of small drinking water systems and the issues facing small systems in maintaining compliance and providing safe drinking water to the populace served by these systems. The chapter begins with a detailed snapshot profile (Section 2.2) of the distribution of small systems based on the number of people served and then provides brief overviews on the compliance status (Section 2.3) of these small systems and source water issues (Section 2.4). This chapter also provides a brief introduction to the following topics:

- Common technologies currently used by small systems to treat source water to meet drinking water standards (Sections 2.5, 2.6, 2.7 and 2.8),
- Distribution system infrastructure (including storage facilities, pumping facilities and distribution lines) currently employed by small systems (Section 2.9),
- Status of the use of remote telemetry to monitor small systems operation (Section 2.10)
- Key questions to be answered through ongoing research (Section 2.11)

## 2.2 Profile of Small Systems in the U.S.

The EPA's Safe Drinking Water Information System (SDWIS) estimates that there are 159,796 public water systems (PWSs) in the U.S. (EPA, 2005a). The SDWIS is a living database and portions of it are periodically updated. The profile data presented in this section includes a conglomeration of data extracted periodically from the SDWIS during the preparation of this report (between 2004 and 2005). Depending upon when the data was extracted and when the underlying SDWIS was updated, the exact numbers and percentages for individual categories described in the figures may vary slightly. However, the overall trends and statistics are consistent throughout the period during which the SDWIS was updated. Most of the SDWIS updates were performed between the years 2000 and 2005; where information is available, the specific year of the data presented is clearly identified. Unless otherwise stated, the graphs and statistics relating to system types, population served, ownership, violations, sizes, treatment scheme, piping distance were all developed using the Pivot tables underlying SDWIS (EPA, 2005b). Pivot tables are multidimensional spreadsheets/databases that provide analytical processing capability. The Pivot tables allow for quick summarization, cross-tabulation, and analysis of large amounts of data.

A PWS is any water system which provides water to at least 25 people for at least 60 days annually. These PWSs provide water from wells, rivers and other sources to the majority (~85%) of the population in the U.S. and territories (EPA, 2005b). The PWSs are classified as follows:

- Community Water Systems (CWS) – A water system which supplies drinking water to 25 or more of the same people year-round in their residences.
- Non-Transient Non-Community Water Systems (NTNCWS) – A water system which supplies water to 25 or more of the same people at least six months per year in places other than their residences. Some examples are schools, factories, office buildings, and hospitals that have their own water systems.
- Transient Non-Community Water Systems (TNCWS) – A water system which provides water in a place such as a gas station or campground where people do not remain for long periods of time. These systems do not have to test or treat their water for contaminants that pose long-term health risks because fewer than 25 people drink the water over a long period (6 months/year). They still must test their water for microbes and several chemicals.

There are differing standards for PWSs of different sizes and types. Most (approximately 55%) of the PWSs in the U.S. belong to the TNCWS variety (EPA, 2005b). Figure 2.1 illustrates the percentage breakdown of the different system types. Most of these systems represent the very small category (serving 25 – 500 people). Figure 2.2 shows the breakdown of the number of small systems by system type. For the purposes of this document, a small system is defined as a CWS, NTNCWS, or TNCWS serving fewer than 10,000 persons (please note that a PWS serving 3001-10,000 persons may be referenced as medium in some graphics).

While most of the PWSs are TNCWSs, the vast majority

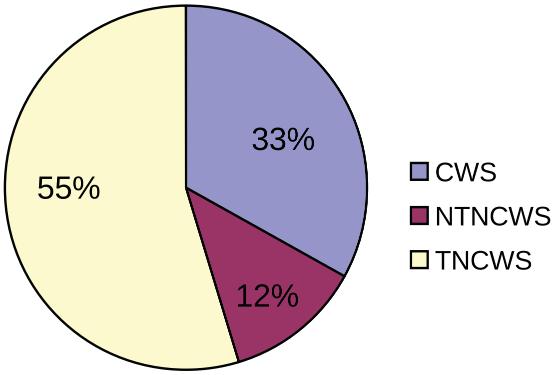



*Figure 2.1 PWSs by system type (EPA, 2005b).*

of people using PWSs actually obtain their water from CWSs. As illustrated in Figure 2.3, approximately 90% of all people using public drinking water systems obtain their water from CWSs. Figure 2.4 shows the breakdown of system types by population category. As indicated, approximately 84% of CWSs serve populations of 3,300 or less. TNCWSs are mostly represented in the very small category.

There are 159,796 CWSs, which includes both large and small systems. There exists a great discrepancy between the number of systems and the distribution of the population served. Very small CWSs account for 57% of the total number of systems, although these

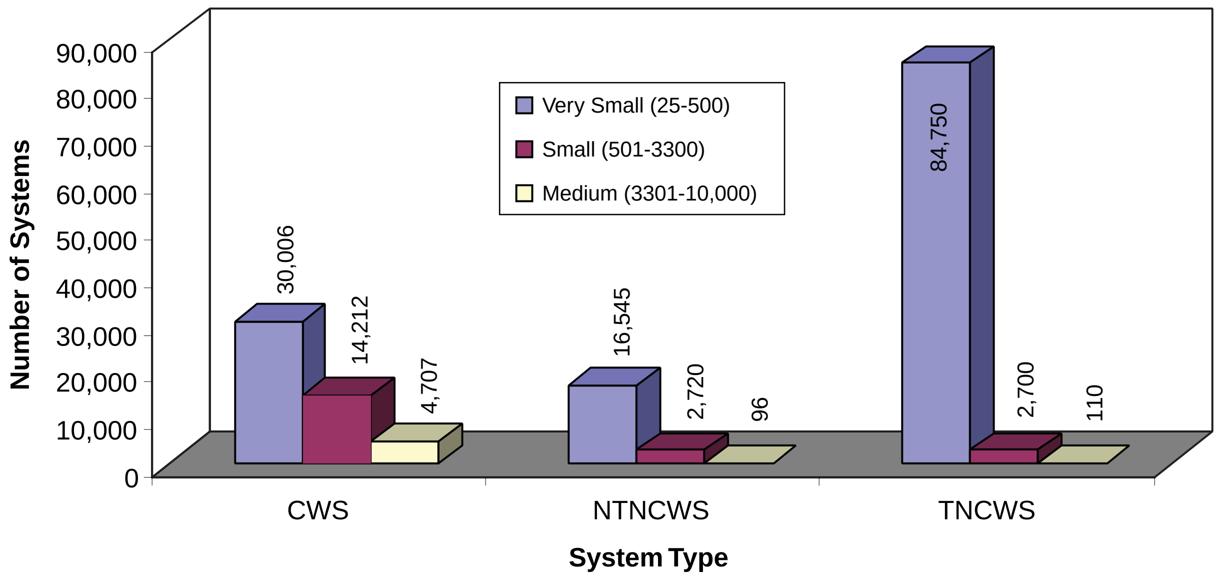



*Figure 2.2 Small systems by system type - FY2004 (EPA, 2005b).*

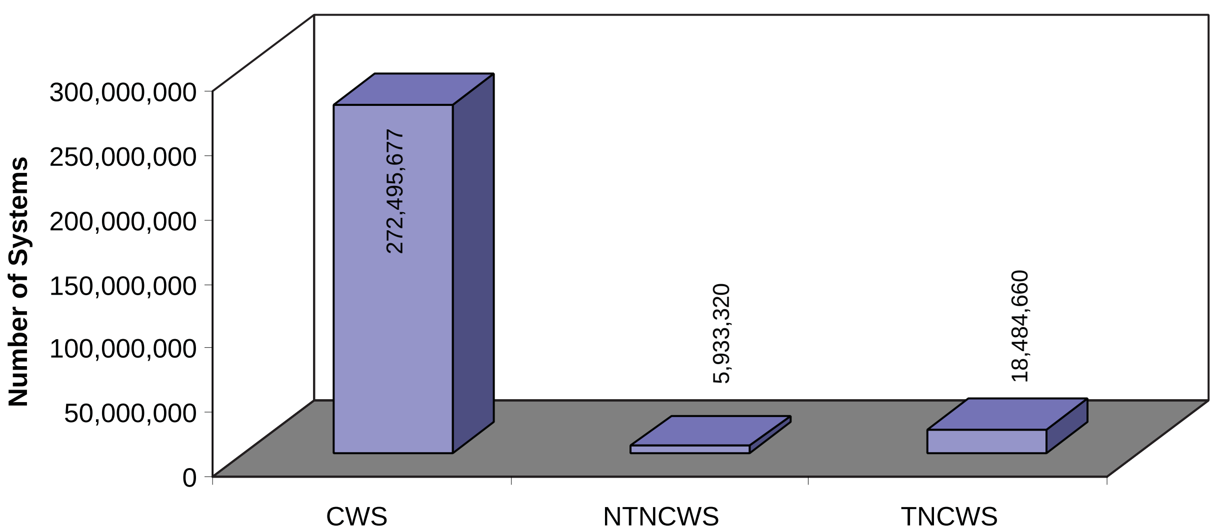



*Figure 2.3 Number of people served by system type - All systems FY2004 (EPA, 2005b).*

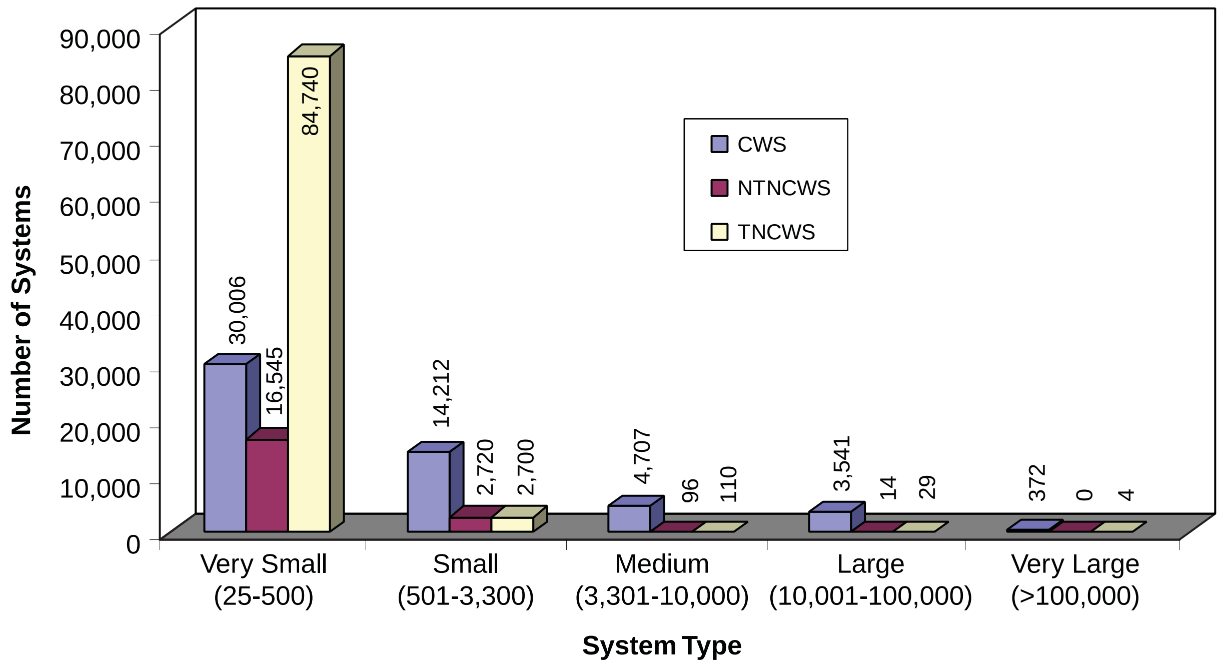
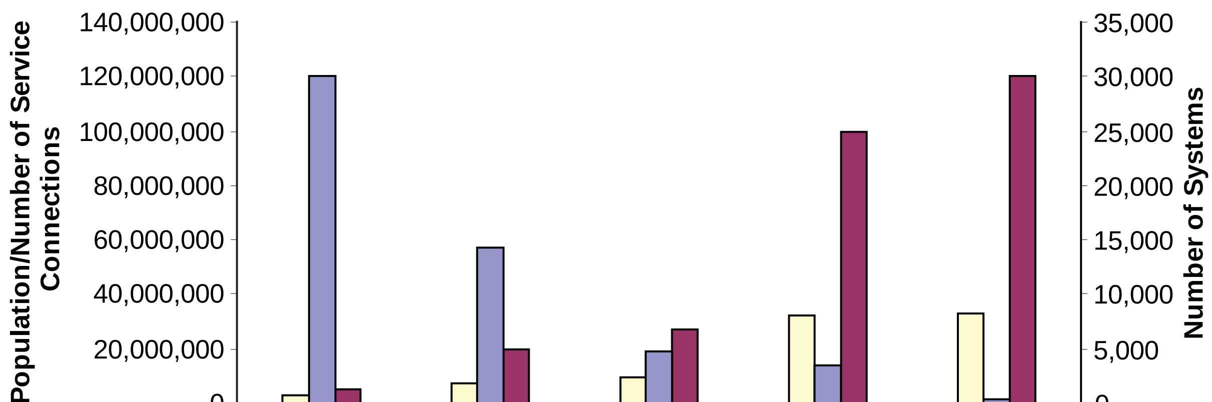



*Figure 2.4  Number of PWSs for each service population group (EPA, 2005b).*



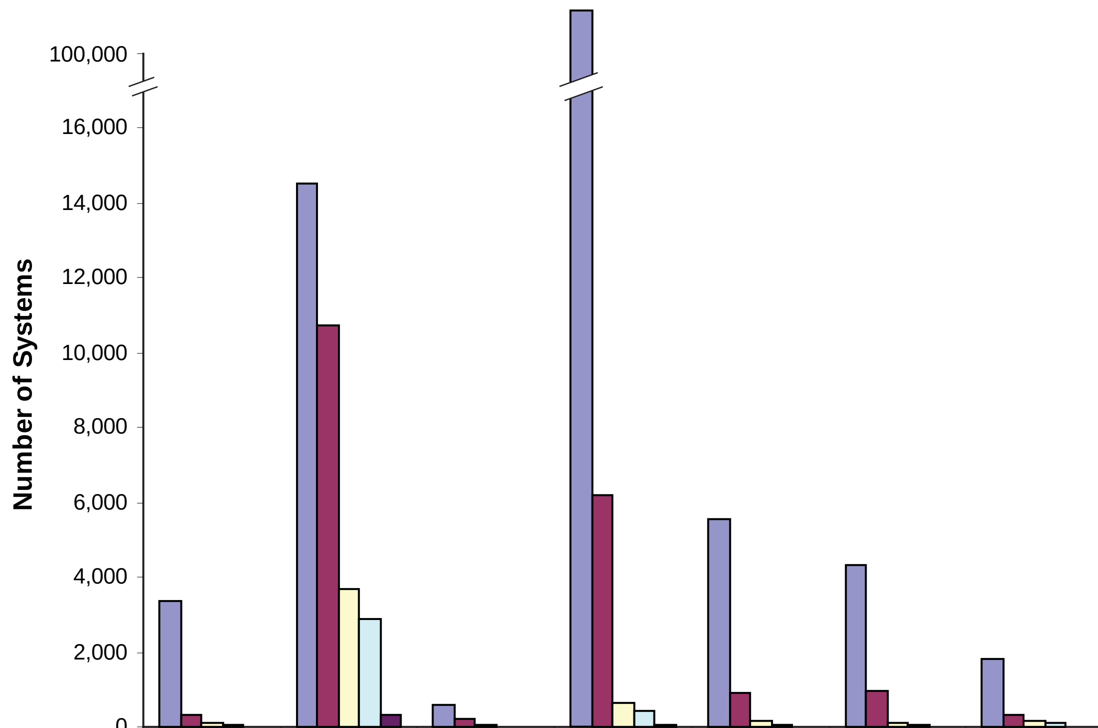

| | Very Small | Small | Medium | Large | Very Large |
|---|---|---|---|---|---|
| Service Connections | 2,594,626 | 7,333,945 | 9,473,250 | 32,152,151 | 32,984,472 |
| Population | 4,957,131 | 20,137,604 | 27,346,264 | 99,808,668 | 120,246,010 |
| Systems | 30,006 | 14,212 | 4,707 | 3,541 | 372 |

**System Size**

*Figure 2.5  Population served, service connections and number of systems - CWSs only FY2004 (EPA, 2005b).*

systems serve less than 2 percent of the population served by CWSs. In contrast, the large and very large systems account for roughly 7 percent of the total number of systems but serve over 80% of the population. Figure 2.5 shows a breakdown of population served, number of service connections, and number of systems for CWSs by system size.

PWSs are owned by various governmental, tribal, public, or private entities. There is a relationship between system size and ownership, with the vast majority of very small systems (25-500 persons served) being privately owned and a majority of larger systems being owned by local government. Figure 2.6 shows the breakdown of ownership for all systems.




| | Federal Govt | Local Govt | Tribal Govt | Private | Public/Private | State Govt | Unknown |
|---|---|---|---|---|---|---|---|
| Very Small 25-500 | 3,374 | 14,522 | 583 | 101,108 | 5,580 | 4,328 | 1,796 |
| Small 501-3,300 | 307 | 10,755 | 210 | 6,210 | 885 | 959 | 306 |
| Medium 3,301-10,000 | 106 | 3,681 | 32 | 658 | 145 | 130 | 161 |
| Large 10,001-100,000 | 71 | 2,878 | 6 | 407 | 69 | 43 | 110 |
| Very Large >100,000 | 0 | 312 | 0 | 53 | 6 | 4 | 1 |

*Figure 2.6 Drinking water system owners – FY 2004-159,796 total systems (EPA, 2005b).*

## 2.3 Status of Drinking Water Plant Violations

The SDWIS classifies drinking water system violations into the following four major categories:

- Maximum contaminant level (MCL) violations; Chapter 3 discusses MCLs in detail.
- Treatment Technique (TT) violations; according to EPA, a treatment technique is a required process intended to reduce the level of a contaminant in drinking water. A few examples of treatment techniques are disinfection, filtration, and aeration (further discussed in Chapter 3).
- Monitoring or Reporting (M/R) Violations. These violations are primarily record-keeping issues.
- Violations other than the three types mentioned above.

Figure 2.7 shows the breakdown of system violations for all PWSs. This figure shows that most PWS violations are attributed to M/R.

Figure 2.8 shows system violations by population served, number of systems, and violation type. Very small systems have the largest number of violations, with the vast majority of these being M/R violations.

Figure 2.9 shows the breakdown of system violations for small systems. Figure 2.9 looks very similar to Figure 2.8 because the total violation statistics are overwhelmingly dominated by small systems. Very

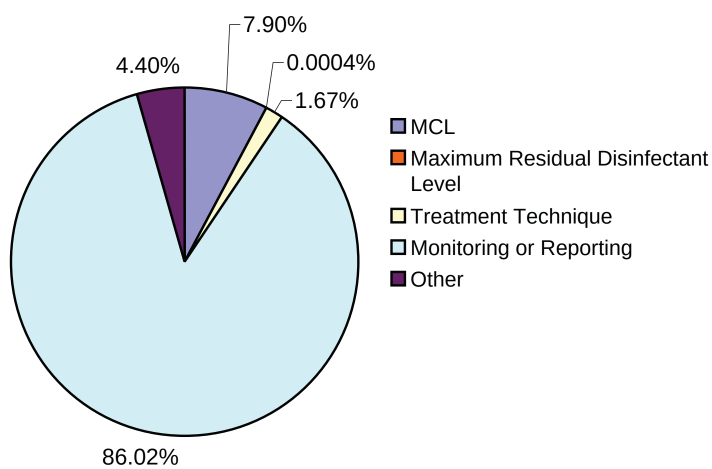



*Figure 2.7 Violations reported FY2005 (EPA, 2005b).*

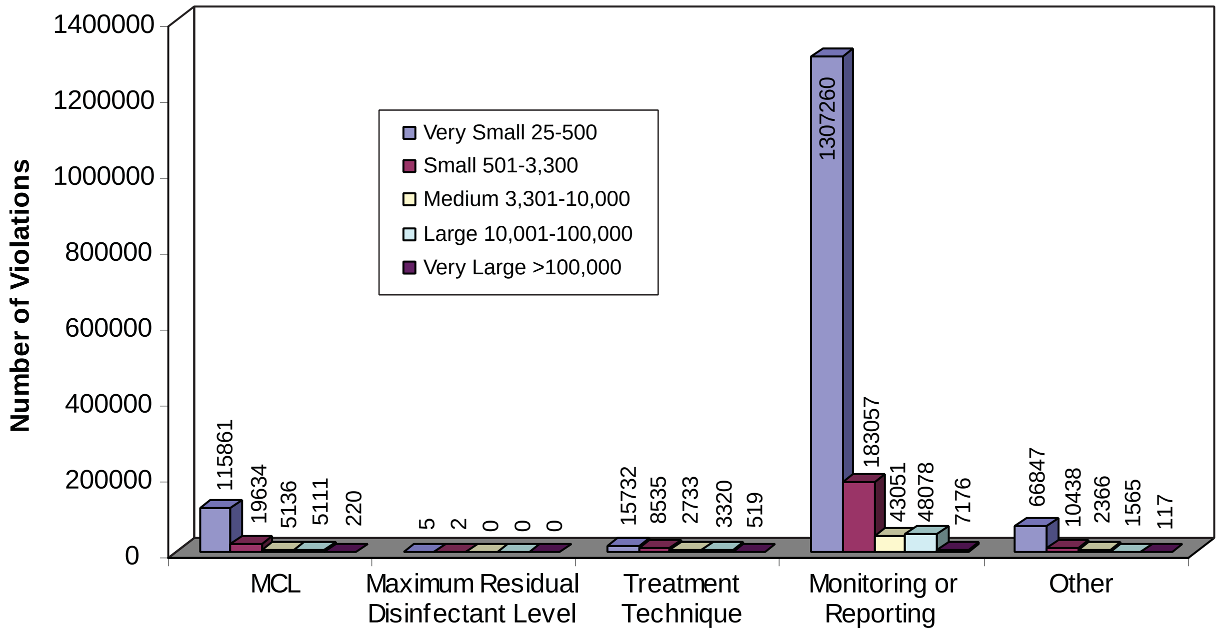



*Figure 2.8  Drinking water system violations for all system sizes - FY2005 (EPA, 2005b).*

small systems also experience the greatest number of MCL and TT violations. In addition, PWSs experienced a total of 145,962 MCL violations (2005 data), with 135,495 (93%) of the violations attributed to small systems (population served less than 3,300).

Figure 2.10 illustrates the relationship between the number of MCL violations and population served. Very small systems (those serving 25 to 500 people) experience approximately one MCL violation for every 80 persons served, which is the highest ratio of all system service population categories. In comparison, very large systems (population served greater than 100,000) experience approximately one MCL violation for every 196,204 persons served.

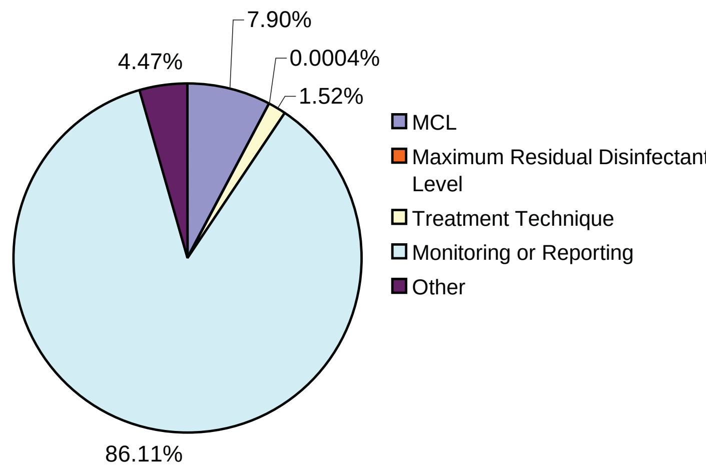



*Figure 2.9 Violations reported for systems serving population from 25-10,000 - FY2005 (EPA, 2005b).*

## 2.4 Source Water Issues

PWSs obtain drinking water from either surface or ground water sources. Over 90% of the PWSs obtain their water from ground water sources, with a vast majority (87%) of those using ground water being represented by small systems (serving a population less than 3,300). Figure 2.11 shows the distribution of water sources, by each of the five size categories.

Source waters from streams, rivers, lakes, or aquifers are used to supply private water systems and PWSs. The source water moves within a watershed via overland flow (i.e., surface water), shallow subsurface storm flow or ground water flow. The surface water is vulnerable to contamination from both surface runoff and ground water infiltration. Ground water can become contaminated through infiltration from the surface, incursion of contaminants from underground storage tanks, septic systems, injection wells, or by naturally occurring substances in the soil or rock through which it flows. These issues are discussed in further detail in Chapter 4.

## 2.5 Common Current Treatment Technologies

Most PWSs treat drinking water so that it will be safe and palatable for the consumer. The application of a specific TT depends on source water quality, system size, and operator sophistication. Figures 2.12, 2.13 and 2.14 illustrate the variety and percent predominance of individual TTs used by the different size classes of PWSs.

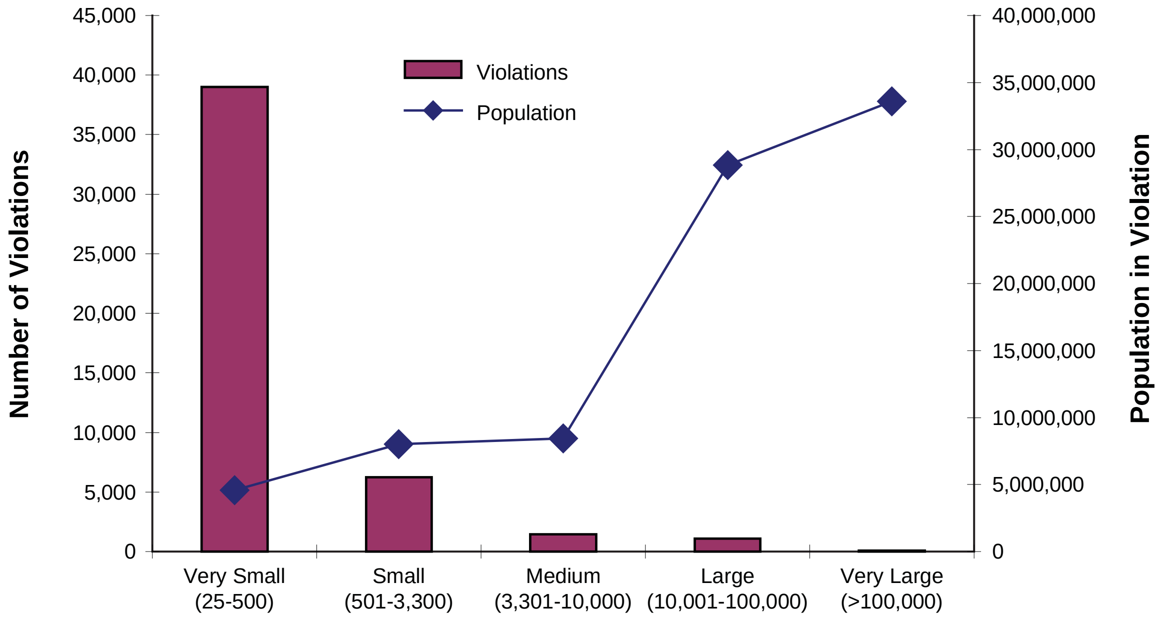



*Figure 2.10 MCL violations vs. populations served FY2005 (EPA, 2005b).*

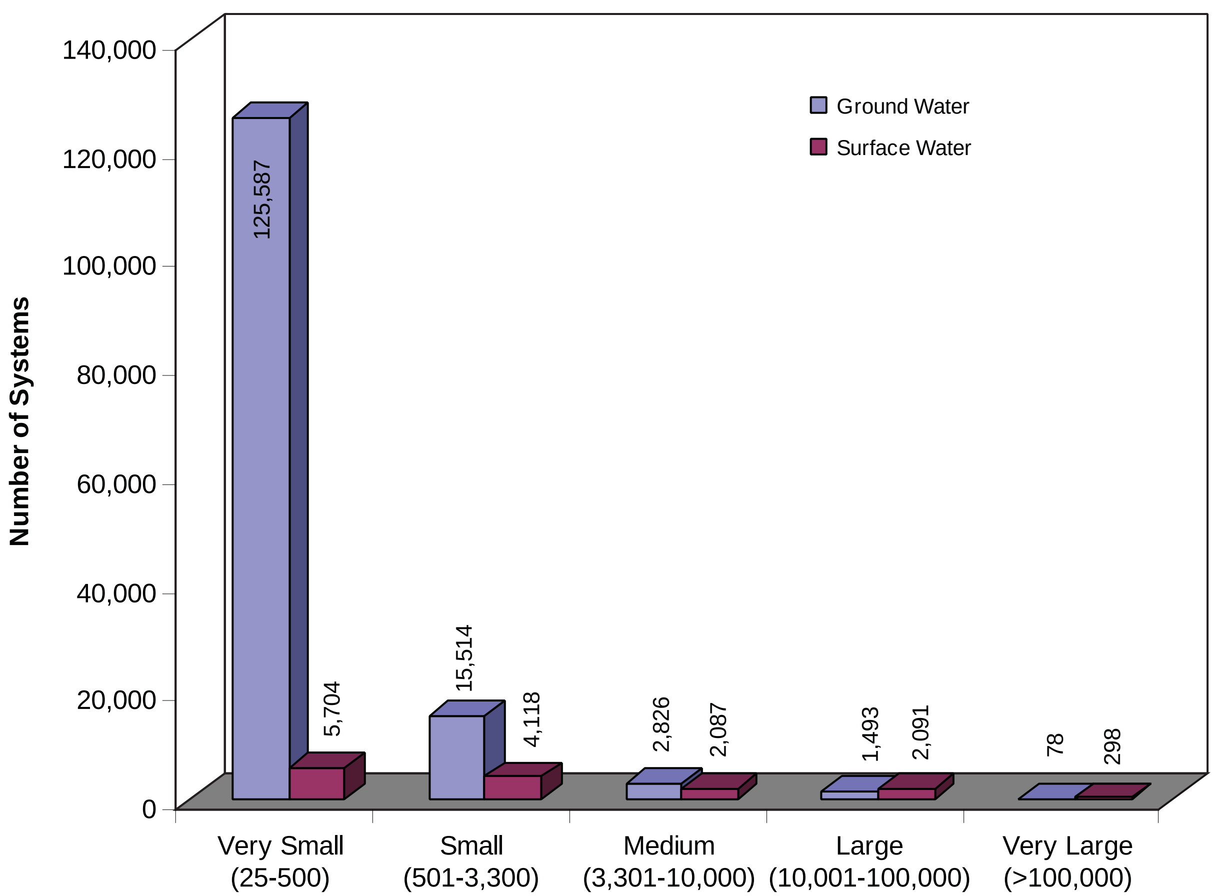



*Figure 2.11 Source water comparison by size category (EPA, 2005b).*

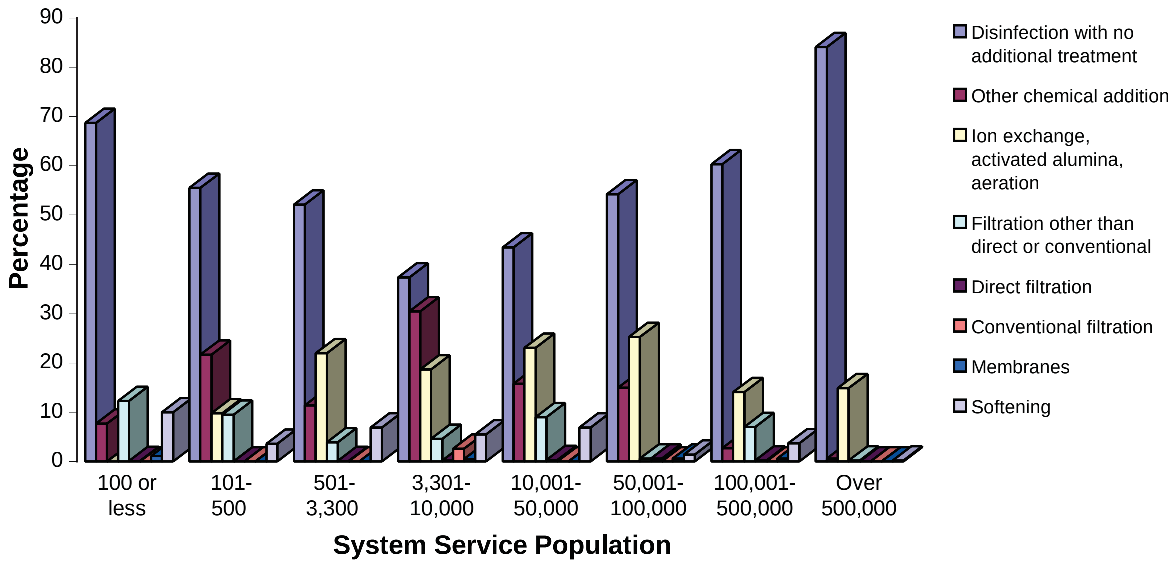



*Figure 2.12  Percentage of ground water plants using each treatment technique (EPA, 2002).*

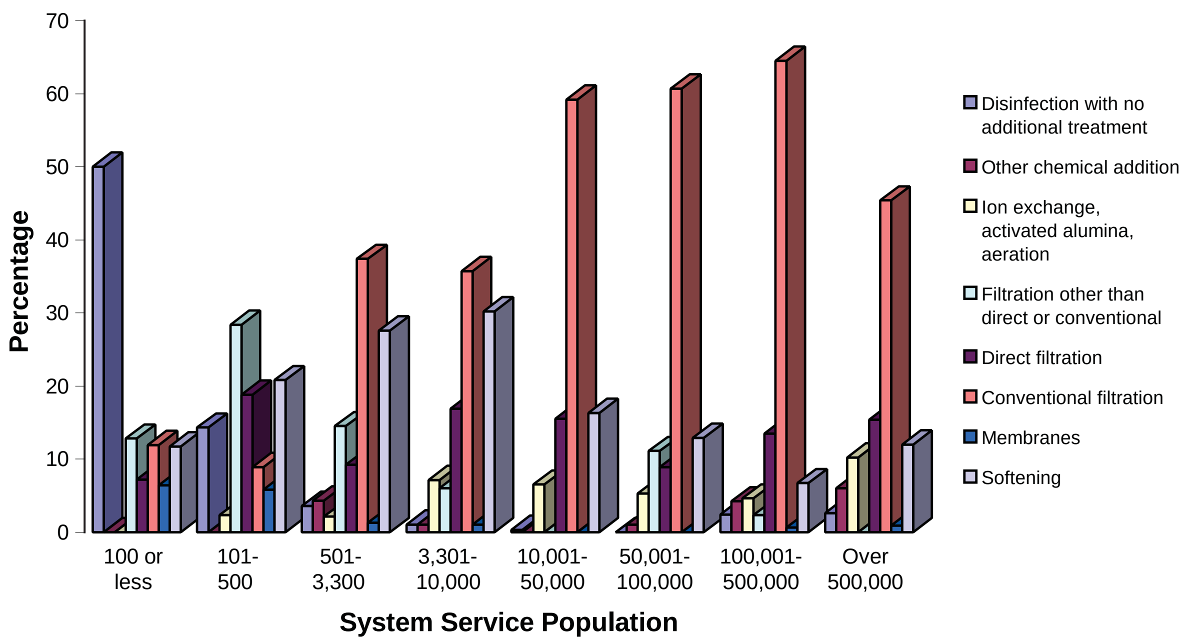



*Figure 2.13  Percentage of surface water plants using each treatment technique (EPA, 2002).*

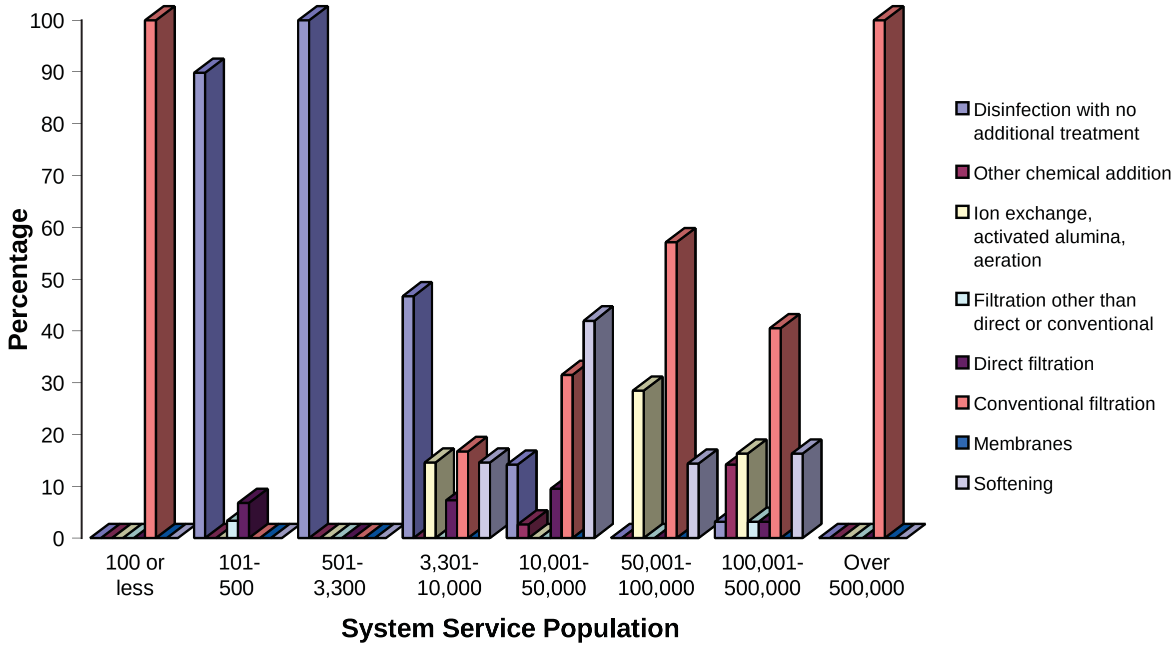



*Figure 2.14 Percentage of mixed plants using each treatment technique (EPA, 2002).*

The individual TTs are designed to be effective in removing one or more types of contaminants including particulate, chemical and biological contaminants. Depending upon the type of contamination present in the source water, one or more TTs may be applied by the PWS to provide safe drinking water to consumers. A general discussion of available TTs to remove particulate (Section 2.6), chemical contaminants (Section 2.7) and biological contaminants (Section 2.8) is presented in this Chapter. A more comprehensive discussion of TTs is presented in Chapter 5.

## 2.6 Particulate/Turbidity Removal Technologies

Particulate and turbidity removal is an almost universally used technology for the primary treatment of drinking water. The primary means of particulate removal is by means of simple filtration either by using media filtration (e.g., sand filter) or by the use of bag and/or cartridge filters. Advanced filtration techniques include membrane filtration and other technologies. This section provides a very brief overview of these technologies.

### 2.6.1 Simple Filtration

Filtration is a process for removing particulate matter from water by passage through porous media. There are numerous types of filtration processes. Some common filtration processes are summarized below (these descriptions are available in many standard text books, where applicable references have been provided for specific usage and equipment descriptions):

Slow Sand Filtration – is a process where untreated water percolates slowly down through a layer of fine sand, then through a layer of gravel, and ultimately collects in a system of underdrains. A biological layer or "schmutzdecke" forms on the surface of the sand, trapping small particles. The schmutzdecke also helps to degrade organic material in the water.

Diatomaceous Earth (DE) – also known as pre-coat or diatomite filtration, can be used to directly treat low turbidity raw water supplies or chemically coagulated, more turbid water sources. DE filters consist of a pre-coat layer of DE, approximately 1/8-inch thick, supported by a septum or filter element (EPA, 1998).

Conventional Filtration – is a method of treating water to remove particulates. The method consists of the addition of coagulant chemicals, flash mixing, coagulation-flocculation, sedimentation and filtration.

Direct Filtration – also known as "dead-end filtration" is similar to conventional filtration with the sedimentation process omitted.

Packaged Filtration – consists of all of the features of filtration – chemical addition, flocculation, sedimentation, filtration – mounted as a unit on a frame for simple hookup of pipes and services. It is most widely used to treat surface water supplies for removal of turbidity, color, and coliform organisms with filtration processes. Packaged filtration is often used to treat small community water supplies, as well as supplies in recreational areas, state parks, construction sites, ski areas, and military installations (NDWC, 1996).

### 2.6.2 Advanced Filtration

Membrane Filtration – Membrane filtration (as defined under the Long Term 2 Enhanced Surface Water Treatment Rule-LT2ESWTR) is a pressure-driven separation process in which particulate matter larger than 1-micrometer is rejected by an engineered barrier, primarily through a size-exclusion mechanism and which has a measurable removal efficiency for a target organism that can be verified through the application of a direct integrity test (EPA, 2003a). Some common types of membrane filtration are:

Microfiltration – is a pressure-driven membrane filtration process that typically employs hollow-fiber membranes with a pore size range of approximately 0.1 – 0.2 micrometers (nominally 0.1 micrometers) (EPA, 2003a).

Ultrafiltration – is a pressure-driven membrane filtration process that typically employs hollow-fiber membranes with a pore size range of approximately 0.01 – 0.05 micrometer (nominally 0.01 micrometers) (EPA, 2003a).

Nanofiltration – is a pressure-driven membrane separation process that employs the principles of reverse osmosis to remove dissolved contaminants from water and is typically applied for membrane softening or the removal of dissolved organic contaminants (EPA, 2003a).

### 2.6.3 Reverse Osmosis (RO)

RO resembles membrane filtration processes in that contamination from water is removed by the use of a membrane. However, unlike membrane filtration where water is forced through a media leaving behind the contaminant, RO uses hydraulic pressure to oppose the liquid osmotic pressure across a semipermeable membrane, forcing the water from the concentrated solution side to the dilute solution side. Thus, the RO membrane allows the passage of the solvent (water) but not the dissolved solids (solutes). Since the membrane is non-porous, the water does not travel through pores, but rather dissolves into the membrane, diffuses across, and then dissolves into the permeate (EPA, 1998b). RO can effectively remove nearly all contaminants from water including arsenic (III), arsenic (V), barium, cadmium, chromium (VI), radium, natural organic substances, pesticides, and microbiological contaminants. The liquid produced is demineralized water.

## 2.7 Chemical Contaminant Removal

Chemical contaminants are commonly removed using ion exchange and sorption technologies. This section provides a brief overview of these technologies along with other TTs that are used to remove chemical contaminants in drinking water.

### 2.7.1 Ion Exchange (IX)

Ion exchange involves the selective removal of charged inorganic species from water using an ion-specific resin. The surface of the ion exchange resin contains charged functional groups that hold ionic species by electrostatic attraction. As water containing undesired ions passes through a column of resin beds, charged ions on the resin surface are exchanged for the undesired species in the water. The resin, when saturated with the undesired species, is regenerated with a solution of the exchangeable ion (EPA, 1998b).

Generally, resins can be categorized as anion exchange or cation exchange resins. Anion exchange resins selectively remove anionic species such as nitrate ($NO_3^-$), sulfate ($SO_4^{2-}$), or fluoride ($F^-$) and exchange them for hydroxyl ($OH^-$) or chloride ($Cl^-$) ions. Cation exchange resins are used to remove undesired cations such as cadmium ($Cd^{2+}$) or Barium ($Ba^{2+}$) from water and exchange them for protons ($H^+$), sodium ions ($Na^+$) or potassium ions ($K^+$) (EPA, 1998b). The pH of the source water is important when employing IX resins. For example, uranium exists in water at pH levels of 6.0 and higher as a carbonate complex, which is an anion, and thus has a strong affinity for anion resin in the chloride form. The process is effective on water with a pH of up to 8.2. A higher pH could result in uranium precipitation; a lower pH changes the nature of uranium to non-ionic and/or cationic species, which would prevent the exchange reaction from operating efficiently. It is advisable to control the inlet water pH to above 6.0. Sudden pH changes to below 5.6 can dump any previously removed uranium off the resin (DeSilva 1996).

### 2.7.2 Sorption Technologies

Adsorption involves the removal of ions and molecules from solution and concentrating them on the surface of adsorbents. Adsorption is driven by the interfacial forces of the ions and the adsorbent. Adsorption media employed at drinking water plants include granular activated carbon, activated alumina, and iron media. Sorption technologies are used for the removal of organics, taste and odor, and inorganic contaminants (such as arsenic).

### 2.7.3 Other Technologies

Aeration Technologies – Aeration technologies are typically used for removal of volatile organic compounds and for removal of excess carbon dioxide. In general, aeration is the contacting of the water with air wherein the target chemical is transferred from the water to the air stream. There are a number of methods used for the mixing of air and water including packed aeration towers, shallow tray air strippers, mechanical aeration, and spray aeration.

Softening – Softening is used to remove calcium and magnesium ions from water. Types of technologies used include ion exchange, chemical flocculation, and precipitation.

Electrodialysis (ED) – Another less commonly used technology for chemical removal is ED, which is a process in which ions are transferred through ion-selective membranes by means of an electromotive force from a less concentrated solution to a more concentrated solution (EPA, 2003a). ED is very effective in removing fluoride and nitrate, and can also remove barium, cadmium, and selenium (NDWC, 1997).

Reverse Osmosis – Can remove many chemical contaminants effectively. See Section 2.6.3 for further details.

## 2.8 Biological Contaminant Removal

Disinfection is a process for reducing the number of pathogenic microbes in water and is required by the Surface Water Treatment Rule (SWTR) for all PWSs that obtain their water from surface water or ground water under the influence of surface water. In addition, PWSs must maintain a residual level of disinfectant in the distribution system per 40 CFR 141.72. It is required that, at the point where the water enters the distribution system, the residual disinfection concentration not fall below 0.2 mg/L. In addition, the residual disinfection concentration must be maintained throughout the distribution system such that non-detection results are measured in no more than 5% of the samples collected each month.

### 2.8.1 Chlorination

Chlorine is the most common method used for disinfection. There are a number of methods of delivery and chemical reactions utilized for chlorination. These include chlorine gas, chloramines, chlorine dioxide, and sodium hypochlorite. The goal of all these methods is to release free chlorine in the form of hypochlorite, or in the case of chloramines, combined available chlorine ($NH_2Cl$ and $NHCl_2$).

### 2.8.2 Ultraviolet Light (UV)

Contaminated water is exposed to UV light, which penetrates the cell walls of an organism. UV disrupts the organism's genetic material which inactivates the organism. A special lamp generates the radiation that creates UV light by striking an electric arc through low-pressure mercury vapor (low-pressure UV). This lamp emits a broad spectrum of radiation with intense peaks at UV wavelengths of 253.7 nanometers (nm) and a lesser peak at 184.9 nm. Research has shown that the optimum UV wavelength range to destroy bacteria is between 250 nm and 270 nm. At shorter wavelengths (e.g.185 nm), UV light is powerful enough to produce ozone, hydroxyl, and other free radicals that destroy bacteria (NDWC, 2000).

### 2.8.3 Ozone

Ozone is a colorless, very unstable gas that is effective as an oxidizing agent in removing bacteria with a relatively short exposure time. Since the gas is unstable and has a very short life, ozone generators are used to produce ozone gas on site.

### 2.8.4 Other Disinfection Technologies

There are a number of other disinfection technologies used in ultra pure water applications, but are not applicable nor typically used in water supply situations. These include ammonium compounds, non-oxidizing biocides (i.e. formaldehyde), heat, and peracetic acid.

Tables 2.1, 2.2, 2.3, 2.4, 2.5 and 2.6 present candidate technologies for treatment of inorganic contaminants, volatile organic contaminants, synthetic organic contaminants, radionuclides, disinfection, and filtration respectively. Table 2.7 identifies compliance technology for the Total Coliform Rule.

## 2.9 Distribution System Infrastructure

Drinking water is delivered from a water treatment facility to its customers by means of a distribution system. This infrastructure generally consists of a combination of three key elements: treated water storage facilities (e.g., ground storage tanks, elevated storage tanks, standpipes, hydropneumatic tanks), pumping facilities (e.g., booster pumps, piping, control, pump building), and the distribution lines (e.g., piping, valves, fire hydrants, meters). Most of the distribution system infrastructure is located underground, making it more difficult to detect problems such as leaks and pipe deterioration. Various standards and procedures for design, material selection, plumbing code, operation, and maintenance have been established that help maintain the integrity of the system (EPA, 1999). The distribution system issues facing small systems are

## *Table 2.1 Technologies for inorganic contaminants (NDWC, undated).*

| Unit Technology | Limitations* | Operator Skill Level Required | Raw Water Quality Range |
|---|---|---|---|
| 1. Activated Alumina | (a) | Advanced | Ground waters, competing anion concentrations will affect run length. |
| 2. Ion Exchange | | Intermediate | Ground waters with low total dissolved solids, competing ion concentrations will affect run length. |
| 3. Lime Softening | (b) | Advanced | Hard ground and surface waters |
| 4. Coagulation/ Filtration | (c) | Advanced | Can treat wide range of water quality. |
| 5. Reverse Osmosis (RO) | (d) | Advanced | Surface water usually require prefiltration. |
| 6. Alkaline Chlorination | (e) | Basic | All ground waters. |
| 7. Ozone Oxidation | | Intermediate | All ground waters. |
| 8. Direct Filtration | | Advanced | Needs high raw water quality. |
| 9. Diatomaceous Earth Filtration | | Intermediate | Needs very high raw water quality. |
| 10. Granular Activated Carbon | | Basic | Surface waters may require prefiltration. |
| 11. Elecrodialysis Reversal | | Advanced | Requires prefiltration for surface water. |
| 12. Point of Use (POU)-IX | (f) | Basic | Same as Technology #2. |
| 13. POU-RO | (f) | Basic | Same as Technology #5. |
| 14. Calcium Carbonate Precipitation | (g) | Basic | Water with high levels of alkalinity and calcium. |
| 15. pH and Alkalinity Adjustment (chemical feed) | (g) | Basic | All ranges. |
| 16. pH and Alkalinity Adjustment (limestone contactor) | (h) | Basic | Waters that are low in iron and turbidity. Raw water should be soft and slightly acidic. |
| 17. Inhibitors | | Basic | All ranges. |
| 18. Aeration | (i) | Basic | Waters with moderate to high carbon dioxide content. |

*Limitation Footnotes*

*a) Chemicals required during regeneration and pH adjustments may be difficult for small systems to handle.*
*b) Softening chemistry may be too complex for small systems*
*c) It may not be advisable to install coagulation/filtration solely for inorganics removal.*
*d) If all of the influent water is treated, post-treatment corrosion control will be necessary.*
*e) pH must exceed pH 8.5 to ensure complete oxidation without build-up of cyanogen chloride.*
*f) When POU devices are used for compliance, programs for long-term operation, maintenance, and monitoring must be provided by water utility to ensure proper performance.*
*g) Some chemical feeds require high degree of operator attention to avoid plugging.*
*h) This technology is recommended primarily for the smallest size category.*
*i) Any of the first five aeration technologies listed for volatile organic contaminants (Table 2.2) can be used.*

## *Table 2.2 Technologies for volatile organic contaminants (NDWC, undated).*

| Unit Technology | Limitations (see footnotes) | Operator Skill Level Required | Raw Water Quality Range |
|---|---|---|---|
| 1. Packed Tower Aeration (PTA) | (a) | Intermediate | All ground waters. |
| 2. Diffused Aeration | (a,b) | Basic | All ground waters. |
| 3. Multi-Stage Bubble Aerators | (a,c) | Basic | All ground waters. |
| 4. Tray Aeration | (a,d) | Basic | All ground waters. |
| 5. Shallow Tray Aeration | (a,e) | Basic | All ground waters. |
| 6. Spray Aeration | (a,f) | Basic | All ground waters. |
| 7. Mechanical Aeration | (a,g) | Basic | All ground waters. |
| 8. Granular Activated Carbon (GAC) | (h) | Basic | All ground waters. |

*Limitation Footnotes*

*a) Pretreatment for the removal of microorganisms, iron, manganese, and excessive particulate matter may be needed. Post-treatment disinfection may have to be used.*
*b) May not be as efficient as other aeration methods because it does not provide for convective movement of the water thus limiting air-water contact. It is generally used only to adapt existing plant equipment.*
*c) These units are highly efficient; however, the efficiency depends upon the air-to-water ratio.*
*d) Costs may increase if a forced draft is used. Slime and algae growth can be a problem but can be controlled with chemcials such as copper sulfate or chlorine.*
*e) These units require high air-to-water ratios (100-900 m3/m3).*
*f) For use only when low removal levels are needed to reach a MCL because these systems may not be as energy efficient as other aeration methods because of the contacting system.*
*g) For use only when low removal levels are needed to reach an MCL because these systems may not be as energy efficient as other aeration methods. The units often require large basins, long residence times, and high energy inputs, which may increase costs.*
*h) See table 2.3 for limitations regarding these technologies.*

## *Table 2.3 Technologies for synthetic organic contaminants (NDWC, undated).*

| Unit Technology | Limitations (see footnotes) | Operator Skill Level Required | Raw Water Quality Range and Considerations |
|---|---|---|---|
| 1. Granular Activated Carbon (GAC) | (h) | Basic | Surface water may require prefiltration. |
| 2. Point of Use GAC | (a, h) | Basic | Surface water may require prefiltration. |
| 3. Powdered Activated Carbon | (b, h) | Intermediate | All waters |
| 4. Chlorination | (c) | Basic | Better with high quality waters. |
| 5. Ozonation | (c) | Basic | Better with high quality waters. |
| 6. Packed Tower Aeration (PTA) | (d) | Intermediate | All ground waters. |
| 7. Diffused Aeration | (d,e) | Basic | All ground waters. |
| 8. Multi-Stage Bubble Aerators | (d,f) | Basic | All ground waters. |
| 9. Tray Aeration | (d,g) | Basic | All ground waters. |
| 10. Shallow Tray Aeration | (d,f) | Basic | All ground waters. |

*Limitation Footnotes*

a) *When POU devices are used for compliance, programs for long-term operation, maintenance, and monitoring must be provided by water utility to ensure proper performance.*

b) *Most applicable to small systems that already have a process train including basins, mixing, precipitation or sedimentation, and filtration. Site specific design should be based on studies conducted on the system's particular water.*

c) *See the Surface Water Treatment Rule compliance technology tables for limitations associated with this technology.*

d) *Pretreatment for the removal of microorganisms, iron, manganese, and excessive particulate matter may be needed. Post-treatment disinfection may have to be used.*

e) *May not be as efficient as other aeration methods because it does not provide for convective movement of the water thus limiting air-water contact. It is generally used only to adapt existing plant equipment.*

f) *These units are highly efficient; however, the efficiency depends upon the air-to-water ratio.*

g) *Forces may increase if a forced draft is used.*

h) *Pretreatment for removal of suspended solids is an important design consideration. Spent carbon must be regenerated or disposed properly.*

## *Table 2.4 Technologies for radionuclides (NDWC, undated).*

| Unit Technology | Limitations (see footnotes) | Operator Skill Level Required | Raw Water Quality Range and Considerations |
|---|---|---|---|
| IX | (a) | Intermediate | All ground waters. |
| Point of Use (POU) IX | (b) | Basic | All ground waters. |
| Reverse Osmosis (RO) | (c) | Advanced | Surface waters, usually require prefiltration. |
| POU RO | (b) | Basic | Surface waters, usually require prefiltration. |
| Lime Softening | (d) | Advanced | All waters. |
| Green Sand Filtration | (e) | Basic | |
| Co-precipitation with Barium Sulfate | (f) | Intermediate to Advanced | Ground waters with suitable water quality |
| Electrodialysis/Electrodialysis Reversal | | Advanced | All ground waters. |
| Pre-formed Hydrous Manganese Oxide Filtration | (g) | Intermediate | All ground waters. |

*Limitation Footnotes*

a) *The regeneration solution contains high concentrations of the contaminant ions. Disposal options should be carefully considered before choosing the technology.*

b) *When POU devices are used for compliance, programs for long-term operation, maintenance, and monitoring must be provided by water utility to ensure proper performance.*

c) *Reject water disposal options should be carefully considered before choosing this technology. See other RO limitations described in the Surface Water Treatment Rule Compliance Table.*

d) *The combination of variable source water quality and the complexity of the chemistry involved in lime softening may make this technology too complex for small surface water systems.*

e) *Removal efficiencies can vary depending on water quality.*

f) *This technology may be very limited in application to small systems. Since the process requires static mixing, detention basins, and filtration; it is most applicable to systems with sufficiently high sulfate levels that already have a suitable filtration treatment train in place.*

g) *This technology is most applicable to small systems that already have filtration in place.*

## *Table 2.5 Technologies for disinfection (NDWC, undated).*

| Unit Technology | Limitations (see footnotes) | Operator Skill Level Required | Raw Water Quality Range and Considerations |
|---|---|---|---|
| Free Chlorine | (a,b) | Basic | Better with high quality. High iron or manganese may require sequestration or physical removal. |
| Ozone | (c,d, h) | Intermediate | Better with high quality. High iron or manganese may require sequestration or physical removal. |
| Chloramines | (e) | Intermediate | Better with high quality. Ammonia dose should be tempered by natural ammonia levels in water. |
| Chlorine Dioxide | (f) | Intermediate | Better with high quality. |
| Onsite Oxidant Generation | (g) | Basic | Better with high quality. |
| Ultraviolet (UV) Radiation | (h) | Basic | Relatively clean source water required. Iron, natural organic matter and turbidity affect UV dose. |

*Limitation Footnotes*
*a) Providing adequate CT may be a problem for some water supplies.*
*b) Chlorine gas requires special caution in handling and storage, and operator training.*
*c) Ozone leaks represent hazard: air monitoring required.*
*d) Ozone used as primary disinfectant (i.e., no residual protection).*
*e) Long CT. Requires care in monitoring of ratio of added chlorine to ammonia.*
*f) Chlorine dioxide requires special storage and handling precautions.*
*g) Oxidants other than chlorine not detected in solution by significant research effort. CT should be based on free chlorine until new research determines appropriate CT values for electrolyzed salt brine.*
*h) No disinfectant residual protection for distributed water.*

## *Table 2.6 Technologies for filtration (NDWC, undated).*

| Unit Technology | Limitations (see footnotes) | Operator Skill Level Required | Raw Water Quality Range and Considerations |
|---|---|---|---|
| Conventional Filtration (includes dual-stage and dissolved air flotation | (a) | Advanced | Wide range of water quality. Dissolved air flotation is more applicable for removing particulate matter that doesn't readily settle: algae, high color, low turbidity--up to 30-50 nephelometric turbidity units (NTU) and low-density turbidity. |
| Direct Filtration (includes in-line filtration | (a) | Advanced | High quality. Suggested limits: average turbidity 10 NTU; maximum turbidity 20 NTU; 40 color units; algae on a case-by-case basis. |
| Slow Sand Filtration | (b) | Basic | Very high quality or pretreatment. Pretreatment required if raw water is high in turbidity, color, and/or algae. |
| Diatomaceous Earth Filtration | (c) | Intermediate | Very high quality or pretreatment. Pretreatment required if raw water is high in turbidity, color, and/or algae. |
| Reverse Osmosis | (d,e,f) | Advanced | Requires prefiltrations for surface water-may include removal of turbidity, iron, and/or manganese. Hardness and dissolved solids may also affect performance. |
| Nanofiltration | (e) | Intermediate | Very high quality of pretreatment. See reverse osmosis pretreatment. |
| Ultrafiltration | (g) | Basic | High quality or pretreatment. |
| Microfiltration | (g) | Basic | High quality or pretreatment required. |
| Bag Filtration | (g,h,i) | Basic | Very high quality or pretreatment required, due to low particulate loading capacity. Pretreatment if high turbidity or algae. |
| Cartridge Filtration | (g,h,i) | Basic | Very high quality or pretreatment required, due to low particulate loading capacity. Pretreatment if high turbidity or algae. |
| Backwashable Depth Filtration | (g,h,i) | Basic | Very high quality or pretreatment required, due to low particulate loading capacity. Pretreatment if high turbidity or algae. |

*Limitations Footnotes*
*a. Involves coagulation. Coagulation chemistry requires advanced operator skill and extensive monitoring. A system needs to have direct full-time access or full-time remote access to a skilled operator to use this technology properly.*
*b. Water service interruptions can occur during the periodic filter-to-waste cycle, which can last from six hours to two weeks.*
*c. Filter cake should be discarded if filtration is interrupted. For this reason, intermittent use is not practical. Recycling the filtered water can remove this potential problem.*
*d. Blending (combining treated water with untreated raw water) cannot be practiced at risk of increasing microbial concentration in finished water.*
*e. Post-disinfection recommended as a safety measure and for residual maintenance.*
*f. Post-treatment corrosion control will be needed prior to distribution.*
*g. Disinfection required for viral inactivation.*
*h. Site-specific pilot testing prior to installation likely to be needed to ensure adequate performance.*
*i. Technologies may be more applicable to system serving fewer than 3,300 people.*

*Table 2.7 Compliance technology for the Total Coliform Rule (NDWC, undated).*

| 40 CFR 141.63(d) - Best technologies or other means to comply (Complexity level indicated) | Comments/Water Quality Concerns |
|---|---|
| Protecting wells from contamination, e.g., placement and construction of well(s) (Basic). | Ten State Standards and other standards (AWWA, 1995) apply; interfacing with other programs essential (e.g., source water protection program). |
| Maintenance of a disinfection residual for distribution system protection (Intermediate). | Source water constituents may affect disinfection: iron, manganese, organics, ammonia, and other factors may affect dosage and water quality. Total Coliform Rule (TCR) remains unspecific on type/amount of disinfectant, as each type differs in concentration, time, temperature, pH, interaction with other constituents, etc. |
| Proper maintenance of distribution system: pipe repair/replacement, main flushing programs, storage/reservoir, and O&M programs (including cross-connection control/backflow prevention), and maintenance of positive pressure throughout (Intermediate). | O&M programs particularly important for smaller systems needing to maintain water purity. States may vary on distribution protection measures. See also EPA's Cross-Connection Control Manual (EPA, 2003b) |
| Filtration and/or disinfection of surface water or other ground water under direct influence; or disinfection of ground water (Basic thru Advanced). | Same issues as cited above under maintaining disinfection residual; pretreatment requirements affect complexity of operation. Refer to Surface Water Treatment Rule Compliance Technology List; and other regulations under development. |
| Ground waters: Compliance with State Wellhead Protection Program (Intermediate). | EPA/State Wellhead Protection Program implementation (per §1428 SDWA): may be used to assess vulnerability to contamination, and in determination of sampling and sanitary survey frequencies. |

further discussed in Chapter 6. The following is a brief description of each of the key distribution system infrastructure elements.

### 2.9.1 Storage Facilities

Storage facilities may be closed tanks or reservoirs and are designed to store treated water (ground storage) or to maintain adequate service pressure (elevated, hydropneumatic, or ground storage that is built at a location to act as elevated storage).

A clearwell tank is generally the first treated water storage tank and is located at the end of the treatment train or at the end of a well system. Their primary purpose is to provide for contact time when chemical treatment additives (e.g., chlorine) are used. These storage structures have limited use as storage reservoirs due to their location. The added storage or reserve capability of clearwells are an advantage for small system operators that need time for maintenance of equipment or structures, or other storage needs such as fire flows, but this is not their intended use. Utilities should not rely on clearwell storage as their only means of reserve for the distribution system. The clearwell tank also serves as a reservoir for the storage of filtered water of sufficient capacity to prevent the need to vary the filtration rate with variations in demand. Clearwell tanks provide both a treated water reserve for delivery to the distribution system and additional detention time for more effective disinfection (EPA, 1999). Figure 2.15 shows the percentage of CWSs that use clearwell tanks for treated-water storage.

Depending on the complexity and size of the distribution system, the other storage tanks are designed to provide pressure maintenance for the distribution system. If the system serves a small number of customers, a pressurized tank called a hydropneumatic tank (controlled by both water and air pressures) is used to maintain the system pressure, because it is cheaper to build than an elevated tank. Different sections of the distribution system are maintained at different pressures (commonly referred to as pressure zones), depending on the water demand and pressure head requirements. (EPA, 1999).

Tables 2.8 and 2.9 show the percentage of CWSs that have treated-water storage either before or within the distribution system.

Storage tank capacities are designed to be adequate to meet the water demands of the system, meet applicable state requirements and industry standards, and be consistent with accepted engineering practice. For example, the total capacity of both ground and elevated storage tanks could be based on a recommended level of 200 gallons per connection. For elevated storage tanks alone, a recommended capacity of 100 gallons per connection is often used. For systems using hydropneumatic tanks instead of elevated tanks, recommended capacities are 20 gallons per connection with ground storage and 50 gallons per connection without ground storage (EPA, 1999).

*Table 2.8 Percentage of CWSs (within each system service population category) that have treated-water storage, before distribution system.*

| Primary Source of Water | Configuration | System Service Population Category: 25-500 | 501-3,300 | 3,301-10,000 | 10,001-100,000 | Over 100,000 |
|---|---|---|---|---|---|---|
| Ground Water Systems | With Dedicated Entry and Exit Points | 31.6 | 17.0 | 23.1 | 26.2 | 32.4 |
| | With a Common Inlet and Outlet | 16.8 | 15.6 | 8.8 | 16.5 | 25.3 |
| Surface Water Systems | With Dedicated Entry and Exit Points | 41.3 | 16.6 | 27.7 | 32.3 | 33.1 |
| | With a Common Inlet and Outlet | 6.5 | 18.3 | 16.7 | 7.4 | 25.9 |
| Purchased Water Systems | With Dedicated Entry and Exit Points | 10.6 | 5.3 | 13.5 | 11.9 | 33.6 |
| | With a Common Inlet and Outlet | 10.5 | 7.6 | 15.3 | 1.5 | 0.0 |

*Table 2.9 Percentage of CWSs (within each system service population category) that have treated-water storage within the distribution system.*

| Primary Source of Water | Configuration | System Service Population Category: 25-500 | 501-3,300 | 3,301-10,000 | 10,001-100,000 | Over 100,000 |
|---|---|---|---|---|---|---|
| Ground Water Systems | With Dedicated Entry and Exit Points | 2.9 | 10.0 | 16.5 | 31.9 | 51.8 |
| | With a Common Inlet and Outlet | 11.9 | 68.6 | 54.0 | 70.7 | 82.8 |
| Surface Water Systems | With Dedicated Entry and Exit Points | 6.0 | 4.1 | 29.2 | 39.8 | 58.6 |
| | With a Common Inlet and Outlet | 20.5 | 73.6 | 73.0 | 72.8 | 72.0 |
| Purchased Water Systems | With Dedicated Entry and Exit Points | 3.5 | 8.8 | 22.6 | 35.5 | 56.8 |
| | With a Common Inlet and Outlet | 14.4 | 55.4 | 61.6 | 63.9 | 64.6 |

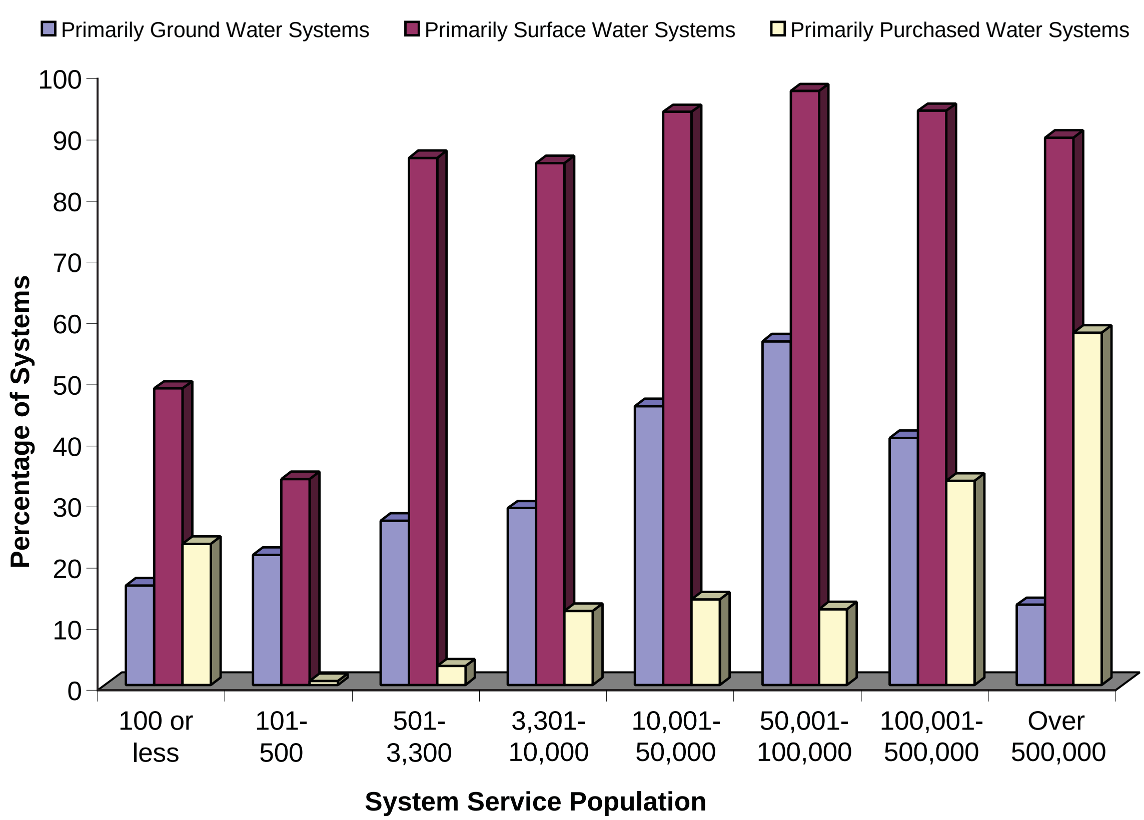



*Figure 2.15 Percentage of CWSs within each system service population category that have a clearwell type finished water storage (EPA, 2002).*

### 2.9.2 Pumping facilities

Pumps are used for moving fluid (e.g., water, chemical) through the distribution system, sludge removal, air compression and sampling. The three types of pumps generally used to pump water at a treatment plant are: positive displacement, centrifugal, and ejector. A positive displacement pump delivers water at a constant rate regardless of the pressure it must overcome. A centrifugal pump is used when an even flow rate is needed to meet the demands placed on it. Ejector pumps are typically used to deliver treatment chemical to the water being treated. Pump capacity is typically dependent on the application or purpose.

Most pumping applications rely on a pumping station that includes a pump(s), a structure to house or support the pump, piping – suction and discharge, lighting, ventilation, an electrical center and control panel for the pump(s) and lighting, and appurtenances.

### 2.9.3 Distribution Lines

Underground pipes are the largest component of the distribution system and as such, design standards are established that specify the minimum requirements for all water lines. Typically, the design standards also specify many of the following items (EPA, 1999):

- Minimum pipe size (typically there should be no lines less than 2-inch);
- Minimum line size criteria (either maximum water velocity or number of connections served for a given line size);
- Minimum line size where fire hydrants are to be provided (6-inch is the minimum);
- Minimum line size for specific requirement of the distribution system (e.g., transmission line should be at least 12-inches);
- Design flow for each type of connection (e.g., residential, commercial, industrial);
- Design fire flow for specific areas of development (e.g., residential, commercial, industrial);
- Location of line relative to other utilities (sanitary sewer, in particular) and right-of-way limits;
- Location or spacing of valves;
- Direction of valves (right or left opening);
- Type of valves to be used (vacuum/air release, butterfly, or gate valve);
- Location or spacing of fire hydrants;
- Type of fire hydrants to be used (dry or wet barrel);
- Pipe material, including requirements for internal as well as external corrosion;
- Appurtenances required for flushing of dead-end lines;

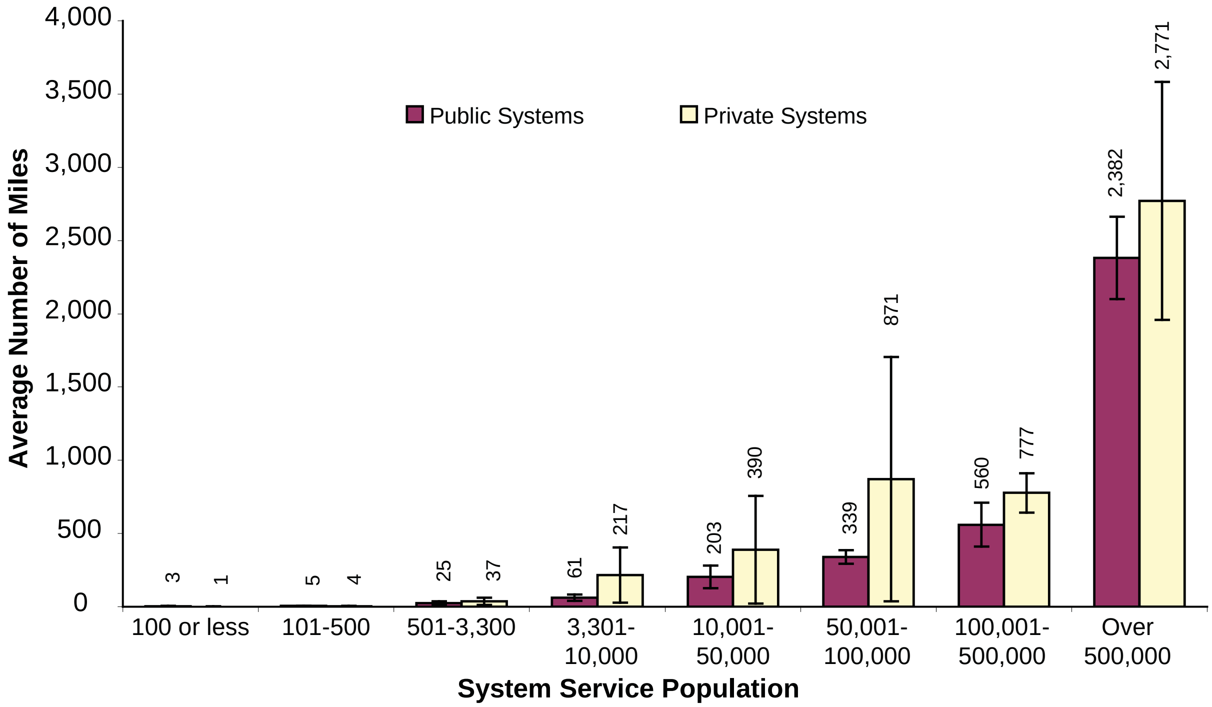



*Figure 2.16 Average number of miles of distribution mains (public vs. private systems). Error bars represent the 95% confidence interval (EPA, 2002).*

- Minimum cover or depth-to-bury requirements;
- Pressure testing to determine that there are no leaks in the line;
- Construction or installation requirements; and
- Location and construction of appurtenances in the floodplain.

The vast majority of piping used for distribution lines in CWSs is used by very large systems serving populations over 500,000 persons. Also, for small systems, private systems tend to have more miles of pipe in place than public systems (when comparing the same system service population size) (Figure 2.16).

Most of the piping replaced each year is performed in the private rather than the public sector (Figure 2.17) and as would be expected, very large systems replace more piping per year than smaller systems.

There are 293,087,350 customer connections, over 55% of which are part of CWSs (Figure 2.18). Very small systems account for almost 73% of customer connections, with the majority of those systems being privately owned (Table 2.10).

CWS distribution pipes are of various diameters. In all but the very largest of systems (those serving over 500,000 persons), there is a tendency to use more distribution pipes that average less than 6-inches than it is to use distribution pipes of 6-to 10-inches or greater than 10-inches. Very large systems (especially those that are privately owned) on average use more distribution pipes of the 6-to 10-inch variety than either of the other two sizes (Figures 2.19 and 2.20). Typically, as would be expected, the distribution mains (or trunk lines) are of the larger diameter in size.

The vast majority of CWS piping (approximately 78%) is less than 40 years old. Approximately 18% is between 40 and 80 years old and the remaining 4% is over 80 years old (Figure 2.21). Publicly owned systems tend to have slightly older piping on average than do privately owned systems, with approximately 24% of public systems piping averaging 40 to 80 years old as compared to approximately 8% of private systems in the same age range (Figure 2.22).

## 2.10 Remote Telemetry – Supervisory Control and Data Acquisition (SCADA)

Remote telemetry or SCADA is used to control all aspects of a device from a centralized location. In the past, small systems did not always use SCADA to their fullest potential due to complex operating systems and controls that usually required specially

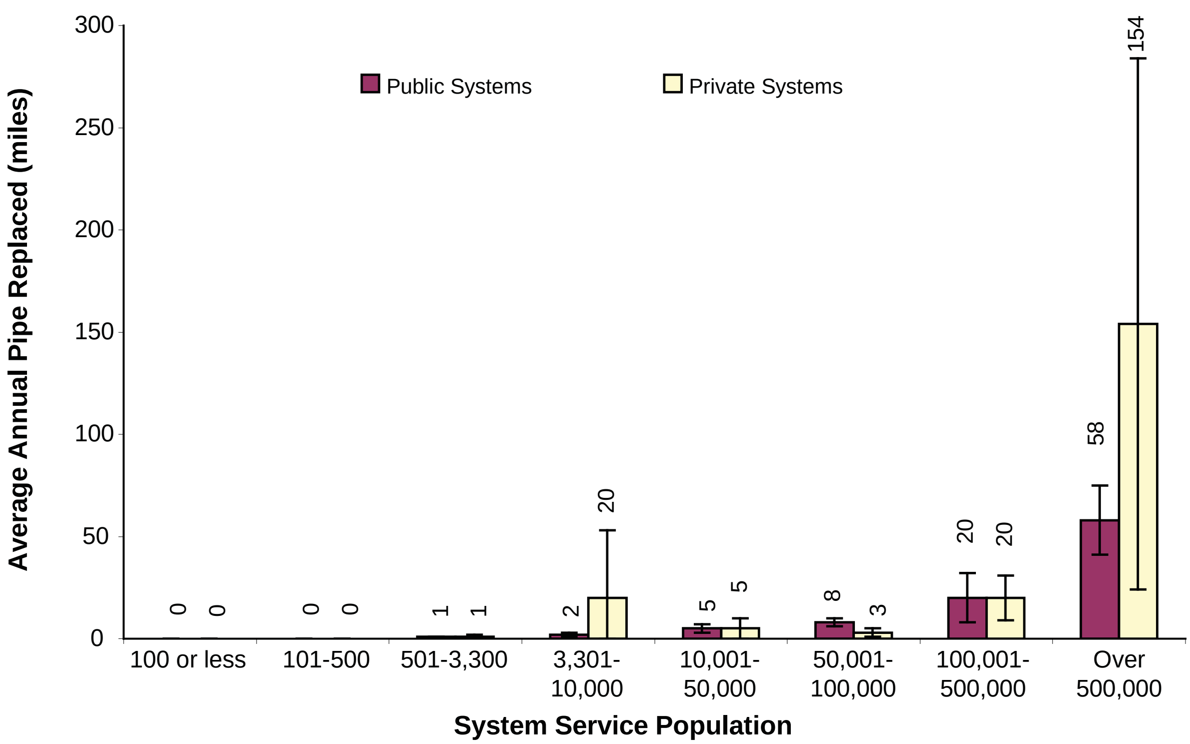
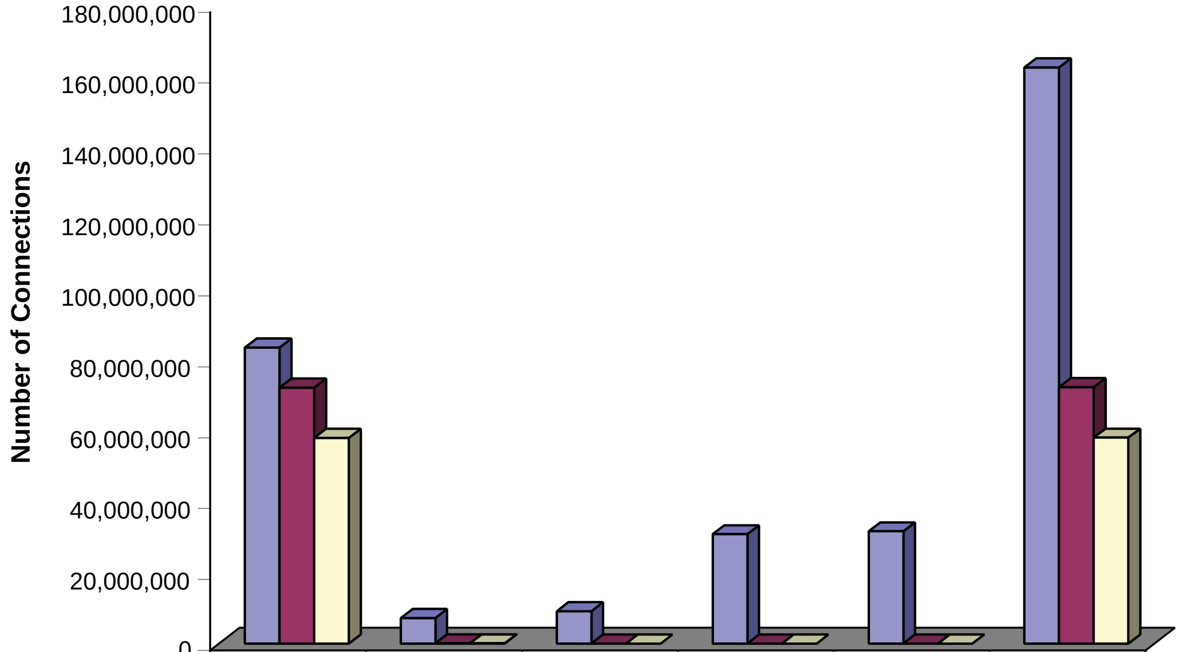



*Figure 2.17 Public vs. private average annual pipe replaced (for CWSs) 5-year average. Error bars represent the 95% confidence interval (EPA, 2002).*




| | Very Small (25-500) | Small (501-3,300) | Medium (3,301-10,000) | Large (10,001-100,000) | Very Large (>100,000) | Grand Total |
|---|---|---|---|---|---|---|
| CWS | 83,572,950 | 7,279,586 | 9,140,490 | 30,871,660 | 31,703,961 | 162,568,647 |
| NTNCWS | 72,247,798 | 111,881 | 24,432 | 1,931 | 98 | 72,386,140 |
| TNCWS | 58,042,062 | 84,909 | 3,253 | 141 | 2,198 | 58,132,563 |

**System Service Population**

*Figure 2.18  System service connections (EPA, 2002).*

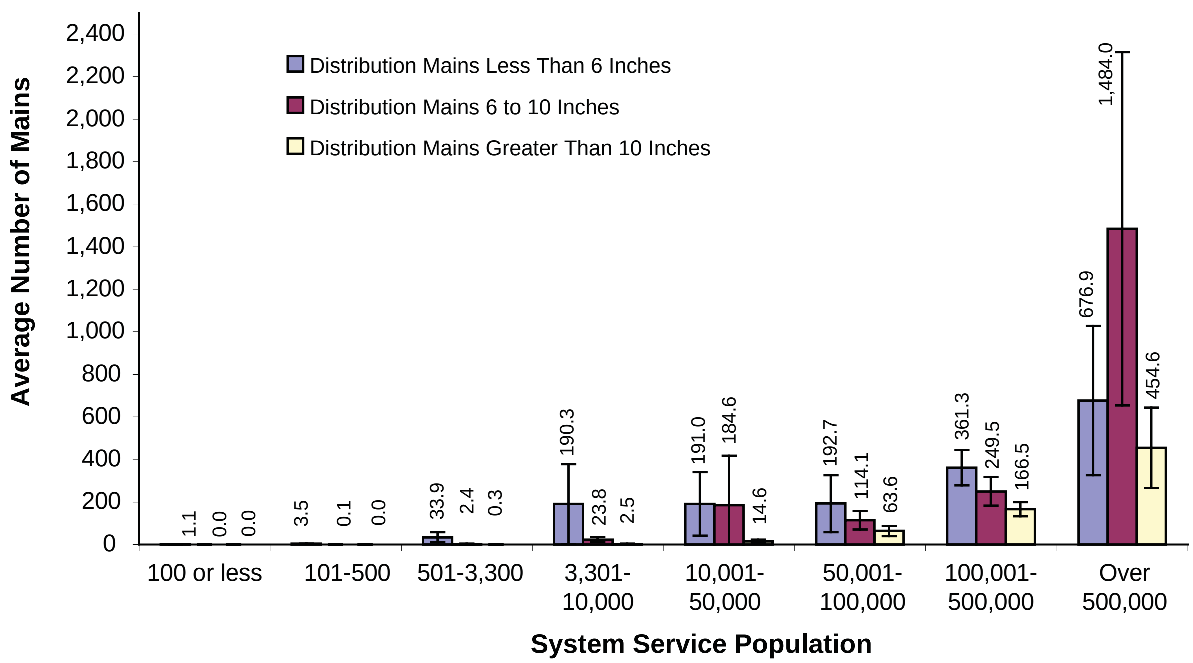



*Figure 2.19  Average number of miles of pipes in distribution systems – privately owned (EPA, 2002).*

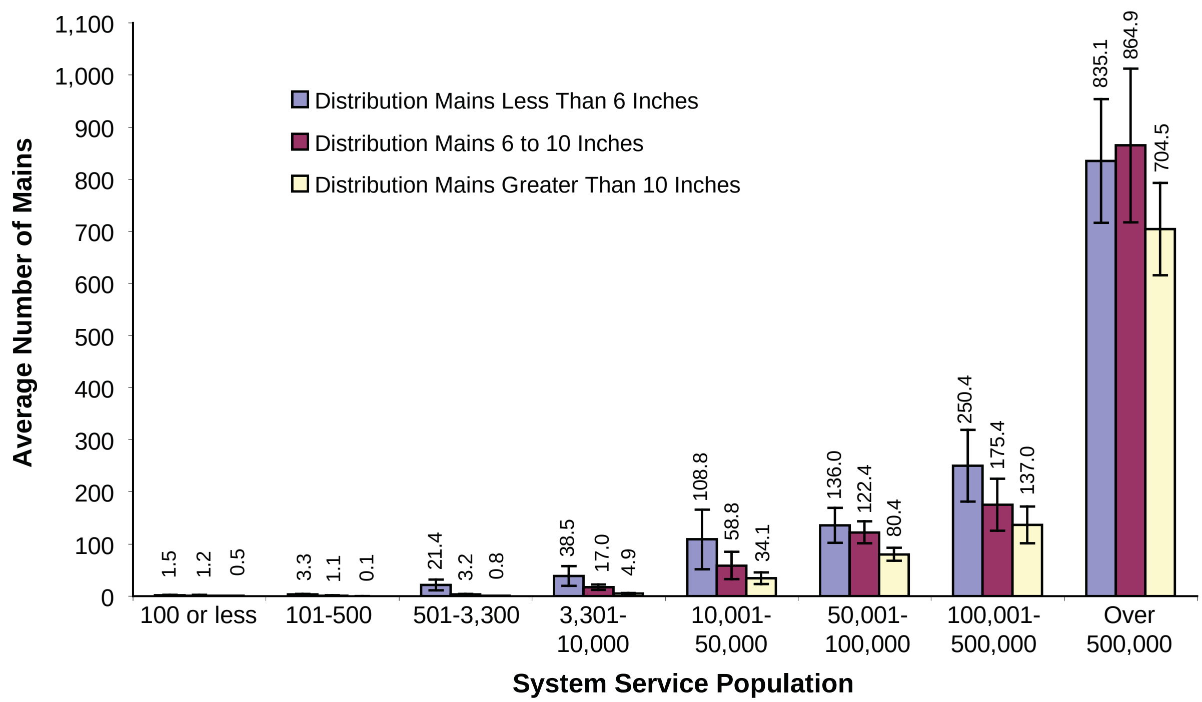



*Figure 2.20 Average number of miles of pipes in distribution systems – publicly owned (EPA, 2002).*

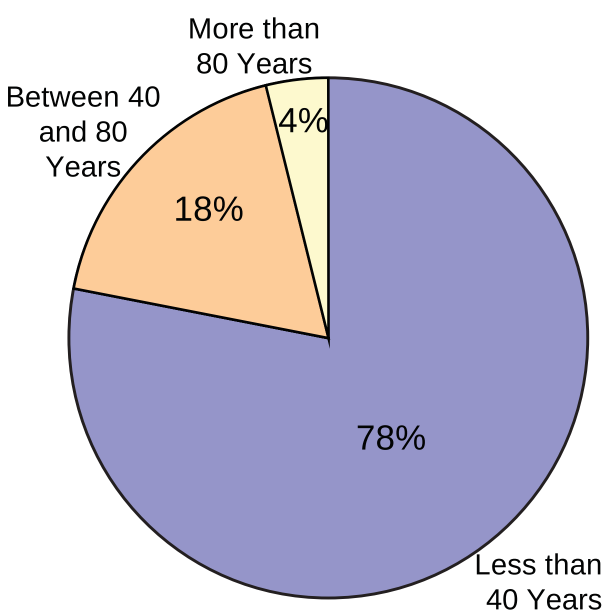



*Figure 2.21 Percentage of pipe in each age category for CWSs (EPA, 2002).*

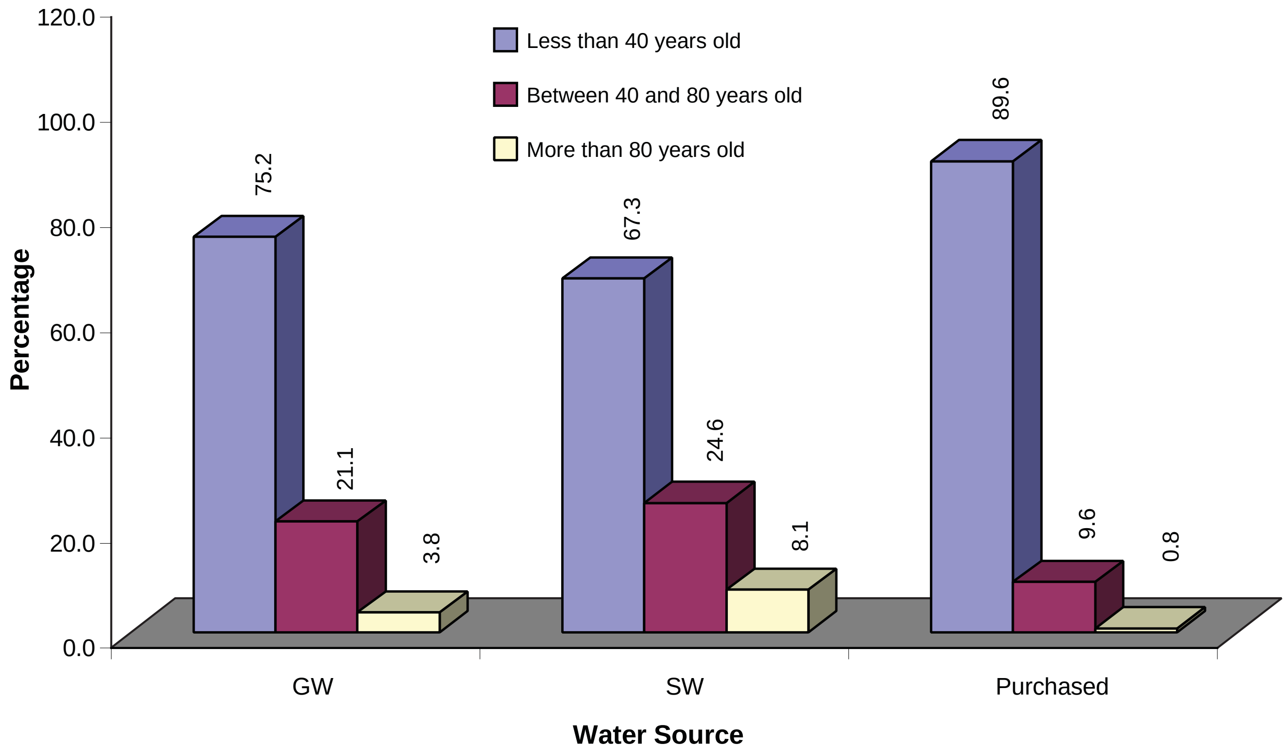



*Figure 2.22 Percentage of Pipe in Each Age Category by Source for CWSs (EPA, 2005b).*

trained computer programmers or technicians and costly service agreements. In the last few years, SCADA vendors have changed the way they design and fabricate their systems, thus making them more accessible to small drinking water treatment operators (EPA, 2003c).

Figures 2.23 and 2.24 illustrate how large CWSs (lacking continuous operator presence) use more SCADA systems than small CWSs, for both process control and process monitoring. Chapter 9 presents further details on the use of SCADA for small systems.

## 2.11 Key Questions

- How will demographic changes in the US change the way small systems obtain, treat, and distribute drinking water?
- How can the EPA help minimize monitoring and reporting violations? (e.g., develop simple, standardized forms with sampling timetables, etc., with input from primacy agencies).
- Should resources be concentrated in any one area between NTNCWS, TNCWS, and CWS?

*Table 2.10 System service connections by system owner (EPA, 2002).*

| | System Service Population | | | | | |
|---|---|---|---|---|---|---|
| Owner | Very Small 25-500 | Small 501-3,300 | Medium 3,301-10,000 | Large 10,001-100,000 | Very Large >100,000 | Grand Total |
| Federal Government | 5,539,450 | 42,023 | 99,527 | 210,244 | 3 | 5,891,247 |
| Local Government | 38,323,943 | 5,306,605 | 7,455,702 | 25,591,319 | 27,338,611 | 104,016,180 |
| Native American | 24,287 | 44,279 | 15,852 | 66 | NA | 84,484 |
| Private | 169,809,399 | 1,685,804 | 1,267,290 | 4,408,959 | 3,995,009 | 181,166,461 |
| Public/Private | 95,004 | 298,709 | 190,848 | 422,711 | 372,491 | 1,379,763 |
| State Government | 38,750 | 55,126 | 91,817 | 180,955 | 143 | 366,791 |
| Unknown | 31,977 | 43,830 | 47,139 | 59,478 | NA | 182,424 |
| Grand Total | 213,862,810 | 7,476,376 | 9,168,175 | 30,873,732 | 31,706,257 | 293,087,350 |

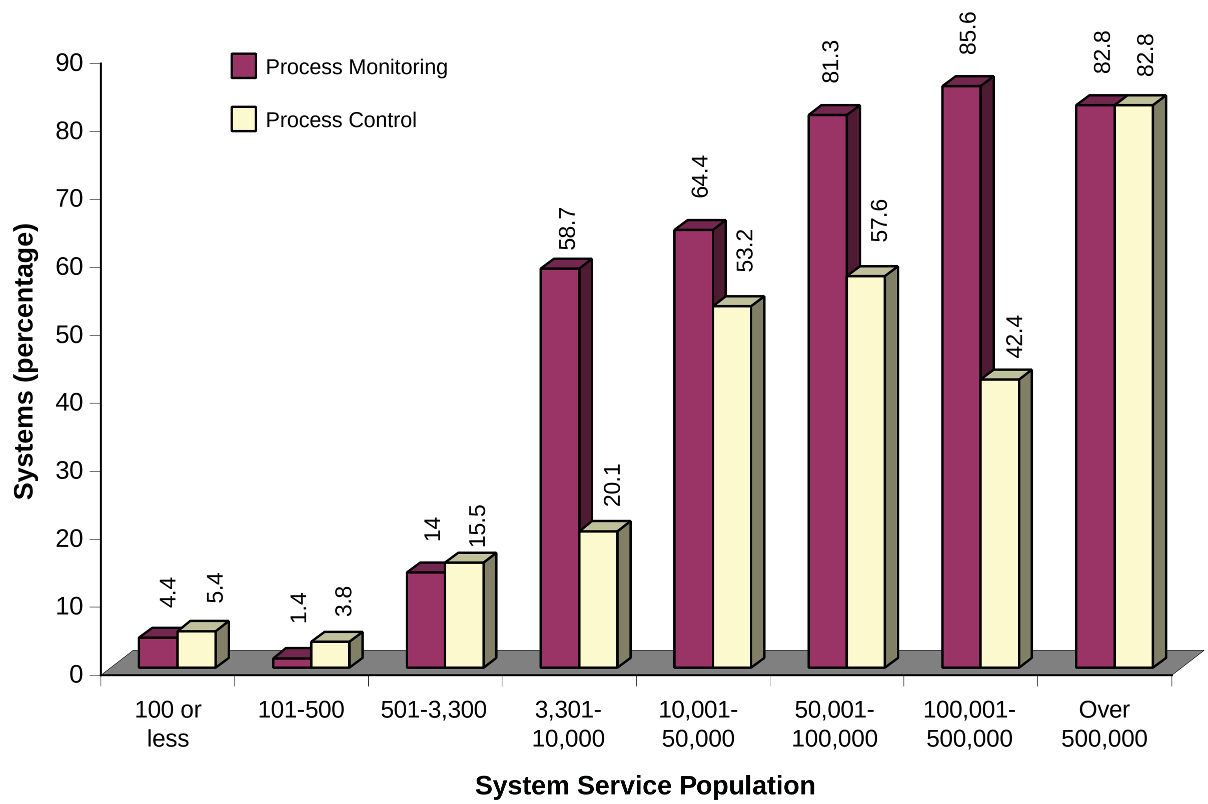



*Figure 2.23 Percentage of ground water CWS plants (lacking 24/7 operator presence) that have SCADA systems for process monitoring or control (EPA, 2002).*

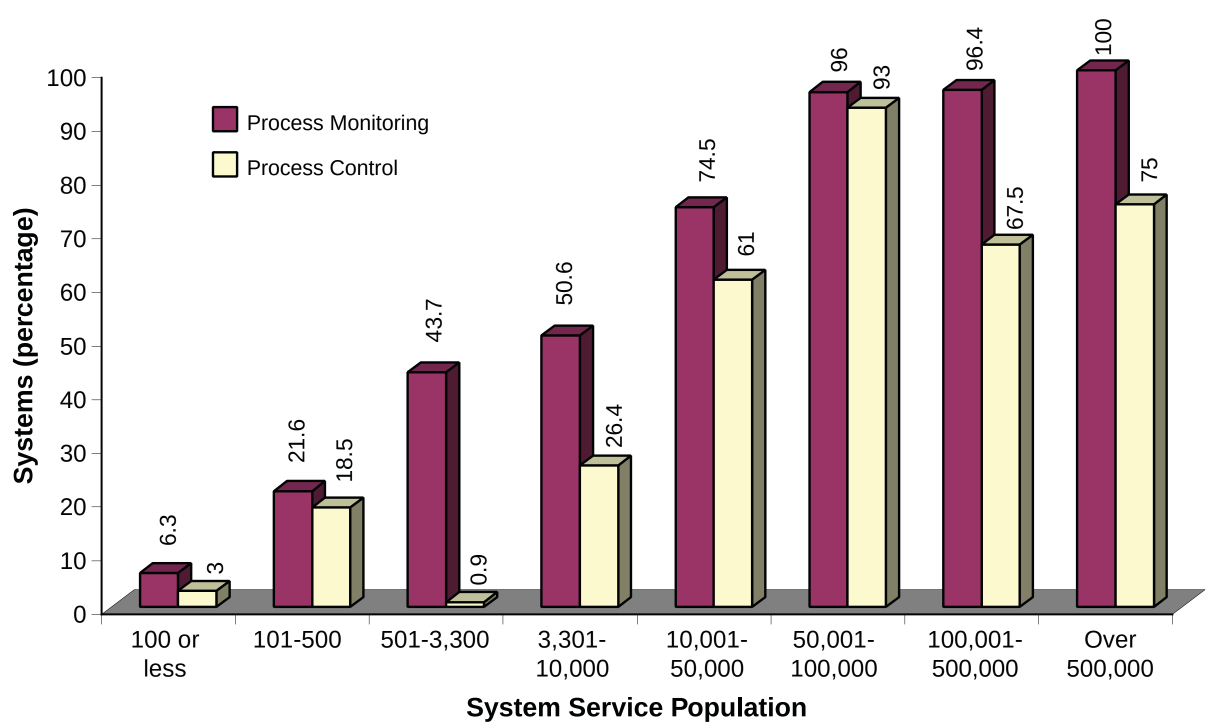



*Figure 2.24 Percentage of surface water CWS plants (lacking 24/7 operator presence) that have SCADA systems for process monitoring or control (EPA, 2005b).*

(These systems have different demands. For example, CWSs typically have demands throughout the year, while the non-community systems may have more sporadic demands.)

## 2.12 References


All references to Code of Federal Regulations (CFR) Documents in this chapter may be found at http://www.access.gpo.gov/nara/cfr and Federal Register Documents may be found at http://www.gpoaccess.gov/fr/index.html

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NDWC. NDWC Fact Sheet – Technical Brief on Ultraviolet Disinfection, available at: http://www.nesc.wvu.edu/ndwc/pdf/OT/TB/OT_TB_f00.pdf, 2000.

NDWC. NDWC Fact Sheet – Technical Brief Poster on Treatment Technologies for Small Drinking Water Systems, available at: http://www.nesc.wvu.edu/ndwc/pdf/OT/TB/TB11_TTposter.pdf, undated.

# Chapter 3 Regulatory Background

## 3.1 Safe Drinking Water Act (SDWA)

In response to the public health community's and general public's increased concern and awareness of drinking water contamination, Congress passed the Safe Drinking Water Act (SDWA) in 1974. The Act was intended to protect public health by regulating the Nation's public drinking water supply. The SDWA establishes national enforceable standards for drinking water quality and makes certain that water suppliers monitor their water to ensure that it meets national standards.

From 1974 to 1986 when the SDWA was amended, state regulations varied in many respects, including differing requirements for ground water disinfection, mandated filtration, monitoring of organic chemicals, and operator certification requirements. Interim standards known as maximum contaminant levels (MCLs) were developed in 1975. The 1986 Amendments declared these interim standards to be final, required the EPA to regulate 83 contaminants within three years after enactment, and required disinfection of all public water supplies and filtration for surface water systems. States that have primary enforcement responsibility, known as primacy, were required to adopt regulations and begin enforcing them within 18 months of EPA's promulgation. The 1986 Amendments also required the EPA to regulate an additional 25 contaminants every three years and to designate the best available treatment technology for each contaminant regulated. The amendment initiated the ground water protection program, established funding for sole source aquifer special needs identification and protection, and created a new category of water system (non-transient, non-community water system) which greatly increased the number of systems that states were required to regulate.

The SDWA was amended again in 1996 (Public Law [P.L.] 104-183), addressing concerns about an overly burdensome regulatory structure and funding needs for PWS infrastructure and state program management. The Amendments allowed EPA to establish a process for selecting contaminants to regulate based on scientific merit rather than having to regulate an additional 25 contaminants every three years and established the Drinking Water State Revolving Fund (DWSRF) to help public water systems finance the costs of drinking water infrastructure needs. The Amendments also changed the emphasis from drinking water treatment to contaminant prevention (through source water protection and enhanced water system management). The 1996 Amendments allowed for flexibility of regulations and monitoring for small systems, and required the EPA to conduct cost-benefit analyses of new regulations and analyze the likely effect of the regulation on the viability of public water systems (EPA-Drinking Water Academy, 2003). Over the years, EPA has released many documents related to SDWA. The most recent document that provides a detailed understanding of the SDWA was released on the 30th Anniversary of its promulgation in June 2004 (EPA, 2004).

## 3.2 SDWA Provisions

The SDWA has many regulatory provisions; a detailed review of all these provisions is beyond the scope of this document. A brief overview of SDWA regulatory provisions related to PWS operations is presented in the following subsections.

### 3.2.1 National Primary Drinking Water Regulations (NPDWR)

The 40 CFR 141 establishes the NPDWR and 40 CFR 142 establishes the implementation of NPDWR pursuant to section 1412 of the SDWA of 1974, as amended (P.L. 93-523). The NPDWR established both Recommended Maximum Contaminant Levels (RMCLs) and MCLs. As part of the 1986 amendments to the SDWA, RMCLs were renamed MCLGs or Maximum Contaminant Level Goals and the National Interim Drinking Water Regulations were renamed as the NPDWR. The NPDWR is designed to protect drinking water quality by limiting the levels of specific contaminants that can adversely affect public health and are known or anticipated to occur in water. The NPDWR specifies two types of numeric standards. The first is the primary standard which is enforceable and establishes the MCL. The other (non-enforceable) secondary standard is referred to as a MCLG.

The 40 CFR 141.2 defines MCL as the maximum permissible level of a contaminant in water which is delivered to any user of a PWS. This is water "delivered to the free flowing outlet of the ultimate user of a PWS, except in the case of turbidity where the maximum permissible level is measured at the point of entry to the distribution system." Contaminants added to the water under circumstances controlled by the user are excluded from this definition, except those contaminants resulting from the corrosion of piping and plumbing caused by water quality.

MCLGs are set at a level at which no known or anticipated adverse human health effects occur. Where it is not economically or technologically feasible to determine the level of a contaminant, a treatment technique (TT) is prescribed by EPA in lieu of establishing an MCL. For example, *Giardia lamblia* is a microbial contaminant that is difficult to measure. To ensure proper removal, experimental work has established optimum treatment conditions for the water at a specified pH, temperature, and chlorine concentration for a specified length of time to achieve a fixed level of inactivation.

### 3.2.2 National Secondary Drinking Water Regulations (NSDWR)

The 40 CFR 143 establishes NSDWR pursuant to section 1412 of the SDWA, as amended (42 U.S.C. 300g-1). These standards are non-enforceable guidelines for controlling contaminants in drinking water for aesthetic considerations, such as taste, color, and odor. Although the EPA recommends secondary standards, it does not enforce compliance. States may, however, choose to adopt them as enforceable standards.

### 3.2.3 Contaminant Candidate List (CCL)

The 1996 SDWA Amendments require the EPA to publish a list of contaminants that are not regulated by any NPDWR provisions (at the time the list is published), are anticipated or known to occur in PWSs, and may later require regulation under the SDWA. This list, CCL, was required to be published initially within 18 months of enactment of the Amendments and every 5 years thereafter. Contaminants for priority drinking water research, occurrence monitoring, and guidance development, including health advisories, are drawn from the CCL. The first CCL was published in 1998. The second was issued in February of 2005.

## 3.3 Current Regulatory Issues

Besides the SDWA, there are several other rules and contaminants of interest which may impact small systems. A brief summary of these rules and contaminants of interest are presented in the following subsections.

### 3.3.1 Perchlorate

The EPA's National Center for Environmental Assessment first released an external review draft report concerning perchlorate in 1998 and later released a revised document entitled Perchlorate Environmental Contamination: Toxicological Review and Risk Characterization in 2002. According to this document, "perchlorate ($ClO_4^-$) is an anion that originates as a contaminant in ground water and surface waters when the salts of ammonium, potassium, magnesium, or sodium dissolve in water. One major source of contamination is the manufacture or improper disposal of ammonium perchlorate that is used as the primary component in solid propellant for rockets, missiles, and fireworks." The document also states that an "appreciation of widespread contamination in the United States emerged in the Spring of 1997 when development of an analytical method with a quantitation level at 4 ppb became available."

The EPA draft assessment concludes that the potential human health risks of perchlorate exposures include effects on the developing nervous system and thyroid tumors and presents a reference dose (RfD) that is intended to be protective for both types of effects. The draft RfD is 0.00003 milligrams per kilogram per day (mg/kg/day), which is a preliminary estimate of a protective health level. The RfD is undergoing science review and deliberations by the external scientific community and within EPA. The National Research Council (NRC) released a report that suggested a safe level of perchlorate at 24.5 micrograms/liter (based on 2 liter/day consumption by a 70 kg individual) (NRC, 2005).

EPA may at some point issue a Health Advisory that will provide information on protective levels for drinking water. The draft document goes on to state that "this is one step in the process of developing a broader response to perchlorate including, for example, technical guidance, possible regulations and additional health information. A federal drinking water regulation for perchlorate, if ultimately developed, could take several years."

Perchlorate was placed on EPA's CCL, for consideration for possible regulation, in 1998. The next year EPA required drinking water monitoring for perchlorate under the Unregulated Contaminant Monitoring Rule (UCMR). Under this rule, monitoring was required of all large public water systems and a representative sample of small public water systems over a two year period (from 2001 to 2003) to determine whether the public was being exposed to perchlorate in drinking water nationwide. As of March 2004, the sampling period had expired; however, the EPA had not received all the data from the PWSs. The EPA will not disseminate a final revision of its draft risk assessment until it has fully evaluated the recommendations made by a National Academy of Science (NAS) panel.

### 3.3.2 Arsenic

The first arsenic drinking water standard was established by the U.S. Public Health Service in 1942 for interstate water carriers. The standard was set at 0.05 mg/L, and under the SDWA of 1974 the EPA issued this limit as a National Interim Primary Drinking Water Regulation (NIPDWR). The 1986 SDWA renamed the NIPDWRs to NPDWRs, directed the EPA to revise NPDWRs by 1989, and specified that MCLGs be promulgated simultaneously with MCLs (EPA, 2002a)

The 1996 SDWA Amendments set deadlines for regulating arsenic. The EPA was required to propose a revised Arsenic Rule by January 1, 2000, and issue a Final Rule by January 1, 2001. On June 22, 2000, the EPA proposed to revise the existing NPDWR MCL for arsenic to 0.005 mg/L. The Final Rule was published on January 22, 2001 and established an MCL for arsenic at 0.010 mg/L, which became enforceable on January 23, 2006 (40 CFR 141) (EPA, 2002a).

According to EPA's Report to Congress: Small Systems Arsenic Implementation Issues (EPA, 2002b), "small systems are being asked – in some cases for the first time – to grapple with a whole new set of public health challenges. This situation poses enormous implementation, timing, resource, technical, and capacity challenges for public water systems across the country." The document also states that small system infrastructure may be outdated and in poor condition. Source water available to small systems may be of poor quality and limited quantity. Technical water system planning and operations expertise necessary to evaluate and install new treatment technologies may also be lacking. In addition, small systems face considerable financial challenges in that they have a small customer base and, thus, often lack the opportunity to benefit from economies of scale.

The above referenced Report to Congress estimates that 3,341 small systems out of a total of an estimated 75,000 potentially affected systems nationally will have to make improvements or take other measures (e.g., locate a different source of water) to meet the new arsenic standard. This represents a substantial number of small systems, particularly ground water systems, that will need to make treatment changes.

Because of the importance of the Arsenic Rule and the national debate surrounding it related to science and costs, EPA's Administrator publicly announced on March 20, 2001, that the Agency would take additional steps to reassess the scientific and cost issues associated with this Rule. After taking public comment on the Agency's plan to review the basis for the Arsenic Rule, EPA extended the effective date to February 22, 2002, while maintaining the compliance dates of January 23, 2006, for the arsenic MCL and January 22, 2004, for the clarifications to compliance and new source contaminants monitoring (66 FR 28350). The EPA implementation guidance (EPA, 2002a) specifies a request by the EPA for a review of the Arsenic Rule by the National Academy of Science (interpretation and application of arsenic research), the National Drinking Water Advisory Council (assumptions and methodologies), and the EPA's Science Advisory Board (benefits). Information on the findings is available in the EPA implementation guidance (EPA, 2002a).

The EPA announced on October 31, 2001 that the 10 ppb standard for arsenic would remain. The "EPA will continue to evaluate the expert panel reports, the voluminous public comments received, and other relevant information and comments as they become available as part of the next round of review of the existing NPDWR under SDWA §1412(b)(9). As part of this review due August 2008, EPA expects to make a decision on whether to further revise the arsenic standard" (EPA, 2002a).

EPA expects that new, more cost effective approaches to comply with drinking water requirements will be developed, and that small systems will be better able to meet the challenges posed by the new arsenic drinking water standard as well as other, future drinking water standards (EPA, 2002b).

### 3.3.3 Compliance with Surface Water Treatment Rule

The Surface Water Treatment Rule (SWTR) was first published in June 1989. A final Long Term 1 Enhanced SWTR (LT1ESWTR) was later published (for systems serving fewer than 10,000 persons - EPA, 2002c). Thereafter, the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) was published for all PWSs using surface water or ground water under direct influence-GWUDI (EPA, 2003a). These regulations appear in 40 CFR 141, Subpart H and establish criteria under which filtration is required as a treatment technique for public water systems supplied by surface water or GWUDI. These regulations also establish TT requirements (in lieu of MCLs) for: *Giardia lamblia*, viruses, heterotrophic plate count bacteria, *Legionella*, and turbidity.

The regulations state that a system is in compliance with 40 CFR 141.70(a) if it meets the requirements for avoiding filtration (40 CFR 141.71) and the disinfection requirements (40 CFR 141.72(a)) or it meets the requirements for avoiding filtration (40 CFR 141.73) and the disinfection requirements (40 CFR 141.72(b)). In other words, "systems must either provide filtration and disinfection or comply with the requirements to avoid filtration" (EPA, 2003b)

The criteria for avoiding filtration may be summarized as follows:

- Limitations on source water quality conditions concerning fecal coliform concentrations and turbidity levels;

- Site-specific conditions concerning disinfection;
- Maintaining a watershed control program which minimizes the potential for *Giardia lamblia* cyst and virus contamination in the source water;
- An annual on-site inspection to assess the watershed control program and disinfection treatment process;
- Conditions for being an identified source of a waterborne disease outbreak;
- Conditions for complying with the MCL for total coliforms; and
- Conditions for complying with specified requirements for total trihalomethanes, haloacetic acids, bromate, chlorite, chlorine, chloramines, and chlorine dioxide.

The regulations for disinfection are presented in 40 CFR 141.72 and are subdivided into disinfection requirements for PWSs that do not provide filtration and those that do provide filtration. The filtration regulations are provided in 40 CFR 141.733. In general, "systems may avoid filtration if they have low coliform and turbidity in their source water and meet other site-specific criteria. Systems that do not meet these criteria must install one of the following filtration treatments: conventional filtration treatment or direct filtration; slow sand filtration; diatomaceous earth filtration; or another filtration if the state determines that, in combination with disinfection, the proper amount of *Giardia* and virus removal and/or inactivation is achieved" (EPA, 2003b).

As stated above, the LT1ESWTR affects those PWSs that use surface water or GWUDI (Subpart H system) serving fewer than 10,000 persons. The regulations governing this rule are meant to improve control of microbial contaminants and prevent increases in microbial risk while systems control for disinfection by products (DBPs) and are presented in 40 CFR 141, Subpart T. The regulations establish requirements for filtration and disinfection that are in addition to Subpart H criteria. The regulations in Subpart T establish or extend treatment technique requirements in lieu of MCLs for: *Giardia lamblia*, viruses, heterotrophic plate count bacteria, *Legionella*, *Cryptosporidium* and turbidity. Management at Subpart T systems must establish a Disinfection Profile and Benchmark. Also, if a Subpart T system plans on making significant changes to its disinfection practices, it must first get approval from the state.

The LT2ESWTR is applicable to all Subpart H systems and is intended to require higher levels of treatment for source waters of lower quality. Depending on the initial monitoring results, systems that filter would be put into groups or "bins." Under the proposed rule, each bin (except the bin for the lowest levels) requires a system to install a treatment technology and sets a monitoring schedule, both based on contamination levels in the source water. Under the proposed rule, some new treatment options could possibly involve watershed control, reducing influent *Cryptosporidium* concentrations, improving system performance, and including additional treatment barriers such as pre-treatment" (EPA, 2003b).

### 3.3.4 Stage 1 and 2 Disinfection Byproducts (DBP) Rules

As discussed in Chapter 2, a disinfectant is any oxidant, including but not limited to chlorine, chlorine dioxide, chloramines, and ozone, that is added to water in any part of the treatment or distribution process and is intended to kill or inactivate pathogenic microorganisms. A DBP is a compound formed by the reaction of a disinfectant such as chlorine with naturally occurring organic material in the water supply. Many of the DBPs are suspected of causing cancer, reproductive and developmental problems in humans (EPA 2003b). The Stage 1 Disinfectants/Disinfection Byproducts Rule (Stage 1 DBPR) was published in December 1998 to reduce the levels of disinfectants and DBPs in drinking water supplies, including byproducts that were not previously covered by drinking water rules. The rule sets MCLs for haloacetic acids (HAA5), chlorite (a major chlorine dioxide byproduct), bromate (a major ozone byproduct), and total trihalomethanes (TTHM). It also set Maximum Residual Disinfectant Levels and Maximum Residual Disinfectant Level Goals for chlorine, chloramines, and chlorine dioxide.

The Stage 1 DBPR affects CWSs and NTNCWSs that add a chemical disinfectant to the water in any part of the drinking water treatment process. Certain requirements apply to TNCWSs that use chlorine dioxide (EPA, 2003b) Systems that use conventional filtration must remove specified percentages of total organic carbon (TOC) using either enhanced coagulation or enhanced softening. The removal requirement depends on the TOC concentration and alkalinity of the source water.

The Stage 2 DBPR builds on the public health protection provided by the Stage 1 DBPR. Along with the proposed LT2ESWTR, it aims to reduce the risks associated with DBPs without increasing the risk of microbial contamination. The rule affects CWSs and NTNCWSs that add a disinfectant other than ultraviolet light or deliver water that has been disinfected (EPA, 2003b).

### 3.3.5 Proposed Ground Water Rule

In addition to regulations guiding surface water treatment, the EPA published the proposed Ground Water Rule in May of 2000. A final rule is expected in late 2006. This rule has the potential to affect small systems that use ground water as a source. The rule proposes periodic sanitary surveys; once every three years for community water systems (CWS) and once every five years for non-community water systems (NCWS). Any deficiencies uncovered during the survey would need to be corrected in 90 days. Sanitary survey methodology would be based on the eight components found in the "Guidance Manual for Conducting Sanitary Surveys of Public Water Systems; Surface Water and Ground Water Under the Direct Influence of Surface Water" (EPA 815-R-99-016). The proposed rule also seeks comment on the use of grandfathered data from surveys used for the Total Coliform Rule (TCR). The proposed Ground Water Rule would also require a hydrogeologic sensitivity analysis for all non-disinfecting ground water systems in order to identify systems that may be prone to fecal contamination (e.g. Karst topography). Source water monitoring would be required for systems that do not treat for 4-log removal of viruses. A system would be required to collect a source water sample within 24 hours of receiving notification of a positive total-coliform sample taken in compliance with the TCR and test the sample for *E. coli*, enterococci or coliphage. Any system deemed hydrogeologically sensitive would be required to conduct monthly monitoring for *E. coli*, enterococci or coliphage. If the deficiency can not be corrected at the source, systems would be required to implement treatment for 4-log removal/inactivation of viruses before or at the first customer. Examples of treatment technologies capable of 4-log virus removal include: chlorination, chloramination, and ultraviolet radiation. Systems serving 3,300 or less people would be required to monitor disinfectant levels via daily grab samples.

### 3.3.6 Methyl Tertiary Butyl Ether (MTBE)

MTBE is a chemical compound that is manufactured by the chemical reaction of methanol and isobutylene. It is a gasoline additive (used to help prevent engine "knocking") that can leak into the environment wherever gasoline is stored, transported, or transferred. MTBE has been used at higher concentrations in some gasoline to fulfill the oxygenate requirements set by Congress in the 1990 Clean Air Act Amendments. A growing number of studies have detected MTBE in ground water throughout the country; in some instances, these contaminated waters are sources of drinking water. Low levels of MTBE can make drinking water supplies undrinkable due to its offensive taste and odor (Squillace et al., 2000).

Most human health-related studies have so far focused on the effects of inhaling MTBE. Researchers have limited data regarding the health effects MTBE may have on a person who ingests it. EPA's Office of Water has concluded that available data are not adequate to estimate potential health risks of MTBE at low exposure levels in drinking water but that the data support the conclusion that MTBE is a potential human carcinogen at high doses. Recent work by EPA and other researchers is expected to help determine more precisely the potential for health effects from MTBE in drinking water (EPA, 2003c).

MTBE is also on the EPA's CCL and the EPA is continuing to study both the potential health effects and the occurrence of MTBE. Beginning in 2001, the EPA required (under the Unregulated Contaminants Monitoring Rule-UCMR) all large drinking water systems and a representative sample of small systems to monitor for MTBE and report their findings.

### 3.3.7 Radionuclides

The EPA began regulating radionuclides in 1976, as interim regulations under the authority of the SDWA of 1974. On December 7, 2000, the EPA issued the Radionuclides Rule, which refined the legally binding requirements for radionuclides set forth in the 1986 SDWA Amendments. The Radionuclide Rule took effect on December 8, 2003, setting MCLs as well as monitoring, reporting, and public notification requirements for radionuclides. Under this rule, all systems must complete initial monitoring for radionuclides by December 31, 2007. States will determine initial monitoring requirements during this 4-year initial monitoring period.

Radionuclides generally enter drinking water through the erosion or chemical weathering of naturally occurring mineral deposits, although human activity (such as mining, industrial activities, or military activities that use or produce man-made radioactive materials) can also contribute to their presence in water (EPA, 2002d).

There are three basic kinds of high-energy radiation: alpha, beta, and gamma. The EPA has set limits (i.e. MCLs) for four groupings of radionuclides: alpha particles, beta particles and photon emitters, Radium-226 and Radium-228 (combined), and uranium (EPA, 2002d).

The Radionuclides Rule changed monitoring requirements for small drinking water systems by requiring monitoring at each entry point to the distribution system (EPTDS), rather that just monitoring at a "representative" point in the distribution system. It may be possible to reduce the frequency of monitoring at each EPTDS based on the initial sample results. The following table (Table 3.1) shows the reduced monitoring frequencies.

*Table 3.1 Reduced monitoring for radionuclides (EPA, 2002d).*

| If the initial monitoring results are: | Monitoring frequency is reduced to: |
|---|---|
| < Defined detection limit | 1 sample every 9 years |
| > Defined detection limit, but less than or equal to ½ the MCL | 1 sample every 6 years |
| > ½ the MCL, but less than or equal to the MCL | 1 sample every 3 years |
| > MCL | Quarterly samples |

Systems with EPTDS on a reduced monitoring schedule (i.e., collecting 1 sample every 3, 6, or 9 years) can remain on that reduced schedule so long as the most recent sample results support that monitoring schedule. An increase in a radionuclide level at an EPTDS may increase the frequency of monitoring for that radionuclide at that sampling point. If an entry point result is above the MCL while on reduced monitoring, the system operator must begin to take quarterly samples in the next quarter. Quarterly sampling must continue until four consecutive quarterly samples are below the MCL" (EPA, 2002d)

Unless told otherwise by the state, a system which uses an intermittent source of supply (i.e., a source that is used seasonally) or that uses more than one source and that blends water from more than one source before distribution, must sample at an EPTDS during periods of normal operating conditions. Normal operating conditions include when water is representative of all the sources being used. (EPA, 2002d)

There are several ways that small systems with high levels of radionuclides can protect their customers, including: source water changes, water blending, consolidation, and treatment (EPA, 2002d). Treatment to lower the levels of radionuclides in drinking water will be necessary if the source water contains high levels of radionuclides and an alternative source is not available or switching sources is cost prohibitive. A listing of the best available technologies (BATs) and small system compliance technologies (SSCTs) for removing radionuclides from water is provided by EPA (EPA, 2002d). Additionally, information on complying with the Radionuclide Rule is also provided by EPA (EPA, 2002e).

## 3.4 Source Water Assessments

Source water is water in its natural state, prior to any treatment for drinking. The water may come from rivers, lakes, or underground aquifers used to supply private wells and PWSs. Source water is vulnerable to contamination by (EPA, 2003d):

- Surface water – runoff (from surface areas in a watershed, either near a drinking water supply intake or in upstream tributaries) and ground water infiltration (recharge streams or lakes)
- Ground water – infiltration from the surface, injection of contaminants through injection wells (including septic systems), or by naturally occurring substances in the soil or rock.

Source water may contain many different contaminants prior to treatment, such as:

- microbial contaminants (viruses and bacteria, primarily from human and animal wastes),
- inorganic contaminants (salts and metals),
- pesticides and herbicides,
- organic contaminants (including synthetic and volatile organic chemicals), and
- radioactive contaminants.

Contaminated source water can be very costly to a community and state, both economically and public health-wise, as the burden falls to the community to solve the problem. "Reducing the threat of waterborne illnesses helps save hundreds of millions of dollars annually by eliminating costly health care expenses, lost wages, work absences, decreased job productivity, and additional treatment costs incurred by PWSs required to meet federal drinking water quality standards" (EPA, 2002f). In the long term, it is much more economical to protect source water from contamination than it is to treat contaminated water or find a new source. Source water protection is also the first line of defense in preventing waterborne illnesses. "The government regulates land-use and the construction-location(s) of water treatment facilities to control potential source(s) of pollution from contaminating source water" (EPA, 2003e).

The 1996 Amendments to the SDWA (Section 1453) placed a new focus on source water protection, requiring each state to develop and implement a Source Water Assessment Program (SWAP). Indian tribes are not explicitly required by the amendments to implement SWAPs; however, the EPA recommends such implementation. Source water assessment is unique to each water system which provides basic information about the water used to provide drinking water. These assessments identify the area of land that most directly contributes the raw water used for drinking water, and identifies the major potential sources of contamination to drinking water supplies. The information gathered can then be used to determine how susceptible the water system is to contamination. The State Source Water Assessment and Protection Programs Guidance, Final Guidance (EPA, 1997) provides implementation guidance for State SWAPs and Source Water Protection (SWP) Programs. This document also defines the goals for SWAPs as follows: "to provide for the protection and benefit of public water systems and for the support of monitoring flexibility." SWAPs are further discussed in Section 4.3.

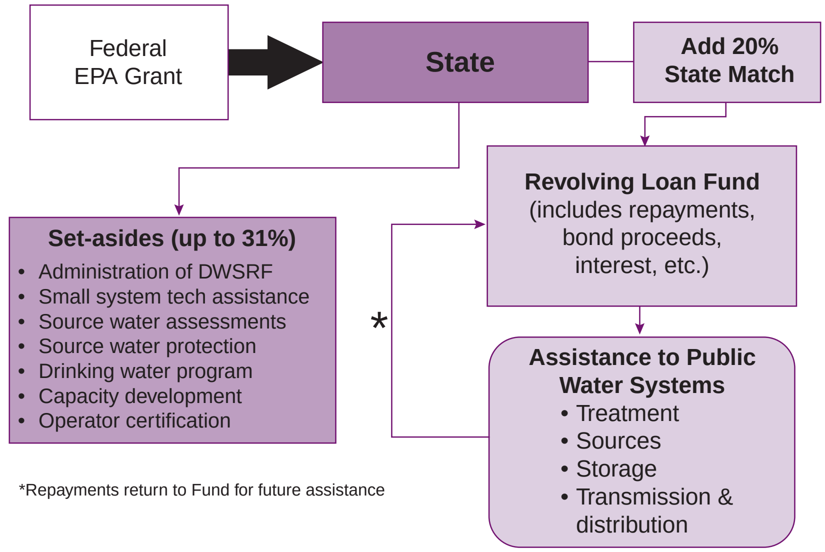


*Figure 3.1 Structure of the DWSRF program (EPA 2003f).*

## 3.5 Wellhead Protection

The 1986 Amendments to the SDWA, specifically Section 1428, strengthened the regulations governing ground water protection by requiring each state to develop and implement a Wellhead Protection Plan (WHPP). The SDWA requires that every state wellhead protection plan address the following areas of concern (Thompson et al., 1997):

- The roles and duties of state and local governments and public water suppliers with respect to the development and implementation of a wellhead protection plan for a public water supply.
- Acceptable criteria and methodologies for delineation of Wellhead Protection Areas (WHPAs) for each wellhead based on reasonably available hydrogeologic data and other information.
- Identification and risk assessment of contaminant sources within each WHPA, including all potential sources that may have an adverse health impact.
- Management approaches that may include technical assistance, financial assistance, implementation of control measures, education, training, and demonstration projects.
- Development of contingency plans for PWSs indicating the location of alternate drinking water supplies in the event of well or well-field contamination.
- Recommendations for proper siting of new wells to minimize potential contamination.
- Development of processes to ensure public participation.

State WHP Programs vary greatly. For example, some require CWSs to develop management plans, while others rely on education and technical assistance to encourage voluntary action. WHPPs are the foundation for many of the state SWAPs required under the 1996 SDWA amendments.

Despite the obvious need for source water protection, just 28 percent of the smallest systems and only 50 percent of systems serving 10,000 or more persons participate in some form of source water or wellhead protection program. Some small systems might be less likely to adopt wellhead protection or SWP programs than larger systems because they lack the technical and financial resources to implement and manage such programs (EPA, 1999).

## 3.6 Vulnerability Assessments (VA), Emergency Planning and Security

The Public Health Security and Bioterrorism Preparedness and Response Act of 2002 (Bioterrorism Act) amended the SDWA by adding Section 1433 (Public Law 107-188). The Bioterrorism Act required every community water system that serves a population of greater than 3,300 persons to conduct a vulnerability assessment and to develop an Emergency Response Plan (ERP). Chapter 8 presents further information on VAs, ERPs and other security related information.

## 3.7 Variances and Exemptions

PWSs can request variances or exemptions from the primacy agency. Variances and exemptions allow PWSs to not meet a specific drinking water standard while continuing to protect public health to the maximum extent possible. They are identified and defined in the SDWA. The following subsections present a brief overview of these allowances. A more detailed summary of variances and exemptions specific to small systems may be found in Variances and Exemptions for Small Drinking Water Systems (EPA, 1998).

### 3.7.1 Small System Variances

Section 1415(e) of the SDWA authorizes the Administrator i.e., EPA (for states that do not have primary enforcement responsibility) or a state (for states that do have primary enforcement responsibility) to issue variances from the requirement to comply with MCLs or treatment techniques to systems serving fewer than 10,000 persons.

States exercising primary enforcement responsibility may grant a small system variance to PWSs serving 3,300 or fewer persons without EPA approval, but must receive EPA approval to grant a small system variance to PWSs serving more than 3,300 persons but fewer than 10,000 persons. 40 CFR 142.312 specifies what EPA action is necessary when a state proposes to grant a small system variance to a PWS serving a population of more than 3,300 and fewer than 10,000 persons. A small system variance is not available for microbial contaminants or for contaminants regulated prior to 1986 (if the EPA revises a pre-1986 MCL making it more stringent, then a small system variance could be granted but only up to the pre-1986 MCL).

In order to obtain a small system variance, it must be determined that the PWS cannot afford to comply with the NPDWR (in accordance with state criteria or, for states that do not have primary enforcement responsibility, with the EPA established criteria). According to 40 CFR 142.306, this includes:

- Treatment;
- Alternative sources of water supply;
- Restructuring or consolidation changes, including ownership change and/or physical consolidation with another public water system; or
- Obtaining financial assistance pursuant to Section 1452 of the SDWA or any other federal or state program.

Another requirement for obtaining a small system variance is that the PWS must meet the source water quality requirements for installing the small system variance technology developed pursuant to guidance published under Section 1412(b)(15) of the SDWA. The PWS must also be financially and technically capable of installing, operating and maintaining the applicable small system variance technology. The terms and conditions of the small system variance must ensure adequate protection of human health, taking into consideration the quality of the source water and the removal efficiencies and expected useful life of the small system variance technology. 40 CFR 142.307 specifies the terms and conditions that must be included in a small system variance.

Notice of a proposed small system variance must be provided to all persons served by the PWS at least 15 days prior to the date of proposal and at least thirty days prior to a public meeting to discuss the variance. The state or EPA will decide who does the notifying (i.e. state, EPA, or PWS). Also, a state or the EPA must hold at least one public meeting on the variance no later than 15 days after the variance is proposed.

Any person served by the PWS may obtain an EPA review of a state proposed small system variance by petitioning the EPA to object to the granting of a small system variance. The petition must be submitted within 30 days after a state proposes to grant a small system variance for a PWS. The Administrator has 60 days (from petition receipt) to respond.

40 CFR 142.311 specifies what procedures allow the EPA to object to a proposed small system variance or overturn a granted small system variance for a PWS serving 3,300 or fewer persons. Periodically EPA must review each state program to determine if state-granted small system variances comply with the requirements of the SDWA, 40 CFR 142.313, and the affordability criteria developed by the state.

### 3.7.2 Exemptions

For granting an exemption, the state or EPA must determine whether management or restructuring changes (or both) would improve water quality or achieve compliance. Additionally, a schedule for compliance must be developed when granting an exemption. Schedules for compliance must include “increments of progress” (retained from old law) or “measures to develop an alternative source of water supply” (new law). A system is not eligible for an exemption if the system receives a small system variance. The period of an exemption is lengthened from 1 year (old law) to 3 years. Eligibility for renewable exemptions is expanded from systems serving fewer than 500 service connections (approximately 1500 persons) under the old law, to systems serving fewer than 3,300 persons.

Renewals are limited to a total of 6 years (SDWA 1416 Sec. 117).

In granting exemptions, a state may consider whether a community may be defined as “disadvantaged” for the purpose of receiving Drinking Water State Revolving Funds (DWSRF), or whether DWSRF funds are reasonably likely to be received. If qualified, the community (PWS operator) may receive funding that can be used improve the infrastructure to meet the drinking water standards. The DWSRF is further discussed in Section 3.8.

## 3.8 DWSRF

The 1996 SDWA Amendments addressed the problem many PWSs were facing; a lack of funding for infrastructure improvements that would enable systems to comply with NPDWS and protect public health. The SDWA Amendments created the DWSRF which makes funding available to PWSs to finance infrastructure improvements. EPA provides these funds to states in the form of capitalization grants; states, in turn, provide low-interest loans to drinking water systems (EPA, 2002g). The DWSRF program encourages states to develop long-term sources of drinking water infrastructure funding. States that do not meet certain requirements are subject to withholding of a portion of their DWSRF allotment. EPA provides capitalization grants to states based on the DWSRF allotment. States must annually prepare “intended use plans” (IUP) as part of their DWSRF capitalization grant application. IUPs identify eligible projects and their priorities based primarily on three criteria:

- Projects that address the most serious human health risks;
- Projects that ensure or maintain compliance; and
- Projects that assist systems with greatest economic needs.

Public involvement in developing the IUP is mandated. Figure 3.1 shows the overall structure of the DWSRF program.

As Figure 3.1 shows, a state may set-aside up to 31 percent of its capitalization grant for other eligible drinking water program related activities. Of this set-aside, the state may use (EPA, 2003f):

- Up to 4 percent for administering the DWSRF and/or providing technical assistance
- Up to 10 percent for source water protection, capacity development, and operator certification programs, as well as for the state’s drinking water program.
- Up to 15 percent (but no more than 10 percent for any one purpose) for projects in water systems, including source water protection loans, technical and financial aid for capacity development, source water assessments, and wellhead protection.
- Up to 2 percent for technical assistance for water systems serving fewer than 10,000 people.

Referring to set-asides, the EPA report to congress (EPA, 2003f) states “Nationally, states have reserved approximately 16 percent of federal grants for these purposes, although on an individual state basis the amount reserved has ranged from 7 to 31 percent. Through state FY 2001, states had expended 43 percent of the $576 million in funds they reserved to conduct set-aside activities.” In this report, EPA also expressed concerns about slow progress in expenditures of set-asides, but expenditures have increased from 9 to 42 percent from state FY 1998 through 2001.

States must make funds available to small systems and can establish provisions for disadvantaged community assistance as part of their DWSRF programs. Through its disadvantaged assistance program, a state may provide additional subsidies such as principal forgiveness, or extend loan repayment periods for up to 30 years. The DWSRF program also encourages the use of funds for programs that use pollution prevention to ensure safe drinking water (EPA, 2002g).

## 3.9 Key Questions

- What are the most crucial areas of research for small systems with regard to regulations that have already been promulgated? (e.g. radionuclides, arsenic, residual disposal?)
- What contaminants on the CCL should WSWRD researchers focus on with respect to treatment, distribution system issues, and source water protection?
- How can research help small systems to comply with the LT2ESWTR (e.g. source water monitoring costs)?

## 3.10 References

All references to Code of Federal Regulations (CFR) Documents in this chapter may be found at http://www.access.gpo.gov/nara/cfr and Federal Register Documents may be found at http://www.gpoaccess.gov/fr/index.html

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# Chapter 4
# Source Water Issues

## 4.1 Background

PWSs derive their source water from both ground and/or surface water. Most (over 90%) systems use ground water as their source of drinking water; however, the majority of people (65%) are served by PWSs that use surface water as their source (EPA, 2005). Source water is untreated water from streams, rivers, lakes, or aquifers which is used to supply private wells and public drinking water systems. Most public and some private well drinking water is treated prior to delivery to our homes. While some treatment is usually necessary, the treatment costs and public health risks can be reduced by ensuring that source water is protected from contamination.

Contaminated source water can cause both acute and chronic health effects if consumed without proper treatment. Acute health effects are immediate effects that may result from exposure to certain contaminants such as pathogens (e.g. viruses, bacteria, parasites, protozoa or cysts), organic chemicals (e.g. pesticides), and/or inorganic chemicals (e.g. arsenic) that may be in source water. Sources of contaminants that cause acute health effects include industry, animal feeding operations, agriculture, septic systems, and cesspools. Chronic health effects are the possible result of exposure over many years to a drinking water contaminant at levels above its maximum level established by EPA. Sources of contaminants that cause chronic health effects include industrial and commercial activities, agriculture, landfills, surface impoundments, and urban activities.

Long-term exposure to contaminants such as volatile organic chemicals, inorganic chemicals, or synthetic organic chemicals can result in chronic health effects including birth defects, cancer, and other long-term health effects.

Considerable information about source water protection is already available, much of it from EPA. This chapter presents a strategy for small systems source water research based on the EPA ORD's Multi-Year Plan, descriptions of source water assessment and protection tools, and problems and solutions for building sustainable community water systems.

## 4.2 Drinking Water Research Program Multi-Year Plan

The scientific questions associated with source water protection encompass a broad range of issues. Source water protection is a component of other ORD research programs, although the protection of drinking water quality may not be their primary goal. The water industry has an active research program in source water protection. ORD's drinking water research program is therefore focused on areas that are not being fully addressed by other means and that match ORD's technical capabilities.

The Drinking Water Research Program Multi-Year Plan (EPA, 2003) presents ORD's proposed research in source water issues over the next 5 to 8 years. Many of these issues are broad in scope and are intended to apply to all PWSs. The source water program goals focus on the protection of the source water supply, including both surface and ground water. Because most of small CWSs use ground water as their source, programs that address ground water have the potential to have the greatest benefit to small community water systems. The plan establishes long-term goals and research projects that are discussed in the following sub-sections.

### 4.2.1 Long-Term Goals

Annual Performance Goals (APGs) for source water protection from FY 2006 to 2009 are designed to assist decision makers at the national, state and local level by providing tools and information that contribute to more effective management practices. Annual Performance Measures (APMs) include reports that describe how to better assess the vulnerability of watersheds, how to detect specific contaminants and other changes in water quality using improved diagnostic tools, and how to more effectively manage different types of contamination problems. Potential areas of additional research include:

- Source water assessment and protection, with a focus on such areas as reducing impacts of septic systems and other non-point sources, wet weather flow and the development of real-time monitoring systems.
- Expansion of the new program on molecular technologies for screening, prioritizing and monitoring contaminants of concern. This would have applications for risk assessment (e.g., to support hazard evaluations), risk management (e.g., to monitor water sources), and research planning in general.

### 4.2.2 Ongoing and Future Research

Research projects have been developed specific to source water assessments. These are applicable to drinking water systems of all sizes and source water, but several will benefit small community water systems that do not have the resources to complete this type of work.  Specific projects include the following:

- Report on siting of wells and operations to control arsenic.
- Report on the use of geochemical data to manage risks to public water supply wells from arsenic contamination.
- Report on early warning upstream monitoring network to protect source waters.
- Report on the role of municipal sewage effluents in contributing to the occurrence of enterohemorrhagic Escherichia coli in watersheds.
- Assessment of Best Management Practices (BMPs) for atrazine in rural watersheds.
- Optimization of BMPs design/location for atrazine.
- Final report on the characterization of *Cryptosporidium* and *Giardia* in combined sewer overflows (CSOs).
- Biosensor evaluation and demonstration as a tool to protect source waters.
- State-of-the-science report for on-site sewage management and septic systems technology.
- Placement of BMPs in urban watersheds to meet water quality goals.
- Watershed boundary condition identification.
- Report on modeling and placement of structural BMPs as a source water protection approach.
- Report on molecular microarrays for detection of non-pathogenic bacteria and bacterial pathogens in drinking water source waters.
- State-of-the-science report on real time early warning systems for source water protection.
- Determine the fate and transport of Nitrosodimethyl Amine and other disinfection byproducts in aquifer and large multiple-use source waters.
- Evaluate the effectiveness of selected structural BMPs to help macronutrient balances and sediments in source water turbidity, algae, taste and odor.

By 2009, EPA plans to provide data, tools, and technologies to support management decisions by the Office of Water, state, and local authorities to protect source waters.

## 4.3 Source Water Assessments

Under the SDWA, states are required to develop comprehensive Source Water Assessment Programs (SWAPs) that will:

- identify the areas that supply public drinking water;
- inventory contaminants and assess water system susceptibility to contamination;
- inform the public of the results.

States are required by the SDWA Amendments of 1996, Sections 1453 and 1428(b), to complete a source water assessment for each public water system PWS. These assessments can be done for each system or on an “area-wide” basis involving more than one PWS.

A source water assessment provides important information for carrying out protection programs.  This “know your resource and system susceptibility” part of protection involves identifying the land that drains to the drinking water source and the most prominent potential contaminant risks associated with it.  To be considered complete, a SWAP must include various elements described in the following sub-sections (EPA, 1997).

### 4.3.1 Delineation

The source water protection area should be delineated in accordance with wellhead protection methods. Sometimes, it may be necessary to delineate source water protection areas either inside of or in addition to typical wellhead protection areas.  A wellhead protection area is the surface and subsurface area surrounding a well or well field though which contaminants can reach a water supply.

### 4.3.2 Contamination Sources

Community groups can become especially involved in the second step of an assessment: identifying potential sources of pollutants that could contaminate the water supply.  This inventory usually results in a list and a map of facilities and activities within the delineated area that may release contaminants into the ground water supply (for wells) or the watershed of the river or lake (for surface water sources).

Some examples of the many different types of potential pollutant sources include landfills, underground or above-ground fuel storage tanks, residential or commercial septic systems, storm water runoff from streets and lawns, farms that apply pesticides and fertilizers, and sludge disposal sites.

### 4.3.3 Susceptibility Determination

A susceptibility determination refers to a determination of the susceptibility of the water supply to contamination, based on the contamination source inventory and other relevant factors. The susceptibility determination is useful for decisions regarding management of the source water protection area and source water protection activities. The susceptibility determination may be based on:

- Hydrologic and hydrogeologic factors such as ground water or surface water movement;
- Characteristics of the contaminants (e.g., toxicity, environmental fate and transport);
- Characteristics of the potential source of the contaminant (location, likelihood of release, effectiveness of mitigation measures); and
- Other factors such as well intake and well integrity.

The susceptibility determination may be an absolute measure of the potential for contamination of the public water supply, a relative comparison between sources within the source water protection area, or a relative comparison to findings by other assessments.

### 4.3.4 Public Involvement

After a state completes the assessment of a particular water system, it will summarize the information for the public. Such summaries help communities understand the potential threats to their water supplies and identify priority needs for protecting the water from contamination. States will make the assessment summaries available to the public in a variety of ways including: public workshops, making copies available in public libraries and from local government offices or water suppliers, and posting assessment summaries on the Internet. The results of the assessments will also be included in the annual water quality reports that community water systems are required to prepare for their customers.

### 4.3.5 Benefits of Source Water Assessment Plans (SWAPs)

The 1996 Safe Drinking Water Act Amendments has given states access to funding for implementation of SWAPs. With this funding, states are now able to assess areas serving as public sources of drinking water in order to identify potential threats and initiate protection efforts.

Once completed, the source water assessments can be used to focus prevention resources on drinking water protection. EPA strongly encourages linking the source water assessments to implementation of source water protection programs.

### 4.3.6 Source Water Protection

Protection of drinking water at the source can be successful in providing public health protection and reducing the treatment challenge for public water suppliers. Source water quality can be threatened by many everyday activities and land uses, ranging from industrial wastes to the chemicals applied to suburban lawns. Water systems are heavily regulated through the Public Water System Supervision Program, and must respond to this threat to public health with regular water quality monitoring and actions ranging from well closure to expensive treatment. In some cases, source water protection can eliminate or forestall the need to change or modify treatment processes, saving consumers significant money.

## 4.4 Other Source Water Assessment and Protection Tools

Two valuable tools for source water assessment and protection activities include the Sanitary Survey and the Wellhead Protection Program.

### 4.4.1 Sanitary Survey

A sanitary survey is an inspection of all components of a water system from source to tap. The inspection should identify potential sources of contamination and can provide the opportunity for states to conduct source water delineations and assessments, update SWAPs, and follow up on the development of source water protection (SWP) activities. In addition, states could use information collected in source water assessments, whether done separately or concurrently, to enhance sanitary survey information and to identify systems of concern that should receive priority for surveys.

### 4.4.2 Wellhead Protection Program (WHPP)

Wellhead protection (WHP) efforts are significant because many small community water systems use ground water as their primary source of drinking water. Establishing and implementing a local WHP program includes: forming a WHP planning team, delineating a WHP area, identifying potential sources of contamination, choosing management tools, and planning for contingencies.

The public information requirements for the SWP program do not apply to the WHP program. However, throughout its development and implementation, education and outreach are essential to the success of a local WHP effort.

## 4.5 Sustainability of Community Water Systems (CWSs)

A water system must have technical, managerial, and financial "capacity," according to the SDWA. Technical capacity may be defined in terms of three issues: source water adequacy, infrastructure adequacy, and technical knowledge. Source water adequacy is related to the availability of reliable water sources, awareness of source water issues, and should be included a SWAP plan. Source water assessments can provide information directly relevant to determining source water adequacy, and, in turn, building of the infrastructure capacity and an infrastructure capacity development strategy. The technical knowledge of a fully-trained operator, as the on-site professional, requires understanding the benefits of multiple barriers to prevent contamination of drinking water supplies. The technical knowledge of the operator should also include insights into the risks to water supplies from different, potential sources of contamination. The managerial and financial capacities are self explanatory. The three major problems that can potentially impede the sustainability of a CWS include:

- A major source of contamination of drinking water source water from wastewater intrusion from septic systems and/or contaminant spills from industrial activities. It is costly to provide supplemental treatment processes to improve the water quality of contaminated drinking water source waters.
- Seasonal weather changes can result in floods and droughts. Remedies include design options to bypass treatment during rain and storm events and identification of alternative water supplies (including water reuse sources) to increase capacity during droughts.
- Deteriorating collection and distribution systems compromise source water quality and increase the cost of water treatment. Remedies include replacement of collection and distribution systems and the use of point of use systems in homes and businesses.

## 4.6 EPA Source Water Assessment and Protection Programs

The EPA's Office of Ground Water and Drinking Water has extensive information available about source water protection on the Internet at: http://www.epa.gov/safewater/protect.html.

## 4.7 Key Questions

The key scientific questions for source water protection fall into the following categories: (a) water quality criteria; (b) source water assessments; (c) preventative measures to address sources of contamination; and (d) contingency planning. A range of scientific issues exists within each of these categories. Some of the most important questions include (EPA, 2003):

- How adequately do the Ambient Water Quality Criteria (AWQC) that address the major drinking water contaminants protect public health?
- What improved techniques are needed to better define source water characteristics and sources of contamination?
- What are the fate and transport characteristics of certain types of contaminants in surface water and ground water?
- How effective are candidate protection measures (i.e., Best Management Practices) on improving the quality of the source water?
- What are the impacts of sudden increases in source water contaminant concentrations on drinking water treatment performance?
- What early warning and monitoring systems should be developed to alert utility operators of contaminant incursions at the source so that corrective actions might be employed?
- Should source water research focus on ground water for small systems?

## 4.8 References

EPA. State Source Water Assessment and Protection Programs Guidance, Final Guidance, EPA-816-R-97-009, 1997.

EPA. Drinking Water Research Program Multi-Year Plan, available at: http://www.epa.gov/osp/myp/dw.pdf, 2003

EPA. Data & Databases PivotTables, available at: http://www.epa.gov/safewater/data/pivottables.html, 2005

# Chapter 5
# Treatment Processes

## 5.1 Introduction

When the SDWA was reauthorized in 1996, it addressed Small System drinking water concerns and required EPA to assess treatment technologies relevant to small systems serving fewer than 10,000 people. The 1996 SDWA Amendments also identified two classes of treatment technologies for small systems:

- Compliance technologies which may refer to:

1. a technology or other means that is affordable and that achieves compliance with the MCL, and
2. a technology or other means that satisfies a treatment technique requirement.

- Variance technologies which are only specified for those system size/source water quality combinations for which there are no listed compliance technologies (EPA, 1998a).

While variance technologies may not achieve compliance with the MCL or treatment technique requirement, they must achieve the maximum reduction or inactivation efficiency that is affordable considering the size of the system and the quality of the source water. Variance technologies must also achieve a level of contaminant reduction that is protective of public health. Possible compliance technologies include packaged or modular systems and point-of-use (POU) or point-of-entry (POE) treatment units.

The 1996 SDWA Amendments do not specify the format for the compliance technology lists and state that the variance technology lists can be issued either through guidance or regulations. Rather than provide the compliance technology list through rule-making, EPA provided the listing in the form of guidance without any changes to existing rules or the passing of new ones. A sample of this guidance for disinfection technologies is summarized in Table 5.1, which may also be found in:

- Small System Compliance Technology List for the Surface Water Treatment Rule and Total Coliform Rule (EPA, 1998b)
- Small System Compliance Technology List for the Non-Microbial Contaminants Regulated Before 1996 (EPA,1998a)
- Variance Technology Findings for Contaminants Regulated Before 1996 (EPA, 1998c)

## 5.2 Packaged Filtration

Table 5.2 presents a summary of filtration compliance technology for surface water (EPA, 2003), a majority of the EPA WSWRD small systems research has focused on the evaluation of "packaged" filtration and disinfection technologies that are most useful to small system operators. Filtration efforts have focused on evaluating various bag, cartridge and membrane filters. Disinfection techniques evaluated include a variety of onsite chlorine generators and packaged UV/ozonation plants. Details regarding these treatment methods and research are presented in Table 5.2.

*Table 5.1 Surface Water Treatment Rule compliance technologies for disinfection (EPA, 2003).*

| Unit Technologies | Removals: Log *Giardia* & Log Virus w/CT's indicated in ( ) | Comment |
|---|---|---|
| Free Chlorine | 3 log (104) & 4 log (6) | Basic operator skills. Better for larger drinking water systems with good quality source water, low in organics and iron/manganese. Concerns with disinfection byproducts. Storage and handling precautions required. |
| Ozone | 3 log (1.43) & 4 log (1.0) | Intermediate operator skills. Ozone leaks can be hazardous. Does not provide residual disinfection protection for distributed water. |
| Chloramines | 3 log (1850) & 4 log (1491) | Intermediate operator skills. The ratio of chlorine to ammonia must be carefully monitored. Requires long CT. |
| Ultraviolet Radiation | 1 log *Giardia* (80-120) & 4 log viruses (90-140) mWsec/cm2 doses in parentheses 2 | Basic operator skills. Relatively clean water source necessary. Does not provide residual disinfection protection for distributed water. |
| On-Site Oxidant Generation | Research pending on CT values | Basic operator skills. May be inexpensive to procure and operate. Chlorine production rates may vary. |
| Chlorine Dioxide | 3 log (23) & 4 log (25) | Intermediate operator skills. Better for larger drinking water systems. Storage and handling precautions required. |

*Table 5.2 Surface Water Treatment Rule compliance technologies for filtration (EPA, 2003).*

| Unit Technologies | Removals: Log *Giardia* & Log Virus | Comment |
|---|---|---|
| Conventional Filtration and Specific Variations on Conventional | 2-3 log *Giardia* & 1 log viruses | Advanced operator skills required. High monitoring requirements. May require coagulation, flocculation, sedimentation or flotation as prefiltration. Will not remove all microorganisms. |
| Direct Filtration | 0.5 log *Giardia* & 1-2 log viruses (and 1.5-2 log *Giardia* with w/coagulation) | Advanced operator skills required. High monitoring requirements. May require coagulation, flocculation, sedimentation or flotation as prefiltration. Will not remove all microorganisms. |
| Slow Sand Filtration | 4 log *Giardia* & 1-6 log viruses | Basic operator skills required. Most effective on high quality water source. Will not remove all microorganisms. |
| Diatomaceous Earth Filtration | Very effective for *Giardia* (2 to 3-log) and *Cryptosporidium* (up to 6-log); low bacteria and virus removal | Intermediate operator skills required. Good for source water with low turbidity and color. Will not remove all microorganisms. |
| Reverse Osmosis | Very effective, absolute barrier (cysts and viruses) | Intermediate to advanced operator skills required, depending on the amount of pretreatment necessary. Post disinfection required under regulation. Briny waste can be toxic for disposal. |
| Nanofiltration | Very effective, absolute barrier (cysts and viruses) | Intermediate to advanced operator skills required, depending on the amount of pretreatment necessary. Post disinfection required under regulation. |
| Ultrafiltration | Very effective *Giardia*, >5-6 log 7 ; Partial removal viruses disinfect for virus credit) | Intermediate to advanced operator skills required, depending on the amount of pretreatment necessary. Post disinfection required under regulation. |
| Microfiltration | Very effective *Giardia*, >5-6 log; Partial removal viruses (disinfect for virus credit) | Intermediate to advanced operator skills required, depending on the amount of pretreatment necessary. Disinfection required for viral inactivation. |
| Cartridge/ Bag/Backwashable Depth Filtration | Variable *Giardia* removal & Disinfection required for virus Removal | Basic operator skills required. Requires low turbidity water. Disinfection required for viral inactivation. Care must be taken towards end of bag/cartridge life to prevent breakthrough. |

### 5.2.1 Filtration

Source water may contain turbidity, particles, and/or organic material. Filtration is the removal of particulates, and thus some contaminants, by water flowing through a porous media. Filtration is considered to be the most likely and practical treatment process or technology to be used for removal of suspended particles and turbidity from a drinking water supply. Federal and state laws require all surface water systems and systems under the influence of surface water to filter their water. Filtration methods include slow and rapid sand filtration, diatomaceous earth filtration, direct filtration, membrane filtration, bag filtration, and cartridge filtration. The other filtration methods typically use natural filtration media (e.g., granulated media particles such as carbon, garnet, or sand, alone or in combination). Bag and cartridge filtration media are commonly made from synthetic fibers designed with a specific pore size. The type of filter media most suited for an application depends mainly on the impurities present in the source (raw) water. Specifically, the particle size of the impurity present in the raw water typically dictates the type of filter media. The particle sizes of common water contaminants and the filtration devices required for their treatment (or removal) are shown in Figure 5.1.

If the source water contains particle (large size) impurities, prefiltration is generally applied in front of bag or cartridge type filters. Prefiltration removes the larger particulate material from the water stream by using coarse, often back-washable granular media. The prefilters protect the more expensive bag and/or cartridge type units from frequent "fouling." Figure 5.2 shows a picture of a clogged prefilter.

Bag and cartridge filters can be used to remove contaminants down to around the 1-micron particle size (1/10th the size of a human hair). However, a prefilter (such as another bag or cartridge filter of greater pore size) is typically recommended prior to using a submicron filter. Microfiltration is used to remove particles in the 0.5 to 10 micron size range with the membrane acting as a simple sieving device. In ultrafiltration, nanofiltration, and reverse osmosis processes, one stream of untreated water enters the unit but two streams of water leave the unit: one is treated water and the other is reject water containing the concentrated contaminants removed from the water. Microfiltration systems will remove some microbes such as protozoa and bacteria but not viruses. Unlike nanofiltration and reverse osmosis, microfiltration cannot remove calcium and magnesium from water. Ultrafiltration is

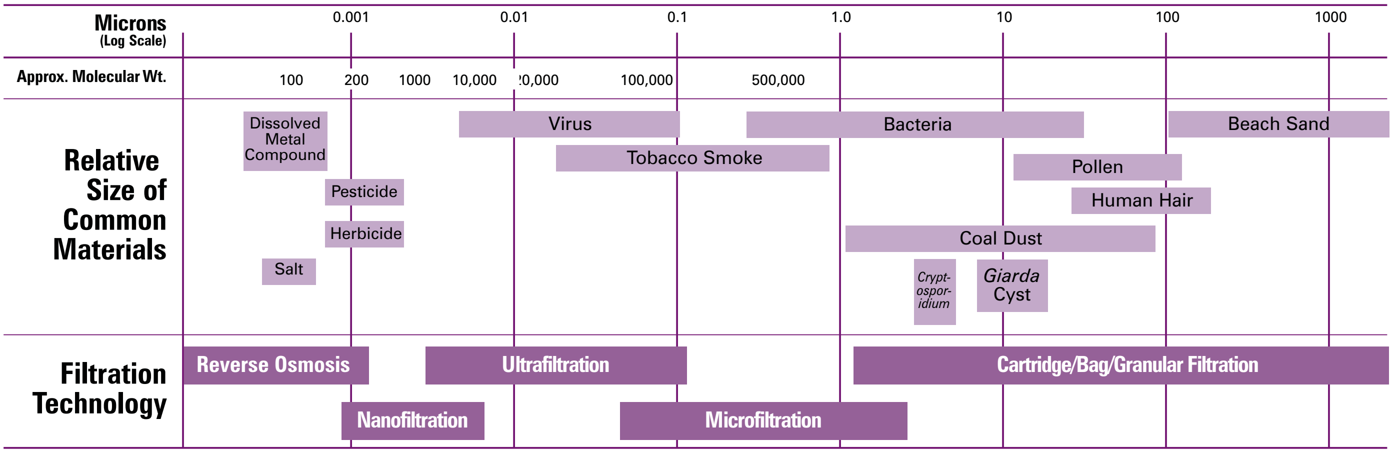


*Figure 5.1 Particle size distribution of common contaminants and associated filtration technology (EPA, 2003).*

used to remove some dissolved material (such as large organic molecules) from water (0.001 to 0.02 micron size range). Most microbial contaminants are removed by ultrafiltration including bacteria, protozoa, and the larger virus sizes. Nanofiltration is used to remove particles in the 0.001 to 0.002 micron size range, polyvalent ions, and smaller organic molecules (down to a molecular weight of about 200–500 daltons). Reverse osmosis (RO) can remove most contaminants dissolved in water including arsenic, asbestos, protozoa, pyrogens, sediment, and viruses (Craun et al., 1997).

### 5.2.2 Bag Filtration

Bag filtration systems are based on physical screening processes. If the pore size of the bag filter is smaller than the microbe, some removal will occur. Depending on the quality of the raw water, EPA suggests a series of filters, such as sand or multimedia filters followed by bag or cartridge filtration, to increase particulate removal efficiencies and to extend the life of the secondary filter. Bag filters can be used as prefiltration for other filters as well.

*Figure 5.2 Clogged Prefilter (EPA, 2003).*

Bag filters are disposable, non-ridged replaceable fabric units contained either singly in series or parallel or grouped together in multiples within one vessel. The vessels are usually fabricated of stainless steel for corrosion resistance, strength, cleaning, and disinfection. Supply (non-treated or treated) water can be introduced into the vessel from the top, side, or bottom, and flows from the inside of the bag to the outside. Research conducted by EPA has not shown any specific method of water introduction into the vessel to be superior to others (EPA, 2003).

Bag filtration is generally not recommended for use as a single barrier to remove parasites such as *Cryptosporidium*. However, it can be used as a pretreatment step before cartridge filtration to remove large particles and high levels of turbidity to improve parasite removal. The water can then be polished or treated to remove any remaining microbial or bacterial contaminant (EPA, 2003). For smaller systems that have a very high quality of source water, such as ground waters under the influence of surface waters, bag filters may serve as an effective single barrier against parasites such as *Cryptosporidium*. In an EPA sponsored Environmental Technology Verification (ETV) study conducted by NSF, a log removal range between 1.9 and 3.7 was observed for similar sized micro-sphere particles. Micro-spheres of 3.7 µm and 6.0 µm size were selected for testing due to their similarity in size to *Cryptosporidium* oocysts and *Giardia* cysts, respectively. The source water characteristics for this testing were: turbidity average 0.75 NTU, pH 7.1, and temperature 12.1°C (NSF, 2001).

### 5.2.3 Cartridge Filtration

Cartridge filtration is a technology suitable for removing microbes and reducing turbidity. These filters are easy to operate and maintain, making them suitable for treating low-turbidity water. They can become fouled relatively quickly and must be replaced with new units. Although these filter systems are operationally simple, they are not automated and can require relatively large operating budgets. A disinfectant may be recommended to prevent surface-fouling via microbial growth on the cartridge filters and to reduce microbial pass-through.

Cartridge filters are rigid cores (usually poly vinyl chloride-PVC) with surrounding deep-pleated filter media. Cartridge filters housings are generally made of stainless steel or fiberglass-reinforced plastic for chemical resistance. The filters are available in various pore sizes and materials depending on the intention of filtration and the source water quality. The filter media are typically constructed of polypropylene or polyester but may be of other fibers for specific applications. The pore sizes available may vary by vendor and material, but are typically 100, 50, 25, 10, 5, and 1 micron. Cartridge filters may be disposable or washable, depending on the material and vendor. Depending on the inlet water quality, flow rate, and filter pore size, a filter may last from one hour to longer than a month. If inlet water quality is poor, a pre-filtration step may be best to reduce filter changes and minimize cost. This can be achieved by using one cartridge filter system with a 50 or 25 micron filter for pre-filtration, followed by another cartridge filter system with a 5 or 1 micron filter for finer filtration (EPA, 2003).

Like a bag filter, one of the most cost-effective benefits of the cartridge filter is that it is commonly used without costly chemical additions such as those used in coagulation and flocculation. Like bag filtration technology, cartridge filters are designed for protozoan, parasite, or oocyst capture. These filters have “absolute” pore sizes designed and engineered into them that are reported to be uniform to contain and capture oocysts, protozoans, or parasites. At the same time, these filters permit bacteria, viruses, and fine colloids to pass through, depending on the pore size (EPA, 2003).

### 5.2.4 Membrane Filtration

Membranes act as selective barriers, allowing some contaminants to pass through the membrane while blocking the passage of others. Membranes may be made from a wide variety of polymers consisting of several different materials for the substrate, the thin film, and other functional layers of the membranes. The thin film is typically made from materials like cellulose acetate that have tiny pores that allow the passage of water while blocking bigger molecules (EPA, 2003).

The movement of material across a membrane typically requires water pressure as the driving force. There are four categories of pressure-driven membrane processes: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and RO. Membrane filters (such as MF and UF) act as sieves, much like the bag and cartridge filters, just with smaller pore sizes (0.003 to 0.5 microns). Other membrane systems, NF and RO, actually block contaminants dissolved in water down to the molecular level. RO and NF processes are typically applied for the removal of dissolved contaminants, including both inorganic and organic compounds (EPA, 2003).

### 5.2.5 Ultra Filtration (UF)

UF systems have shown to be effective for the removal of pathogens, while being affordable for small systems. UF is one of many processes used to remove particles and microorganisms from water. The UF technology falls between NF and MF on the filtration spectrum. Systems may be designed to operate in a single pass or in a recirculation mode.

UF systems are operated by pumping water through a recirculation loop containing the membrane housing, and through several membranes, which are usually positioned in series. The UF membranes are usually large cartridges that can range in pore size from 0.003 to 0.1 microns. They are usually constructed of plastic material. These can be hollow-fiber or spiral-wound membranes. The membranes are also classified by pore diameter cut off (PDCO) which is the diameter of the smallest particles that are retained by it, typically in the range of 0.1 to 10 microns. UF is used for the separation of large macromolecules such as proteins and starches in other industry sectors. Sometimes, UF membranes are classified by the molecular weight cut off (MWCO) number. MWCO is defined as the molecular weight of the smallest molecule, 90% of which is filtered by the membrane. The range of UF systems typically spans between 10,000 to 500,000 MWCO (EPA, 2003).

## 5.3 Disinfection

Disinfection is the process used to reduce the number of pathogenic microbes in water. The Surface Water Treatment Rules require PWSs to disinfect water obtained from surface water supplies or ground water sources under the influence of surface water (EPA, 1989). The Ground Water Rule requires PWSs to disinfect their well water supplies. As shown by the MCL and M/R violations of the SDWA and its amendments over the years, small systems are either (1) unable to simply disinfect their water or (2) record and submit their data to the appropriate state agency. Typically, some form of chlorine is used as a disinfectant; more recently, ultraviolet (UV) radiation, ozonation (O3) or a combination of UV/O3 technologies are being used for disinfection.

On-site ozone generating equipment is costly compared to other disinfection technologies. The effectiveness of the forms of chlorine and ozone in killing micro-organisms (i.e., biocidal efficiency) varies with the type of micro-organism and the water quality conditions (such as pH). The relative effectiveness of chlorine and ozone in killing microbes and the stability of each disinfectant are summarized in Table 5.3.

The use of UV light as a mean for water disinfection has been a proven process for many years. The benefit of the UV disinfection process is that it does not use any chemicals and is effective for *Cryptosporidium* inactivation. However, residual disinfection via UV (to account for contamination via the distribution system) is not possible.

The optimum amount of disinfecting agent needs to be used to achieve appropriate disinfection and minimize DBP formation. Currently, the regulated DBPs in the United States are total triaholmethanes (TTHMs) with a MCL of 80 parts per billion (ppb). However, the practice of chlorination for pre-oxidation or for disinfection purposes can result in the formation of chlorinated organic by-products. The Stage 1 DBP Rule will result in the regulation of several other by-products of chlorination such as haloacetic acids (HAA5) to 0.060 mg/L, along with a potential reduction in the current trihalomethane (THM) standard of 80 ppb. In some cases, this might result in a change to an alternative pre-oxidant, or disinfectant, use of membranes, or elimination of the use of free chlorine (Pollack et al., 1999). To minimize the formation of DBPs under the SWTR (EPA, 1989) and the Enhanced Surface Water Treatment Rule (EPA, 2002), most utilities are required to filter their water unless the following conditions are met in the surface water prior to disinfection:

- fecal coliform bacteria <20/100 mL in 90% of samples,
- total coliform bacteria <100/100 mL in 90% of samples,
- turbidity <5 Nephelometric Turbidity Units (NTU), and
- other MCLs met.

Treatment plants exempted from filtration must disinfect to achieve 99.99% inactivation of viruses, and 99.9% inactivation of *Giardia lamblia* cysts. For systems that use chlorine for disinfection, compliance with these requirements must be demonstrated with the CT approach (the product of the average disinfectant concentration and contact time). CT values estimated for actual disinfection systems must be equal to or greater than those published in the SWTR Guidance Manual for viruses and *G. Lamblia* cysts (Pollack et al., 1999).

Also, EPA studies have demonstrated that the pliability of *Cryptosporidium* oocysts may permit the pass-through of oocysts through a filtration system thus making disinfection that much more important as a barrier (Li, 1994). Just like large systems, small systems have to be concerned with the safety, ease of handling, shipping, storage, capital costs, and operation and maintenance (O&M) costs associated with the use of appropriate disinfectant technology.

EPA has evaluated several disinfection technologies that are affordable and easy to use from a small systems perspective. A summary of these technologies is presented in the following subsections.

### 5.3.1 Disinfection by Chlorination

The use of chlorine as a disinfectant is commonly accepted worldwide. Chlorination is a popular choice because of its residual disinfection characteristics. Its effectiveness is very simple to test; one needs only to measure the residual chlorine at the point of consumption to ensure proper disinfection.

People are becoming more concerned about the DBPs

*Table 5.3 Summary of disinfectant characteristics relating to biocidal efficiency (Lykins et al., 1990).*

| Disinfectant | Rank[a] | | pH Effects on Efficiency (pH ranges 6-9) |
|---|---|---|---|
| | Biocidal Efficiency | Stability | |
| Ozone | 1 | 4 | Little effect |
| Chlorine dioxide[b] | 2 | 2 | pH increase is beneficial |
| Free Chlorine[b] | 3 | 3 | pH increase is detrimental |

[a]*Ranking: 1 = best, 4 = worst.*
[b]*Ranking influenced by pH.*

of chlorine, and alternatives to chlorine are being investigated. Chlorine reduces bacteria levels, but it also reacts with other organic impurities present in water producing various DPBs which are listed as probable or possible human carcinogens (cancer-causing agents). Other disadvantages of chlorination are undesirable tastes and odors, requirement of additional equipment (such as tanks) to guarantee proper contact time, and extra time to monitor and ensure proper residual concentration level. It also performs poorly in reducing viruses (such as enterovirus and hepatitis A) and protozoa (such as *Cryptosporidia* and *Giardia*) (EPA, 2003).

Chlorine is generally obtained for disinfection in the form of gaseous chlorine, onsite chorine dioxide generators, solid calcium hypochlorite tablets, or liquid sodium hypochlorite (bleach). Gaseous chlorine and onsite chlorine dioxide generators are typically found at larger drinking water systems. Small drinking water systems sometimes use solid calcium hypochlorite, which is typically sold as a dry solid or in the form of tablets for use in proprietary dispensers. This method of disinfection however, is expensive, suitable mainly for low flow applications, and the use of calcium can lead to scale formation. For the most part, small system operators continue to disinfect water using common household liquid bleach or swimming pool chlorine (EPA, 2003).

There are, however, other chlorination processes that small system operators should consider. One such alternative that has been evaluated extensively by EPA's WSWRD is the on-site salt brine electrolysis chlorine generator system. The salt brine solution, together with the electrolytic cell, generates a solution (liquor) of primarily sodium hypochlorous (chlorine) acid. Operators should be aware that some vendors claim that their electrolytic generator enhances pathogen (*Cryptosporidium sp.* and *Giardia sp.*) inactivation by using the combined actions of various mixed oxidant reactions that are generated from the electrolytic cell. The claim is that this mix of oxidants minimizes the formation of DBPs. However, EPA has not been able to demonstrate the presence of any other oxidant (other than sodium hypochlorous acid) generated from these units (EPA, 2003).

### 5.3.2 Disinfection by Ozonation

Ozonation is another disinfection method. Ozone is effective as an oxidizing agent in removing bacteria with a relatively short exposure time. Ozone generators are used to produce ozone gas on site, since the gas is unstable and has a very short life. These generators must be installed and monitored cautiously, because high concentration levels of ozone will oxidize and deteriorate all downstream piping and components. With home ozone systems, leftover ozone must be removed with an off-gas tank to ensure homeowners are not exposed to ozone gas, which is a strong irritant. Ozone reacts with bromide resulting in the formation of highly carcinogenic DBPs including bromate, bromoform, and dibromeacetic acid. In PWSs, UV equipment or biological filters are typically installed to remove ozone residuals prior to filtration (EPA, 2003).

### 5.3.3 Advanced Oxidation Process for Disinfection & Destruction

EPA evaluated a packaged UV/O3 (also referred to as Advanced Oxidation Process or AOP) system for removal of microorganisms. The unit evaluated was capable of processing up to 10 gpm of water and engineered to ensure adequate UV intensity and ozone residuals for AOPs.

The combined UV/O3 system achieved the highest removal rates for bacterial contamination. The UV/O3 disinfection technology is also useful in removing chemical organic contaminants such as MTBE, perchloroethylene, and trichloroethylene (EPA, 2003).

Advanced oxidation processes use oxidants to destroy organic and microbial contaminants in drinking water. Several different oxidants, such as ozone, hydrogen peroxide, and hydroxyl radicals, may be used. EPA evaluated the use of an AOP system comprised of UV/O3 for disinfection potential and MTBE destruction. This effort was intended to investigate if an AOP system could be used to disinfect the water and, at the same time, destroy organic compounds.

Ultraviolet irradiation and ozonation are known to effectively destroy organic compounds in drinking water and other matrices. Thus, in addition to treatment for *Cryptosporidium*, UV/O3 systems have also shown the ability to treat MTBE in drinking water. The combined UV/O3 process showed the best potential for MTBE removal. Complete MTBE removal was observed within a 20 minute reaction time. Several byproducts are generated as a result of MTBE treatment. These by-products include t-butyl alcohol, t-butyl formate, formaldehyde, isopropyl alcohol, acetone, and acetic acid methyl ester (Vel Leitner et al., 1994, Liang, 1999).

In anticipation of the states' needs for innovative and cost-effective small system treatment technology, EPA's WSWRD has focused on the smallest of these systems in the 25-500 population range and on those technologies that are easy to operate and maintain. Alternative treatment systems/technologies (package plants) are perceived as "high tech" and are sometimes more expensive to purchase than state-accepted conventional technologies. However, in many cases, alternative treatment systems/technologies are easier to operate, monitor, service, and less expensive to maintain and service in the long-term (EPA, 2003).

Operators should find a mechanism to filter particles, turbidity or organic material from the source water and should realize that each particle removed by a filter could be a microscopic parasite such as *Cryptosporidium sp.* . Removing particles also allows the disinfectant to be more effective. However, the best option would be to find a good quality source water, i.e., a source water that has very low particle counts, turbidity, or organic material (EPA, 2003).

In anticipation of small system needs in meeting the Stage 1 DBPR, the proposed Ground Water Rule, and the LT1ESWTR, the EPA's WSWRD has investigated alternative technologies focusing on their ability to inactivate *Cryptosporidium* while at the same time being affordable and easy to operate and maintain.

Several guidance manuals are available to assist PWS operators in complying with the Stage 1 DBP Rule. Examples of such guidance manuals include:

- Disinfection Profiling and Benchmarking Guidance Manual (EPA, 1999a).
- Alternative Disinfectants and Oxidants Guidance Manual (EPA, 1999b).
- Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual (EPA, 1999c).

On-site salt-brine electrolysis chlorine generator systems can be very attractive to small system operators, because they are generally safer to handle and operate than chlorine gas or liquid (sodium hypochlorite or calcium hypochlorite) systems. EPA conducted studies to evaluate three different on-site salt brine based chlorine generators and compared them to each other and to liquid bleach. EPA noted a wide variation in prices when purchasing these units. The costs for the three salt-brine generators, designed specifically for small systems, range from $18,000 to $35,000 (depending on the manufacturer). Since most small treatment system operators and facilities have a limited budget, EPA evaluated other avenues and options for the small system operator. As a fourth system, EPA purchased a salt-brine generator from a swimming pool supply company for $750 and added other accessories such as plumbing, a pump, a pressure gauge, flow control and a brine tank for $525 for a total equipment cost of $1,275 (EPA, 2003).

### 5.3.4 Disinfection System Observations

Research on on-site chlorine generators and UV/O3 treatment technologies has resulted in the following observations:

The disinfection capabilities of disinfection systems are a function of dosage and contact time. For the on-site chlorine generators, the chlorine dosage and free residual chlorine are critical performance parameters. For UV/O3 treatment technologies, the UV intensity and ozone dosage are critical performance parameters. For both technologies, a reaction chamber or a contact tank provides a mixing "area" for the disinfecting agent(s) and microorganisms in the water.

On-site chlorine generators are designed to convert salt to chlorine via an electrolytic cell. As a result, the hazards associated with the handling of liquid chlorine are not a concern. Salt is added to the chlorine generator or contact tank in bulk and requires lifting by the operator. Brine concentration levels are critical for proper operation of on-site chlorine generators. The accumulation of salt residue requires maintenance of system tanks and piping.

UV/O3 systems oxidize organics instantaneously. Ozone reacts quickly without leaving a residual disinfectant. UV disinfection is dependent on the intensity of the light contacting the water. As a result, waters with low turbidity and color are preferred for UV treatment. Providing stable ozone dosage and UV intensity is critical for providing consistent disinfection.

Several things can be done to improve UV/O3 system performance. The air dryer dessicant can be replaced on a regular basis to improve ozone generation. Ozone dosage can be improved by increasing the air flow into the ozone generator and optimizing the vacuum at the venturi injector. For optimal performance, the UV/O3 system should be operated as specified by the manufacturer. Alternatively, an oxygen generator can be used to feed the ozone generator; this, however, can be an expensive option.

## 5.4 Sorption Technologies

Sorption is the common term used for both absorption and adsorption. When a substance is incorporated into another substance, the process is called absorption. Adsorption is a surface phenomenon in which the ions and molecules of one substance physically adheres or bonds onto the surface of another molecule. In many cases, it is not always clear which process (or both) is responsible for the removal of a contaminant. Sorption is the preferred term for these processes.

Sorption mechanisms are generally categorized as either physical adsorption, chemisorption, or electrostatic adsorption. Weak molecular forces, such as Van der Waals forces, provide the driving force for physical adsorption, while a chemical reaction forms a chemical bond between the compound and the surface of the solid in chemisorption. Electrostatic adsorption involves the adsorption of ions through Coulombic forces, and is normally referred to as ion exchange, which is addressed separately in the ion exchange modules. Common sorption technologies include ion exchange, activated alumina, iron-based media, and Granular Activated Carbon (GAC) (EPA, 2000).

### 5.4.1 Ion exchange (IX)

IX is a physical/chemical process in which ions held electrostatically on the surface of a solid phase are exchanged for ions of similar charge in a solution (i.e., drinking water). The solid is typically a synthetic ion exchange resin which is used to preferentially remove particular contaminants of concern. Ion exchange is commonly used in drinking water treatment for softening (i.e., removal of calcium, magnesium, and other cations in exchange of sodium), as well as removing nitrate, arsenate, chromate, and selenate from municipal water. Due to its higher treatment cost compared to conventional treatment technologies, IX application is limited primarily to small/medium-scale and point-of-entry (POE) systems.

Anion exchange resins come in two classes, strong-base anion (SBA) and weak-base anion (WBA). The functional groups on the SBA resins are strongly basic and ionized to act as ion exchangers over the pH range of 0 to 13. The WBA resins are useful only in the acidic pH region where the functional groups are protonated to form positively charged exchange sites for anions. Both SBA and WBA resins may be present in the hydroxide or chloride form. Typically, SBA resins are used for arsenic removal because they tend to be more effective over a larger pH range than WBA resins (EPA, 2000).

### 5.4.2 Activated Alumina (AA) and Iron-based Media

AA adsorption is a physical/chemical process by which ions in solution are removed by the available adsorption sites on an oxide surface. AA is porous and highly adsorptive. AA filters a variety of contaminants, including fluoride, arsenic, and selenium. The alumina can be regenerated. AA is usually prepared through dehydration of $Al(OH)_3$ at high temperatures and consists of amorphous and gamma alumina oxide. AA is used primarily in packed beds to remove contaminants such as fluoride, arsenic, selenium, silica, and natural organic matter (NOM). To remove contaminants, feed water is passed continuously through one or more AA beds. When all available adsorption sites are occupied, the AA media may be regenerated with a strong base, NaOH, or simply disposed of. Many studies have shown that AA is an effective treatment technique for arsenic removal. Factors such as arsenic oxidation state (As [III] vs. As[V]), pH, competing ions, and empty bed contact time (EBCT) significantly affect arsenic removal. Other factors affecting the use of the AA process include regeneration practice, spent regenerant disposal, and alumina disposal (EPA, 2000).

The competition for adsorption sites by other ions such as phosphate, silicate, sulfate and fluoride somewhat limits the use of AA. More recently, iron based media such as granular ferric hydroxide (GFH) and zero-valent iron are being used for arsenic removal. Both of these methods involve chemical adsorption of As(III) and As(V) species to iron oxides. In most cases neither media is intended to be regenerated. The spent iron media generally passes the EPA leaching tests. Recent adsorption tests conducted by EPA (EPA, 2001), demonstrate the potential of iron-based media and resins to remove arsenic. In the adsorption testing, the iron-based GFH media have outperformed the AA-based media and IX resin for removal of arsenic over a wide pH range. Although the GFH appears to be more specific than AA for arsenic binding, it also suffers from competitive adsorption of phosphate and silicate. Competitive displacement of arsenic by sulfate is minor. The optimal system design will depend upon the specific treatment scenario and source water quality.

### 5.4.3 Powdered Activated Carbon/Granular Activated Carbon (PAC/GAC)

Activated carbon is carbon that has been exposed to very high temperatures, creating a vast network of internal pores. Two types of activated carbon, granular and powdered, are used widely in drinking water treatment. Powdered activated carbon (PAC), which is frequently used for taste and odor control, is added directly to raw water and removed by settling in sedimentation basins (NDWC, 1997).

PAC and GAC remove many organic contaminants as well as taste and odor from water supplies. GAC removes contaminants through adsorption, primarily a physical process in which dissolved contaminants adhere to the porous surface of the carbon particles. In some cases, the adsorption process can be reversed relatively easily. The ease of reversing adsorption is another key factor in activated carbon's usefulness because it facilitates the recycling or reuse of the carbon (NDWC, 1997).

GAC can be used as a replacement for existing media (such as sand) in a conventional filter, or it can be used in a separate contactor (a vertical steel pressure vessel used to hold the activated carbon bed) (NDWC, 1997).

## 5.5 Lime Softening

Although lime softening has been used successfully by ground water systems serving fewer than 3,000 people, it is unlikely to be suitable for treating ground water in systems serving 500 or fewer people unless those systems have some form of contract or satellite operation that would enable a trained operator to monitor the treatment process. Prefabricated lime softening equipment is available for small systems. Also, there is an American Water Works Association Standard for quicklime and hydrated lime (ANSI/AWWA B202-93) that provides purchasers, manufacturers, and suppliers with the minimum requirements, including physical, chemical, packaging, shipping, and testing requirements (NDWC 1998).

Either hydrated lime [$Ca(OH)_2$] or quicklime ($CaO$) may be used in the softening process. The choice depends upon economic factors, such as the relative cost per ton of the two materials as well as the size and equipment of the softening plant. Hydrated lime is generally used more in smaller plants because it stores better and does not require slaking (producing a chemical change in lime by combining it with water) equipment. On the other hand, quicklime costs less per ton of available calcium oxide and is thus more economical for use in large plants (NDWC, 1998).

Softened water has high causticity and scale-formation potential; hence, recarbonation is employed to reduce pH and mitigate scaling of downstream processes and pipelines. Onsite combustion generation of carbon dioxide ($CO_2$) or liquid $CO_2$ is the most common source of carbon dioxide for recarbonation (NDWC, 1998).

## 5.6 Affordability of Recommended Treatment Technologies and Protectiveness of Public Health by Variance Technologies for Small Systems

Many small system operators have argued that some of the treatment technologies mentioned in this report are simply not affordable to them. The SDWA requires EPA to identify affordable compliance treatment technologies for small systems for each new drinking water standard. EPA must evaluate treatment technologies and their costs for three categories of small systems: systems serving 25 to 500 people, systems serving 501 to 3,300 people and systems serving 3,301 to 10,000 people. If EPA cannot identify affordable compliance technologies for some or all of the systems in these categories, EPA must identify variance treatment technologies that achieve the maximum reduction affordable, and determine if the variance technologies are protective of public health.

EPA currently determines if compliance with a drinking water standard is affordable by comparing the current cost of water plus the estimated additional treatment cost of the new standard to an affordability threshold of about $1,000 (this threshold is calculated by taking 2.5% of the annual median household income (MHI) of ~$40,000 among small systems). Since the small system variance provisions became a part of the SDWA in 1996, EPA has found compliance with all new drinking water regulations to be "affordable" using the 2.5% of MHI criteria for all small systems. As a result, states have not had the ability to grant small system variances. However, evidence suggests that there may in fact be significant numbers of systems that have struggled with compliance costs for some recent regulations.

As part of the 2002 appropriations process, Congress directed EPA to review the methodology by which it evaluates the affordability of drinking water standards for small systems. In response, EPA sought the advice of Science Advisory Board (SAB) and National Drinking Water Advisory Council (NDWAC). The SAB and NDWAC both recommended that EPA consider modifications to its current methodology. Additionally, small system operators have argued that the current criteria are too stringent and fail to recognize situations in which small systems may find a regulation unaffordable. After seven years of experience with the current criteria, EPA agreed that it was time to consider refinements to address the situations of communities with below average incomes and/or above average drinking water and treatment costs.

The SAB and NDWAC made a number of recommendations regarding the method by which EPA evaluates the affordability of compliance with drinking water standards. Some key recommendations made by both the SAB and the NDWAC include: (1) EPA should consider the household cost of each new regulation on an incremental basis rather than a total cost of all water treatment regulations, and (2) EPA should consider reducing the current affordability threshold. The options being considered by EPA are based on a range of income percentages significantly below the current threshold (2.5% of MHI) and are much more likely to make variances available to small drinking water systems. Both SAB and NDWAC reports (listed below) are available online on the EPA website.

- SAB report - Affordability Criteria for Small Drinking Water Systems: An EPA Science Advisory Board Report
- NDWAC report - Recommendations of the National Drinking Water Advisory Council to U.S. EPA on Its National Small Systems Affordability Criteria - July 2003

Even after these variance technologies become available to small systems, the SDWA limits these variance technologies to those that are determined to be "protective of public health." The SDWA does not specify how one makes this determination; however, it is clear from the provisions, that Congress intended that a technology could be considered "protective" for the purpose of SDWA even if the concentration of a contaminant in the treated water was greater than the concentration allowed by the drinking water standard (i.e. a MCL). Subsequently, on March 2, 2006, EPA issued a proposed regulation for small drinking water systems variances that proposed revisions to the existing national-level affordability methodology and the methodology to identify variance technologies that are protective of public health. In this regulation, EPA proposed that a variance technology for future regulated contaminants is considered to sufficiently protective of public health for purposes of the SDWA provision 1412(b)(15) if the concentration of the target contaminant after treatment by the variance technology is no more than three times the MCL. EPA views this 3x level as a general guideline which might be modified for a specific contaminant if unusual factors are associated with the contaminant or if risk assessment suggests that an alternate level, whether higher or lower, was appropriate. In addition, EPA requested comments on a number of questions related to the methodology EPA uses to evaluate the affordability of national primary drinking water regulations. Three of the key issues are:

1. The size of the system EPA should consider as representative of each of the system size categories specified under the SDWA. This question is critical to determining the cost each household must pay for the treatment to comply with a new regulation. Smaller systems have fewer households over which the fixed costs of treatment can be distributed and, therefore, experience higher household costs. EPA specifically asked if the median (or middle sized) or tenth percentile (a system that serves fewer people than 90 percent of the other systems in the category) should be selected as the representative system for the category.
2. The affordability threshold (the maximum cost that is affordable to customers served by small systems). EPA proposed to calculate the affordability threshold by taking a percentage of the MHI among small systems (which as of September 2005 was between $40,000 and $44,000). EPA requested comments on the following three different alternative thresholds:
   - 0.25% MHI ($100 to $110 under Sept. 2005 income estimates)
   - 0.50% MHI ($200 to $220 under Sept. 2005 income estimates)
   - 0.75% MHI ($310 to $330 under Sept. 2005 income estimates)
3. Whether or not EPA should evaluate affordability strictly on a national level, or use a two step process that includes both a national level evaluation of affordability, and a second analysis conducted at the County level. EPA would perform this second step only when the first step found a standard to be affordable at the national level. EPA would evaluate economic data to identify economically disadvantaged areas in the U.S. that cannot afford to comply regardless of the outcome of the national determination.

These methodologies, once finalized, will be applied by EPA in evaluating small system affordability for future drinking water standards with the exception of regulations that address microbial contaminants (including bacteria, viruses, or other organisms) or indicators for microbial contaminants. The law does not allow small system variances for microbial contaminants (SDWA section 1415(e)(b)(B)).

## 5.7 Point-of-Use/Point-of-Entry (POU/POE) Applications

In many cases, small drinking water treatment systems such as POU/POE units may be the best solution for providing safe drinking water to individual homes, businesses, apartment buildings, and even small towns. Such consumers may not have the financial resources, technical ability, or physical space to own and operate custom-built treatment plants. These small system alternatives can be used for not only treating some raw water problems, but are excellent for treating finished water that may have degraded in distribution or storage or to ensure that susceptible consumers such as the very young, very old, or immuno-compromised receive safe drinking water.

The 1996 SDWA Amendments provided that POU/POE units could now be considered a "Final Solution". The 1996 regulations required the POU/POE units to be "owned, controlled, and maintained by the PWS or by a person under contract with the PWS operator to ensure proper operation and maintenance and compliance with the MCLs or treatment technique and equipped with mechanical warnings to ensure that customers are automatically notified of operational problems" (EPA, 1998a). Under this rule, POE devices are considered an acceptable means of compliance because POE can provide water that meets MCLs at all points in the home. It is also possible that POE devices may be cost effective for small systems or NTNCWS. In many cases, these devices are essentially the same as central treatment. In 1998, POU devices were listed as "compliance technologies" for inorganics, synthetic organic chemicals, and radionuclides, but not for volatile organic chemicals.

Basically, the same technology used in treatment plants for community water systems can be used in POU/POE treatment. POU/POE treatment is applied to reduce levels of organic contaminants, turbidity, fluoride, iron, chlorine, arsenic, nitrate, ammonia, microorganisms including cysts, and many other contaminants. Aesthetic parameters such as taste, odor, or color can also be improved with POU/POE treatment (Lykins et al., 1992). Table 5.4 summarizes key features of commonly used POU/POE technologies (EPA, 2003).

### 5.7.1 POU/POE Treatment Cost

The cost and application of POU/POE units as a final solution for a small system or portion of a larger system is highly dependent on the situation. A major factor is whether there is an in-place distribution system versus whether additional treatment must be installed in the existing central system. Approximately 80% of the total cost of any water utility is the installation and maintenance of the distribution system. In cases where a distribution system would have to be installed to treat a contaminated drinking water source, it may be more cost-effective to install POU/POE units (EPA, 2003). An example of this would be a community where each home has a well and it was discovered that the ground water was contaminated with a pesticide, fertilizer, or chemical. Rather than install miles of pipe, pumps, and storage facilities, a small system could get state approval to install and maintain units in each home. This might be economical for upward of 100 homes depending on the cost of the home units versus the amount and difficulty of installing a distribution system and central treatment facility. For those small systems that already have a distribution system in-place, the break-even point could be for fewer home units (< 50). However, in situations where the existing treatment plant could not be economically or physically upgraded or if the water quality is severely degraded while in the distribution system, POU/POE treatment may once again be a practical alternative (Goodrich et al., 1992).

A recent report from EPA (EPA, 2005) on POU/POE systems for As removal in a small rural town (pop. 400) concluded that centralized treatment modifications would result in monthly cost increases of $24.71 per connection. POU/POE unit costs ranged from $11.46 to $18.00 per connection depending on frequency of monitoring and POU/POE cartridge replacement.

### 5.7.2 Use of POU/POE Treatment and Bottled Water in Small Systems

The financial instability of many small PWSs to comply with the SDWA often forces state and local governments to seek alternatives to centralized treatment as sources of safe drinking water. For example, EPA's new arsenic standard of 10 μg/L is expected to affect 5% of CWSs, but 77% of these affected CWSs serve 1,500 or fewer customers. POU treatment, approved by EPA for permanently complying with this drinking water standard, may be an economical alternative for arsenic removal when compared to a centralized treatment for these smaller CWSs. Gurian and Small (2002) studied three (base-case, high-cost, and low-cost) POU scenarios to meet the 10 μg/L arsenic standard by calculating the per-household cost for implementing each POU option. The per-household costs were compared with those of the least-expensive centralized treatment methods for removing arsenic (presented in published studies). The authors found that POU treatment costs varied significantly with the monitoring and maintenance schedule adopted by the CWS; annual arsenic monitoring of each POU device coupled with frequent maintenance and filter replacement increased the POU costs to the point where centralized treatment was more cost-effective. The published costs of centralized treatment, however, also varied significantly, and these discrepancies somewhat masked the economic advantage of POU treatment. Also, the results of this study point out some of the difficulties in designing and running a POU treatment program. For a POU program to be successful, CWS operators must get cooperation from their customers. This POU treatment scenario complexity may discourage CWSs from implementing POU treatment, even when centralized treatment is not cost feasible. In these cases, the authors suggest providing bottled water to customers as a temporary compliance measure.

Bottled water can be considered as a principal alternative source for use in emergencies and/or on an interim (or permanent) basis for small PWSs. Bottled water can serve as a permanent supply of potable water for

*Table 5.4 Key Feature Summary of commonly used POU/POE technologies (EPA, 2003).*

| Technology | Comments |
|---|---|
| Filtration | Filtration and disinfection of water supplies are highly effective public health practices. MF, UF, and RO filtration systems have been shown to be effective technologies for the removal of pathogens while being affordable for small systems. Generally, pore-size of the filtration media determines its effectiveness in teh removal of a specific pathogen. Filtration media such as bags, cartridges and membranes require periodic maintenance and/or replacement. |
| Activated Carbon | Activated Carbon is the most widely used POU/POE systems for home treatment of water. Easy to install and maintain with low operating costs, usually limited to filter replacement. Can remove most organic and some inorganic contaminants. |
| Membranes | Most POU membrane systems are reverse osmosis filters installed under the kitchen sink, typically with either an activated carbon prefilter or an additional UV light disinfection step such as to combat bacteria since the water is often stored under the sink until used. |
| Ion Exchange | Commonly called water softeners when used for removal of calcium and magnesium from water. Other types of units remove anions such as arsenic (arsenate), hexavalent chromium, selenium (selenate), and sulfate. |
| Distillation | Distillation is most effective in removing inorganic compounds such as metal (iron and lead) and nitrates, hardness, and particulates from contaminated water. Distillation also removes most pathogens. The effectiveness of distillation in removing organic compounds varies, depending on the chemical characteristics of the compounds such as water solubility and boiling point. Distilling units have relatively high electrical demands and require about 3 kilowatt-hours per gallon of water treated. |
| Air Stripping or Aeration | Aeration is a proven technology for removing volatile organic chemicals (for example, dry cleaning fluid) from drinking water supplies for POE applications. Aeration systems include: packed tower systems, diffused bubble aerators, multiple tray aerators, spray aerators, and mechanical aerators. Storage, re-pumping, and possibly disinfection facilities are needed after air stripping to distribute treated water. Air stripping is typically used for POE applications where high concentrations of volatile organics have to be removed from drinking water where carbon can be used only for short periods of operation. Radon gas can also be removed by aeration. |
| Modular Slow Sand Filtration | Slow sand filters housed in round fiberglass tanks (approx. 6 ft tall x 2.5 ft in diameter) can treat 400-500 gallons daily. The systems are simple to operate and have low capital (approx. $2,000) and operating costs. The unique feature of this system is a very thin 1/8" thick filter blanket followed by a 1" thick polypropylene filter blanket (similar to a furnace filter) to replace the biological mat that typically grows on top of the sand (schmutzdecke). The blankets can simply be replaced when flow is restricted without losing much sand or significant down-time. |
| Disinfection and Destruction | Disinfection is an important consideration for POU/POE systems. Disinfectants that are usually used in POU/POE systems are ultraviolet light, ozone, chlorine, silver impregnated carbon, and iodine.<br>Chlorine - The most widely used water disinfectant. Can be used in the form of liquid bleach, solid tablets, or generated onsite in portable generators.<br>Ultraviolet Light (UV) - Ultraviolet light is a popular home disinfection method in combination with other treatment techniques. Does not add chemicals that can cause secondary tast and odor problems. Units require little maintenance and overdose is not a danger.<br>Ozone – Ozone has been for disinfection and destruction of iron, manganese, and some chemical contaminants. Ozone has to be generated and used on-site as needed.<br>Iodine – Iodine has been used as an alternate disinfectant to chlorine because it is easier to maintain a residual.<br>Silver impregnated carbon - These units contain a small amount of silver to keep bacteria growth under control. They are not designed to remove or kill bacteria. However, the effectiveness of the silver in the carbon filter is questionable. The only advantage noted in studies of silver-impregnated carbon was that in the first month of use, the bacterial counts were lower than carbon without silver (Seelig, B., Bergsrud, F., and Derickson, R, 1992). |

an entire small community or non-community system, or for residential areas served by private wells in an aquifer that has become contaminated. This option is attractive when centralized treatment is costly. Bottled water can serve as a temporary solution during the intermediate period while permanent solutions are being devised. Bottled water may be used by water systems facing water quality problems due to an emergency situation. The use of bottled water has been expressly recognized by the U. S. Army Corps of Engineers (USACE), the Federal Emergency Water Administration and the EPA under the National Contingency Plan for responding to contamination of drinking water supplies. Bottled water can serve as a permanent alternative source for special segments of the population such as small children and pregnant women who require low nitrate levels in the water supply. The SDWA allows EPA to authorize the use of bottled water, where appropriate, to achieve the goals of the SDWA. Other government policies authorizing the use of bottled water to meet drinking water needs are: EPA's National Contingency Plan under the Superfund Act, the Department of Interior's Emergency Water Supply Plan, and the USACE's' Emergency Water Plan (Harker, 1985). In some scenarios, a central treatment station with bottled water delivered to each customer may be advantageous. This option provides high quality water for consumption and at the same time obviates the need for expensive treatment of water that is used for activities such as toilets, yard watering, and laundry.

## 5.8 Key Questions

- How can WSWRD research begin to address treatment of multiple contaminants in Small Systems?
- Should research focus on treatment of ground water since most Small Systems source waters are underground?
- What are the most pressing future needs for water treatment technology in small systems?
- Should research focus on inexpensive treatment technologies rather than “cutting-edge” technologies which tend to be more expensive?

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# Chapter 6
# Distribution Systems

## 6.1 Distribution System Overview

Drinking water distribution system infrastructure is generally the most valuable asset of a water utility, even though most of the components are either buried or located inconspicuously. These systems are designed to deliver water from a source (usually a treatment facility) to individual consumers in a utility's service area in the required quantity at a satisfactory pressure. In general, to continuously and reliably move water between a source and a customer, a distribution system requires storage reservoirs/tanks, pipes, pumps, valves and other appurtenances. This infrastructure is collectively referred to as the distribution system (Walski et al. 2003).

Almost universally, the manner in which industrial and residential customers use water drives the overall design and operation of a water distribution system. Generally, water use varies both spatially and temporally. Besides customer consumption, a major function of most distribution systems is to provide adequate standby fire-flow (Fair and Geyer 1956). For this purpose, fire hydrants are installed in areas that are easily accessible by fire fighters and are not obstacles to pedestrians and vehicles. In order to satisfy this need for adequate standby capacity and pressure, most distribution systems use standpipes, elevated tanks, and large storage reservoirs. Additionally, for service areas with significant differences in ground elevation, the distribution systems are "zoned" to maintain relatively constant pressures. Sometimes, zoning may also result from the way in which the system has expanded over time.

## 6.2 Distribution System Issues

Proper operation and maintenance of distribution systems plays a key role in ensuring that safe drinking water is provided to the consumers. The PWS operators need to adequately understand and address the following three categorical issues facing the distribution system infrastructure components:

- Infrastructure issues (repair and rehabilitation).
- Operational issues (e.g., biofilm growth/disinfectant by product [DBP] formation, nitrification, and finished water aging).
- Contamination events (e.g., cross-connections, permeation/leaching, and intrusion/infiltration).

A brief discussion of these three categorical issues is presented in this chapter.

## 6.3 Infrastructure Issues

A majority of distribution piping installed in the U. S., beginning in the late 1800s and up until the late 1960s, was manufactured from cast iron. Specifically, the three older vintages of cast iron pipe (pit cast, spun cast, and spun cast with leadite joints) that were primarily installed prior to the 1960s are of biggest concern to PWSs. The thicknesses of the pipes between the 1800s and 1960s were gradually lowered as new technology improved the performance of the pipe during this period. However, because of the design changes during this period, the failure rates also increased over time. The result is that the three aforementioned vintage types of cast iron pipes, installed in different time periods, may be reaching the end of their respective service lives at approximately the same time. This will increase the financial burden on the PWSs, as the cost of replacement will be borne over a shorter time span than that of the original installation period (EPA, 2002a).

The American Society of Civil Engineers (ASCE) rates the Nation's drinking water infrastructure at a D- (A through F scale). The report card states that the Nation's 54,000 drinking water systems face an annual shortfall of $11 billion needed to replace facilities that are nearing the end of their useful life and to comply with federal water regulations (ASCE, 2005). However, most (77.6% - 80.5%) small PWS pipes are less than 40 years old (EPA, 2002b). Small PWS piping age ranges are as follows (according to EPA's 2000 Community Water System Survey, EPA, 2002b): less than 40 years old (77.6% - 80.5%), between 40 and 80 years old (17.5% - 19.4%), and more than 80 years old (0.1% - 4.0%). Furthermore, the small system piping age ranges for private systems are as follows: less than 40 years old (92.6% - 98.7%), between 40 and 80 years old (1.3% - 7.4%), and more than 80 years old (0.0% - 0.6%).

For small PWSs that have to repair, replace, and/or install new pipes, an understanding of the risks to distribution systems is necessary. The American Water Works Association (AWWA) white paper, "New or Repaired Water Mains" (AWWA, undated) indicates that the installation and/or repair of water mains provides a potential route for direct contamination of the distribution system. According to the white paper, contamination can occur before, during, or after construction/repair activities. For example, before the construction activities have commenced, the piping materials may be exposed to contaminant sources at the manufacturer, including:

- Accumulation of soils, sediments, and trash which can carry and/or harbor microbial contaminants.

- Exposure to storm water runoff and other waters that can carry microbial and chemical contaminants.
- Exposure to harmful chemicals.
- Exposure to chemically contaminated soils and sediments.
- Exposure to animals and humans and their wastes.

Water main construction or repairs are most commonly done in open trenches or excavations. Therefore, during construction activities, the interiors of pipes and fittings can come into contact with soil and water in the trench. In addition, the chance of soil and water contacting pipe materials during construction or repair activities is potentially much greater than it is during storage and handling prior to construction/repair. The damp soil of a main repair trench is a potential source of bacterial contamination during repairs (EPA, 2002c).

Finally, after construction or repair activity has been completed, contamination can occur from external sources such as:

- Leaking pipe joints with stagnant, unsanitary water infiltrating into the distribution system,
- Cross-connections, back-flow, and
- Transitory pressures.

To address these potential infrastructure issues, the small PWS operators must carefully inspect and disinfect the pipe material before commencing the repairs. The AWWA Standard C-651-99 (AWWA, 1999) has been developed to address potential microbial contamination during main construction or repair. Small PWS operators should closely follow the guidance provided in this Standard C-651-99. The external contamination events are discussed in Section 6.5 of this report.

## 6.4 Operational Issues

PWS operators must operate their distribution system in a manner to minimize the deterioration of water quality delivered to the consumer after it leaves the treatment plant. The water quality can potentially degrade in a distribution system due to a variety of reasons. The main reasons include: excessive growth of biofilm, DBP formation, nitrification, and improper storage of finished water. These issues are briefly discussed in the following subsections.

### 6.4.1 Biofilm Growth

Virtually anywhere a surface comes into contact with the water in a distribution system, one can find biofilms. Biofilms are formed in distribution system pipelines when microbial cells attach to pipe surfaces and multiply to form a film or slime layer on the pipe (EPA, 2001). Biofilms are complex and dynamic microenvironments, that include processes such as metabolism, growth, and product formation, and finally detachment, erosion, or "sloughing" of the biofilm from the surface. The rate of biofilm formation and its release into a distribution system can be affected by many factors including surface characteristics, availability of nutrients, and flow velocities. Biofilms grow until the surface layers begin to slough off into the water (Geldreich and Rice 1987). The pieces of biofilm released into the water may continue to provide protection for the organisms until they can colonize a new section of the distribution system. In addition, biofilms may increase pipe corrosion (microbially induced corrosion), adversely affect pipe hydraulics and reduce the utility of total coliforms as indicator organisms. Thus, microbial growth in biofilms may result in deterioration of water quality, generation of bad tastes, colors, and odors, and proliferation of macroinvertebrates (EPA, 2002d).

Few organisms living in distribution system biofilms pose a threat to the average consumer. Bacteria, viruses, fungi, protozoa, and other invertebrates have been isolated from drinking water biofilms (EPA 1992). The fact that such organisms are present within distribution system biofilms shows that, although water treatment is intended to remove all pathogenic (disease-causing) bacteria, treatment does not produce sterile water. In fact, some otherwise harmless organisms (opportunistic pathogens) may survive the treatment process and cause disease in individuals with low immunity or compromised immune systems (EPA, 2001). Therefore, a disinfectant residual in the distribution system is necessary to inactivate pathogens, maintain water quality, and protect the distribution system against regrowth (Snead et al., 1980). The SWTR provides minimum requirements on the amount of disinfection residual that must exist in treated water. Specifically, the SWTR requires that filtration and disinfection must be provided to ensure that the total treatment of the system achieves at least a 3-log (99.9 percent) removal/inactivation of *Giardia* cysts and a 4-log (99.99 percent) removal/inactivation of viruses (EPA, 1989). In addition, the PWS must demonstrate, by monitoring and recording, that the disinfectant residual concentration in water entering the distribution system is never less than 0.2 mg/L and that a detectable residual is maintained in the distribution system.

Although a disinfectant residual is generally necessary to maintain water quality, it is recognized that an excessive amount of disinfectant residual may also pose a threat to health by contributing to the increased formation of harmful DBPs. Natural organic matter (NOM) contained in water (in the form of humic and non-humic [or fulvic] substances) serves as a precursor in DBP formation. NOM belongs to a family of compounds having similar structural and chemical properties and are formed during the decomposition of carbon-based life forms. The NOM reacts with the residual disinfectant (e.g., chlorine, chloramine) in the distribution system to form DBPs such as chloroform, bromodichloromethane, and haloacetic acids (HAA5). Many of these DBPs are suspected of causing cancer, reproductive and developmental problems in humans. To minimize the formation of DBPs, EPA has promulgated regulations that specify maximum residual disinfectant level goals (MRDLGs) for chlorine (4 mg/L), chloramines (4 mg/L), and chlorine dioxide (0.8 mg/L). In addition, MCLs for TTHMs and HAA5 have been established at 0.080 mg/L and 0.060 mg/L, respectively. The TTHMs include: chloroform, bromodichloromethane, dibromochloromethane and bromoform. The HAA5 include: monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid and dibromoacetic acid. In order to meet these requirements, PWSs may need to remove the DBP precursor material from the water prior to disinfection by applying appropriate treatment techniques.

In a cooperative effort with the Montana State University's Biofilm Research Center, EPA is studying the interactions among factors that influence biofilms, bacterial regrowth, and corrosion in distribution systems. The goal of this work is to generate information which can lead to a better understanding of the interactions among those factors which influence microbial growth in water distribution systems and the mitigating effects of chlorination and commonly used corrosion control techniques. This research is also designed to address specific fundamental questions about the availability of sorbed humic substances for biofilm growth. Figure 6.1 shows the various distribution system interactions that can potentially affect water quality.

In summary, the distribution system can act as a giant reactor; with excess residence times, the water quality can deteriorate substantially. Small PWSs must be aware of these issues and optimally operate their system to control both biofilms and DBPs.

### 6.4.2 Nitrification

Nitrification is a microbial process by which reduced nitrogen compounds (primarily ammonia) are sequentially oxidized to nitrite ($NO_2^-$) and nitrate ($NO_3^-$). Ammonia is present in drinking water through either naturally-occurring processes or through ammonia addition during secondary disinfection to form chloramines (EPA, 2002e). The use of chloramine is expected to increase in the near future as a result of more stringent DBP MCLs associated with the Stage I and Stage II DBP rule. Nitrification can adversely impact the distribution system by increasing nitrite and nitrate levels, reducing alkalinity, pH, dissolved oxygen, and chloramine residuals, and promoting bacterial regrowth (EPA, 2002e).

The formation of nitrite and nitrate within the distribution system poses a potential direct public health threat. Human babies are extremely susceptible to acute nitrate poisoning because of certain bacteria that may live in their digestive system during the first few months of life. These bacteria change nitrate into toxic nitrite ($NO_2^-$). The nitrite reacts with hemoglobin (which carries oxygen to all parts of the body) to form methemoglobin, which does not carry oxygen. The level of oxygen being carried throughout the body decreases in proportion to the amount of hemoglobin converted to methemoglobin. As the oxygen level decreases, the baby is suffocated. This condition is called methemoglobinemia. The most obvious symptom of nitrate poisoning is a bluish color of the skin, particularly around the eyes and mouth. These symptoms are referred to as cyanosis (Runyan, C. 2002).

Under the Safe Drinking Water Act (SDWA), primary MCLs have been established for nitrite (measured as Nitrogen [N]), nitrate (as N), and the sum of nitrite plus nitrate. The MCLs are 1 mg/L for nitrite, 10 mg/L for nitrate, and 10 mg/L for nitrite + nitrate (as N). These standards are measured at the point of entry to the distribution system; any subsequent elevated nitrite/nitrate levels resulting from nitrification within

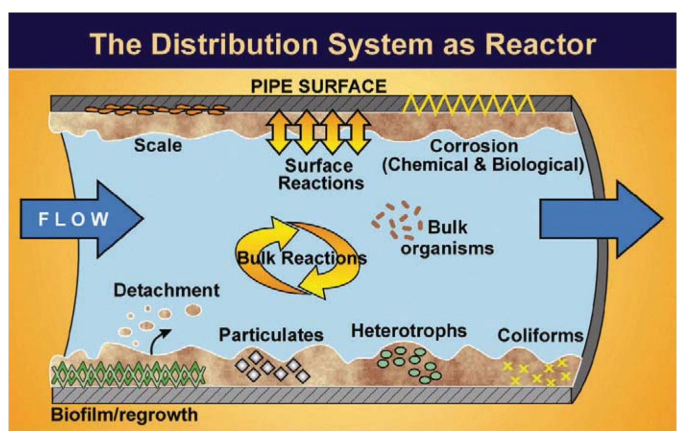


*Figure 6.1 Distribution System as a "Reactor" (Figure used with permission from the Montana State University Center for Biofilm Research).*

the distribution system are typically not identified by compliance monitoring. Therefore, small PWS operators must be aware of nitrification and optimally operate their system to minimize it.

### 6.4.3 Finished Water Storage and Aging

Finished water facilities (including ground storage and elevated storage, but not clearwells which are part of treatment) are designed to meet temporary surges in water demands, reduce pressure fluctuations in the distribution system, and provide reserves for fire-fighting, power outages, and other emergencies. Many finished storage facilities are operated to provide adequate pressure and are kept full to be better prepared for emergency demands. This emphasis on hydraulic considerations in past designs has resulted in many storage facilities operating today with larger water storage capacity than is needed for normal (non-emergency) usage (EPA, 2002c). This built-in excess capacity, if not properly utilized, can result in water quality deterioration. In addition to underutilization, short circuiting within a storage reservoir can also cause long detention times, resulting in excessive water age. Furthermore, poor mixing (including stratification) can exacerbate the water quality problems by creating zones within the storage facility where water age significantly exceeds the average water age throughout the facility. For larger distribution systems that contain storage facilities where water cascades from one facility to another (such as pumping up through a series of pressure zones), poor mixing can result in exceedingly long water age in the most distant tanks and reservoirs (EPA, 2002c).

Long detention times can allow the disinfectant residual to be completely depleted, thereby not protecting the finished water from additional microbial contaminants that may be present in the distribution system downstream of the storage facility. Although the loss of disinfectant residual within a storage facility does not necessarily pose a direct public health threat (many systems throughout the world are operated without use of a disinfectant residual), disinfectant decay can contribute to biofilm growth and related problems described in Section 6.4.1. The rate of residual disinfectant decay can be further affected by external contamination, temperature, nitrification, exposure to ultraviolet light (sun), and the amount and type of chlorine demanding compounds present such as organics and inorganics. Chlorine decay in storage facilities can normally be attributed to bulk water decay rather than wall effects due to the large volume-to-surface area ratio (EPA, 2002c).

Sediment accumulation may also occur within storage facilities due to quiescent conditions which promote particle settling. Potential water quality problems associated with sediment accumulation include increased disinfectant demand, microbial growth, DBP formation, and intermittent increased turbidity within the bulk water (EPA, 2002c).

Finally, uncovered finished water storage reservoirs provide the greatest opportunity for contaminant entry into the distribution system. These reservoirs are potentially subject to contamination from bird and other animal excrement that can transmit disease-causing organisms to the finished water. Microorganisms can also be introduced into open reservoirs from windblown dust, debris and algae. Algae proliferate in open reservoirs with adequate sunlight and nutrients and impart color, taste and odor to the water on a seasonal basis. Organic matter, such as leaves and pollen, is also a concern in open reservoirs. Water fowl are known carriers for many different waterborne pathogens and have the ability to disseminate these pathogens over a wide area. Even reservoirs with floating covers are susceptible to bacterial contamination and regrowth from untreated water that collects on the cover surface. Also, if the cover rips or is otherwise damaged, any untreated water on the cover would mix with the stored water, potentially causing health problems. Floating covers on storage reservoirs are susceptible to rips and tears due to ice damage, vandalism, and/or variable operating water levels (EPA, 2002c).

## 6.5 Contamination Events

Distribution systems are vulnerable to a variety of external contamination events such as cross-connections, permeation/leaching, and intrusions/infiltrations. These issues are briefly discussed in the following subsections.

### 6.5.1 Cross-connection Control

Distribution systems contain locations where non-potable water can be accidentally cross-connected to potable sources. These cross-connections can provide a pathway for backflow of non-potable water into potable sources. Backflow can occur either because of reduced pressure in the distribution system (termed backsiphonage) or the presence of increased pressure from a non-potable source (termed backpressure). Backsiphonage may be caused by a variety of circumstances, such as main breaks, flushing, pump failure, hilly terrain, limited pumping capacity, high demand by consumers, or emergency firefighting water drawdown. Backpressure may occur when heating/cooling, waste disposal, or industrial manufacturing systems are connected to potable supplies and the pressure in the external system exceeds the pressure in the distribution system. Both situations act to change the direction of water, which normally flows from the distribution system to the customer, so that non-potable and potentially contaminated water from industrial, commercial, or residential sites flows back into the distribution system through a cross-connection (EPA, 2002f).

The risk posed by cross-connection backflow can be mitigated through preventive and corrective measures. For example, preventative measures include the installation of backflow prevention devices and assemblies and formal programs to seek out and correct cross-connections within the distribution system and, in some cases, within individual service connections. Corrective measures include activities such as flushing and cleaning the distribution system after a detected incident. This may help mitigate any further adverse health effects from any contaminants that may remain in the distribution system (EPA, 2002f).

There are no national reporting requirements for backflow incidents, and no central repository for backflow incident information. Nonetheless, data on backflow incidents have been actively collected by several organizations. EPA compiled data on 459 reported backflow incidents that occurred in the U. S. between 1970 and 2001. During these reported incidents of backflow, chemical and/or biological contaminants have caused illness and deaths, with contamination affecting a number of service connections. This number of reported incidents is believed to be a small percentage of the total number of backflow incidents in the U. S. (EPA, 2002f). Because backflow incidents are underreported, this data cannot support conclusions about the full magnitude of risks associated with backflow (EPA, 2002f).

The American Backflow Prevention Association (ABPA) created and distributed a survey to collect data on cross-connection control programs throughout the country. Two separate surveys were created. One survey of water system programs was mailed to approximately 400 systems in 44 states asking details of their cross-connection control program. Only 135 surveys were returned, representing 30 states. Of the 135 returned surveys, 25 were from small systems (those serving less than 10,000 people). One hundred and three responses represented systems serving populations larger than 10,000. Seven systems did not report their population size, making it unable to determine if they were small or large (ABPA, 1999). Based on the survey responses, ABPA estimates that average annual cost for cross-connection control programs is $3.40 per water service connection for a small system and $1.28 per water service connection for a large system. The EPA's SDWIS database (for FY2002) shows a total of 230,507,361 service connections for small systems and a total of 62,579,989 service connections for large systems.

There is a lack of public general awareness about the threat posed by cross-connections and backflow through illegal and unprotected taps into the distribution system. PWS operators must be aware that there is a potential for intentional contamination of a distribution system through such cross-connections. See Chapter 8 – Homeland Security/Emergency Response for additional information for responding to such events.

### 6.5.2 Permeation and Leaching

As presented in Section 6.4.1, distribution system infrastructure and appurtenances including piping, linings, fixtures, and solders can react with the water supply as well as the external environment. Permeation and leaching are two mechanisms that can result in the degradation of the distributed water (EPA, 2002g).

Permeation of piping materials and non-metallic joints can be defined as the passage of contaminants external to the pipe, through porous, non-metallic materials, into the drinking water. The problem of permeation is generally limited to plastic, non-metallic materials. Volatile organic compounds (VOCs) present in the ground water or vadose zone can permeate plastic piping and gaskets. Permeation is typically most severe for small diameter, low-flow pipes. The smaller water lines contain the highest ratio of mass transfer surface area to pipe volume, and are often associated with stagnant or low-flow conditions. Also, there are instances where VOC MCL violations have occurred at the point-of-consumption. However, current provisions of the SDWA do not require monitoring for VOCs beyond the point-of-entry to the distribution system. Additionally, in most instances, the risk threshold of chemical contaminants such as VOCs is substantially lower than either the taste or odor thresholds, suggesting that utilities cannot rely confidently on customers' perception of taste and odor for identifying contamination events (EPA, 2002g).

Leaching can be defined as the dissolution of metals, solids, and chemicals into drinking water. Leaching from cement linings can occur in soft, aggressive, poorly buffered waters. Under static conditions, metals such as aluminum, arsenic, barium, chromium, and cadmium can leach from cement linings, even when NSF-approved materials are used and linings are applied according to AWWA standards. Current provisions of the SDWA do not require monitoring for heavy metals beyond the point-of-entry to the distribution system, and additional research would be required to assess the degree of metals accumulation within the distribution system. Vinyl chloride can leach from pre-1977 PVC pipe. No instances of MCL violations were cited in association with post-1977 PVC pipe (EPA, 2002g).

Unidirectional flushing can be used to rid the distribution system of stagnant, contaminated water, but additional research is needed to determine the fraction of heavy metals and organics that can be removed through flushing. Permeated plastic piping must be replaced since the piping retains its swollen porous state after permeation (EPA, 2002g). NSF Standard 61 and numerous AWWA Standards have been developed to prevent the degradation of drinking water due to contact with pipe materials. Materials selection, design, and installation considerations based on water quality and environmental conditions are addressed in these Standards.

Small PWS operators using non-metallic pipes must be aware of permeation and leaching problems and address them appropriately.

### 6.5.3 Intrusion and Infiltrations

A pressure transient in a drinking water pipeline caused by an abrupt change in the velocity or direction of water can cause a surge or "water hammer." When a rapidly closed valve suddenly stops water flowing in a pipeline, pressure energy is transferred to the valve and pipe wall. Shock waves are set up within the system and pressure waves travel backward until encountering the next solid obstacle, resulting in a series of forward and backward movements. The pressure wave's velocity is equal to the speed of sound; therefore it "bangs" as it travels back and forth, until dissipated by friction losses.
A less severe form of water hammer is called surge where a slow motion mass oscillation of water is caused by internal pressure fluctuations in the system (EPA, 2002h). If these pressure transients are not controlled, they can damage pipes, fittings, and valves, causing leaks and shorten the life of the system. Both the pipe and the water are incompressible and therefore do not absorb the shock. The production of transient low- and negative-pressures creates the opportunity for contaminated water to enter the pipe from outside.

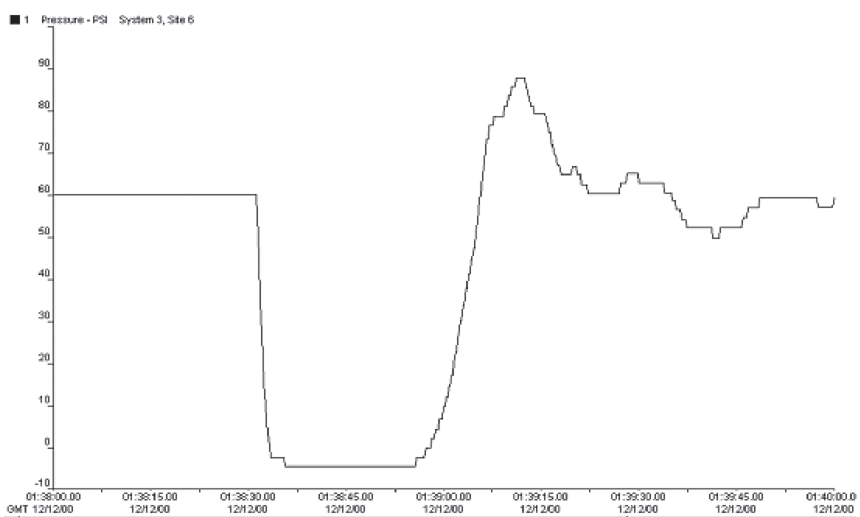


*Figure 6.2 Negative Pressure Transient Associated with a Power Outage. (Figure used with permission from Kala K. Fleming, Ph.D. at American Water.)*

In a series of research projects (LeChevallier et al., 2003; Gullick et al., 2004), the frequency and location of low-and negative-pressures in representative distribution systems were measured under normal operating conditions and during specific operational events. Figure 6.2 illustrates a transient event that results in a negative pressure transient for 20-seconds caused by a power outage associated with a lightning strike.

These investigators also confirmed that fecal indicators and culturable human viruses were present in the soil and water exterior to the distribution system pipes. Therefore, they concluded that it was possible for these micro-organisms to infiltrate/intrude into the distribution system. Their research also shows that a well-calibrated hydraulic surge model can be used to simulate the occurrence of pressure transients under a variety of operational scenarios, and a model can also be used to determine optimal mitigation measures.

Although there are insufficient data to indicate whether pressure transients pose a substantial risk to water quality in the distribution system, mitigation techniques can be implemented. These techniques include the maintenance of an effective disinfectant residual throughout the distribution system, leak control, redesign of air relief venting, installation of hydro-pneumatic tanks, and more rigorous application of existing engineering standards.

## 6.6 Distribution System Summary

EPA research indicates that there is a different level of risk associated with the various distribution system infrastructure components. The relative risk of pathogens entering a distribution system (through the various mechanisms discussed in the previous sections of this chapter) can be summarized as follows (EPA, 2002d):

- High risk – treatment breakthrough, intrusion, cross-connections, main repair/break
- Medium risk – uncovered water storage facilities
- Low risk – New main installation, covered water storage facilities, growth and re-suspension, purposeful contamination.

## 6.7 Key Questions

- Do flow models need to be improved/developed specifically for small distribution systems?
- What are typical water residence times in small distribution systems? (This will play a key role in contaminant sorption/desorption and biofilm development).
- What are the interrelations between biofilms and contaminants?
- How do changes in water chemistry affect sorption/desorption of contaminants?

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Montana State University (MSU) Center for Biofilm Engineering. Image provided by Pat Dirckx. 2005

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# Chapter 7 Waste Residuals Generated by Small Systems

## 7.1 Introduction

Issues concerning the generation and treatment of waste residuals from small-scale drinking water treatment plants have received little attention in past and current research. Yet in a national survey of consulting engineers, residual disposal was voted the second most pressing need (behind disinfection by-products) in the area of "treatment processes and facilities needing additional studies" (AWWARF, 1997). Many small systems simply dispose of waste residuals on-site and/or by utilizing local waste treatment venues (landfills, sewer lines, etc.). There are currently no regulations or standards from the EPA that specifically cover water treatment plant residuals (National Drinking Water Clearinghouse, 1998). Depending on the residuals' composition and method of disposal, general regulations governing the disposal of solid and liquid wastes will determine the fate of these materials. These general regulations can be found under the Clean Water Act (CWA), the Resource Conservation and Recovery Act (RCRA), Safe Drinking Water Act (SDWA), and in some instances, the Clean Air Act.

On December 7, 2000, EPA promulgated the NPDWR for radionuclides. With this rule, EPA updated its standards for radionuclides in drinking water. In addition, EPA set a new standard for uranium, as required by the 1986 amendments to the SDWA. The revised standards are: combined radium 226/228 (5 pCi/L); beta emitters (4 mrems); gross alpha standard (15 pCi/L); and uranium (30 µg/L). Treating water to remove naturally occurring radioactive material (NORM) results in residual streams that are classified as "technologically enhanced naturally occurring radioactive materials," or TENORM. TENORM is defined as naturally occurring materials, such as rocks, minerals, soils, and water whose radionuclide concentrations or potential for exposure to humans or the environment is enhanced as a result of human activities (e.g., water treatment). Numerous regulations govern the disposal of waste streams containing radionuclides (although there are no federal waste disposal regulations specifically for TENORM wastes), and their interaction is complex. States and disposal facilities can place additional restrictions on TENORM disposal.

Little has been published on the quantities and types of residuals generated by PWSs, but waste residuals are certainly going to be as varied as are the methods used for water treatment in small system scenarios. This chapter will discuss the types of waste residuals that small systems can potentially generate, disposal possibilities, and future waste residual issues that small systems could face in the near future.

## 7.2 Types of Waste Residuals and Disposal

Liquid residuals from water treatment operations include brines, caustics, filter backwash, sedimentation basin wash water, and solutions used for recharging solid media. Solid residuals can include sludge, schmutzdecke (biological surface layer in slow sand filtration units), and spent treatment media. The residuals (both solid and/or liquid), classified as TENORM, may contain non-exempt levels of radioactive material. Section 7.5 presents an overview of the options for disposing TENORM residual with non-exempt levels of radioactive material. Figure 7.1 summarizes federal regulations involved with the disposal of solid and liquid residuals that contain exempt levels of radioactive material. The majority of liquid waste residuals generated by PWSs are most likely disposed on-site (land application) or by sanitary sewer. Solid residuals are disposed on-site (land application) or discarded for transport and disposal in municipal landfills.

## 7.3 Liquid Residuals Handling & Disposal

A significant source of liquid residuals is filter backwash. In 2001, EPA published the final version of the Filter Backwash Recycling Rule (FBRR). The primary goal of the FBRR is to minimize consumer exposure to microbial contaminants (e.g. *Cryptosporidium*) during cleaning/backwashing operations. The rule was developed following the findings that filter backwash waters contributed to the outbreak of waterborne disease. The rule applies to all public water systems that:

1. Use surface water or ground water under direct influence of surface water
2. Utilize direct or conventional filtration processes, and
3. Recycle filter backwash water, sludge thickener supernatant, or liquids from dewatering processes.

The FBRR essentially requires that backwash water, thickener supernatant, or dewatering liquids be processed through the system's existing conventional or direct filtration units or through an alternate recycle location as approved by the state and/or local agencies.

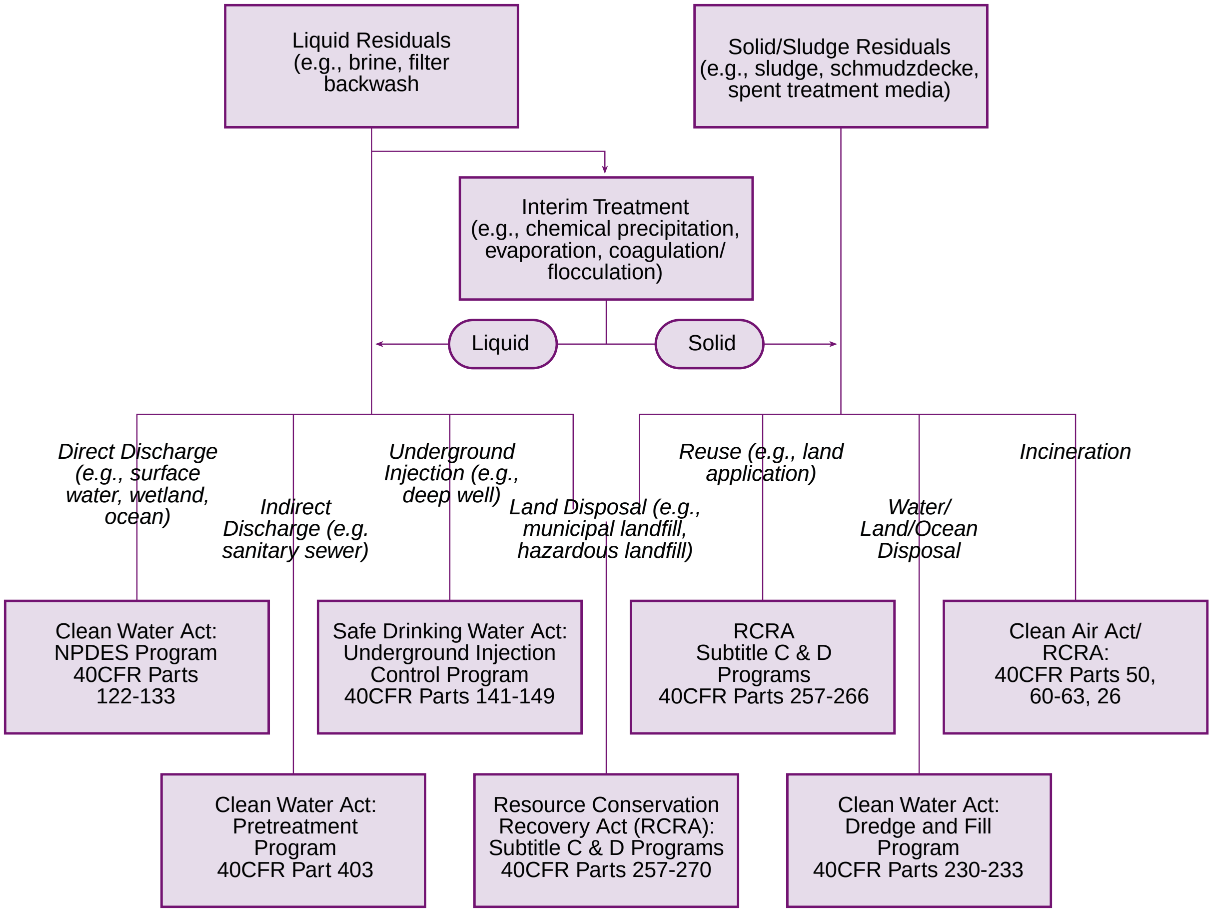


*Figure 7.1 Federal regulations governing the disposal of residuals (EPA, 2000).*

Conventional filtration treatment is defined as a series of processes including coagulation, flocculation, sedimentation, and filtration resulting in substantial particle removal. Direct filtration is defined as a series of processes including coagulation and filtration but excluding sedimentation that results in substantial particle removal (CWA - 40 CFR Section 141.2). The FBRR was implemented on June 8, 2004.

Small systems that recycle filter backwash (and other liquid residuals listed in the FBRR) will need to ensure that the recycle is sent to the appropriate re-entry point in the system. The FBRR also requires that PWSs notify the primacy agency that the PWS will recycle backwash and provide the primacy agency with:

1. A plant schematic showing recycle origin, transport, and location of recycle back into the plant,
2. Typical recycle flow (gpm),
3. Highest observed plant flow experienced in the previous year (gpm),
4. Design flow for the treatment plant (gpm), and
5. If applicable, the state-approved operating capacity for the plant.

Public water systems must also collect and maintain information for review by the primacy agency including copies of all materials submitted to the primacy agency, list of recycle flows and recycling frequency, average and maximum flows and durations of recycling events, filter run length, type of treatment for recycle flows, and information on the physical and chemical parameters involved in the recycle treatment process (see [EPA, 2001] for details).

As shown in Figure 7.1, liquid waste residuals may be disposed by direct/indirect discharge, underground injection, and land disposal. The following subsections briefly describe direct and indirect discharge options. For PWSs, underground injection is not a viable option because of cost (except in extreme situations).

### 7.3.1 Direct Discharge of Liquids

Direct discharge to surface waters can be performed by PWSs under the guidance of the CWA's National Pollutant Discharge Elimination System (NPDES – 40 CFR Section 122). The Federal Water Pollution Control Act (which, after the 1977 amendments, became known as the CWA) defines "pollutant" as dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste. The NPDES requires that direct dischargers hold a permit and may discharge only those pollutants in accordance with the terms in the permit (see http://cfpub.epa.gov/npdes/index.cfm for more information). The NPDES permits generally include technology-based effluent limits for a particular industry. Currently, EPA does not have technology-based effluent limits for water treatment plants. In this situation, discharge permits are usually based on best professional judgment and water quality-based effluent limits. Individual states conduct discharge permitting. Alaska, Idaho, Arizona, Massachusetts, and New Hampshire are not currently authorized to implement the NPDES program (EPA, 2003).

Public water systems opting to discharge liquid residuals such as filter backwash and sedimentation basin wash water to the waters of the Nation must obtain a NPDES permit for such discharge. To obtain a permit, the PWS operator must first submit a completed Notice of Intent to the appropriate state agency delegated to implement the NPDES program. The Notice of Intent requires the submittal of information such as location of the facility, name of the owner/operator, contact details, location of the receiving waters, description of the plant operations including a listing of any additives used in the treatment process, design capacity of the plant, the number and volume of sedimentation basins, the source of raw water, the number of filters that are backwashed, the frequency and volume of backwashes and sedimentation basin washouts, a water balance for backwashes and sedimentation basin washouts, a description of how sludge is disposed, type of treatment provided for backwash and sedimentation basin wash waters and the design capacity of the system. In addition, a facility location map with boundaries that extend a few miles beyond the site property (annotated with the specific locations of the discharges) is generally required. Also, the PWSs must comply with the Total Maximum Daily Load (TMDL) requirements developed and approved for the receiving water body. If a TMDL is not developed, the PWS must certify that the treatment and control methods employed at this location are most appropriate for the reduction of pollutants generated at this site. The PWSs must certify that they will neither degrade the environment (commonly referred to as the "anti-degradation" certification) nor threaten any endangered species as a result of this discharge.

It should be noted that as long as a facility producing an industrial waste stream has a NPDES permit, liquid residuals that could otherwise be classified as hazardous waste under RCRA can be legally discharged assuming that the discharge is in compliance with the RCRA terms cited in 40 CFR Section 261.4. Direct discharges to marine environments are subject to additional restrictions under the CWA (see 40 CFR Section 125.123 for details).

### 7.3.2 Indirect Discharge of Liquids

Public water systems could also discharge liquid residuals to sanitary sewers (i.e. "down the drain"). Indirect discharge does not require a NPDES permit, but a pretreatment (prior to indirect discharge) program may have to be implemented by the operator. EPA has developed pretreatment guidance and regulations for industrial discharges to water treatment plants (see Effluent Guidelines cited in 40 CFR Section 403). The small quantities of waste generated by PWSs typically do not meet the criteria that EPA uses for requiring pretreatment of industrial waste. Additionally, the pretreatment program places most of the responsibility on organizations at the municipal level. Publicly owned treatment works (POTWs) that process 5 MGD (or more) or smaller plants that have "significant industrial users" are required to have a pretreatment program in place (EPA, 1999). Included in the definition of significant industrial users are those operations that could adversely affect the POTW operations and/or violate any pretreatment standards. Thus, it may be necessary for some small systems that are utilizing sanitary sewers for liquid residual disposal to coordinate with local POTWs to ensure that they are meeting the requirements set by the POTW and/or state authorities. Furthermore, several states (e.g., Ohio) require that significant industrial users discharging to a POTW obtain a permit for discharge.

### 7.3.3 Land Disposal of Liquids

Liquid residuals are generally not disposed in landfills due to the prohibitive costs involved with transport and disposal, the regulations surrounding such disposal, and the availability of alternative methods. Liquid residuals generated by PWSs that are reused through land application and not classified as hazardous waste are subject to little federal regulation, but may be regulated by the state. States generally implement and enforce the provisions defining sanitary landfills (as opposed to open dumping, see RCRA Section 4005). These provisions include (but are not limited to) requirements that address location requirements, protection of endangered species, source water protection, non-point discharge violations, minimization of disease vectors, protection of air quality, and minimization of explosive gases. Thus, on-site disposal of non-hazardous liquid residuals by PWSs may be regulated by the state. Liquid residuals classified as hazardous waste are subject to comprehensive generator, transport, storage, treatment, and land disposal restrictions defined in RCRA (see solids disposal section).

It is possible that some PWSs may discharge liquid residuals to lagoons or evaporation ponds. In these cases, the SDWA and RCRA impose requirements for non-hazardous wastes that aim to protect wellhead/source waters, surface water, and ground water. States may have further requirements concerning non-hazardous liquid residual lagoons. Lagoons containing hazardous waste are subject to RCRA regulations covering design and operation standards (40 CFR Part 264, Subpart K).

## 7.4 Solid Residuals

Examples of solid waste residuals (SWR) generated by PWSs include sludge, spent treatment media, and schmutzdecke. Solid waste residuals are subject to RCRA regulations and therefore classified as hazardous or non-hazardous (as defined in RCRA). A waste is characterized as hazardous or non-hazardous based on its ignitability, corrosivity, reactivity, and/or toxicity (see RCRA 40 CFR Sections 261.21 to 261.24). In most cases, state and local regulations may also govern the treatment/disposal of SWR as many of the regulations set forth in RCRA are administered by state and local governments. Some PWSs may qualify as conditionally exempt small quantity generators (CESQG) of hazardous waste (RCRA 40 CFR Section 261.5). To be classified as a CESQG, the operation must not generate more than 100 kg (220 lbs.) of hazardous waste per month. The CESQG may not store more than 1000 kg (2200 lbs.) of hazardous waste on-site at any time. The regulations governing CESQGs are generally less stringent than those governing small quantity generators or large quantity generators. At a minimum, a PWS that qualifies as a CESQG must characterize each waste as hazardous or non-hazardous, maintain monthly waste generation inventories for amounts of hazardous waste stored on-site, and manage hazardous wastes in compliance with federal, state, and local regulations.

Sludge generated by PWSs is not subject to regulation under the Biosolids Rule (Sewage Sludge Rules defined in 40 CFR Section 503.6(i)(e)). The Biosolids Rule (included in the CWA Amendments of 1987) was promulgated to protect public health and the environment from any anticipated effects from the beneficial recycling of sewage sludge biosolids (EPA, 1994).

### 7.4.1 Land Disposal of Solids

Waste residuals generated by PWSs will predominantly be characterized as hazardous or non-hazardous based on toxicity. The toxicity of SWRs is assessed by the Toxicity Characteristic Leaching Procedure (TCLP). If contaminant concentrations in the TCLP leachate are in excess of those listed in the Land Disposal Restrictions (RCRA 40 CFR 268.40), the SWR would be classified as hazardous and must be disposed in a RCRA Subtitle C class landfill. Transport and disposal costs for SWRs classified as hazardous will be considerably higher than costs for non-hazardous SWRs, which can be sent to municipal solid waste landfills.

### 7.4.2 Land Application of Solids

Because sludge generated by PWSs is not subject to the Biosolids Rule, on-site recycling of SWR by land application may be an option for PWSs to pursue with certain kinds of SWRs (e.g. schmutzdecke from slow-sand filtration processes).

### 7.4.3 Incineration of Solids and Liquids

Incineration processes are most likely cost-prohibitive for small systems and would not be an option except in extreme cases (e.g. disposal of acutely toxic waste). Regulations governing incineration are covered in the Clean Air Act.

## 7.5 Technologically Enhanced Normally Occurring Radioactive Material (TENORM) Residuals

Low-Level Radioactive Waste (LLRW) landfills may be an option for some systems generating wastes with radionuclide concentrations deemed to be unacceptable for disposal at a solid or hazardous waste landfill. LLRW landfills are licensed by the Nuclear Regulatory Commission (NRC) or by a state under agreement with NRC, and guidelines for disposing of radioactive sludges and solids are more stringent than in a standard landfill. These facilities are licensed, based on projected performance and have packaging and burial requirements that are progressively stricter as the radionuclide concentrations increase. Currently, there are three LLRW disposal facilities in operation that are located at Barnwell, SC, Richland, WA and Envirocare, UT. EPA has developed a guidance document titled, "A Regulators' Guide to Management of Radioactive Residuals from Drinking Water Treatment Technologies (EPA, 2005)." Small system operators are encouraged to review this document for guidance and then contact the state regulators for state-specific requirements and disposal options.

## 7.6 Conclusions and Future Research

Residuals transport, treatment, and disposal can be a significant cost to small communities. For small community wastewater treatment operations, handling of residuals may account for 50 percent of the total operating budget (EPA, 1992). While it is expected that waste residual generation at PWSs would be less than that of a wastewater treatment plant, costs and regulatory issues surrounding waste residuals may still be of concern. It will be important in the short term (1 to 2 years) to ascertain both the types and quantities of waste residuals generated by small systems. Another area that will require more research will be on arsenic, radium, and uranium chemistry and its behavior in waste residuals (an active research area for large-scale systems also). Once more accurate data are obtained on the quantities and types of waste residuals, more focused efforts may be made in developing new techniques for the disposal of waste residuals, including on-site land application which would minimize transport and disposal costs.

## 7.7 Key Questions

- What types of waste residuals are generated by small systems?
- What quantities of waste residuals are generated by small systems?
- Are small systems' waste residual transport/disposal issues significant?
- What are future issues regarding small systems' waste residuals?

## 7.8 References

All references to Code of Federal Regulations Documents in this chapter may be found at http://www.access.gpo.gov/nara/cfr and Federal Register Documents may be found at http://www.gpoaccess.gov/fr/index.html

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# Chapter 8 Homeland Security/ Emergency Response

## 8.1 Background and Directives

Under Presidential Decision Directive (PDD) 63 - Protecting America's Critical Infrastructures, issued in May 1998, EPA was designated as the lead agency for the water supply sector. In November 1998, a preliminary plan (National Infrastructure Assurance: Water Supply Sector) was drafted. While the preliminary plan showed a scheduled completion date of the end of 2003 for these activities, the schedule was accelerated in response to the terrorist acts of September 11, 2001. In October 2001, a Water Protection Task Force was established to ensure that activities to protect and secure water supply infrastructure were comprehensive and were carried out expeditiously. Also, in October 2001, EPA disseminated information to the water utilities about steps they could take to protect their sources of supply and infrastructure, which include pumping stations, treatment facilities, and computer systems. EPA worked with the Sandia National Laboratory to develop training materials for water utilities to help them conduct thorough assessments of their vulnerabilities.

The Public Health Security and Bioterrorism Preparedness and Response Act (Bioterrorism Act), passed in June 2002 (P. L. 107-188), provided EPA the mandate to work in water security. This law, coupled with the Homeland Security Presidential Directives (HSPDs) 7, 8, 9, 10 and EPA's own strategic plan for homeland security, guides the Agency's research and technical support activities to protect the Nation's water and wastewater infrastructure. The Bioterrorism Act of 2002, HSPDs 7, 8, 9, 10 and EPA's overall strategic plan are briefly discussed below.

### 8.1.1 Bioterrorism Act

The Bioterrorism Act amended the Safe Drinking Water Act and required all public water suppliers serving populations greater than 3,300 to complete Vulnerability Assessments (VAs) and to develop or modify Emergency Response Plans (ERPs). Smaller systems were encouraged, but not required, to follow the same planning and management activities. VAs were intended to identify potential threats, assess the critical assets of the system, evaluate the likelihood and consequences of an attack, and develop a prioritized set of system upgrades to increase security. Once completed, VAs were required to be submitted to the EPA according to a pre-set schedule based on the size of the utility. The deadline for medium and small size systems (serving populations between 3,300 and 50,000) was June 30, 2004. Additionally for these systems, ERPs providing details on response, recovery and remediation actions in the event of a contamination or flow disruption event were to be submitted within 6-months of the submittal of VA and no later than December 31, 2004.

### 8.1.2 Homeland Security Presidential Directive (HSPD)-7 - Critical Infrastructure Identification, Prioritization, and Protection

Under this HSPD, EPA is identified as the "Sector-Specific Agency" for drinking water and water treatment systems. The term "Sector-Specific Agency" means a federal department or agency responsible for infrastructure protection activities in a designated critical infrastructure sector or key resources category. The Sector-Specific Agencies are required to conduct their activities under the various HSPD directives in accordance with guidance provided by the Department of Homeland Security (DHS) Secretary. Under this directive, EPA must:

- Collaborate with all relevant federal departments and agencies, state and local governments, and the private sector;
- Conduct or facilitate vulnerability assessments of the sector; and
- Encourage risk management strategies to protect against and mitigate the effects of attacks against critical infrastructure and key resources.

### 8.1.3 HSPD-8 - National Preparedness

HSPD-8 directs the federal government agencies and departments to be prepared to respond to nationally significant terrorist incidents. EPA is identified as an agency that provides assistance for first responder preparedness, and has responsibilities under this HSPD.

### 8.1.4 HSPD-9 - Defense of United States Agriculture and Food

Under this HSPD, the EPA Administrator is required to build upon/expand current drinking water monitoring and surveillance programs. This work requires both detection methods as well as laboratory networks needed to accomplish this task.

### 8.1.5 HSPD-10 - BioDefense for the 21st Century

Under this HSPD, EPA is required to survey Chemical, Biological, Radiation and Nuclear laboratory capacity and capability. EPA and other agencies are required to develop standards, protocols, and capabilities to address the risks of contamination following a biological weapons attack. EPA and other agencies are also required to develop strategies, guidelines, and plans for decontamination of persons, equipment, and facilities.

### 8.1.6 EPA's Strategic Plan for Homeland Security

In September 2002, EPA published a Draft Strategic Plan for Homeland Security which describes the expansion of EPA activities under existing programs and new initiatives in direct response to potential threats and vulnerabilities. The strategic plan (EPA, 2002) is organized into four mission-critical areas:

1. Critical Infrastructure Protection
2. Preparedness, Response, and Recovery
3. Communication and Information
4. Protection of EPA Personnel and Infrastructure.

To meet the responsibilities specified under the aforementioned directives, EPA's Office of Water established the Water Protection Task Force which was formally organized as the Water Security Division (WSD) in August 2003. Additionally, EPA's ORD officially established the National Homeland Security Research Center (NHSRC) in February 2003.

These organizations work synergistically to provide research and technical support to the drinking water and wastewater sectors. NHSRC's Water Security Team contributes by conducting applied research and then reporting on ways to better secure the Nation's water systems from threats and attacks. The Team is producing various products, such as analytical tools and procedures, technology evaluations, models and methodologies, decontamination techniques, technical resource guides and protocols, and risk assessment methods. All of these products are for use by EPA's key water infrastructure customers — water utility operators, public health officials, and emergency and follow-up responders. Other research programs in NHSRC deal with the protection of buildings and rapid risk assessment. WSD provides support to drinking water and wastewater systems by preparing vulnerability assessment and emergency response systems and tools, providing technical and financial assistance, and developing information exchange mechanisms. WSD is also charged with supporting best security practices, providing security enhancement guidance, and incorporating security into the day-to-day operations of the drinking water and wastewater industries. In addition, WSD works closely with NHSRC in delivering research results in a timely and appropriate fashion. EPA's WSWRD provides technical support to NHSRC in conducting bench-and pilot-scale research at the EPA's Test and Evaluation (T&E) Facility in Cincinnati, Ohio. Assistance is also provided for field implementation of technologies to complement NHSRC's research.

## 8.2 EPA's Homeland Security and Emergency Response Initiatives and Resources

Many of EPA's ongoing homeland security and emergency response initiatives and resources are summarized on the EPA website link on water security (EPA, 2005c). Additionally, the water security resources for small systems are summarized at the EPA website (EPA, 2005c). The resources available for small water systems at this web site include links to:

- VA Tools
- Self-Assessment Guide for Drinking Water Systems.
- Guide for Wastewater Systems.
- Security Emergency Managements Systems (SEMS) software program developed by the National Rural Water Association (NRWA).
- Automated Security Survey and Evaluation Tool developed by New England Water Works Association.
- Emergency/Incident Planning
- ERP Guidance - This document provides guidance to small and medium-sized community drinking water systems on developing or revising their ERPs.
- Response Protocol Toolbox (RPTB) - This document is composed of six interrelated modules that provide guidance on planning for and responding to both threats and actual incidents of intentional contamination of public drinking water supplies.
- Emergency Response Workshops - EPA is conducting a series of ongoing nationwide workshops for all sizes of water utilities that provides instruction on the RPTB and the Incident Command System. This workshop also includes an enhanced tabletop exercise that will test and develop emergency response skills.
- ERP Enhancement to Vulnerability Self-Assessment Tools Software.
- Tools & Technical Assistance
- Security Product Guides - EPA has developed these guides to provide information on products available to enhance physical and cyber security and to present information on monitoring protocols.

- Top Ten List to protect small ground water suppliers from contamination events.
- Water Security Guide - This guide, currently under development, will provide security guidance to drinking water managers and operators of systems serving 3,300 people or fewer. The guide is expected to be available in Calendar Year 2005.

As indicated earlier in this chapter, the VAs and ERPs have already been completed by most small systems. Therefore, the tools and resources related to these topics are not discussed further in this document.

## 8.3 Threats and Risks to the Water Supply

Smaller PWSs, where source areas are known to occur at some significant distance from an actual supply, are more likely to be severely threatened (Field, 2002). The risk of contamination using chemical, biological and/or radiological substances with subsequent consequences must be understood by small system managers to provide appropriate security, employ suitable detection systems and develop strategies to deal with contamination events.

### 8.3.1 Chemical and Radiological Contaminants

Chemical contaminants include inorganic, organic, radiological and other chemical warfare compounds that have a wide range of impacts on water quality and the consumer. For example, the impacts can range from a harmless change in color to introduction of highly toxic neurotoxins (e.g., Sarin, VX) that would cause significant fatalities in the exposed population.

### 8.3.2 Biological Contaminants

According to Providing Safe Drinking Water in Small Systems (NSF International World Health Organization, 1999), there is an average of 10 to 15 outbreaks of disease from tap water in the U.S. per year, with "over 100 types of bacteria, viruses and protozoa that can be found in contaminated water." The book states that "in both developed and developing countries water quality has continued to deteriorate (Bank, 1992)." The book also summarizes that "the potential rise in waterborne disease outbreaks may be due to increasing susceptible populations, political upheaval and high numbers of refugees in developing countries. Natural disasters such as flooding and droughts due to climatic changes may also be affecting global water quality."

### 8.3.3 Risk Assessment and Mitigation

Risk assessment was a required element of the federally mandated VAs. Furthermore, small systems were encouraged to implement actions that specifically addressed the potential threats and vulnerabilities identified during the federally mandated vulnerability assessments. Some key measures that were recommended include:

- Routine or around-the-clock monitoring of treatment and key supply infrastructure (using video surveillance, intrusion detection, alarm systems).
- General increase in security procedures such as identification for employees and visitors with continuing emphasis on security at staff meetings.
- Routine inspection of key facilities and suspension of public access to these facilities.
- Routine testing of water quality to ensure that it continues to meet or exceed the required federal and state standards.

Along with providing research and technical support, WSWRD, NHSRC and WSD encourage information sharing and risk communication strategies among key water infrastructure customers. This includes making use of the Water Information Sharing and Analysis Center. Small system operators are encouraged to contact (through available state and local channels or directly) both WSD and NHSRC periodically for resources and technology related inputs that might be available to address their needs.

## 8.4 Response Protocol Toolbox

EPA released the "Interim Final Response Protocol Toolbox: Planning for and Responding to Contamination Threats to Drinking Water Systems," in December of 2003 (EPA, 2003). The RPTB is composed of six interrelated modules, in addition to an overview, which focus on different aspects of planning a response to contamination threats and incidents. The module titles are listed below:

Overview (EPA-817-D-03-007)

Module 1 - Water Utility Planning Guide (EPA-817-D-03-001)

Module 2 - Contamination Threat Management Guide (EPA-817-D-03-002)

Module 3 - Site Characterization and Sampling Guide (EPA-817-D-03-003)

Module 4 - Analytical Guide (EPA-817-D-03-004)

Module 5 - Public Health Response Guide (EPA-817-D-03-005)

Module 6 - Remediation and Recovery Guide (EPA-817-D-03-006)

These modules provide emergency response planning tools that may be adopted voluntarily. The RPTB is designed to help the water sector to effectively and appropriately respond to intentional contamination threats and incidents. EPA produced the RPTB, building on the experience and expertise of several drinking water utilities, particularly the Metropolitan Water District of Southern California. The users are encouraged to review the overview before using other Modules.

Since the release of RPTB, EPA received feedback and suggestions from several sources concerning improvements in the RPTB. Subsequently, EPA developed RPTB: Response Guidelines (EPA, 2004)- An action oriented document (easy to use document for field and crisis conditions) to assist drinking water utilities, laboratories, emergency responders, state drinking water programs, technical assistance providers, and public health and law enforcement officials during the management of an ongoing contamination threat or incident. The RPTB Response Guidelines are not intended to replace the RPTB and do not contain the detailed information contained within the six complete modules. The RPTB Response Guidelines are to be viewed as the application of the same principles contained in the RPTB during an actual incident.

## 8.5 Recommended Procedures for Securing Small Systems

The Association of State Drinking Water Administrators (ASDWA)/NRWA document, titled Security Vulnerability Self-Assessment Guide for Small Drinking Water Systems (ASDWA/NRWA, 2002), suggests the following:

- restrict or limit access to the critical components of the water system (i.e., a part of the physical infrastructure of the system that is essential for water flow and/or water quality) to authorized personnel only;
- secure the facility perimeter with a fence;
- lock all building doors and windows, hatches and vents, gates, and other points of entry to prevent access by unauthorized personnel, and check the locks regularly;
- assure adequate lighting around the critical water system components, which is a good deterrent to unauthorized access (motion detectors that activate switches that turn lights on or trigger alarms also enhance security;
- post warning signs (tampering, unauthorized access, etc.) on all critical components;
- patrol and inspect critical components;
- clear the area around critical components of any objects that may be used for breaking and entering;
- assure that entry points to the water system are easily seen (clear fence lines of vegetation, including overhanging or nearby trees);
- consider installing an alarm system that notifies the authorities or designated contact when there has been a breach of security;
- record locks and associated keys and to whom the keys have been assigned;
- limit entry codes and/or keys to water system personnel only;
- form a neighborhood watch system;
- properly seal wellheads;
- properly install vents and caps to help prevent the introduction of a contaminant into the water supply;
- properly secure observation/test and abandoned wells;
- secure surface water sources, where possible, with fences or gates;
- control the use of hydrants and valves;
- monitor distribution system for positive pressure;
- implement a backflow prevention program.

## 8.6 Infrastructure and Bulk Water

The DHS developed a document entitled National Strategy for the Physical Protection of Critical Infrastructures and Key Assets (DHS, 2003). This Strategy document identifies a clear set of national goals, objectives and outlines, and guiding principles that underpin the Nation's efforts to secure the infrastructures and assets vital to national security, governance, public health and safety, economy, and public confidence.

This Strategy also provides a unifying organization and identifies specific initiatives to drive the near-term national protection priorities and inform the resource allocation process. Most importantly, it establishes a foundation for building and fostering the cooperative environment in which government, industry, and private citizens can carry out their respective protection responsibilities effectively and efficiently. The

Strategy states the following concerning water:

"On the supply side, the primary focus of critical infrastructure protection efforts is the Nation's 170,000 public water systems. These utilities depend on reservoirs, dams, wells, and aquifers, as well as treatment facilities, pumping stations, aqueducts, and transmission pipelines." The Strategy also states that "in order to set priorities among the wide range of protective measures that should be taken, the water sector is focusing on the types of infrastructure attacks that could result in significant human casualties and property damage or widespread economic consequences. In general, there are four areas of primary concentration:

- Physical damage or destruction of critical assets, including intentional release of toxic chemicals;
- Actual or threatened contamination of the water supply;
- Cyber attack on information management systems or other electronic systems; and
- Interruption of services from another infrastructure.

The Strategy also states that water infrastructure protection initiatives are guided both by the challenges that the water sector faces and by recent legislation. Additional protection initiatives include efforts to:

- Identify high-priority vulnerabilities and improve site security
- Improve sector monitoring and analytical capabilities
- Improve sector-wide information exchange and coordinate contingency planning
- Work with other sectors to manage unique risks resulting from interdependencies

The Drinking Water Needs Survey (EPA, 1997) states that "community water systems need to invest significant amounts of money in infrastructure improvements if they are to continue providing water that is safe to drink. Much of the Nation's drinking water infrastructure suffers from long term neglect and serious deterioration. Recent events, including waterborne disease outbreaks and extended boil water notices in major cities, have focused national attention on the dangers associated with contamination of public water supplies. Current needs for minimizing health threats from microbiological contaminants (those needs associated with the SWTR and the TCR) are especially critical. Water systems around the country must make immediate investments in infrastructure to protect public health and ensure the availability of safe drinking water."

## 8.7 Telemetry

Small water utilities typically have their customer and billing information system computerized (a traditional Information Technology-IT system) along with some remote components potentially on a Supervisory Control and Data Acquisition (SCADA) System (a.k.a. telemetry). These IT/SCADA systems are vulnerable to attacks which may disrupt the operations of the utility and potentially damage equipment. The Association of State Drinking Water Administrators/National Rural Water Association document, titled Security Vulnerability Self-Assessment Guide for Small Drinking Water Systems (ASDWA/NRWA, 2002), suggests the following:

- password protect all computer access;
- install a firewall protection program;
- consider subscribing to a virus protection update program;
- back up computers regularly;

The U.S. Department of Homeland Security's website (www.dhs.gov) provides information on reporting cyber-security incidents. It specifies that individuals can report to the United States Computer Emergency Readiness Team at www.us-cert.gov and federal agencies/department report to www.us-cert.gov/federal. The DHS website also provides information on current threats, including the advisory system, advisories, and information bulletins.

Panguluri et al, (2004), provide an overview of a utility's computer system infrastructure along with identifying methods for mitigating cyber-attacks. This document also has a compilation of sources from where common vulnerabilities can be identified. An overview of planning for incident response and business continuity is also provided in this document.

## 8.8 Early Warning Systems for Drinking Water Systems

According to Online Monitoring for Drinking Water Utilities (AWWARF-PROAQUA, 2002) "a water utility's primary responsibility is to consistently produce and distribute water that will satisfy the customer in terms of quality and quantity. Water quality in the distribution system can significantly deteriorate due to bacterial growth, corrosion, and direct contamination. Assuring stable, high-quality drinking water depends on the utility's ability to ensure that the water put into the distribution system maintains its quality until it is consumed. Online monitoring of a limited number of variables can substantially contribute to achieving this goal."

"Water quality monitoring sensor equipment may be used to monitor key elements of water or wastewater treatment processes (such as influent water quality, treatment processes, or effluent water quality) to identify anomalies that may indicate threats to the system. Some sensors, such as sensors using biological organisms or measuring radiological contaminants, measure "surrogate" parameters that may indicate problems in the system but do not identify sources of contamination directly, while others, particularly chemical monitoring systems measure potential contamination directly. In addition, sensors can provide more accurate control of critical components in water and wastewater systems and may provide a means of early warning so that the potential effects of certain types of attacks can be mitigated. One advantage of using chemical and biological sensors to monitor for potential threats to water and wastewater systems is that many utilities already employ sensors to monitor potable water (raw or finished) or influent/effluent for SDWA or CWA water quality compliance or process control.

Chemical sensors that can be used to identify potential threats to water and wastewater systems include inorganic monitors (e.g. chlorine analyzer), organic monitors (e.g. total organic carbon analyzer) and toxicity meters. Radiological meters can be used to measure concentrations of several different radioactive species. Monitors that use biological species can be used as sentinels for the presence of contaminants of concern, such as toxics. "At the present time, biological monitors are not in widespread use and very few biomonitors are used by drinking water utilities in the U.S. (EPA, 2005b)." "Proof that the delivered water meets the quality requirements must be gained during and after the treatment process. For that reason, online monitoring of key parameters, in combination with other tools, will help the system operator to:

- Identify areas in the system that are vulnerable to water quality deterioration or external contaminant sources
- Take proper preventive or corrective measures to improve system integrity
- Substantially increase the capability of early detection methods for regulated parameters
- Optimize the system in terms of energy consumption and water supply patterns
- Document that some parameters (disinfectant residuals, fluoride, etc.) comply with required concentrations for a specified period of time (e.g., over 95 percent of operation period)
- Inform customer on water quality (via the Internet or other communication systems)." (AWAARF, 2002)

## 8.9 Disinfection in Distribution Systems

Disinfection of drinking water is considered to be one of the major public health advances of the 20th century. Disinfection ensures that dangerous microbial contaminants are inactivated before they can enter the distribution system. The successful application of chlorine as a disinfectant was first demonstrated in England. In 1908, Jersey City (New Jersey) initiated the use of chlorine for water disinfection in the U.S. This approach subsequently spread to other locations, and soon the rates of common epidemics such as typhoid and cholera dramatically dropped in the U.S. Today, disinfection is an essential part of drinking water treatment. Chlorine gas, hypochlorite, chlorine dioxide, and chloramines are most often used because they are very effective disinfectants, and residual concentrations can be maintained in the water distribution system. Some European countries use ozone and chlorine dioxide as oxidizing agents for primary disinfection prior to the addition of chlorine or chlorine dioxide for residual disinfection. The Netherlands identifies ozone as the primary disinfectant, as well as common use of chlorine dioxide but typically uses no chlorine or other disinfectant residual in the distribution system (Connell, 1998).

## 8.10 Preparedness Assessment for Handling Threats

The NRWA has customized the Standardized Emergency Management Systems/Incident Command System (SEMS/ICS) training for small systems to manage, respond and mitigate real or perceived threats. SEMS/ICS is based on the use of commonly accepted terminology that clearly describes needs and expectations between response agencies. This terminology is based on the established and accepted common names for emergency response equipment, organizational units, functions, resources, and facilities. A SEMS/ICS response organization is based on the type and size of the incident. Modular organization allows for the addition and reduction of positions based on current and future needs. All SEMS/ICS organizations build from the top down as the incident grows.

SEMS/ICS is made up of five functions: Management; Operations; Planning; Logistics; and Finance. These functions may, as the incident grows, be organized and staffed into Sections. Initially, the Director of Emergency Services may be performing all five functions. Then, as the incident grows, each function may be established as a Section with several Units under each Section. Only those functional elements that are required to meet current objectives will be activated. Those functions which are needed but not staffed will be the responsibility of the next higher element in the organization. Several states mandate the use of SEMS/ICS when responding to any of the following emergency operations:

- Single jurisdictional responsibility with multiple agency involvement
- Multiple jurisdictional responsibility with multiple agency involvement

The SEMS/ICS provides an efficient tool for the management of emergency operations. SEMS / ICS is designed to be adaptable to any emergency or incident. The system expands in a rapid and logical manner from an initial response to a major incident call-out. When organizational needs dictate, the system also contracts just as rapidly. SEMS/ICS allows for continuous notification of intelligence from state and local level agencies to information and alerts from the Office of Homeland Security, Federal Bureau of Investigation, Environmental Protection Agency, Department of Energy, Department of Transportation, U.S. Bureau of Reclamation and the Awareness National Security Intelligence Reports, as well as the Association of Metropolitan Water Agencies and the American Water Works Association.

## 8.11 Local/State Emergency Planning Committees

Local Emergency Planning Committees (LEPCs) were established by the Emergency Planning and Community Right-to-Know Act (EPCRA), which includes emergency planning and community right-to-know requirements. The purpose of the LEPC includes:

- Development, training, and testing of the hazardous substances emergency response plan for the community
- Development of procedures for regulated facilities to provide informational and emergency notification to the LEPC
- Development of procedures for receiving and processing requests from the public under EPCRA
- Provision for public notification of LEPC activities

A major role for LEPCs is to work with industry and the interested public to encourage continuous attention to chemical safety, risk reduction, and accident prevention by each local stakeholder. The EPA's Office of Emergency Management (OEM) maintains a LEPC database (EPA, 2005a) which contains over 3,000 listings. This database can be searched by state, name address or by zip code. The database is updated monthly. In addition, the Local Governments Reimbursement (LGR) Program provides federal funds to local governments for costs related to temporary emergency measures conducted in response to releases or threatened releases of hazardous substances. The program serves as a "safety net" to provide supplemental funding to local governments that do not have funds available to pay for these response actions. Eligible local governments may submit applications to EPA for reimbursement of up to $25,000 per incident.

On February 18, 1998, EPA published a new LGR regulation that simplifies and streamlines the process for applicants. EPA has designed the reimbursement process to be very straightforward. Local governments obtain and complete a simple LGR application form that requires a local government to provide basic information about the incident, document its response costs by attaching copies of receipts, and certify that certain program requirements have been met. An applicant may receive a reimbursement check from the federal government in as little as three months after EPA receives the application. Local governments can take action today to help ensure that they are eligible to participate in the LGR program in the future.

EPA's LGR Program HelpLine can be reached by calling 800-431-9209 or via e-mail at lgr.epa@epamail.epa.gov.

## 8.12 Alternative Drinking Water Supplies in the Event of an Incident

Public water systems may at some time need to utilize an alternate source of water. This need may arise due to drought, contamination of the primary source, or failure at the source (e.g. a dam). Use of an alternate source of water can be complex, and will require advance approval by the state agencies. Prior to submitting an application for approval, the PWS should perform a preliminary evaluation to assess the difficulty of locating pipes to transport water on a temporary basis, obtaining right-of-way or access rights, and securing financing to construct temporary or permanent structures. If a PWS anticipates the need to utilize an alternate source of raw water and the preliminary evaluation indicates that the project can be accomplished, the PWS should proceed by contacting the regulating state agency to obtain approval. Typically, a state agency will require basic information, such as identification of proposed alternate source(s), surface and ground, including location and name of source. In addition, specific information on each proposed alternate source is usually required, such as estimated days of water available and potential sources of contamination within the vicinity of each proposed source (e.g., domestic or hazardous waste sites, oil and gas wells, abandoned wells, mining operations, discharges from sewage treatment plants, industrial discharges). Also, depending upon the size and location of the alternative source, there may be many other requirements that a PWS must meet to be able to utilize that source. Furthermore, alternate sources of raw water must be tested (for evaluating the water quality), evaluated against available treatment techniques, and finished water testing must be performed in order to ascertain that the water provided to the public will meet all regulatory requirements.

If an alternate source(s) is(are) approved, the results of the raw water testing are typically used in part to determine the amount of testing necessary for the finished water. Other factors would include the operation and maintenance of the treatment plant and the water treatment practices in place to remove contaminants if they are encountered. Typically, at a minimum, testing is required for total coliform bacteria in the treated water. Continued use of the alternate sources will also be subject to routine monitoring requirements. In many cases it may be more economical and practical to contract with a neighboring water supplier and form a partnership for sharing raw and/or finished water during emergencies. If such sources are not available, the PWS should implement other appropriate emergency water conservation measures outlined in their ERP.

## 8.13 Key Questions

- Are information sources adequate for small systems? Can information dissemination be improved through cooperation with NRWA?
- Are emergency response procedures/protocol adequate? Are small systems satisfied with these procedures?

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# Chapter 9 Remote Monitoring and Control

## 9.1 Introduction

Drinking water regulations require all conventional drinking water treatment system operators to provide water quality monitoring to ensure that good quality water is provided to the consumers (EPA, 1996). Most treatment systems/technologies can be equipped with sensors and operating devices that can be monitored from remote locations. Remote monitoring and control technology can be used to improve monitoring/reporting and reduce operation and maintenance (O&M) costs. Remote monitoring and control technologies or remote telemetry systems are also known as Supervisory Control and Data Acquisition (SCADA) systems. A SCADA system consists of three key components: monitoring/control device(s) (e.g., a sensor/analyzer that measures and reports the desired parameter, a variable frequency drive pump the speed of which can be controlled remotely), data transmission equipment/media (e.g., phone, wire and radio), and data collection and processing unit (typically a central computer that analyzes the reported parameter value and programmatically decides what controls, are warranted based on the reported value). For example, when a tank level sensor reports that a remote reservoir is full, this information is processed by the SCADA central computer which instructs the associated pump to shut down. For small packaged treatment systems, such equipment could easily double the purchase cost. However, operational payback can be quickly realized through lower use of chemicals, low residue generation (disposal), and increased reliability. Also, the cost of subsequent networking of multiple package plant sites or water quality monitoring devices is also decreased after the initial cost for installing the basic SCADA equipment has been incurred. It has been demonstrated that various remote monitoring technologies are being appropriately designed for small systems and these will ultimately produce a better quality of drinking water, accommodate the resources of small systems, increase the confidence level of the customer, operator and regulator, and comply with the monitoring and reporting guidelines.

SCADA systems are not always used to their fullest potential by small systems due to complex operating systems and control (software and hardware) that usually require specially trained computer programmers or technicians and costly service agreements. In the last few years, SCADA vendors have changed the way they design and fabricate their systems, thus making them more accessible and affordable to small drinking water treatment operators.

## 9.2 Rationale for Online Monitoring

The application of SCADA to operate, monitor, and control small systems from a central location is believed to be one mechanism that can reduce violations of MCLs as well as Monitoring/Reporting (M/R) violations. Through the application of SCADA, EPA has demonstrated that filters could be operated more efficiently for particle removal, disinfectant doses altered in real-time in response to varying raw water conditions, and routine maintenance and chemical re-supply can be scheduled more efficiently. Small independent systems could contract with an off-site O&M firm or join with other small system communities or utilities to either work out schedules to monitor via SCADA or hire an O&M services provider, while maintaining ownership. This type of approach would provide the small system the economies-of-scale that the medium and larger systems have in purchasing supplies, equipment, and power.

EPA has been evaluating a variety of "small" SCADA systems that would allow a single qualified/certified operator to monitor and control the operation of several small treatment systems from a central location. The use of a SCADA system results in optimum utilization of time for onsite inspections and maintenance, thus allowing the operator to visit only the problematic systems/sites and better schedule the maintenance of these systems. The expected results from an appropriately designed and successfully deployed SCADA system are (Panguluri et al., 2005a):

- enhanced security and control,
- improved water quality,
- regulatory compliance, and
- reduced overall maintenance costs

## 9.3 Selection and Implementation of Supervisory Control and Data Acquisition (SCADA) Systems

It is important to understand the treatment system operation, location and other environmental factors when engineering and designing a SCADA system for remote operation and maintenance. The treatment system operation, location and site-specific factors (the site-specific factors are discussed later in this section) will determine the need and the basic design of the SCADA system. These factors will also help to determine if the system will complement the needs of the treatment system and the utility services. Retrofitting a treatment system for remote operations can be cost prohibitive; many of the small treatment systems currently in use were not originally designed for remote operations. Rural areas have little or no electronic hardware to communicate with a SCADA system. Thus, the cost of upgrading the treatment system for remote operations could be significant. Therefore, it is essential that the treatment system be fairly amenable to automation. Table 9.1 identifies the current amenability of small package plant treatment technologies to SCADA.

Many of these treatment technologies are available as package plants with some degree of automation designed specifically for small systems. The membrane technologies are extremely amenable to automation and remote control and also provide efficient removal for a wide range of drinking water contaminants.

Federal regulations require all small PWS operators to provide monitoring to assure quality of the treatment processes. Constant remote monitoring of the water quality has the potential to provide savings in costs of time and travel for O&M. It has been determined that remote telemetry can support regulatory reporting guidelines by providing real-time continuous monitoring of the water quality and reporting the information electronically. However, current guidelines are not available on how to interpret the online data. For example, if the data shows that for a period of 5-minutes (in a particular month) the measured chlorine levels were below the regulated levels does that constitute a violation? Additionally, states do not have a mechanism to accept large quantities of data There is need for developing guidance on how to interpret the online monitoring data both from compliance and security perspectives.

*Table 9.1 Amenability of treatment technologies to remote monitoring used for small water (EPA, 2003).*

| Technology | Amenability for Automation/Remote Monitoring & Control* |
|---|---|
| Air Stripping | 4 – 5 |
| Oxidation/Filtration | 1 - 2 |
| Ion Exchange | 3 - 4 |
| Activated Alumina | 1 – 2 |
| Coagulation/Filtration | 1 – 2 |
| Dissolved Air Flotation | 1 - 2 |
| Diatomaceous Earth Filtration | 3 - 4 |
| Slow Sand Filtration | 3 - 4 |
| Bag and Cartridge Filtration | 3 – 4 |
| Disinfection | 4 – 5 |
| Corrosion Control | 3 - 4 |
| Membrane Filtration Systems | 3 - 4 |
| Reverse Osmosis/Nanofiltration | 4 - 5 |
| Electrodialysis Systems | 4 - 5 |
| Adsorption | 3 - 4 |
| Lime Softening | 1 – 2 |

**A rating scale of one to five (1 to 5) is employed with one (1) being unacceptable or poor and five (5) being superior or acceptable.*

Long-term real-time remote monitoring can provide data that can be used to significantly enhance treatment system operation and reduce system downtime. Real-time remote monitoring (Clark et al., 2004; EPA, 2003; Haught, 1998; Haught and Panguluri, 1998) has the following advantages:

- Can lead to improved customer satisfaction, improved consumer relations and other health benefits.
- Can be used to satisfy regulatory recordkeeping and reporting requirements.
- Can reduce labor costs (associated with time and travel) for small system operators.
- Provides the capability to instantly alert operators of undesirable water quality and/or other changes in treatment system(s).
- Reduces downtime and increases repair efficiency; troubleshooting can be performed remotely.
- Can identify monitored parameter trends and adjust operating parameters accordingly.
- Can provide an attractive alternative to fixed sampling and operation and maintenance schedules.

The following questions must be addressed before purchasing a SCADA System (Clark et al., 2004; EPA, 2003; Haught, 1998; Haught and Panguluri, 1998):

- Does the water treatment system justify the requirement for a SCADA system (is it remotely located)?
- Is the treatment system amenable (can water quality instrumentation and operational controls “send and receive” data in real-time) to automation?
- What types of communication media can be used (phone, radio, cellular, etc.)? See Figure 9.1
- How much automation and control is available on the treatment system?
- What type of SCADA system is needed (is the goal to monitor, control or both)?

- How many parameters are going to be monitored and/or controlled?
- What are the specific regulatory monitoring and reporting requirements?

Figure 9.1 shows the possible schematic layout of a remote monitoring network.

## 9.4 Fundamentals of SCADA

As discussed previously, the three key components of SCADA are: monitoring/control device(s), data transmission equipment/media, and data collection and processing unit. This equipment is briefly discussed in the following sub-sections of this report.

### 9.4.1 Monitoring Equipment

In general, monitors can be categorized by the types of parameters (contaminants, agents, characteristics) that the monitor is used to measure. For establishing water quality, the monitors are designed to measure one or more parameters that represent physical, chemical and/or biological characteristics of the system. The online remote monitoring devices are fairly complex devices that are designed to automatically measure, record, and display specific physical, chemical or biological parameters. Online monitoring equipment can be the most expensive component of a SCADA system. The sensors used in a SCADA system may vary widely, depending upon the parameters that need to be monitored. The cost for these devices can range from $ 300 to $ 85,000. The costs associated with maintenance and calibration of the monitoring equipment should be considered when planning the acquisition and implementation of a SCADA network. The basic types of monitoring devices that may be employed in a water distribution system for monitoring water quality are discussed below.

#### 9.4.1.1 Physical Monitors

Physical monitors are used to measure physical characteristics of the water. They include a variety of instruments that measure various characteristics, such as flow, velocity, water level, pressure and other intrinsic physical characteristics of water. Examples of intrinsic physical characteristics include: turbidity, color, conductivity, hardness, alkalinity, radioactivity, temperature and oxidation-reduction potential. In general, physical monitors tend to be relatively inexpensive, quite durable, and readily available.

#### 9.4.1.2 Chemical Monitors

Chemical monitors are used to detect and measure inorganic or organic chemicals that may be present in the water. A wide range of chemicals may be of interest and a large variety of technologies can be used. A specific technology or multiple technologies must be properly selected for a particular chemical or group of chemicals. Examples of chemical monitors include: Chlorine analyzer, nitrate sensor, Total Organic Car-

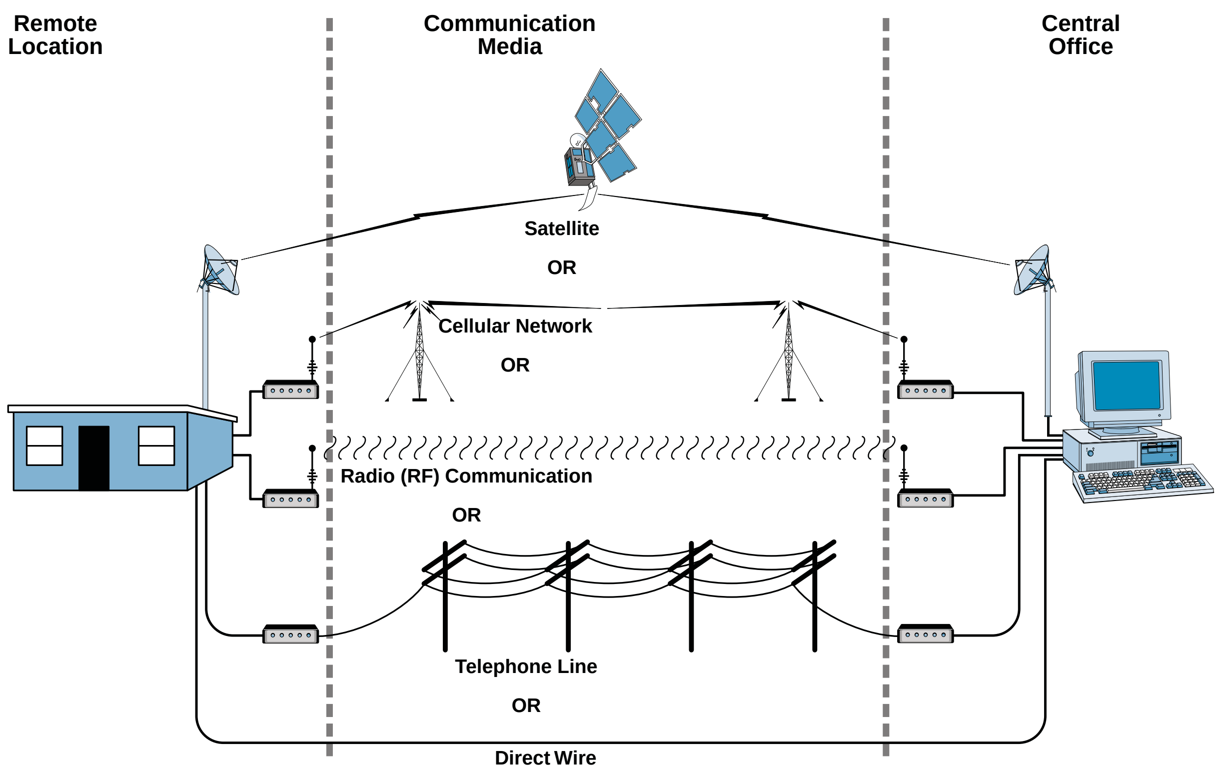


*Figure 9.1 Possible layout of remote monitoring system (EPA, 2003).*

bon (TOC) analyzer, etc. Typically, the same general type of technology may be available for either automated online monitoring capability or for manual grab sample analysis.

#### 9.4.1.3 Biological Monitors

Biological monitors (biomonitors) include bio-sensors and bio-sentinels. Bio-sensors detect the presence of biological species of concern, such as some forms of algae or pathogens. The general operating principles of bio-sensors may include: photometry, enzymatic and/or some form of bio-chemical reaction. The bio-sentinels use biological organisms as sentinels to determine the likely presence of toxicity in a water sample. In general, bio-sentinels cannot be used to identify the presence of a specific toxic contaminant – rather only that there is some form of toxic contaminant present. Most bio-sentinels operate by observing the behavior of selected organisms. Examples of such organisms include: fish, mussels, daphnia and algae. When the sentinel organism senses the presence of toxic contaminant(s), the organism reacts in some manner. The bio-sentinel instruments respond to these reactions and note that some form of event is occurring.

While bio-sensors can be directly applied in distribution systems, the bio-sentinels are typically used in source waters. This is because most organisms are sensitive to the presence of chlorine (or other disinfectants) in the water. Therefore, if a bio-sentinel is proposed to be used for distribution system monitoring, the water must be de-chlorinated prior to entering the bio-sentinel instrument. Also, the bio-sentinels require a protected housing environment along with some sort of nutritional supply to keep the sentinel organism alive and healthy. The use of bio-monitors is ideally more suitable for security issues.

### 9.4.2 Control Equipment

Control equipment such as switches and controllers are used widely in SCADA systems. Cost of the control units such as pumps or shut-off valves are generally less expensive (Panguluri et al., 2005a) compared to the monitoring equipment.

### 9.4.3 Data Collection and Processing Unit(s)

Depending upon the system design requirements, there can be more than one central data collection and processing unit. The SCADA system can be designed in a way such that the field SCADA units are "dumb" units that simply collect and transmit data to the central station for analysis and action. Alternatively, field SCADA units can be "smart" and be automated to perform some of the control decisions locally and interact with the central station as necessary for additional analysis and support.

### 9.4.4 Communication Media and Field Wiring

Depending upon availability, cost, user preference, and the relative location of the sensors to the data acquisition system, the communication media can be either wired (e.g., direct, phone line) or wireless (e.g., radio, cellular). In field environments, distributed input/output is typically employed. A remote data acquisition hardware unit employed at the field location performs the appropriate signal conditioning and transmits the data to a central hub (Clark et al., 2004; EPA, 2003; Haught, 1998; Haught and Panguluri, 1998; Pollack et al., 1999). More recently, mesh or grid computing systems are used in remote locations to add redundancy in cases of link failures. The field wiring between the sensor and the remote data acquisition hardware unit is typically direct wire.

Typically, direct wire and phone line (including cellular) communication media are the most inexpensive. The primary limitations associated with selecting the communication media include installation and operating costs, which can vary between $200 (for a simple telephone or cellular modem) to several hundred dollars for a satellite-based system per location. Ongoing monthly operating costs can range from $25 for a phone line to approximately $200 per month for satellite-based services within the U. S (per monitored location). The overall costs for individual SCADA components are summarized in Table 9.2 (EPA, 2003). For a small system, it is expected that (except for the sensor instrumentation) the actual costs will be on the lower side of the presented ranges in Table 9.2.

## 9.5 Remote Telemetry Applications for Small Systems

Over the years, EPA has funded several remote monitoring applications in the field. The very first field implementation for a small system was in West Virginia and the most recent implementation was in Puerto Rico. A brief summary of these case studies is presented in this section.

### 9.5.1 West Virginia Remote Monitoring Case Study

In May 1991, EPA provided funding to support a research project titled "Alternative Low Maintenance Technologies for Small Water Systems in Rural Communities" (Goodrich et al., 1993). This project involved the installation of a small drinking water treatment package plant in a rural location in West Virginia. The primary objective of this study was to evaluate the cost-effectiveness of package plant technology in

*Table 9.2 Cost estimates of SCADA system components (Updated from EPA, 2003).*

| SCADA System Component | Component Option | Range of Costs, $ |
|---|---|---|
| Hardware | Main Computer<br>SCADA Unit | 1,000 – 3,500<br>500 – 30,000 |
| Software | Operating System<br>Telemetry System<br>Data Collection & Loggers | 250 – 750[a]<br>500 – 30,000[b]<br>250 – 8,000 |
| Communication Medium | Telephone<br>Cellular<br>Radio<br>Satellite | 75 – 125[c]<br>250 – 500[d]<br>200 – 3,500[e]<br>200 – 700[f] |
| Instrumentation | Valves<br>Switch<br>Sensor | 25 – 1,500[g]<br>25 – 300[g]<br>350 – 85,000[h] |

*[a]Operating system software is usually included in the purchase price of a computer.*
*[b]SCADA software is usually included in the purchase price of the hardware.*
*[c]Monthly service charges are estimated.*
*[d]Activation, roaming, and monthly service are estimated and included.*
*[e]Updated: Equipment cost + transmission cost unlicensed frequency ($0), other vary by radio frequency.*
*[f]Updated: Starband satellite system monthly cost ~ $200, dish and installation ~ $500.*
*[g]Cost per valve and/or switch.*
*[h]Cost per individual sensor or sensor system.*

removing microbiological contaminants. The secondary objectives of this project included: remote monitoring and automation of the system to minimize the O&M costs, assessment of the community's acceptance of such a system, ability to pay, and the effect of the distribution system on water quality at the tap. The following is a brief summary of the overall project.

The treatment system was located in rural Coalwood (McDowell County), WV, approximately 12 miles from the McDowell County Public Services Division office in Appalachian Mountain terrain. Prior to 1994, an aerator combined with a slow sand filter was being used for water treatment at this site. This combined unit had been operational for over 30 years and needed substantial repairs. The water flowed by gravity from an abandoned coal mine to an aerator built over a six-foot diameter slow sand filter. A hypochlorinator provided disinfection to the treated water, and the water flowed by gravity through the distribution system to the consumer. The volume of water from the mine was considered sufficient for the small rural community.

Based on a review of existing technology, EPA determined that a packaged ultrafiltration (UF) system would be ideally suited for this location. In 1992, a UF unit was purchased and installed at this site. In 1996, EPA developed, installed, and tested a remote monitoring system at the site. The system used commercially available hardware along with proprietary EPA-developed software. The software was not user-friendly and the overall cost of ownership was very high. Therefore, in 1998, EPA updated the SCADA system with a scalable commercially available off-the-shelf user-friendly SCADA system. The total cost (including instrumentation, technical support, training, and set-up) was about $33,000. After the success of this project in 2000, EPA installed similar SCADA systems at Bartley and Berwind sites in McDowell County, WV, for remote monitoring of the water quality.

### 9.5.2 Puerto Rico Remote Monitoring Case Study

For small system operators, depending upon surface water sources, various environmental factors heavily impact system operations. For example, in tropical areas, storm events can be followed by extreme turbidity swings in surface waters (especially during the rainy season). While the turbidity increase may be short-lived, the high solids loading following a storm event can overwhelm the treatment capacity of the system. Frequent occurrence of these events may lead to high maintenance costs or, at worst, premature equipment failure. Thus, knowledge of the watershed and source water conditions prior to the influx of high-turbidity water to a treatment system is expected to provide an operational advantage. Online remote monitoring of smaller systems located in remote areas has the potential to solve these operational issues and enhance the quality of water delivered to the consumer.

In early 2005, EPA funded the field implementation of a web-based remote monitoring system in San German, Puerto Rico. An overview of the treatment system is presented in Figure 9.2 (Panguluri et al., 2005b).

The system-specific challenges included:

- Topography - Steep mountainous region with dense vegetative cover and significant distance between system components

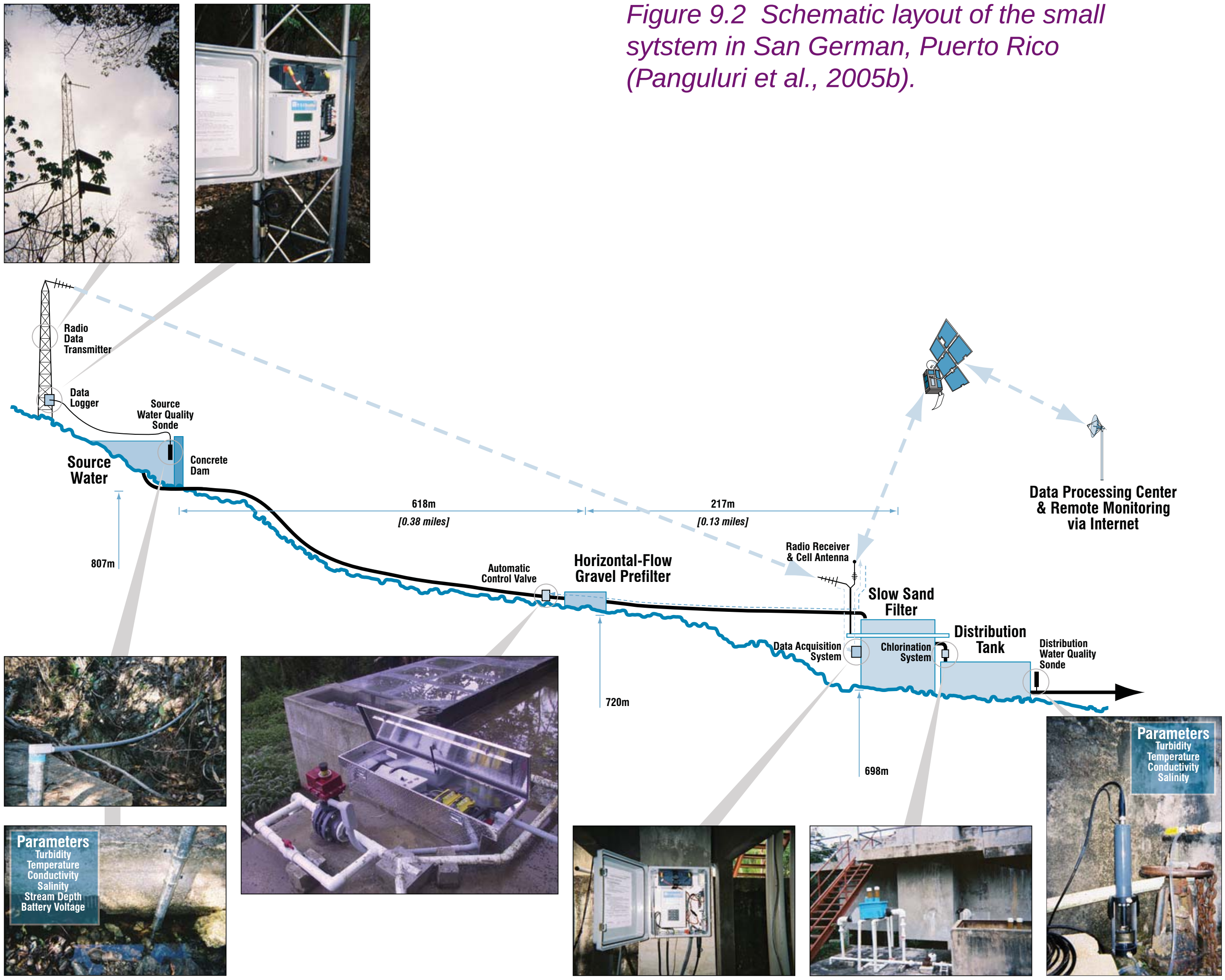


*Figure 9.2 Schematic layout of the small sytstem in San German, Puerto Rico (Panguluri et al., 2005b).*

- Source Variability - 200 inches of rain/year results in flooding events and source water turbidity swings, lack of water under drought conditions
- Other - Lack of electric power and vandalism

Phase 1 of the implementation was completed in April 2005. In this phase, a solar powered real-time web-based remote monitoring system was installed at the source water (dam) location and at the distribution system location. The monitoring systems at both locations are equipped with sensors (multi-parameter sondes) that monitor various water quality parameters (e.g., pH, temperature, and turbidity),. During periods of high-turbidity (>25 NTU) at the source water (dam) location, the system is designed to close an automatic control valve to protect the horizontal-flow gravel pre-filter (HFGP). The source water monitoring location has a built-in option for weather monitoring. In Phase 2 of this implementation, EPA plans to install weather sensors and evaluate alternative water treatment technologies.

The equipment installed at the project site during Phase 1 include: met-tower (without sensors), solar panels, storage batteries, water quality/level sensors (sondes), SCADA units (controller and controlled units) and an automatic control valve. The controller

*Table 9.3 Puerto Rico remote monitoring system component costs (Panguluri et al., 2005b).*

| Monitoring System Component | Total Cost, $ |
|---|---|
| Towers, antenna, solar panel, and batteries | $3,000 |
| YSI Sondes (2 units) | $6,000 |
| Automated control valve | $2,000 |
| Two SCADA units (one equipped with radio and other with radio and cellular access) | $7,000 |
| Website hosting, data warehousing, and digital cellular service | $300/month |

and controlled SCADA units communicate using radio frequency and data is transmitted to a central location via a cellular access at the master location to a central web-site for operator or user access. Table 9.3 shows the costs for system components.

Prior to the installation of the remote monitoring equipment several repairs to the treatment system were performed. The repairs included: cleaning and replacing of the sand filter and gravel filter. The overall Phase 1 installation and repair cost (excluding the equipment costs shown in Table 9-3) was approximately $30,000.

## 9.6 General Security Issues with Remote Monitoring

Because SCADA systems can provide automatic control of a system, system security is an important consideration. The primary security vulnerabilities for SCADA systems are the communication links, the computer software, and power sources for the various system components. A brief discussion about security considerations for communications and software are provided in Chapter 8 of this document. Protection of power sources for individual system components will be dependent on the power sources used in the system. However, security can be improved by ensuring that there are backup power systems for emergency situations.

## 9.7 Contamination Warning Systems

EPA's WSWRD is providing technical support to NHSRC at the T&E Facility to research and develop monitoring systems that measure relatively standard parameters, such as TOC, pH, turbidity, conductivity, chlorine, oxidation-reduction potential and temperature. For both water quality- and security-related monitoring, the instrument response time is critical. Therefore, online monitors are typically used in these types of applications. The parameters monitored may vary widely depending upon the type of process and security monitoring. Currently, WSWRD is assisting in the development of a database repository based on bench-and-pilot-scale experiments that reveal how these traditional parameters, if monitored online, can serve as triggers for contamination events. This measured information can then be automatically analyzed to determine (1) whether there is an indication of unusual contamination in the sample; and (2) what the likely contaminant is based on the water quality signature of these parameters. The interpretation of online data is currently an important research topic and a number of companies are offering data mining software or analytical engines to help identify a contamination event.

The American Society of Civil Engineers (ASCE), in concert with other leading organizations, entered into a cooperative agreement with the EPA to develop standards documents and guidance aimed at enhancing the physical security of the Nation's water, and wastewater/storm water systems. Under this agreement, ASCE is leading the effort to develop guidelines for designing an online contaminant monitoring system (OCMS). The Interim Voluntary Guidelines for Designing an OCMS were published in December 2004. This document provides comprehensive information on several topics including: rationale for OCMS and system design basics, selection and siting of instruments, data analysis and use of distribution system models.

## 9.8 Key Questions

- What is the current status of Remote Telemetry usage?
- What types of SCADA systems can small systems afford, operate, and maintain?
- If affordable, what parameters can currently be monitored and is there room for improvement?
- What is the purpose: Security or water quality?
- What are the main maintenance issues for online monitoring systems?

## 9.9 References

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# Chapter 10
# Summary

## 10.1 Introduction

The challenges facing small drinking water treatment systems are numerous. Research at EPA must focus resources on the most pressing issues that apply to as many systems as possible. The sheer number of small systems and the degrees to which they vary make this a difficult task. Research in treatment technology and monitoring/reporting must be sensitive to cost restrictions which tend to play a much greater role in small systems compared to large systems (serving greater than 10,000 people). Furthermore, future research must be adaptable to upcoming challenges. These factors result in the fact that this Small System Research Strategy Document must be considered as a "living document"; one that has the capability of being flexible to meet new challenges. While searching for breakthroughs in the latest technologies, future work must always consider applicable, affordable technologies. This document attempts to assess the current status of small systems with the primary goal of informing decision-makers so that resources can be brought to bear on the most pressing issues concerning small systems. It will be crucial to consider input from small systems personnel and the public at every stage.

## 10.2 Memorandum of Understanding (MOU) with the National Rural Water Association (NRWA)

In an effort to focus resources where they are most needed, EPA-WSWRD will work with the NRWA through a MOU. The NRWA offers an enormous amount of resources concerning access at the grass roots level with small systems across the country. It is hoped that through cooperation with NRWA, WSWRD will be able to provide research results to meet the most pressing needs for small systems.

## 10.3 Chapter-Specific Key Questions

At the ends of the chapters in this document, a list of key questions is presented. These questions are meant to stimulate research in subjects that are of importance to small systems in the United States. The questions will also serve in the prioritization of research in EPA-ORD. We hope to work closely with the NRWA in discussing and prioritizing future areas of research to improve technical support to small systems. We also hope that these key questions will be useful to other organizations as they move forward with research to support small systems.

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