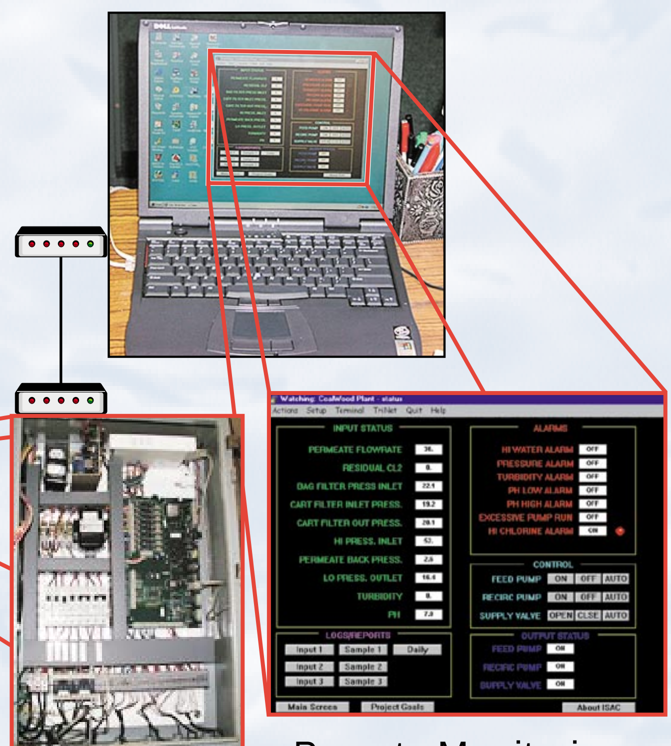
Small Drinking Water Systems Handbook

A Guide to "Packaged" Filtration and Disinfection Technologies with Remote Monitoring and Control Tools

A "Packaged" Solution For A Site In Rural West Virginia

Filtration (Before)

Ultrafiltration System (After)



Remote Monitoring and Control

DISCLAIMER

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Small Drinking Water Systems Handbook

A Guide to “Packaged” Filtration and Disinfection Technologies with Remote Monitoring and Control Tools

U.S. Environmental Protection Agency
Office of Research and Development
National Risk M anagem ent Rese arch Lab oratory
Water Supply and Water Resources Division

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Acronyms and Abbreviations

AOP advanced oxidation process
ARC Appalachian Regional Commission
BAT best available technology
bdl below detection limit
CCL Contaminant Candidate List
cfu colony-forming unit
cm^2 square centimeter
CT contact time
CTA cellulose triacetate
CWS community water systems
DC direct current
D/DBP disinfectants/disinfection by-products
DWS drinking water systems
DWSRF Drinking Water State Revolving Fund
EPA United States Environmental Protection Agency
ESWTR Enhanced Surface Water Treatment Rule
ETV Environmental Technology Verification
GAC granular activated carbon
gpd gallons per day
gpm gallons per minute
HAA haloacetic acid
HFTF high-flow, thin film
hh household
HPC heterotrophic plate count
HUD Housing and Urban Development
IHS Indian Health Service
IRS Internal Revenue Service
MCL maximum contaminant level
MCLG maximum contaminant level goal
MF microfiltration
MHI median household income
µg/L micrograms per liter
MCPSD McDowell County Public Services Division
mg/L milligrams per liter
mL milliliter
mm millimeter
M/R monitoring/reporting
MTBE methyl-tert-butyl-ether
MWCO molecular weight cut-off
mWsec milliwatt second
NCWS non-community water system
nd not detected
NF nanofiltration
nm nanometer
NPDWR National Primary Drinking Water Regulations
NTNCWS non-transient non-community water system
NTU nephelometric turbidity unit
O&M operation and maintenance
O_3 ozone or ozonation
PCE perchloroethylene
PAH polynuclear aromatic hydrocarbon
PDCO pore diameter cut off
PLC programmable logic controller
POE point of entry
POU point of use
ppb parts per billion
psi pounds per square inch
PVC polyvinyl chloride
PWS public water system
REA Rural Electrification Administration
RO reverse osmosis
RTS remote telemetry systems
RUS Rural Utilities Service
SCADA Supervisory Control and Data Acquisition
SOC synthetic organic compound
SDWA Safe Drinking Water Act
SDWR Secondary Drinking Water Regulations
SMCL secondary maximum contaminant level
SWTR Surface Water Treatment Rule
T&E Test and Evaluation
TBA *t*-butyl alcohol
TFB *t*-butyl formate
TCDD tetrachlorodibenzo-p-dioxin
TCE trichloroethylene
TDS total dissolved solids
THM trihalomethane
TNCWS Transient non-community water system
TOC total organic carbon
TT treatment technology
UF ultrafiltration
UV ultraviolet
UV/O_3 ultraviolet/ozone or ozonation
VOC volatile organic compound
WSWRD Water Supply and Water Resources Division

1.0 Introduction

Those of you who live in small communities, enjoy camping, eating in restaurants, or work at a location that provides its own drinking water, are entitled to the safest and most economical supply of water. The federal government recognizes that safe and affordable drinking water is something that all are entitled to and not just those who live in "big" cities. However, with this recognition comes responsibility. Current and future drinking water regulations apply to all drinking water systems that serve at least 25 consumers or 15 connections for at least 60 days per year. These federal and state regulations are designed and implemented to manage, protect and enhance the quality of drinking water provided to all consumers.

To Find Reports on Several Small System Issues:
www.epa.gov/safewater/smallsys/ssinfo.html

These regulatory requirements pose a "serious" challenge to the small, public water system (PWS) operators (serving fewer than 10,000 people) that often do not have the technical, managerial, or financial resources to adequately meet these requirements. Also, there are several different approaches to treating, distributing, and maintaining drinking water quality to meet the same regulatory requirements. Selecting an appropriate approach requires a basic knowledge and understanding of types of contamination, available treatment technologies, distribution system fundamentals, and applicable regulations. Appropriate technology should be selected based upon an understanding of these elements combined with site-specific criteria, such as source water location, availability of funding, vendor support, and ease-of-operation.

Considerable information about small drinking water systems is already available, much of it from the United States Environmental Protection Agency (EPA). The intent of this handbook is to highlight information appropriate to small systems with an emphasis on filtration and disinfection technologies and how they can be "packaged" with remote monitoring and control technologies to provide a healthy and affordable solution for small systems. EPA evaluated several commercially available pre-fabricated "package plants" suitable for small systems. This document provides a background on regulations pertinent to small systems and presents a summary of related research conducted by EPA's Water Supply and Water Resources Division (WSWRD) at the EPA Test & Evaluation (T&E) Facility (Figure 1-1) in Cincinnati, Ohio, and at other field locations. The WSWRD is a division of the National Risk Management Research Laboratory, Office of Research & Development.

Thus, the objective of this handbook is to provide information to the small system operator, manager, and/or owner (you might be all of these) about different approaches to providing safe and affordable drinking water to your community.

This handbook includes the following information:

- Common types of contaminants found in drinking water;
- Common water supply problems and recommended solutions;
- Applicable regulations, monitoring and reporting;
- Common regulatory violations;
- Treatment technologies most likely to work on a variety of contaminants;
- Specific information about innovative filtration and disinfection technologies;
- Information on Point-of-Use/Point-of-Entry systems;
- Information regarding remote monitoring and control of systems from off-site locations (as well as filing state compliance reports on time);
- Real-world "lessons learned";
- Information about funding and technical resources to implement suitable technologies that meet applicable regulations; and
- Sources of additional information.

Figure 1-1. EPA Test & Evaluation Facility, Cincinnati, OH.

2.0 Contaminants in Drinking Water

Water is the universal solvent, and most materials will eventually dissolve in it. Water found in nature generally contains a variety of contaminants such as minerals, salts, heavy metals, organic compounds (compounds that contain carbon and can occur naturally or be man made, such as gasoline, dry cleaning solvents, or pesticides); radioactive residues; and living (microbiological) materials, such as parasites, fungi, and bacteria. These materials enter water through natural processes, such as contact with rocks, soil, decaying plant and animal matter, and other materials. Human and animal wastes are the primary contributors to microbiological contamination of water. Industrial and agricultural sources can also introduce chemical, pesticide, and herbicide residues into water. *[1]*

When most people see or hear the word "contaminated," it signals danger or disease. However, EPA defines a contaminant as "any physical, chemical, biological, or radiological substance or matter in water." Whether water is safe to drink depends on the specific contaminants it contains, how much of each contaminant is present, and how these contaminants affect human health.

For example, cloudy or slightly off-color water sometimes may <u>not</u> be dangerous to drink, while water that is perfectly clear may contain tasteless, odorless, and colorless contaminants that cause serious health effects. Similarly, some substances in small concentrations, such as iron, are good for human health. Others, such as fluoride, may be beneficial at low levels and cause health problems at higher levels.

Therefore, the PWS source(s) must be protected from harmful levels of contamination. The PWSs typically treat the raw source water by filtration and disinfection. Disinfection is usually achieved by applying chlorine or commercial bleaches. Combined filtration/disinfection treatment is usually sufficient to remove visible contaminants and kill most bacteria/viruses. However, too little filtration and disinfection can result in a higher risk of a wide variety of stomach and intestinal illnesses. Too much disinfectant with too little filtration can result in the formation of disinfection byproducts (for example, trihalomethanes) and a higher risk of cancer. Therefore, it is important to have technologies in place to monitor and enhance the treatment system operation, thereby improving the overall water quality provided to consumers.

*Federal and/or state regulations are designed to implement the following **<u>four</u> basic strategies to safeguard the quality of our drinking water:***

- **<u>Source Protection</u>** – Regulations are designed to prevent the contamination of source water, such as lakes, rivers and water wells that PWSs use. 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.
- **<u>Maximum Contaminant Levels (MCLs) and Maximum Contaminant Level Goals (MCLGs)</u>** – The MCLs are the highest level of a particular contaminant that is allowed in drinking water. MCLGs are the highest level of a contaminant in drinking water below which there is no known or expected risk to health. MCLs are Federally enforceable standards, while MCLGs are non-enforceable guidance.
- **<u>Treatment Technology (TT)</u>** – Most PWSs use some form of TT, so that the water will be palatable and safe to drink. Many systems (but not all) require routine disinfection as a safeguard against bacterial or viral contamination.
- **<u>Monitoring/Reporting (M/R)</u>** – M/R is critical for ensuring compliance with the various regulatory requirements. Monitoring and reporting is essential in letting you know whether your system is working properly and protecting your customers. Regulations typically require PWSs to routinely sample treated (or finished) water, and submit the samples to the state or local agencies. The submitted samples are tested for a broad range of potential contaminants. If unacceptable levels of contaminants are found, the water supply owner or operator is legally responsible for informing the people who use the water, and taking steps to eliminate potential health hazards. The frequency of M/R activity varies depending upon location and system size.

[2]

3.0 Common Water Supply Problems and Recommended Solutions

It is important to be able to identify common water supply problems because testing for every possible harmful contaminant (petroleum products, pesticides, heavy metals, bacteria, nitrate, volatile organic compounds, radioactive substances, etc.) is very expensive. Therefore, it is important to be able to identify the potential contaminant and request a specific laboratory test. Table 3-1 provides general guidance on conditions that may prompt you to have your water tested. Generally speaking, if your water changes taste, odor, or color suddenly, you may want to contact the local health department, state, or EPAs regional office for advice before you begin paying for any tests.

Test samples should always be sent to a certified laboratory. The laboratory provides the test results in a report format that typically indicates the amount of a specific contaminant in your water sample expressed as a concentration, i.e., a specific weight of the substance in a specific volume of water (e.g., milligrams/liter or mg/l). The test results also may use other symbols and abbreviations. The laboratory may also report the finding as "bdl" (below detection limit) or "nd" (not detected) or a numerical result using the symbol for "less than" (<). For example, if your report lists a result of <0.03 mg/l for arsenic, this means that 0.03 mg/l [milligrams per liter] is the detection limit of the test for arsenic, and the water had less than 0.03 mg/l arsenic in it, if at all.

The test result provided by the laboratory should then be compared to the federal standards (MCLs, MCLGs, etc.) and to other guidance numbers, such as health advisories, to assess the potential for health problems. Health advisories specify levels of contaminants that are acceptable for drinking water over various lengths of time: one-day, ten-day, longer-term (approximately seven years), and lifetime exposures (essentially the same as MCLGs). These standards are not legally enforceable, and typically the numbers change as new information becomes

For a List of Links to Certified Laboratories:
www.epa.gov/safewater/faq/sco.html

Table 3-1. Troubleshooting/Testing for Common Water Supply Problems [1]

Conditions or nearby activities	Recommended test
Recurrent gastrointestinal illness	Coliform
Distribution system and/or household plumbing contains lead	pH, alkalinity, hardness, lead, copper
Radon in indoor air or region	Radon
Scaly residues and/or soaps do not lather	Hardness
Stained plumbing fixtures, laundry	Iron, copper, manganese
Objectionable taste or smell (such as rotten egg odor)	Hydrogen sulfide, lead, copper, cadmium, pH, alkalinity, hardness, metals
Water is cloudy, frothy, or colored	Color, detergents
Corrosion of pipes, plumbing	pH, lead, copper, cadmium, alkalinity
Rapid wear of water treatment equipment	pH, lead, copper, cadmium, alkalinity, hardness
Nearby areas of intensive agriculture	Nitrate, pesticides, coliform bacteria
Nearby coal, other mining operation	Metals, pH, lead, copper, cadmium
Gas drilling operation nearby	Chloride, sodium, barium, strontium
Gasoline or fuel oil odor	Volatile organic compounds (VOCs)
Nearby industrial activities	VOCs, synthetic organic compounds (SOCs)
Dump, landfill, factory or dry-cleaning operation nearby	VOCs, pH, sulfate, chloride, metals
Salty taste and seawater, or a heavily salted roadway nearby	Chloride, Total Dissolved Solids (TDS), sodium

available. However, if MCLs are not being met and the treatment system is working optimally, alternative treatment technologies should be explored. Section 6.0 provides a brief overview of treatment technologies and their suitability to treat certain type(s) of contaminants.

Emergency water purification

Microbiological contamination of a PWS may come from the failure of a disinfection system, a cross connection (a wastewater pipe gets connected to a water pipe), a breach/break in the piping system (which allows non-treated water into the piping), or a contaminated source (as in a well). In the event of an emergency, or due to a general concern over the potential contamination of a drinking water source, simple measures can be taken to disinfect sufficient quantities of water to satisfy basic household needs until the crisis is resolved. PWS Operators should notify their customers about drinking water emergency situations in the manner specified by their local or state agency. The operator should also advise their customers of emergency water purification methods under such circumstances. Emergency water purification methods include heat and chemical treatment.

<u>Heat Treatment</u>

1. Strain water through a clean cloth into a clean pot to remove any sediment and/or floating debris.

2. Heat and bring to a rolling boil for <u>1 full minute</u> or more. Allow the water to cool, and transfer it to a clean covered container. Refrigerate if possible. (Remember, at higher elevations, water boils at lower temperatures and boiling may not treat parasites or bacteria. Under such scenarios, chemicals or pressure cookers should be used.) *[3]*

<u>Chemical Treatment</u>*

Several chemical treatment alternatives are available for emergency water disinfection. See Table 3-2 for a summary of these methods. Chlorine, in various forms, is used for chemical disinfection. *[3]* The other popular disinfection method uses iodine, such as, the tincture of iodine and tetraglycine hydroperiodide (iodine) tablets. In case of using a manufacturer supplied tablets, the manufacturer's instructions should be followed carefully. This type of purification is intended for short-term use only. Remember to keep all disinfectants out of the reach of children or anyone that may not understand the use of these chemicals.

Also, the data in Table 3-2 indicate the quantity of the product(s) required to release 10 mg of chlorine or iodine per liter of water. Recommended contact time is at least 30 minutes to ensure maximum disinfection. The following is a recommended method for disinfection using chlorine or iodine tablets.

Table 3-2. Emergency Disinfection Treatment for Drinking Water (10-mg/liter dose, 30-min. contact time) [4]

Commercial Product	Available Disinfectant (%)	Disinfectant Quantity	Gallons Treated
Hypochloride pellets	70	1 tablet	80
Iodine or chlorine tablets	1.0-1.6	2 tablets	0.25
Laundry bleach	5.3	1 tablespoon	20
Tincture of iodine	2	1 tablespoon	8

1. Using chlorine tablets: Strain the water and fill a gallon-sized milk jug to approximately ¾ full. Add six (6) drops of chlorine (household bleach) if the water is clear, or twice that amount if the water is cloudy. Shake vigorously and allow it to stand for 30 minutes. A slight odor of chlorine should be present. Poorly strained water (i.e., water with debris) or water that is contaminated with very small particles or bacteria (and may be cloudy or clear) will use more chlorine. Therefore, it is very important to use the proper amount of chlorine. A basic pool grade chlorine test kit can be used to measure residual chlorine or simply smell the water. If there is <u>**no**</u> scent of chlorine, then repeat the dosage and let the water stand for an additional 15 minutes.

2. Using tetraglycine hydroperiodide (iodine) tablets, and iodine taste and odor neutralizing (ascorbic acid) tablets: Strain the water and fill a quart or liter container (canteen). Figure 3-1 shows a picture of a canteen. Add two (2) iodine tablets to the container. Cap the container loosely to allow a small amount of leakage. Wait five (5) minutes (the tablets will dissolve but note that the tablets do not have to completely dissolve to be effective) and shake the container to allow the screw threads to moisten, then tighten the cap. Wait for thirty (30) minutes before drinking the water. If after 30 minutes the taste and odor of the iodine is a problem, then use two (2) tablets of ascorbic acid per liter of water to neutralize the iodine. Never add the iodine and the ascorbic acid at the same time, this will stop the disinfection.

Figure 3-1. Canteen and tablets for emergency purification using iodine.

3. Keep the water in a covered container. Refrigerate if possible.

* Note: Certain organisms, such as *Giardia* and *Cryptosporidium*, are known to be chlorine and iodine resistant. Consequently, the heat-treatment method may be more reliable overall.

4.0 Regulatory Overview

Prior to 1974, each state ran its own drinking water program and set standards that had to be met at the local level. As a result, drinking water protection standards differed from state to state. On December 16, 1974, Congress enacted the original Safe Drinking Water Act (SDWA). The SDWA was designed to protect public drinking water supplies from "harmful contaminants." Congress gave EPA the authority to establish acceptable or "safe" levels for known or suspected drinking water contaminants and to design a national drinking water protection program. Since then, EPA has set uniform nationwide minimum standards for drinking water by promulgating the National Primary Drinking Water Regulations (NPDWR) and Secondary Drinking Water Regulations (SDWR). State public health and environmental agencies have the primary responsibility for ensuring that the PWS meet federal drinking water quality standards (or more stringent ones as required by the state). *[1]*

Between 1974 and 1986, EPA developed MCL standards under the NPDWR for 22 contaminants. Since 1986, EPA has issued seven major rules that establish standards for either a specific contaminant (83 in total) or groups of contaminants.

In 1996, the SDWA was changed again. Among the many changes to the SDWA, the 1996 amendments added provisions to provide funding to communities for drinking water mandates, focus regulatory efforts on contaminants posing health risks, and added some flexibility to the regulatory process.

To Find Out More About the SDWA:
www.epa.gov/safewater/sdwa/sdwa.html
www.epa.gov/safewater/regs/swtrlist.html

The EPA is now required to select at least five new candidate contaminants to consider for regulation every five years. This list of contaminants is known as the Contaminant Candidate List (CCL). The new law also requires EPA to set MCLGs for each contaminant. MCLG is the level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals from a regulatory perspective. EPA must then set an MCL as close to the MCLG as is "feasible" using the best available technology (BAT), taking costs into consideration (for MCL and MCLG definition, see box on page 3).

The SDWA standards are enforced through federal and/or state regulations requiring PWSs to test for contaminants and install new types of treatment technologies if the test results indicate the presence of contaminants in the treated water.

To Find Out More About The MCLs and NPDWR:
www.epa.gov/safewater/mcl.html

EPA also publishes standards for nuisance contaminants under the SDWR. The Secondary Maximum Contaminant Levels (SMCLs) are concentration limits for nuisance contaminants and physical problems, such as offensive taste, color, odor, corrosivity, etc. The secondary standards are not enforced, and PWSs are not required to test for and remove secondary contaminants. However, these standards are useful guidelines for PWS operators who want to ensure that their water will be suitable for all household uses. Typically, water utilities receive more complaints because their water tastes or smells funny, so these secondary standards should not be ignored.

To Find Out More About The SMCLs and SDWR:
www.epa.gov/safewater/consumer/2ndstandards.html

It is important to understand that the regulations you are responsible for depends upon which category of small system you fall under. There are approximately 170,000 community water systems (CWS) and non-community water systems (NCWS) in America. NCWSs serve transient and non-transient populations (see box on page 10). As you can see in Table 4-1, small and very small systems account for the vast majority of systems in the U.S. (>86%). *[2]*

PWSs derive their source water from both ground and/or surface water. Table 4-2 describes the source of water by system size and population served. As you can see, the vast majority of systems use ground water as their source of drinking water (153,697 vs. 14,136); however, the majority of people served are drinking river and lake water (179.9 vs. 103.9 million). Also, almost 100% of non-community systems are small.

Although the federal government defines "small systems" as those serving fewer than 10,000 consumers, it also recognizes that there is a quite a difference between the "larger" small systems and the "smaller"

*There are **two** main categories of PWSs:*

1) **Community Water Systems (CWS)** – CWSs provide drinking water to the same people year-round. Today, there are approximately 54,000 CWSs serving more than 250 million Americans. All federal drinking water regulations apply to these systems.

2) **Non-Community Water Systems (NCWS)** – NCWSs serve customers on less than a year-round basis. NCWSs are, in turn, divided into two sub-categories:

Non-transient (NTNCWS): Those that serve at least 25 of the same people for more than six months in a year but not year-round (e.g., schools or factories that have their own water source); most drinking water regulations apply to the 20,000 systems in this category.

Transient (TNCWS): Those that provide water to places like gas stations and campgrounds where people do not remain for long periods of time; only regulations that control contaminants posing immediate health risks apply to the 96,000 systems in this category. *[2]*

Table 4-1. Size Categories of Public Water Systems [2]

System Size (population served)	Percent of Community Water Systems			
	1980	1985	1990	1995
Very Small (25 - 500)	67	63	63	61
Small (501 - 3,300)	22	24	24	25
Medium (3,301 - 10,000)	6	7	7	8
Large/Very Large (>10,001)	5	6	6	7

Table 4-2. Distribution of Water Systems [2]

System Type	Surface Water Systems	People Served (millions)	Ground Water Systems	People Served (millions)
CWS	11,403	178.1	42,662	85.9
NTNCWS	821	.9	19,738	6.0
TNCWS	1,912	.9	91,298	12.0

ones that serve only a few hundred consumers. The 1996 SDWA Amendments mandated that information about treatment technology performance and "affordability" be developed for the following size categories:

- 3,301–10,000 people (medium)
- 501–3,300 people (small)
- 25–500 people (very small)

Affordability criteria are based on a threshold of 2.5% of the median household income (MHI). Nationally, the MHI is currently about 0.7% for the three size categories (Table 4-3). Thus, any improvements to a small system cannot increase the annual cost of drinking water per household beyond the affordability threshold of 2.5% of the MHI. For example, a drinking water system serving a population between 25–500 cannot put in improvements that raise the annual cost per household by more than $559 annually per household. *[5]*

The 1996 SDWA Amendments not only set in motion the development of a variety of new rules, but a new approach to setting future regulations. Of most concern to small systems is that they are ultimately going to be required to meet the same criteria that the larger, more affluent systems do. Table 4-4 provides the general sample monitoring schedule for small systems. Table 4-5 summarizes the current (2001) and proposed regulations, their goal, and the specific types and sizes of small systems affected. Note that these requirements may vary by state and is dependent upon the size or type of PWS.

A full discussion of each of these regulations and its requirements for specific systems is beyond the scope of this document. The most common types of violations are discussed in Section 5.0 of this handbook.

Table 4-3. National Level Affordability Criteria [5]

System Size (Population Served)	Baseline MHI ($/year)	Baseline Water Bills ($/hh/year)	Baseline Water Bills (% MHI)	Affordability Threshold (2.5% MHI)	Available Additional Expenditure ($/hh/year increase)
25 - 500	$30,785	$211	0.69%	$770	$559
501 - 3,300	$27,058	$184	0.68%	$676	$492
3,301 - 10,000	$27,641	$181	0.65%	$691	$474

MHI - median household income
hh - household

Table 4-4. General Sample Monitoring Schedule for Small Systems[a,b]

Contaminant	Minimum Monitoring Frequency
Acute contaminants - Immediate risk to human health	
Bacteria	Monthly or quarterly, depending on system size and type
Nitrate	Annually
Protozoa and viruses	Future requirements for the Ground Water Rule may require monitoring and testing
Chronic contaminants - Long-term health effects if consumed at certain levels for extended periods of time	
Volatile organics (e.g., benzene)	Ground water systems - quarterly for the first year, annually for years 2 and 3, after that depending on results; surface water systems - annually
Synthetic organics (e.g., pesticides)	Larger systems, twice in 3 years; smaller systems, once in 3 years
Inorganics/metals	Ground water systems - once every 3 years; surface water systems - annually
Lead and copper	Annually
Radionuclides	Once every 4 years

[a]General requirements may differ slightly depending on the State, size or type of drinking-water system.
[b]Source: EPA Office of Ground Water and Drinking Water (OGWDW) web site.

Table 4-5. Small System Regulatory Summary [2] [6] [7] [8]

Regulation	Summary	What Systems are Affected?
Microbiological (National Primary Drinking Water Regulations [NPDWR])	Coliform MCL	All types and sizes
Volatile Organic Chemicals (NPDWR)	MCLs[b]	All CWSs and NTNCWSs
Radionuclides	MCLs[b]	All types and sizes
Radon	MCLs[b]	All types and sizes
Inorganic Chemicals (NPDWR)	MCLs[b]	All CWSs and NTNCWSs; transient systems exempt except for nitrates, nitrites
Total Coliform Rule	No more than 5% of samples positive for Coliform; Distribution system sampling	All types and sizes
Surface Water Treatment Rule	3 Log (99.9%) removal of Giardia, 4 Log (99.99%) virus inactivation Filtration treatment specified	All surface water and ground water under the direct influence of surface water
Lead and Copper Rule	Distribution System Action Levels	All CWSs and NTNCWSs
Arsenic	MCLs[b]	All CWSs and NTNCWSs
Ground Water Rule	Appropriate use of disinfectants, multi-barrier approach	All systems using ground water as source
Long Term 1 Enhanced Surface Water	2 Log removal (99%) of *Cryptosporidium*, 0.3 NTU for Turbidity; TOC[c] reductions for precursor removal	All surface water and ground water under the direct influence of surface water
Filter Backwash Rule	Recycling filter backwash with treatment	All conventional (flocculation/ coagulation/sedimentation) and direct filtration systems
Stage 1 Disinfectants/Disinfection By-Products Rule (D/DBP)	Total Trihalomethane MCL reduced to 0.08 mg/L; 5 Haloacetic acids[d] total of 0.060 mg/L; chlorite MCL 1.0 mg/L; bromate 0.010 mg/L MCL; maximum residual disinfectant levels set (MRDLG/MRDL)	CWSs and NTNCWSs that use a chemical disinfectant
Long Term 2 Enhanced Surface Water Rule and Stage 2 D/DBP Rules	To be enacted together to balance microbial and disinfectant by-product formation; Possible lowering of current MCLs and distribution system requirements	All types and sizes
Contaminant Candidate List (CCL)	Possible new MCLs	All types and sizes

[a]Nephelometric Turbidity Unit
[b]For MCL information, please visit: www.epa.gov/safewater/mcl.html
[c]Total Organic Carbon
[d]includes dichloroacetic acid, trichloroacetic acid, monochloroacetic acid, bromoacetic acid, and dibromoacetic acid

5.0 Common Violations

Generally, larger PWSs have more resources and lower costs per customer to comply with regulations. Thus, larger PWSs incur fewer violations, despite the fact that larger PWSs have historically complied with more regulations than smaller systems.

Small systems, however, account for the vast majority of violations for both MCLs and M/R. According to a 1993 survey, small treatment systems serving fewer than 10,000 people represented 94% of all water supply systems in America and served only 21% of the national population. Also, these Small Systems accounted for 93% of the MCL violations and 94% of the M/R violations. The majority of the MCL violations involved microbial parameters. M/R violations could be the result of no sampling being performed, insufficient recording of data, or failure to report the data. The number of chemical contamination violations were also exceedingly high for small utilities. (See Tables 5-1 and 5-2 below).

EPA has also identified M/R violations associated with human errors related to operators' handwriting,

*There are **three** main types of violations:*

Maximum Contaminant Level (MCL) violation – MCL violation occurs when tests indicate that the level of a contaminant in treated water is above EPA's or the state's legal limit (states may set standards equal to, or more protective than, EPA's). These violations indicate a potential health risk, which may be immediate or long-term.

Treatment Technique (TT) violation - TT violation occurs when a water system fails to treat its water in the way EPA prescribes (for example, by not disinfecting). Similar to MCL violations, TT violations indicate a potential health risk to consumers.

Monitoring/Reporting (M/R) violation – M/R violation occurs when a system fails to test its water for certain contaminants, or fails to report test results in a timely fashion. If a water system does not monitor its water properly, it is difficult to know whether or not the water poses a health risk to consumers. [2]

Table 5-1. Total Coliform Bacteria Violations for the Period October 1, 1992 through December 31, 1994 [9]

Number of Consumers	Systems with Violations		Violations by Source Water	
	Number of Systems	Percent of Total (%)	Ground Water Systems (%)	Surface Water Systems (%)
<500	10,509	29.5	95.0	5.0
501 - 3,300	1,938	13.4	84.8	15.2
3,301 -10,000	592	14.4	71.8	28.2
> 10,000	487	14.4	59.1	40.9

Table 5-2. Chemical Contamination Violations for the Period October 1, 1992 through December 31, 1994 [9]

Number of Consumers	Systems with Violations		Violations by Source Water	
	Number of Systems	Percent of Total (%)	Ground Water Systems (%)	Surface Water Systems (%)
<500	531	1.5	96.4	3.6
501 - 3,300	162	1.1	73.5	26.5
3,301 - 10,000	25	0.6	60.0	40.0
> 10,000	15	0.4	33.3	66.7

such as the way a person records “D,” “P,” entries into the reporting document.

In the past, this type of violation was one of the leading causes for water systems being out of compliance in the Commonwealth of Kentucky. Recently, through a certification course, Kentucky has provided handwriting suggestions to the small system operators, which apparently have reduced the number of M/R violations there. However, there is no way to estimate the number of erroneous entries due to penmanship. Operators should remember that a hand-written report is only as good as the penmanship of the person filling out the document.

Small System operators need to take time and care when filling out the reporting documents. The Commonwealth of Kentucky identified hand-writing problems associated with report forms for bacteriological analysis of water samples sent to various laboratories.

For example, Small System operators may first fill out parts of the form. After analysis, the laboratory (another person, company, etc.) completes the remaining information on the form and forwards a copy to the state (primacy) agency. The portion the operator fills out has a box to identify the type of sample collected. Kentucky uses letter codes to identify the collected sample: the two relevant codes are “D” for “distribution” and “P” for “plant” sample. Each PWS is required to send in an assigned number of “distribution” samples each month. If an operator is not careful and enters a “D” with a small tail, it can appear as a “P.” Even though the primacy agency knows that the PWS purchases water and does not even have a treatment plant, the form still appears to have a “P” and will list the water system as out of compliance (M/R) until the Small System operator that filed the form makes corrections.

6.0 Treatment Technologies

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 distinct 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 that are only specified for those system size/source water quality combinations for which there are no listed compliance technologies. *[10]*

Thus, listing a compliance technology for a size category/source water combination prohibits listing variance technologies for that combination. While variance technologies may not achieve compliance with the MCL or treatment technique requirement, they must achieve the maximum reduction or inactivation efficiency 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 protects public health. Possible compliance technologies include packaged or modular systems and point-of-use (POU) or point-of-entry (POE) treatment units. POU/POE systems are discussed further in Section 7 of this handbook. *[11]*

The 1996 SDWA Amendments did not specify the format for the compliance technology lists and stated 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 passing new ones. This guidance, which is summarized in Table 6-1, may be found in:

– Small System Compliance Technology List for the Surface Water Treatment Rule and Total Coliform Rule (EPA 815-R-98-001)

– Small System Compliance Technology List for the Non-Microbial Contaminants Regulated Before 1996 (EPA 815-R-98-002)

– Variance Technology Findings for Contaminants Regulated Before 1996 (EPA 815-R-98-003)

In anticipation of the states' needs for innovative and cost-effective small system treatment technology, the EPA Water Supply and Water Resources Division (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. WSWRD is a division of EPA's Office of Research & Development, National Risk Management Research Laboratory. 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, and service, and less expensive to maintain and service in the long-run.

A matrix of contaminants that are regulated under the SDWA and possible treatment technologies for water containing these contaminants are shown in Table 6-2.

Of the compliance technologies listed in Table 6-1, a majority of the EPA WSWRD small systems research has focused on evaluating "packaged" filtration and disinfection technologies that are most useful to small system operators. This handbook is a product of ongoing research conducted by the WSWRD to compile and evaluate the best available technology so as to provide information about cost-effective drinking water treatment technology options to the small system operators. Filtration efforts have focused on evaluating various bag filters, cartridge and membrane filters. Disinfection techniques evaluated included a variety of onsite chlorine generators and packaged ultraviolet (UV)/ozonation plants. Details regarding these efforts are presented below.

Filtration

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 removing 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. As discussed earlier, the research at the EPA T&E Facility (Figure 1-1)

Table 6-1. Surface Water Treatment Compliance Technology Table [11]

Disinfection Technologies		
Unit Technologies	Removals: Log Giardia & Log Virus w/CT's indicated in ( )	Comment
Free Chlorine	3 log (104[a]) & 4 log (6)	Requires basic operator skills. Better for 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)	Requires intermediate operator skills. Ozone leaks can be hazardous. Does not provide residual disinfection protection for distributed water. Concerns with disinfection byproducts.
Chloramines	3 log (1850) & 4 log (1491)	Requires intermediate operator skills. The ratio of chlorine to ammonia must be carefully monitored. Requires large CT.
Ultraviolet Radiation	1 log Giardia (80-120), better for *Cryptosporidium*, & 4 log viruses (90-140) (mWsec/cm2 doses in parentheses)	Requires basic operator skills. Relatively clean water source necessary. Does not provide residual disinfection protection for distributed water.
Chlorine Dioxide	3 log (23) & 4 log (25)	Requires intermediate operator skills. Better for larger drinking water systems. Storage and handling precautions required. Concerns with disinfection byproducts.
Filtration Technologies		
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 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	Requires basic operator skills. 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*; low bacteria and virus removal	Requires intermediate operator skills. Good for source water with low turbidity and color. Will not remove all microorganisms.
Reverse Osmosis	Very effective, absolute barrier (cysts and viruses)	Requires intermediate to advanced operator skills, 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)	Requires intermediate to advanced operator skills, depending on the amount of pretreatment necessary. Post disinfection required under regulation.
Ultrafiltration	Very effective *Giardia*, >5-6 log; Partial removal viruses	Requires intermediate to advanced operator skills, depending on the amount of pretreatment necessary. Post disinfection required under regulation.
Microfiltration	Very effective *Giardia*, >5-6 log; Partial removal viruses	Requires intermediate to advanced operator skills, 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	Requires basic operator skills. Requires low turbidity water. Disinfection required for viral inactivation. Care must be taken toward end of bag/cartridge life to prevent breakthrough.

[a]A 3 log (104) removal indicates that 99.9 % (or three 9's) of *Giardia* was removed in 104 minutes of contact time (CT) with free chlorine disinfection. Similarly, 1 log would indicate only one-9 removal i.e., 90% removal and a 4 log removal indicate 99.99% removal. CT is a measurement of the length of time it takes for a disinfectant to kill, for example, *giardia lamblia,* at a specified disinfectant concentration. If the disinfectant concentration is half the specified dosage in a CT table, the contact time should be double the specified number in the CT table to ensure proper disinfection and vice-versa (twice the specified dosage requires only half the contact time). CT requirements also assume there is sufficient mixing of the disinfectant and water and are dependent on the pH and temperature of the water.

Table 6-2. Regulated Contaminant List (partial) and Possible Removal Technologies [10]

Microbial Contaminants and Turbidity		
Turbidity (Suspended material)	Filtration	
Coliform Bacteria, Viruses, *Cryptosporidium* oocysts and *Giardia* cysts	Turbidity reduction by filtration as noted above followed by disinfection	
Radioactivity		
Beta particle and photon activity	Mixed Bed Ion Exchange. Reverse Osmosis	
Gross Alpha Particle activity	Treatment method depends on the specific radionuclide (e.g., radium, radon, or uranium)	
Radium 226 and Radium 228	Cation Ion Exchange, Reverse Osmosis	
Radon	Activated Carbon	
Uranium	Anion Ion Exchange, Activated Alumina, Microfiltration, Reverse Osmosis	
Health-Related Inorganic Contaminants		
Antimony	Microfiltration, Reverse Osmosis	
Arsenic (+3)	Reverse Osmosis	
Arsenic (+5)	Submicron Filtration, Anion Ion Exchange, Activated Alumina, Reverse Osmosis	
Organic Arsenic Complexes	Activated Carbon	
Asbestos	Submicron filtration, Reverse Osmosis	
Barium	Cation Ion Exchange, Reverse Osmosis	
Beryllium	Submicron Filtration & Carbon, Activated Alumina, Cation Ion Exchange, Reverse Osmosis	
Cadmium	Submicron Filtration, Cation Ion Exchange, Reverse Osmosis	
Chromium (+3)	Cation Ion Exchange, Reverse Osmosis	
Chromium (+6)	Anion Ion Exchange, Reverse Osmosis	
Organic Chromium Complexes	Activated Carbon	
Copper, Nickel	Cation Ion Exchange, Reverse Osmosis	
Fluoride	Activated Alumina, Reverse Osmosis	
Lead	Cation Ion Exchange, Submicron Filtration & Carbon, Reverse Osmosis	
Mercury (+2)	Cation Ion Exchange, Submicron Filtration & Carbon, Reverse Osmosis	
Mercury (HgCl3 -1)	Anion Ion Exchange, Reverse Osmosis	
Organic Mercury Complexes	Activated Carbon	
Nitrate and Nitrite	Anion Ion Exchange, Reverse Osmosis	
Selenium (+4)	Submicron Filtration & Carbon, Anion Ion Exchange, Activated Alumina, Reverse Osmosis	
Selenium (+6)	Anion Ion Exchange, Activated Alumina, Reverse Osmosis	
Sulfate	Anion Ion Exchange, Activated Alumina, Reverse Osmosis	
Thallium	Cation Ion Exchange, Activated Alumina	
Health-Related Organic Compounds		
Use Activated Carbon or Aeration to Remove the Following Contaminants		
Adipates Benzene Carbon Tetrachloride Dibromochloropropane Dichlorobenzene (o-, m-, p-) 1,2-Dichloroethane 1,1-Dichloroethene	cis- and trans-1,2-Dichloroethene 1,2-Dichloropropane Ethylbenzene Ethylene Dibromide Hexachlorocyclopentadiene Monochlorobenzene Styrene	Tetrachloroethylene Toluene 1,2,4- Trichlorobenzene 1,1,1-Trichloroethane 1,1,2-Trichloroethane Trichloroethylene Trihalomethanes
Use Activated Carbon to Remove the Following Contaminants		
Alachlor Aldicarb Aldicarb Sulfone Aldicarb Sulfoxide Altrazine Benzo(a)anthracene (PAH) Benzo(a)pyrene (PAH) Benzo(b)fluoranthene (PAH) Benzo(k)fluoranthene (PAH) Butyl benzyl phthlate (PAH) Carbofuran	Chlordane Chrysene (PAH) 2,4-D Dalapon Di (2-ethylhexyl) adipate Dibenz(a,h)anthracene (PAH) Glyphosate Heptachlor Epoxide Hexachlorobenzene Indeno (1,2,3-c,d) Pyrene (PAH)	Lindane Methoxychlor Oxamyl Pentachlorophenol Picloram Polychlorinated Biphenyls Simarzine 2,3,7,8-TCDD (dioxin) Toxaphene 2,4,5-TP (Silvex)

focused on "packaged" bag, cartridge and ultrafiltration units. The other filtration methods typically use natural filtration media (e.g., granulated media particles, such as carbon, garnet, or sand, alone or in combination). Bags 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 6-1.

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 6-2 shows a picture of a clogged prefilter.

A source water may contain turbidity, particles, or organic material. These materials consume and compete for chemicals used in the treatment process, such as chlorine. Thus, operators should find a mechanism to filter the particles, turbidity or organic material out of the water. Filtration can remove certain types of color and particulate matter down to any micron size. Special microfiltration devices or submicron filters are capable of removing various bacteria, viruses, and protozoa.

Bags and cartridge filters can be used to remove contaminants down to approximately 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 used to remove some dissolved material (such as large organic molecules) from water. Particles down to 0.001 to 0.02 micron size range are removed. Most microbial contaminants are removed 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. *[12]*

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

Performance Evaluation of Filtration Media

Different vendors present filtration performance data in different ways, leading to some confusion. For example, the pore size specification for a filter can be the absolute or nominal pore size. Absolute size generally refers to a 100% removal of solids above

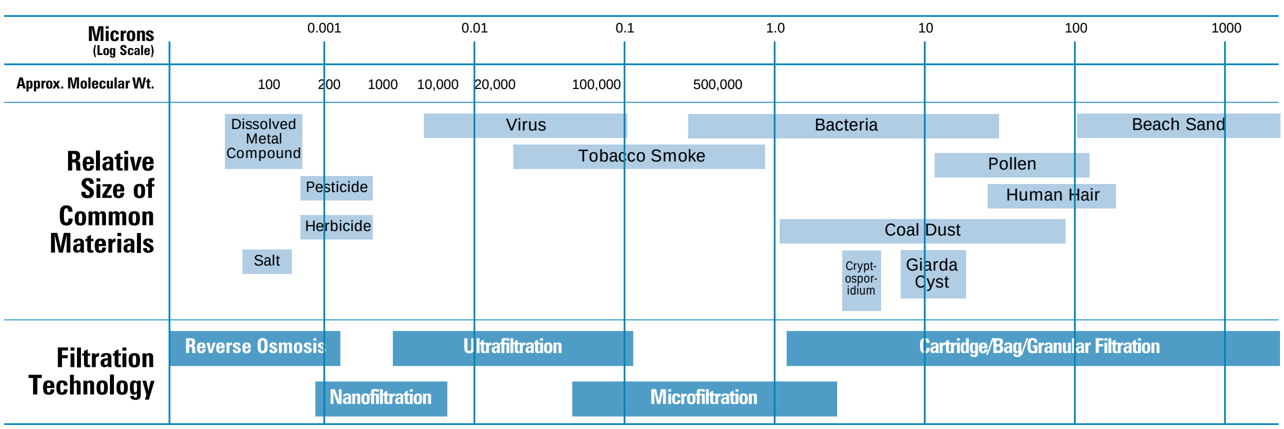


Figure 6-1. Particle Size Distribution of Common Contaminants and Associated Filtration Technology [13]

Figure 6-2. Clogged prefilter.

the specified size rating on a single pass. Nominal pore size generally refers to an average pore size of the filter media itself and typically nominal values indicate a certain percent removal of particles of the specified size and higher.

Different filters have different operating pressure ranges depending on the type of media, construction, flow rates, etc. Filter performance may vary depending on the change in pressures across the filter. As a filter becomes clogged, the difference between the pressure coming into the filter and the pressure leaving the filter becomes larger and is a good operational tool to determine when a filter should be replaced, cleaned, or backwashed. Sudden change in the exiting pressure can mean a bag or cartridge has ruptured and is providing no protection. The high pressure in the operating range typically indicates that the media is clogged and the bag or cartridge needs to be "washed" or replaced.

The performance of each filter can be judged based on the removal of turbidity, particle-count, and microbe (and/or surrogate) removal relative to its run-time. A number of evaluations have been conducted at the T&E Facility using *Cryptosporidium* and/or equivalent size micro-spheres (plastic beads). Turbidity is defined as an "expression of the optical property that cause light to be scattered and absorbed rather than transmitted in straight lines through the sample." Simply stated, turbidity is the measure of relative sample clarity or cloudiness (it is not associated with color). When a light beam passes through a sample of "turbid" water, the suspended solids scatter the light, thus reducing the intensity of the light beam. This reduction in intensity of the light beam is measured optically/electronically using a turbidimeter. Turbidity is reported in Nephelometric Turbidity Unit (NTU); typically, the regulations require PWSs to supply water with turbidity less than 0.50 NTU. However, the mere presence of turbidity cannot be directly related to the presence of microbial organisms; therefore, other measurements such as particle counts might be performed.

Particle counting involves counting each particle individually in a sample of water. Various electronic measuring devices are available that can be used to count particles. One can imagine the difficulty associated with manually counting thousands of microscopic particles. Most particle counters have a "sensing" zone that measures the particles individually. As a particle is detected, it is sorted into a "channel" based on magnitude (or size). Particle counters are expensive ($20,000) and often difficult to operate, thus limiting their usefulness to Small System operators.

Also, different microbial organisms vary in size, *Cryptosporidium* range between 3–7 micrometers in size and *Giardia* range between 6–9 micrometers. Typically, tests are performed to either measure the actual *Crytosporidium* removal, the removal of test surrogates, such as microspheres or naturally occurring spores. The surrogate is considered to be the equivalent for *Cryptosporidium* removal. EPA evaluated the performance of different types of filtration media by operating various filtration systems under various "test" conditions. The evaluation summaries for various types of filters are presented in the following subsections.

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 a pre-filter to other filters as well.

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 (Figure 6-3) 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. However, there are significant differences between manufacturers in the engineering design of closing devices and gasket types used to seal the bag tightly into the vessel and prevent filter by-pass. Each operator

Figure 6-3. Typical bag filter.

EPA found that different bags, even with the same stock and lot numbers, can exhibit a wide range of water treatment capacity. Some bags may treat many thousands of gallons of water while others may treat only a few hundred gallons of water. Thus, although bags may be rated similarly, their performance can vary significantly, and bag selection becomes more involved than a straightforward matching of pore size and the size of the particle or the turbidity to be removed from the water supply. The selection of the best bag depends on the specific water quality characteristics and treated water (effluent) regulatory requirements or objectives.

should be shown by the vessel vendor the proper fit of the filter and lid to the body "housing" before agreeing to purchase or set-up a bag filtration system. Improper filter installation can cause water hammer and can sometimes damage the bag. A vendor may sometimes claim that improper bag "installation" was the reason for poor performance of a bag filter (see box on page 23).

Bag filters are designed in a variety of ways. They can be fabricated of multiple layers and varying materials. One of the most cost-effective benefits of bag filters is their common use without costly chemical additions, such as coagulation, flocculation, or filter-coated chemicals. These filters have pore sizes designed into them to contain and capture oocysts, protozoa, or parasites Figure 6-4 is a picture of a bag filter that has been cut away to view the various layers and configuration. Caution should be taken when handling spent filters due to the potential concentration of the debris, protozoan, parasite, or oocyst. If the operator suspects oocysts are in the filter, then the operator should wear proper personal protective equipment to remove the filter. The filter could then be placed in a secured location where it can dry completely. The operator should then be able to dispose of the filter normally.

Figures 6-5, 6-6, 6-7 and 6-8 show rupture and bypass scenarios. Ruptures in fabric and/or gaps in heat welded bags can allow particles to pass through into the treated drinking water (as shown in Figure 6-5, with a pen inserted to mark the tear, and in Figure 6-6). A bypass is typically associated with significant discoloration of the bag. Figure 6-7 shows discoloration on both ends of the bag filter. The most common location for bypass is generally near the lid of each filter housing as shown in Figure 6-8.

EPA has evaluated several types of bag filters at the T&E Facility. Different configurations of bag filtration systems (see Table 6-3 and Figure 6-9) were challenged under controlled turbidity levels and flow rates. The research was not intended to compare systems but to identify the most important design and operational characteristics that provide for the most economical application in various raw water situations. Important design considerations are bag quality, gasket integrity, and hydraulic reliability. Operational factors include continuous vs. intermittent operation, flow rate, and pressure differential. Turbidity challenges ranged from 1 NTU to 10 NTU.

Table 6-3. Bag Filter Characteristics (see Figure 6-9)

Bag Filter	Pore Size	# of Layers	Surface Area (sq. ft)	Seam Const.
1	3 micron (average)	9	41	Sewn
2	3 micron (average)	1	2 - 3	Sewn
3	99 % removal of 2.5 micron 95 % removal of 1.5 micron	18	35	Sewn

Figure 6-4. Cut-away of bag filter.

Average % reduction ranged from 40% to 93%. Of course, at higher influent turbidity levels, greater removals can be demonstrated but there seems to be a “best” (e.g., 0.50 NTU) turbidity level that each brand of bag filter can reach regardless of the initial influent quality.

During initial start-up, removal was better and then settled into a fairly steady performance rate until near the end of the bag’s life. Flow rate and starting water quality (or lack of) did not seem to be a major factor in filter performance. Once a bag begins to foul at 5 to 10 pounds per square inch (psi) differential, the time until the bag must be replaced quickly decreases. High NTU scenarios (>5 NTU) indicate the need for multiple filtration barriers in order to not be bankrupted by having to buy replacement bags every few days. Bag rupture is more likely near the end of the filter run as the pressure differential reaches its maximum. Once a rupture or hole occurs, the

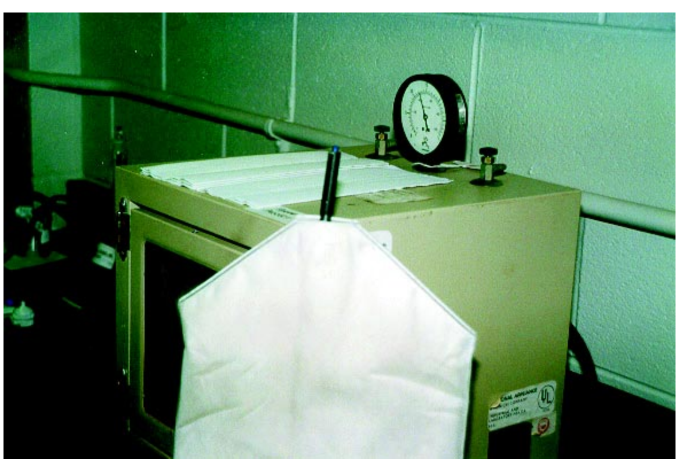


Figure 6-5. Bag filter showing rip in seam (where pen is inserted).

Figure 6-6. Bag filter showing fabric rupture.

Figure 6-7 and 6-8. Bag filters showing discoloration associated with bypass.

Figure 6-9. Different configurations of bag filters tested. (see Table 6-3)

treatment barrier is gone with effluent water quality the same or worse than influent. The results indicate that for systems with little water storage, or without on-site/automatic operator control to stop flow at this point, it is critical to be conservative in estimating bag life.

Particle count analyses were also performed simultaneously. Figure 6-10 demonstrates that during the experiment, one of the bags removed nearly all particles greater than 8 micron in size, although not immediately after installation. All bags in the study were rated with average pore sizes in the 2-5 micron range. Thus, a Small System operator must be aware that pore size only provides a general idea of the filter's capability. The raw water used in these experiments exhibit a majority of small (1-3 micron) particles whereas other water sources with turbidity made up of larger particles may be filtered better by bag filtration. Another operational characteristic observed for all filters was an initial loss of removal efficiency and pressure differential when first turned on after having been out of operation for several hours. Within approximately 30 minutes, removal and pressure differential returned to the levels of the previous day. *[14]*

A fourth bag was initially tested with a 1 micron absolute pore size, 1 layer, and heat-welded seems but could only run for a few hours before becoming clogged. It could however be used in series following one of the other bags.

Cryptosporidium challenges were also conducted along with the beads. Table 6-4 summarizes all the contaminant challenges that took place over a range of flow rates, pressure differentials (bag age), and raw water loadings. Although Bag 3 showed the highest removal rates, it varied considerably during filter runs and was the most likely to experience a rupture. Bag 1 was extremely steady in its removal and would probably be easier to operate over time. *[15]*

Figures 6-11 and 6-12 show the inner structure of a new and used bag (as viewed under an electron microscope). It appears that as a bag continues to be used, the smaller particles (dirt) can work their way through the bag layers and ultimately pass through.

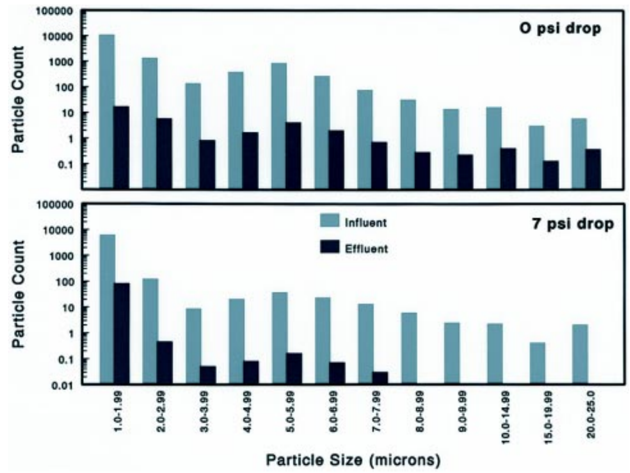


Figure 6-10. Influent vs Effluent Particle Counts

Bag filtration should not be used 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 and then polish or treat with a disinfectant to remove any microbial or bacterial contaminant.

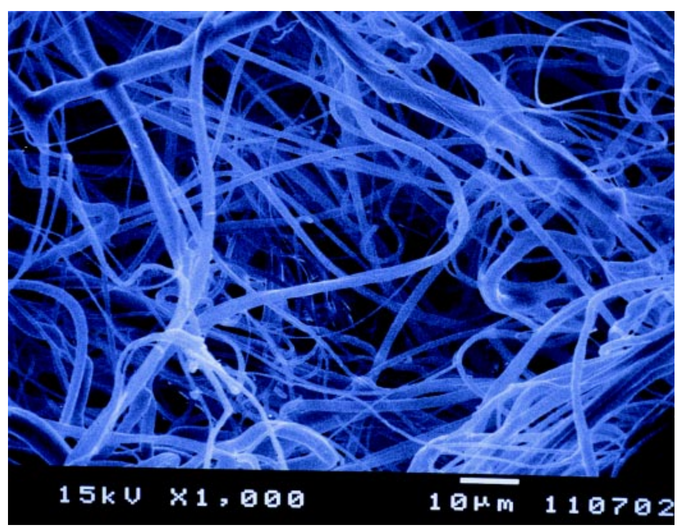


Figure 6-11. New bag.

Table 6-4. Bag Filtration Performance Summary [15]

	Percent Reduction			
Bag Filter System	Beads or Microspheres[a]	Turbidity	Particle Count[b]	Cryptosporidium
Bag 1	93%	80%	95%	94%
Bag 2	50%	10%	10%	40%
Bag 3	99.1%	93%	97%	99.94%

[a]4.5 micron plastic beads
[b]4 to 6 microns

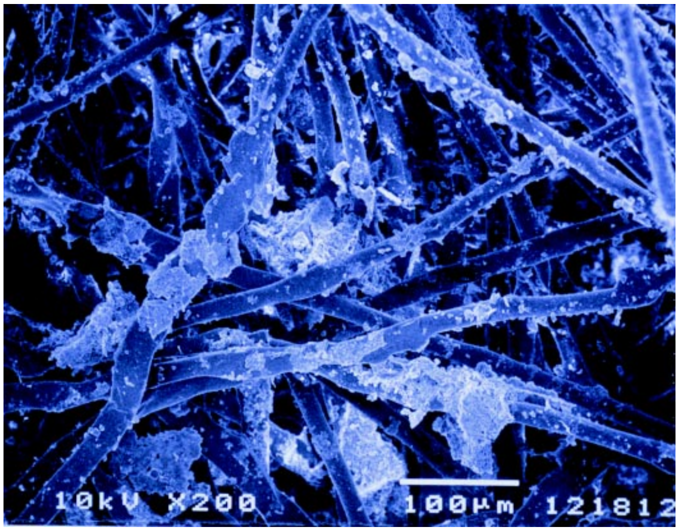


Figure 6-12. Dirty bag.

Bag and Cartridge Filter Observations

Vendor support for systems can vary significantly based on the experience of the representative contacted. One vendor insisted on the use of a special "installation" tool for proper bag filter operation. The special tool turned out to be a baseball bat!

Seasonal variability in source water quality may significantly impact the life of the bag/cartridge filter. For surface water systems, influent turbidity may increase dramatically following rain.

Cartridge Filtration

Cartridge filters are a technology suitable for removing many 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. Figure 6-13 shows a cartridge filter and housing.

Cartridge filters are rigid cores (usually PVC) with surrounding deep-pleated filter media much like a Shop-Vac™ air filter. They 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. 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.

Cartridge filter housings are generally made of stainless steel or fiberglass-reinforced-plastic for chemical resistance. The housings may be equipped with one or two pressure gauges, drain ports, and an air release valve. The typical housing has a top-placement lid, which seals with an o-ring and is clamped or bolted into place after a filter has been inserted (Figure 6-13).

Inlet and outlet pressure gauges are used to determine filter status. The pressure drop is measured and used to indicate when the life of the filter has expired. It is important to adhere to the manufacturer's recommended pressure drops for replacement/cleaning to prevent break-through and contamination of the treated water. Figure 6-14 shows dirty and clean cartridge filters.

Cartridge filters can be "ganged", i.e., bundled together, or set up in various single configurations. The units can be contained either singly in series or parallel or ganged together in multiples within one

Figure 6-13. Cartridge filters and housings.

Figure 6-14. Dirty and clean cartridge filters.

vessel. Like bag filters, cartridge filters can be designed for a variety of filtration applications. Most times the cartridge filter is used as a polishing filter following coarse sand filtration or bag treatment technologies. Again, like bag filters, one of the most cost-effective benefits of the cartridge filter is that it is commonly used without costly chemical additions, such as coagulation, flocculation, or filter-coated chemicals. Like bag filtration technology, cartridge filters are designed to capture protozoa, parasites, or oocysts. 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.

Figure 6-15 shows a filter without internal structure failure. Figure 6-16 shows the filter after water hammered the filter and caused the unit to collapse. These figures of the cartridge filter demonstrate that cartridge filters can be damaged under certain types of operation.

EPA has evaluated several types of cartridge filters at the T&E Facility (see Table 6-5). Please note that the performance of the filters varies widely with the inlet water flowrate, inlet turbidity and particle size. A presentation of performance data that represents a full range of test conditions is beyond the scope of this document. However, a summary of these evaluations is presented in Table 6-6.

Table 6-5. Cartridge Filter Characteristics

Cartridge Filter	Pore Size	Construction	Surface Area (sq. ft.)
Cartridge 1	1 micron	Vertical Pleated	30
Cartridge 2	1 micron	Vertical Pleated	40
Cartridge 3	2 micron	Compound Radial Pleated	117

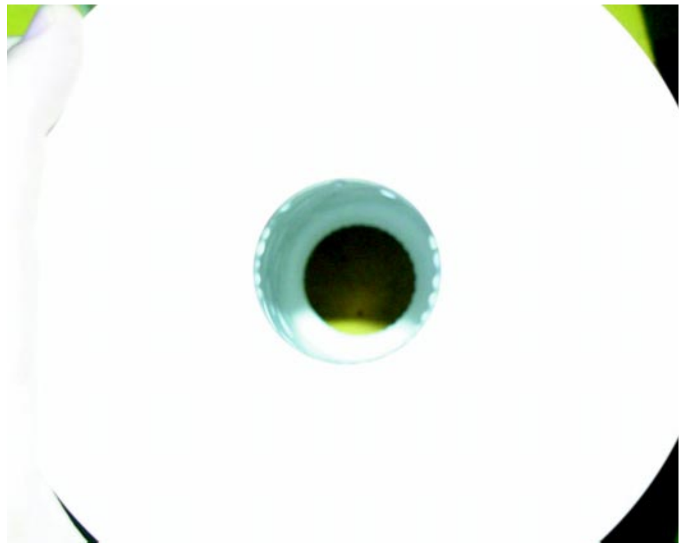


Figure 6-15. Normal cartridge filter.

Figure 6-16. Collapsed cartridge filter.

Membrane Filtration *[13]*

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. 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 reverse osmosis (RO).

Table 6-6. Cartridge Filtration Performance Summary

Filter System	Percent Reduction	
	Turbidity	Particle Count
Cartridge 1	50% - 80%	80% - 96%
Cartridge 2	77% - 88%	89% - 96%
Cartridge 3	70% - 89%	>99%

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 to remove dissolved contaminants, including both inorganic and organic compounds, and these processes operate at pressures significantly higher (e.g., 800–1500 psi) than MF and UF. Low-pressure membrane processes (i.e., MF and UF) are typically applied to remove particulate and microbial contaminants and can be operated under positive or negative pressure (i.e., vacuum pressure). Positive-pressure systems typically operate between 3 and 60 psi, whereas vacuum systems operate between -3 and -12 psi. There is no significant difference between the range of pressures at which MF and UF systems operate. EPA has evaluated both MF and UF systems. The performance summaries for both systems are presented in Table 6-7.

Ultrafiltration

Ultrafiltration (UF) systems are effective for removing pathogens, while being affordable for small systems. Ultrafiltration is one of many processes used to remove particles and microorganisms from water. The ultrafiltration technology falls between nanofiltration and microfiltration 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 (EPA studied 8" x 40" 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 it retains, typically in the range of 0.1 to 10 microns. UF is used for separating 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.

When UF membranes begin to clog, a pressure drop between the inlet and outlet will occur, along with a reduction in flow rate. Adjustments should be made to the raw inlet valve and reject water valve to maintain flow as the membrane fouls. UF membranes must be periodically backwashed according to their rated pressure drops. It is important to follow manufacturer's recommended pressure drops for backwashing and/or manual cleaning to prevent permanent fouling, breakthrough or pressure build-ups. Membranes are typically cleaned with high concentrations of chlorine, acid, or bases. These are typically the only chemicals used for these systems thus reducing operator attention from that required for coagulation and flocculation.

EPA has conducted UF research studies at the T&E Facility using a spiral wound membrane package plant. The UF system had a nominal pore size of 0.005 mm with a MWCO of 10,000. This package plant can treat water at flow rates up to 15 gallons per minute (gpm). Figure 6-17 depicts the UF system operated at the T&E Facility. The results of these studies are included in Table 6-8.

Studies were conducted to determine the efficiency of the UF system to remove *Cryptosporidium*-sized particles (4.5 micron plastic beads termed "microspheres"). Initial testing showed an unacceptable 99.5% removal of the microspheres. However, there was no indication from flow, pressure, or turbidity that the spiral wound system was not properly removing the microspheres. Maintenance/inspection of the membranes showed a crack in a plastic adaptor between the membranes and the downstream end of the permeate tube (see Figure 6-17[b]); this crack allowed raw water to pass directly into the finished water. Figure 6-18 shows a photograph of the cracked adaptor. The malfunctioning unit did not demonstrate any problems with pressure losses through the membrane due to the

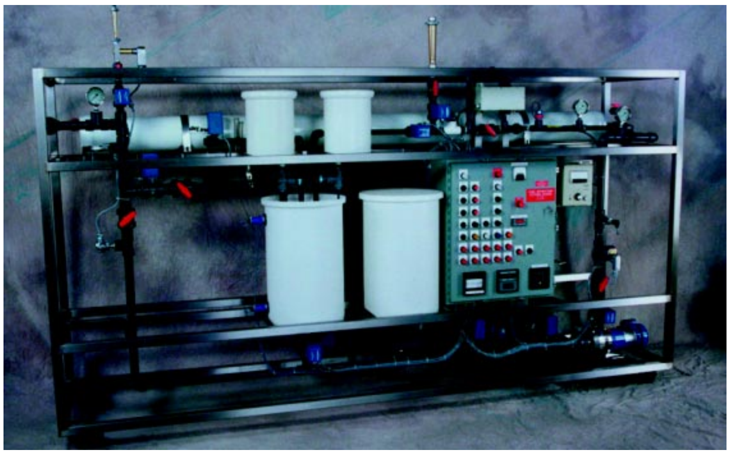
Table 6-7. Membrane Filtration Performance Summary [15]

Filter System	Percent Reduction			
	Microspheres	Particle Count	Cryptosporidium	MS2 Bacteriophages
MF System	99.95 - 99.99	99.985 - 99.914	99.957	NA
UF System	99.3 - 99.998	94 - 99.91	99.95 - 99.994	99.99

Table 6-8. Filtration Summary Table (as tested)

Technology	Average Cryptosporidium Removal (%)	Filter Size (microns)	Flow Rate (gpm)[a]	Purchase Price ($)	Filter Replace-ment Cost ($)	Expected Filter Life
Bag Filter	90.0	1+	Up to 40	2,000	50/bag	Hours/days/weeks
Cartridge Filter	90 - 99.0	0.5+	up to 100	2,000	50-300/cartridge	Hours/days/ weeks
UF Membrane	99.9 - 99.99	0.005 - 1	up to 30	50,000	5,000/element	Up to 3 years

[a]gpm = Gallons per minute



(a)

(b)

(c)

Figure 6-17.
(a) UF System
(b) UF System Cartridges in Series
(c) UF System Cartridge Cut-Out

cracked adaptor and showed acceptable turbidity removal results. Small system operators should be aware that EPA has also observed and identified this situation in the field. Each observance was related to improperly installed UF filters, broken o-rings, or (cracked) adaptors. After each of the units was repaired, results indicated up to 99.998% removal of microspheres using the UF treatment package plant. *Cryptosporidium sp.* was also injected into the feed supply water to the UF package plant. Under laboratory conditions, the UF plant achieved a removal of 99.95% to 99.994%. A test was conducted using bacillus spores to simulate *cyptosporidium* removal. These tests showed removals similar to that obtained in the tests using *cryptosporidium* (about 99.99%).

Twenty-four studies were performed at an average inlet pressure of 29 psi; the effluent flow rate averaged 7.2 gpm. The sample collection duration of each test ranged from 218 to 5,532 minutes with an average of 1,110 minutes. The system was operated continuously and was purged with tap water at least 8 hours between each test run. Results indicated a 99.9% to 99.99% removal range of microspheres from the influent to the permeate, with an overall removal average of 99.5% (Figure 6-19). As a comparison, *Cryptosporidium* filtration achieved a removal of 99.5% oocysts, which was very similar to the average log removal of the 4.5 microns standardized plastic test beads.

However, the last data point in Figure 6-19 is shown in detail in Figure 6-20. This data point represents samples

Figure 6-18. Cracked plastic adaptor used between membranes.

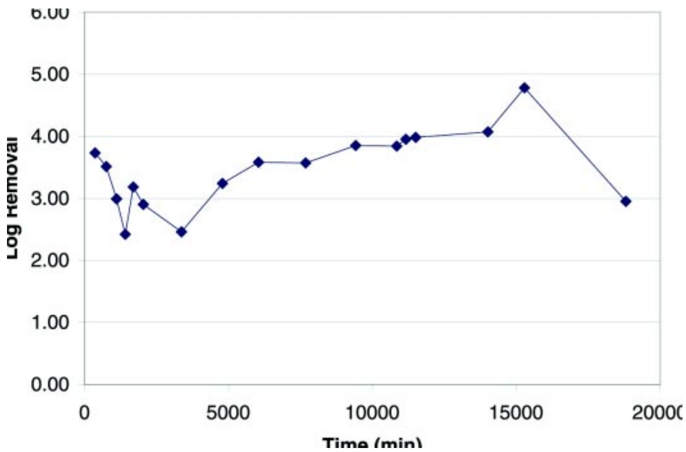


Figure 6-19. Log removal of beads vs. membrane run-time.

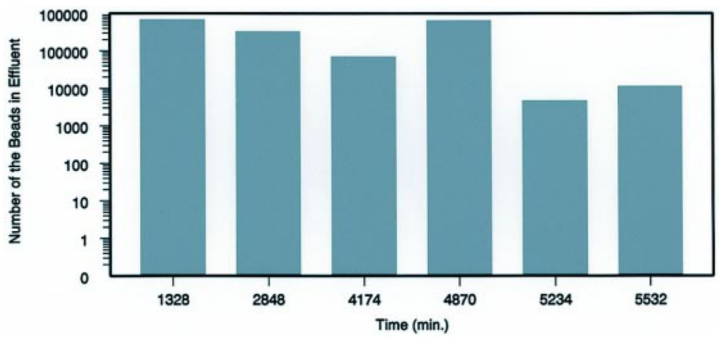


Figure 6-20. Number of Beads in Effluent vs Run Time

being taken from the permeate over almost four days compared to just one day for the other data points shown in Figure 6-19. After 5,532 minutes (approximately 3.84 days) of run time, plastic test beads were still found in the permeate even though influent spiking had occurred over a two-hour period at the beginning of the experiment four days earlier. Removal was 99.5% for the individual experiment, lower than most of the previous experiments. The higher removal rate achieved by the shorter experiments could be the effect of insufficient sample collection time, and suggests that particles may have long residence times in membrane filters but are still capable of ultimately passing through.

Tests were also conducted to evaluate the effectiveness of the UF system in removing a virus. MS2 bacteriophage was used in the experimental runs to simulate a particle similar in size to a virus. The test conditions were similar to the conditions used for the *cryptosporidum* tests. There were no MS2 bacteriophages detected in the permeate from the UF. However, this is a likely result of the sampling technique used since the permeate could be examined in discrete intervals only because of the small size of the MS2 bacteriophage. (In the *cryptosporidum* study, a portion of the permeate was constantly filtered to catch any particles. In this study, this was not possible because a filter to catch the MS2 bateriophages is not available).

It should be noted that although *Cryptosporidium* is 4-6 microns in size, it can still pass through an absolute 3-micron size filter by deforming and squeezing through. The pliability of *Cryptosporidium* is demonstrated in Figures 6-21 (a) and (b).

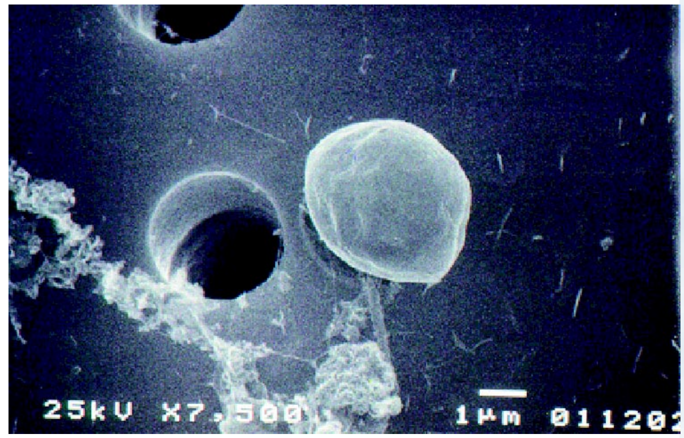


Figure 6-21a. Cryptosporidium oocyst on upper surface of 3 micron pore.

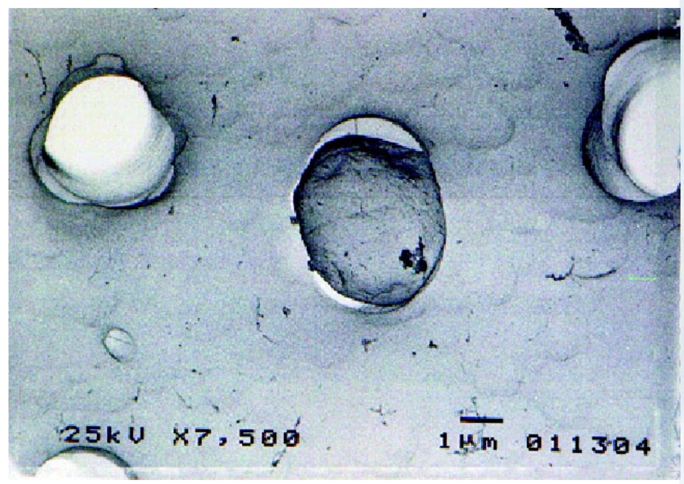


Figure 6-21b. Cryptosporidium oocyst coming through 3 micron pore.

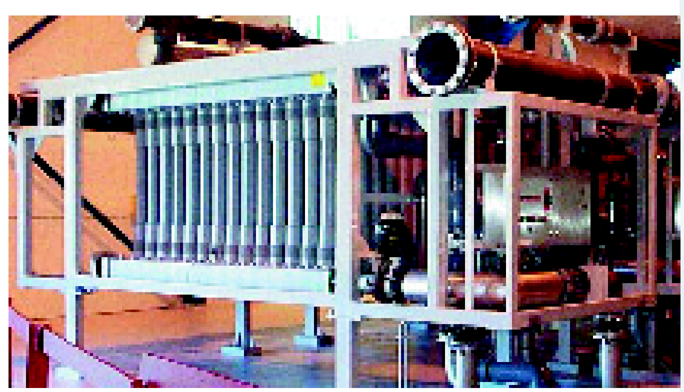


Figure 6-22. Micro Filtration System.

United States Forest Service—Hybrid Filtration/Disinfection System (see Figure 6-24)

A hybrid filtration/disinfection system was commissioned by the United States Forest Service San Dimas Technology and Development Center in Los Angeles, California, as a follow up to EPA's bag filtration and on-site chlorine generation studies. This system incorporated bag or cartridge filters prior to an on-site chlorine generator onto a skid specially designed for intermittent operation at campgrounds. The skid was designed to fit into the bed of a pickup truck capable of being lifted and installed manually (four people) at the campground. An ion-exchange softener was included on the skid to produce brine-free water to maintain pump operation. The system was also designed for remote monitoring and control, and solar power with battery backup. Based on the campground needs, it was determined that cartridge filtration was preferable and more economical because of the low turbidity in the raw mountain water and the desire for a better *Cryptosporidium* and *Giardia* barrier.

In-house research at the San Dimas facility concluded that the cartridge filters can achieve 99% (2 Log) removal of *Giardia*-sized particles (5- to 15-micron size) in low-turbidity (<0.60 NTU) raw waters. Intermittent operation did not appear to cause any additional problems, nor did there appear to be any loss in removal efficiencies immediately after the system was turned off. The removals were achieved 95% of the time, and the system was able to function beyond the 20-psi differential pressure between raw and finished sampling points (that determines cartridge life). The cartridge filters were able to handle short-term spikes, although algae blooms in raw water resulted in short filter life and early filter failure. Particle-counting instruments also proved problematic.

Thus, it is assumed that the UF system effectiveness in removing MS2 bacteriophages is similar to that observed during the *cryptosporidium* study, or about a 99.99% removal.

Microfiltration

Various field evaluations have been conducted to assess the operational performance of microfiltration technology and provide information about the removal of physical and biological contaminants under continuous operation. Figure 6-22 shows a typical MF unit. Microfiltration membranes normally have pore sizes 0.1 microns or greater [16]. The water flow of the test system ranged between 15 and 34 gpm. Standardized plastic test beads of 4.5 microns were injected into the raw untreated test water. The reduction of turbidity was 93.33% and the reduction of *Cryptosporidium* was 99.957%. Particle counts were performed resulting in removals of 99.985% for particles in the 4-6 micron range and 99.914% for particles in the 1-25 micron range. Thus, even though the plastic test beads have a diameter of 4.5 microns, beads are seen to pass through the membrane (or through seals, adapters, or gaskets) even within the 1 to 4 micron range. Collectively, results showed no influence due to the different flow rates. The results indicate that microfiltration technology is a feasible small system drinking water treatment technology for particle removal [13].

In anticipation of small system needs in meeting the Stage 1 Disinfectants/Disinfection Byproducts Rule, the Ground Water Rule, and the Stage 1 Enhanced Surface Water Treatment Rule, the 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.

Note that the final turbidity achieved by a UF system was <0.2 NTU regardless of the influent turbidity. Thus percent removal does not provide a meaningful measure of UF performance for turbidity. This is not, however, true for MF systems where the effluent turbidity is dependent on the influent turbidity. The MF systems tested at T&E achieved removals of 90% to 98% with finished turbidity levels ranging between 0.1 to 0.6 microns. A real-world case study and example of a UF System package plant is included in Section 9 of this document.

Filtration Summary

As discussed previously in this section, EPA has evaluated several types of filtration systems at the T&E Facility and various field locations. The operating conditions, microbe (*Cryptosporidium*) removal efficiency, initial and operating cost for the individual units vary widely. Table 6-8 presents a summary of information for each type of filter.

Based upon the above technology investigations, it appears that there are several alternative filtration technologies. Depending on raw water characteristics, a likely configuration can consist of filters in series with decreasingly small pore sizes that can, in effect, remove most microbiological contaminants, reducing the need for chemical coagulants and disinfectants. Operation and maintenance would be simplified, thus enhancing long-term compliance.

Disinfection

Disinfection is the process used to reduce the number of pathogenic microbes in water. The Surface Water Treatment Rule (SWTR) [18] requires PWSs to disinfect water obtained from surface water supplies or ground water sources under the influence of surface water. The proposed Ground Water Rule may require PWSs to disinfect their well water supplies. MCL and M/R violations of the SDWA and its amendments over the

Several guidance manuals are available to help PWS operators comply with the Stage 1 Disinfectants/ Disinfection Byproducts Rule. Examples of such guidance manuals include:

- Disinfection Profiling and Benchmarking Guidance Manual (EPA 815-R-99-013), August 1999.
- Alternative Disinfectants and Oxidants Guidance Manual (EPA 815-R-99-014), April 1999.
- Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual (EPA 815-R-99-015), August 1999.

years show that small systems are either (1) unable to simply disinfect their water or (2) record and submit their data to the appropriate oversight agency. Typically, some form of chlorine is used as a disinfectant. More recently, ultra-violet (UV) radiation, Ozonation (O_3) or a combination of UV/O_3 technologies are being used for disinfection.

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 need only measure the residual chlorine at the point of consumption to ensure proper disinfection. Test procedures for measuring chlorine are presented later in this section.

However, people are becoming more concerned about the disinfection by-products (DBPs) of chlorine and are looking for alternatives. Chlorine reduces bacteria, but it also reacts with other organic impurities present in water producing various trihalomethanes (THMs) 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 removing viruses (such as enterovirus and hepatitis A) and protozoa (such as *Cryptosporidia* and *Giardia*).

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. High levels of ozone are extremely harmful especially in enclosed or low-ventilation areas. Ozone also forms highly carcinogenic DBPs with bromide to form bromate, broform, dibromeacetic acid, and others. Thus, there is no "silver bullet" for disinfection that does not have some drawbacks. In PWSs, UV equipment or biological filters are typically installed to remove ozone residuals prior to filtration.

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 is summarized in Table 6-9.

The use of UV light as means of 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 appears to be effective for *Cryptosporidium.* However, residual disinfection (to account for contamination via the distribution system) is not possible.

Operators need to use the optimum amount of disinfecting agent to achieve appropriate disinfection and minimize DBP formation. Currently, the regu-

Table 6-9. Summary of Disinfectant Characteristics Relating to Biocidal Efficiency [19]

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

lated DBPs in the United States are trihalomethanes (THMs) with a maximum contaminant level of 80 parts per billion (ppb). However, the practice of chlorination for pre-oxidation or for disinfection can result in the formation of chlorinated organic by-products. The recently promulgated Disinfectant/Disinfection Byproducts (D/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 THM standard of 80 ppb (Federal Register, 1998). 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 *[9]*. To minimize the formation of DBPs, under the SWTR *[18]* and the proposed Enhanced Surface Water Treatment Rule (ESWTR) *[20]* most utilities are also required to filter their water unless the following conditions are met in the surface water prior to disinfection:

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

Treatment plants exempt 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 respectively *[9]*.

For a List of CT Values, go to:
www.epa.gov/safewater/mdbp/pdf/profile/benchpt4.pdf

Also, EPA studies have demonstrated that the pliability of *Cryptosporidium* oocysts may permit the oocysts to pass through a filtration system, thus making disinfection that much more important as a barrier *[17]*. Just like large systems, small systems have to be even more concerned with the safety and ease of handling, shipping, storage, and the capital, 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. An evaluation summary of these technologies is presented in the following subsections.

Chlorine Residual and Monitoring [9]

As identified earlier, chlorination is preferred for disinfection at small treatment plants and for small utilities. The following four methods are popularly used to monitor residual (free and total) chlorine in treated water supplies:

1. N,N-diethyl-p-phenylenediamine (DPD) colorimetric method
2. Iodometric method,
3. Polarographic membrane sensors, and
4. Amperometric Electrodes

The DPD colorimetric method is most commonly used and is based on the American Society for Testing and Materials (ASTM) Standard Method. In this method, DPD is oxidized by chlorine to form two oxidation products with one product being darker in color than the other. The color intensity is measured by either a colorimeter (color wheel) or spectrophotometer and corresponds to the amount of free and total chlorine present in the sample. This method can measure both free and total chlorine.

The Iodometric method involves adding potassium iodide to a water sample to react with the available chlorine to form iodine. The amount of free iodine generated is monitored and correlated to the amount of chlorine present. Since this method does not distinguish between free and combined chlorine, it should only be used when monitoring for total chlorine.

The Polarographic Membrane sensor method consists of a pair of electrodes that monitor free chlorine. The electrodes are immersed in a conductive electrolyte and isolated from the sample by a chlorine-permeable membrane. Free chlorine diffuses through the membrane and is reduced to chloride on the surface of the electrodes, generating a flow of electrons between the two electrodes. The current generated is proportional to the concentration of the free chlorine.

Amperometric Electrodes method consist of two combination probes that use a platinum cathode and a silver anode to amperometrically measure free chlorine along with pH and temperature. Within these electrodes, an electrochemical reaction occurs based on the available chlorine concentration, generating a proportional current. This method can measure free chlorine.

EPA found the cost of the various sensors to range from $400 to over $10,000 for stand-alone, sophisticated sensors that were automated and combined multiple monitoring parameters. A standard, online, process control instrument with sampling assembly and analyzer ranged in cost from $2,000 and $10,000.

Disinfection by Chlorination

Chlorine is generally obtained for disinfection in the form of gaseous chlorine, onsite chlorine 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 is, however, 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.

There are, however, other chlorination processes available 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 generated from the electrolytic cell. The further claim is that this mix of oxidants minimizes DBP formation. However, EPA has not been able to demonstrate the presence of any other oxidant (other than sodium hypochlorous acid) generated from these units.

Electrolysis of salt brine to produce hypochlorite has been practiced for nearly a century and was the early method for industrial preparation of the chemical. The basic operating principle involves electrolyzing a concentrated brine solution which generates chlorine at the anode and hydrogen together with sodium hydroxide at the cathode. The hydrogen is allowed to vent whereas the chlorine is allowed to remain in contact with the electrolyte thus forming sodium hypochlorite. Basically, the formation of sodium hypochlorite occurs as follows:

Salt + Water + Energy => Sodium Hypochlorite + Hydrogen Gas

When selecting an electrolytic chlorine generator, operators should be aware that the performance of each unit may be significantly affected by the quality of the salt. Each vendor will recommend the type of salt to be used in its unit. It is important to note that all salt is not the same. Bromide levels in the salt can significantly affect the level of bromate found in the treated (chlorinated) water. Although safer than conventional chlorine gas treatment, safety can also be an issue with the chlorine salt brine generators. As identified above, hydrogen gas is generated, and although it is in very small amounts and for the most part not considered hazardous, any collection of hydrogen gas can be a potential for explosion or fire. Thus, each electrolytic chlorine generating unit, or the building in which it is set up, should have some type of ventilation system to assure hydrogen gas does not collect. It must be noted that the salt brine electrolysis-based generators are generally safer to handle and operate than conventional liquid or solid sodium hypochlorite, calcium hypochlorite, or chlorine gas systems.

On-site salt-brine electrolysis chlorine generator systems can be very attractive to small 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 prices for the three salt-brine generators designed specifically for small systems cost in the range of $18,000 to $35,000 (depending on the manufacturer). Since most small treatment system operators and facilities have a limited budget, EPA decided to evaluate 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 plumbing, pump, pressure gauge, flow control and brine tank for $525 for a total equipment cost of $1,275! (Figure 6-23)

Breakpoint Chlorination [9]

Small treatment operators should remember that ground water, primarily in rural areas, tends to be seasonally contaminated with ammonia nitrogen from sources that may include crop fertilizers. Because of this, they must achieve a stable residual of stronger disinfectant-free chlorine. In other words, the formation of chloramines must be avoided by practicing "breakpoint chlorination." Breakpoint chlorination is the process in which chlorine is added at levels that result in the oxidation (removal) of ammonia nitrogen. This happens by converting the ammonia-nitrogen to nitrogen gas in the presence of chlorine. The rate of breakpoint chlorination is fastest at pH levels in the range of 7 to 8, and tends to slow-down below and above the optimum pH range. Thus monitoring and controlling the pH is critical for optimization.

Each utility or operator should evaluate the volume and quality of salt being used to generate the required amount of chlorine. Replacement parts and life for items, such as electrolytic cell, static mixers, power supplies and tubing and connectors, should be considered. The operator should note that EPA has demonstrated that drinking water disinfectants, such as chlorine or monochloramine, at typical dosages have virtually no effect on the inactivation of *Cryptosporidium* oocysts. [21]

EPA conducted studies to evaluate three different on-site salt brine–based chlorine generators and compared them to each other and to liquid bleach (see insert). Each unit was capable of generating sodium hypochlorite on an as-needed basis by electrolyzing salt water. Figures 6-23 through 6-25 show pictures of the four on site chlorine generators evaluated.

Figure 6-23. On-Site Chlorine Generator #1.

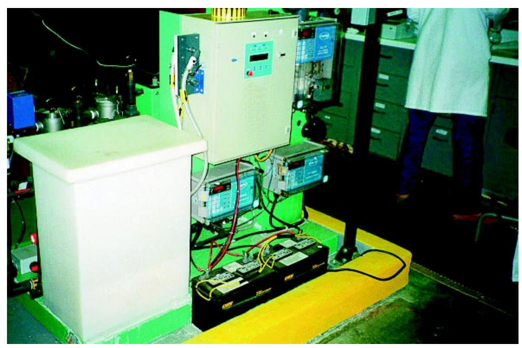


Figure 6-24. On-Site Chlorine Generator #2.

Figure 6-25. On-Site Chlorine Generator #3.

Performance Evaluation of Various Disinfection Technologies

For the on-site chlorine generators, the performance can be evaluated based on the amount of chlorine generated. The overall performance of the disinfection system is based on the removal efficiency of microbial organisms, such as Total Coliforms, Fecal Coliforms, E. Coli, *Cryptosporidium*, etc. EPA evaluated the performance of disinfection systems by operating these systems under various "test" conditions.

Disinfection Summary

Each of the three chlorine generators evaluated showed high concentrations (as much as 400 mg/L) of free chlorine to be generated. A wide variety of analytical methods were used to evaluate the disinfectant generation at the actual anode and cathode cells. Based on the analytical results, EPA concluded that only free chlorine was produced [22]. EPA studies involving *Cryptosporidium* oocysts also did not show any enhanced disinfection from using the electrolyzed salt-brine "chlorine" solutions when compared to liquid bleach "chlorine." *Cryptosporidium* removal efficiencies were less than 90%.

Ultraviolet (UV)/Ozone (O_3)

EPA evaluated a packaged UV/O_3 (also referred to as Advanced Oxidation Process or AOP) system for inactivating microorganisms. The unit evaluated was capable of processing up to 10 gpm of water and is engineered to ensure adequate UV intensity and ozone residuals for advanced oxidation processes. The UV/O_3 system has a custom-built ozone generation, injection and contacting system. The combined system consists of a 13 gallon (49 liter) contact tank, a 5 gram/hour ozone generator with air dryer, and a cylindrical low-pressure 254 nm UV lamp reactor, and a recirculation pump. The use of purity components,

Disinfection System Observations:
Research on on-site chlorine generators and UV/O_3 treatment technologies have 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/O_3 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 handling 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/O_3 systems oxidize organics instantly. Ozone reacts quickly without leaving a residual disinfectant. UV disinfection depends upon 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 are critical for providing consistent disinfection.

Several things can be done to improve UV/O_3 system performance. 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/O_3 system should be operated as specified by the manufacturer. Alternatively, an oxygen generator can be used to feed the ozone generator; this can be, however, an expensive option.

such as a natural kynar venturi injector, a stainless steel UV light housing, stainless steel recirculation loop piping, and a rust proof extruded aluminum frame are also features of this system. The total volume of the UV/O_3 system is 15 gallons (57 liters).

The combined UV/O_3 system by far achieved the highest disinfection rates for bacterial contamination. The UV/O_3 disinfection technology is useful in removing other organic contaminants, such as MTBE, perchloroethylene, and trichloroethylene. Table 6-10 provides a summary of the UV/O_3 disinfection study evaluations.

As discussed before, EPA evaluated several types of disinfection systems at the T&E Facility and various field locations. The operating conditions, microbe removal efficiency, and initial and operating cost for the individual units vary widely. Table 6-9 presents a summary of information for each type of disinfection system. Note that the flow rates and the chlorine generation rates, replacement part(s) cost(s), and replacement frequency varies widely depending upon the generator unit. The chlorine generation rate depends upon the electrolytic cell size and the direct current (DC) capacity of the system. Typically, the parts that need to be replaced on an annual basis (depending upon use) include: feed pump(s), electrolytic cell, and filters. The replacement costs range between $100–$1,000 depending on the unit and the replacement part.

Advanced Oxidation Process for Disinfection & Destruction

Advanced oxidation processes (AOP) use oxidants to destroy organic contamination 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/O_3 for disinfection potential and MTBE destruction. This effort was intended to investigate if an AOP system can be used to disinfect the water, and at the same time destroy organic compounds.

AOP Using UV/Ozonation for MTBE Removal

Methyl-tert-Butyl-Ether (MTBE) is a gasoline additive that has been found in drinking water. UV irradiation and ozonation are known to effectively destroy organic compounds in drinking water and

Table 6-10. Disinfection Summary Table (as tested)

Technology	Cryptosporidium Removal	Flow Rate (gpm)[a]	Purchase Price
Chlorine Generators	<90%	varies	$800 - 20,000
UV	99 - 99.9%	12	$2,000
Ozone	99 - 99.9%	12	$5,000
UV/Ozone	99.9 - 99.99%	12	$7,000

[a]gpm = Gallons per minute

Chlorine exists in water in various forms. These forms include free and combined chlorine and are measures of the residual chlorine in the water supply. [23]

Free Chlorine: Chlorine that is applied to water in its liquid or gas form (hypochlorite) undergoes hydrolysis (chlorine mixed with water) to form free (available) chlorine. This free chlorine is in the form of aqueous molecular chlorine, hypochlorous acid, and hypochlorite ion. The proportions of these free chlorine forms are dependent on pH and temperature. At the normal pH of most waters hypochlorous acid and hypochlorite ion will predominate the solution.

Combined Chlorine: Free chlorine reacts easily with ammonia and certain nitrogenous compounds to form combined chlorine. Chlorine reacts with the ammonia it forms chloramines. The chloramines are monochloramine, dichloramine, and nitrogen trichloride as well as some other chloro-derivatives. The presence and concentrations of these combined forms depend on pH, temperature, initial chlorine-to-nitrogen ratio, absolute chlorine demand, and reaction time. Note that both free and combined chlorine maybe present at the same time and, historically, the principal analytical problem has been to distinguish between free and combined forms of chlorine. Combined chlorine is determined by running free chlorine and total chlorine tests and then subtracting the free chlorine result from the total chlorine result.

Residual Chlorine: Residual chlorine is the amount of chlorine remaining in the water after a specified contact period.

other matrices. Thus, in addition to treatment for *Cryptosporidium*, UV/O_3 systems have also demonstrated the ability to treat MTBE in drinking water. EPA has evaluated the removal of MTBE at influent concentrations of 30 and 75 micrograms per liter (μg/L) in a water supply. Ultraviolet light treatment alone effected negligible MTBE removal. O_3 alone was capable of removing >80% of the MTBE after 60 minutes, but removal efficiency depended strongly on the reaction time and on the initial MTBE concentration. The combined UV/O_3 process showed the best potential for MTBE removal. Complete MTBE removal was observed within 20 minutes reaction time. Several by-products are generated as a result of MTBE treatment. These by-products include *t*-butyl alcohol (TBA), *t*-butyl formate (TBF), formaldehyde, isopropyl alcohol, acetone, and acetic acid methyl ester. [24] [25] Figures 6-26 and 6-27 demonstrate the formation of byproducts and removal of MTBE in the AOP process.

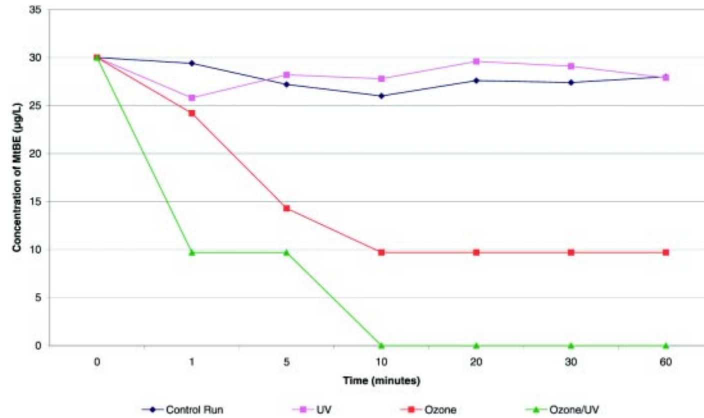


Figure 6-26. Package AOP Plant MTBE Removal vs Time, 30 μg/L Batch Test Run

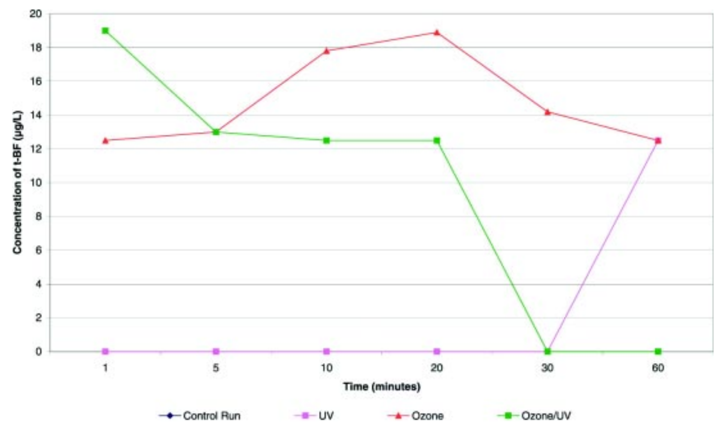


Figure 6-27. Package AOP Plant Formation of t-BF vs Time Injecting 30 μg/L MTBE.

7.0 Point-of-Use/Point-of-Entry Applications

Public water supply consumers may not always possess the financial resources, technical ability, or physical space to own and operate custom-built treatment plants. Small drinking water treatment systems, such as Point-Of-Use and Point-Of-Entry (POU/POE) units, may be the best solution for providing safe drinking water to individual homes, businesses, apartment buildings, and even small towns. These small system alternatives can be used for not only treating some raw water problems, but they 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.

For additional information, please see:
www.nsf.org/water.html
www.wqa.org
www.ndwc.wvu.edu

As discussed in Section 6, the 1996 SDWA Amendments identified two classes of technologies for Small Systems: (1) compliance technologies and (2) variance technologies. *[11]* A "compliance technology" may refer to a technology or any other technique that is affordable by a small system that achieves compliance with the MCL. These could include POU/POE systems. "Variance technologies" are only approved for those system sizes/source water quality combinations when there is no available "compliance technology." So, if there is a "compliance technology" listed for your system, other "variance technologies" will not be allowed. While "variance technologies" might not reach the MCLs, they must achieve the maximum removal or inactivation efficiency affordable considering the size of your system and the water quality of the source water. Public health must be protected.

The 1996 SDWA require that the MCLs be set as close as possible to the MCLGs as is "feasible." Feasible meant that the best technology or treatment technique had to be determined based upon field conditions, taking cost into account. The technologies that meet this criterion are called "Best Available Technology" (BAT). *[10]* Major concerns regarding the use of POU/POE technology are:

– the problem of monitoring treatment performance so that it is comparable to central treatment;

– POU devices only treat water at an individual tap (usually the kitchen faucet) and therefore raise the possibility of potential exposure at other faucets. Also, they do not treat contaminants introduced by the shower (breathing) and skin contact (bathing). Thus, POU/POE devices are <u>not</u> designated as BAT;

– these devices are generally not affordable by large metropolitan water systems.

POU devices are only considered acceptable for use as interim measures, such as a condition of obtaining a variance or exemption to avoid unreasonable risks to health before full compliance can be achieved. *[26]*

POE systems could be used if:

a. The device is kept in working order. The PWS is responsible for operating and maintaining all parts of the treatment system although central ownership is not necessary.

b. An effective monitoring plan must be developed and approved by the state before POE devices are installed. A unique monitoring plan must be installed that ensures that the POE device provides health protection equivalent to central water treatment.

c. Because there are no generally accepted standards for design and construction of POE devices, and there are a variety of designs available, the state may require adequate certification of performance testing and field testing. A rigorous engineering design and review of each type of device is required. Either the State, or a third party acceptable to the State, can conduct a certification program.

d. A key factor in applying POE treatment is maintaining the microbiological safety of treated water. There is a tendency for POE devices to increase bacterial concentrations in treated water. This is a particular problem for activated carbon technologies. Therefore, it may be necessary to use frequent back-washing, post-filter disinfection, and monitoring to ensure the microbiological safety of the treated water. The EPA considers this a necessary condition because disinfection is not normally provided after POE treatment, while it is commonly used in central treatment.

e. The EPA requires that every building connected to a PWS have a POE device that is installed, maintained, and adequately monitored. The rights and responsibilities of the utility customer must be transferred to the new owner with the title when the building is sold (Federal Register, 1987).

In 1996, things changed. POU/POE 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" *[10]*. 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 (VOCs).

POU/POE Treatment

Currently, POU/POE treatment is used to control a wide variety of contaminants in drinking water. When evaluating various POU/POE treatment systems, six major factors need to be considered in the decision process. These factors are:

1. quality and type of water source,
2. type and extent of contamination,
3. cost of water,
4. treatment requirements,
5. waste disposal requirements,
6. state-approved operation and maintenance plan.

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, radium, 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 *[26]*. Table 7-1 summarizes key features of commonly used POU/POE technologies. Figure 7-1 shows a typical POU (under a kitchen sink) RO Unit.

POU/POE Cost

The cost and application of POU/POE as a final solution for a small system or portion of a larger system is highly dependent upon the situation. Table 7-2 summarizes relative costs associated with various POU/POE technologies. A major factor is whether there is already in place a 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. So 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. 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 would 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 may once again be a

Figure 7-1. Typical RO Unit under a kitchen sink.

Table 7-1 Key Feature Summary of Commonly Used POU/POE Technologies [26]	
Technology	Comments
Filtration	Filtration of water supplies is a highly effective public health practice. Microfiltration, ultrafiltration, and reverse osmosis filtration systems have been shown to be effective technologies for removing pathogens while being affordable for small systems.
Activated Carbon	Activated Carbon is the most widely used POU/POE system for home water treatment. 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 and an additional UV light disinfection step to combat bacteria since the water is often stored under the sink until used.
Ion Exchange	Commonly called water softeners when used for removing 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. Also removes most pathogens. Can be effective in removing organic compounds depending on the chemical characteristics of the compounds, such as water solubility and boiling point. Distilling units have relatively high electrical demands and require approximately 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, repumping, 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 need 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 the most important consideration for POU/POE systems. Disinfectants that are generally used in POU/POE systems are ultraviolet light, ozone, chlorine, silver impregnated carbon, and iodine. Chlorine - The most widely used water disinfectant. Can be used in the form of liquid bleach, solid tablets, or generated onsite in portable generators. 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 taste and odor problems. Units require little maintenance and overdose is not a danger. Ozone - Ozone has been used for disinfection, destruction, and precepitation of iron, manganese, and some chemical contaminants. Ozone has to be generated and used on-site as needed. Iodine - Iodine has been used as an alternative disinfectant to chlorine because it is easier to maintain a residual. However, iodine will not remove iron or manganese, nor will it treat for taste and odors.

Table 7-2. Summary of Treatment Technologies and Costs [12]

Technology	Contaminants Removed	Initial Cost	Operating Costs	Operation and Maintenance Skills
Chlorine, Iodine	Microbial	Low	Low	Low
UV, Ozone	Microbial	Moderate	Low	Moderate
Sub-Micron Cartridge Filtration	Protozoa, Bacteria	Low	Low to Moderate	Low
Reverse Osmosis	Microbial, inorganic chemicals, metals, radium, minerals, some organic chemicals	Moderate	High	High
Activated Carbon	Organic Chemicals, radon, odors (solid block can filter protozoa, and some bacteria)	Moderate	Moderate to High	Low
Packed Tower Aeration	Radon, volatile organic chemicals, tastes, odors	Moderate	Low	High
Ion Exchange	Inorganic chemicals, radium, nitrate	Moderate	Moderate to High	Moderate
Activated Alumina	Arsenic, Selenium, fluoride	High	High	High

Low Cost: $0 to $100 Moderate Cost: $100 to $1,000 High Cost: >$1,000

practical alternative. *[27]*

Reverse Osmosis (RO) Home Membrane Systems Field Study

The experiences presented below are from a field study (in Virginia) focusing on removing naturally occurring fluoride at the tap by using a POU system. *[28]* The water being supplied to the homes was provided by a well located within the local subdivision. However, the driving force in the ultimate acceptance by the Commonwealth of Virginia was the POU treatment device's ability to provide finished water with acceptable levels of heterotrophic plate count (HPC). A public-private partnership between Virginia, EPA, and three POU vendors demonstrated the use of RO systems to reduce fluoride for this subdivision. This was a lower cost alternative to abandoning the well and installing a large transmission line to connect with a PWS several miles away.

Prior to this project, no treatment existed at the subdivision's well. The RO POU devices were designed to treat only the water used for drinking and cooking, and in some homes, the ice-making units in refrigerators. The devices consisted of a sediment prefilter, a high-flow, thin film (HFTF) RO membrane, a storage tank, and an activated carbon post filter. Basic parameters, such as conductivity, fluoride, HPC, total coliform, chlorine residual, pH, sodium, total dissolved solids (TDS) and turbidity, were used to evaluate the performance of the RO units.

Fluoride reduction was easily achieved for the entire duration of the study, maintaining levels below the secondary maximum contaminant level (SMCL) of 2.0 mg/L. However, HPC counts were elevated and the decision was made to centrally chlorinate at the well and replace the HFTF membranes with chlorine-resistant cellulose triacetate (CTA) membranes and remove the activated carbon post-filter. Subsequent sampling demonstrated satisfactory fluoride and HPC levels. Variances in fluoride and HPC concentrations from site to site was explained by membrane degradation and water use. The life expectancy of the membrane depends on the environmental conditions. High temperatures, bacteria, and high pH have an adverse affect on the membrane life and result in poor performance. Membranes were replaced when the conductivity reduction decreased to 70% of the influent. It was observed that conductivity reduction was generally lower than fluoride rejection, so this became a convenient, inexpensive, and conservative means of monitoring system efficacy. A correlation between HPC and chlorine residual was also observed. In fact, much of the project focused on maintaining HPC levels below 500 cfu/mL.

Water quality sampling data indicated that the risk of exceeding 500 cfu/mL at the tap was inversely proportional to the chlorine residual in the post-RO holding tank located under the kitchen sink. Any time the residual exceeded 0.5 mg/L free chlorine, the HPC limit was maintained, without exception. This is extremely relevant, because an RO membrane allows some chlorine to pass through, thus maintaining a residual at the tap. In this case, the water reaching each household typically exhibited chlorine residuals of 1 to 1.5 mg/L. Concentrations in the holding tank between 0.5 and 1 mg/L were observed frequently, indicating 33 to 50% passage of chlorine through the membrane. This concentration decreases over time in the finished water holding tank as it is consumed through various oxidation reactions. Because of this, it can be presumed that negligible chlorine residuals indicate the unit has not been used recently.

It was concluded that the HPC concern can be eliminated by using chlorine-tolerant membranes and by continually chlorinating the subdivision's well. In most cases, the RO storage tank unit was continually refilled with chlorinated water. The HPC depended on the chlorine residual in the storage tank, and usually the residual chlorine remained high enough to keep the unit clean. However, if the units were not used daily, stagnant water in the tank caused a loss of residual chlorine, and the water was susceptible to microbiological growth. Researchers found that one way to overcome this was to flush the tank daily. This concept was demonstrated at a business site during the study where the water was only used sporadically.

Public Acceptance

At least 1 gallon per day (gpd) of RO water was consumed by 77% of the homeowners, corresponding to the 75% who used the system for all of their drinking and cooking needs. Just 6% of participants claimed to rarely use the RO water. Although demonstrating fluoride reduction with RO has been done before, the challenge in this study was maintaining microbiological integrity and gaining public and regulatory acceptance for POU treatment. This required an entirely different relationship between the state authorities and the customers. The initial and exit surveys confirmed not only public acceptance, but showed an increase in customer satisfaction with the POU treatment. When asked to rate the water quality on a scale of 1–4, 52% of participants in the initial survey rated the well water (not chlorinated) quality as "fair" or "poor," while 77% rated the RO water as "good" or "very good" shortly after installation. In the exit survey one year later, 94% rated the RO water as good or very good, showing a significant increase in the acceptance of the POU systems. This acceptance may be due, in part, to the treated RO water also being softer than the raw water.

The average RO water quality was rated 1.5 points higher than the average tap water quality. The average rating was calculated by summing the individual ratings and dividing by the number of responses. In the exit survey, RO water quality averaged 3.5 points on a scale of 1–4, while well water quality averaged 2.1 points. Moreover, RO water quality was always rated at least as high or higher than the well water quality, even when the non-chlorinated well water was compared to chlorinated RO water. This is noteworthy because the switch to a chlorinated supply initially precipitated a number of negative comments about taste. Microbiological integrity was not an issue for consumers whereas it was the primary driver from the state perspective.

Documentation of the increasing contamination of U.S. ground water supplies grows almost daily. Small water systems have been, and will continue to be, the most vulnerable and the least capable of meeting current and future drinking water regulations. But, competitive options and alternatives are available in terms of drinking water treatment technology. Central treatment can no longer be thought of as the only solution, nor can it be thought of as temporary or for aesthetics only.

AOP POE for PCE and TCE Removal, Vernon, CT

Most ozone whole-house POE applications for drinking water in the past have been used for oxidation of inorganic contaminants, such as iron and manganese. Recent projects have focused on the use of ozone in conjunction with ultraviolet light and granular activated carbon (GAC) for the destruction of synthetic organic contaminants in groundwater and disinfection of surface water supplies.

Two shallow drinking water wells in Vernon, CT, were found to have elevated perchloroethylene (PCE) and trichloroethylene (TCE) concentrations. As a pilot project, a system comprised of a small AOP was installed on one of these wells and provided up to 10 gallons per minute. The unit successfully served three homes essentially as a packaged central treatment system, although it was originally designed as a home POE unit.

The AOP system consisted of an ozonator, an UV light chamber, two GAC tanks, two treated water storage tanks, a water meter, and an electric meter. Water from the well was sent into the ozonation chamber where ozone was fed into the water by a venturi. A venturi forces a gas into a liquid (such as ozone into water). The ozonated water then entered the UV light chamber and then a contact tank where the water was mixed for 3.5 minutes to achieve 100% ozone saturation. The treated water then entered the two GAC units where any residual ozone is converted to oxygen, and any remaining contaminants are removed. The treated water was then stored in the two storage tanks and then distributed to the three houses via the water meter.

The AOP system was tested over a two-month period, and it treated more than 15,500 gallons of water. The test results show an 80–90% reduction in PCE concentrations following UV/O_3 (with an influent concentration between 250 and 663 μg/L). The PCE concentrations following the GAC units were non-detectable. The capital cost of the system was estimated to be approximately $6,000 (in 1991 dollars) with a maintenance cost of approximately $150 per year. This amount includes electricity cost and GAC replacement costs.

Ozone POE, Spruce Lodge, ME

Figure 7-2 shows the POE unit installed in the cellar of a sportsman's camp in Spruce Lodge, Maine, that served up to 30 hunters and fishermen daily in a lodge and four cabins. The raw water is filtered through garnet followed by ozone injection (0.4 mg/L) and then passes by a UV light to a holding tank.

The lake's raw water quality was good. Finished and distributed water was negative for total coliform. HPC values varied somewhat with one episode exceeding 500 cfu/mL. The variability could have been the result of biofilm in the plumbing leading to one of the cabins. The cabin had not been occupied for days prior to sampling, thus resulting in old stagnant water in the plumbing system's service lines.

Ozonation byproducts for the treated water were analyzed during this brief study and indicated lower levels of all but one of the DBPs found in the raw water. This could have been the result of the overall good quality of the raw water and lack of ozone-demanding compounds, allowing reduction of the by-products already formed in the raw water.

Low-humidity oxygen is required to produce ozone. This POE unit used silica gel to remove moisture from the air in the cellar rather than install an expensive oxygen generator. Operational concerns centered on the frequency of reconditioning the air-drying material. Because of the high humidity in the cellar of the Lodge, the silica gel had to be reconditioned every few days. Although not expensive or time consuming (30 minutes in an oven at 325°C), constant attention to this might not be maintained in a household and hence affect ozone generation and disinfection efficiency. *[26]*

Figure 7-2. AOP POE unit installed in a cellar.

8.0 Remote Monitoring/Control

Many alternative treatment systems/technologies can be equipped with up-to-date and modern sensor and operating devices that can be monitored from remote locations. This fact led EPA to consider remote monitoring and control technology to improve monitoring/reporting and reduce operation and maintenance (O&M) costs. Although such telemetry equipment could double the purchase cost of a package plant, payback can be quickly realized through reduced chemical use, low residue generation (disposal), and increased reliability. Also, the cost of subsequently networking multiple package plant sites or water quality monitoring devices also decreases after the initial cost for the telemetry equipment. It has been demonstrated that various technologies are being appropriately designed for small systems. 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. This section will discuss the "lessons learned" in the use of remote monitoring and control for treatment systems.

Small systems did not always use Remote Telemetry Systems (RTS - a.k.a. Supervisory Control and Data Acquisition [SCADA]) to their fullest potential due to complex operating systems and controls that usually required specially trained computer programmers or technicians and costly service agreements. In the last few years, RTS vendors have changed the way they design and fabricate their systems, thus making them more accessible to small drinking water treatment operators.

The application of RTS to operate, monitor, and control small systems from a central location (an electronic "circuit rider") is believed to be one mechanism that can reduce both MCL and M/R violations.

Through the application of RTS, the EPA has demonstrated that filters can 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 resupply scheduled more efficiently. Small independent systems can 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 telemetry or hire an O&M services provider, while maintaining ownership. This type of approach would provide the small system with the economies-of-scale medium and larger systems have in purchasing supplies, equipment, and power, while also possibly receiving a better trained operator.

The following factors must be considered before purchasing a RTS:

- Does the water treatment system justify the requirement for a remote RTS 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 8-1
- How much automation and control is available on the treatment system?
- What type of RTS system is needed? Is the goal to monitor, control, or both?
- How many parameters are going to be monitored and/or controlled?
- Are there any specific regulatory monitoring and reporting requirements? *[32]*

EPA has been evaluating a variety of "small" RTSs that allow a single qualified/certified operator to monitor and control the operation of several small treatment systems from a central location. Using RTS 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 RTS are *[31]*:

- enhanced water quality,
- regulatory compliance, and
- reduced cost for small communities

RTS Selection and Implementation

It is important to understand the treatment system operation, location, and other environmental factors when engineering and designing a RTS for remote operation and maintenance.

The above factors will determine the need and the basic design of the RTS system. These factors will also help to determine if the system will complement the needs of the treatment system and the utility services. The cost of retrofitting a treatment system for remote operations can be prohibitive. Many small

Table 8-1. Amenability of RTS to Treatment Technologies Used for Small Water Systems [32]

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
lectrodialysis 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.

treatment systems currently in use were not originally designed for remote operations. Rural areas have little or no electronic hardware to communicate with a telemetry system. Thus, the cost of upgrading a treatment system for remote operations can be significant. It is essential that the treatment system be fairly amenable to automation. Table 8-1 identifies the current amenability of small package plant treatment technologies to remote telemetry.

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 monitor to assure the quality of the treatment processes. Constant remote monitoring of the water quality has provided substantial savings in time and travel cost 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, due to concerns of assuring the best water quality to the consumer, many state regulators resist accepting the remote monitoring guidelines. Table 8-2 presents a range of costs for RTS system components.

Long-term real-time remote monitoring can provide data that can be used to significantly enhance treatment system operation and reduce system downtime. The overall benefits include:

- Improved customer satisfaction, improved consumer relations and, other health benefits.
- Satisfies regulatory recordkeeping and reporting requirements.
- Reduces 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).
- Troubleshooting can be performed remotely, reducing downtime and increasing repair efficiency.
- Fully automated treatment systems can identify monitored parameter trends and adjust operating parameters accordingly.
- Provides an attractive alternative to fixed sampling and operation and maintenance schedules.

A real world example of a small system equipped with remote monitoring and control is included in Section 9.0 of this document.

Table 8-2. Cost Estimates of SCADA System Components [32]

SCADA System Component	Component Option	Range of Costs
Hardware	Main Computer SCADA Unit	$1,000 - 3,500 500 - 30,000
Software	Operating System Telemetry System Data Collection & Loggers	$250 - 750[a] 500 - 30,000[b] 250 - 8,000
Communication Medium	Telephone Cellular Radio Satellite	$75 - 125[c] 250 - 500[d] 1,500 - 3,500[e] 20,000 - 75,000[f]
Instrumentation	Valves Switch Sensor	$25 - 1,500[g] 25 - 300[g] 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]Transmission cost of Integrated phone, cellular, radio frequency, and satellite system.
[f]Satellite systems cost for transmissions, monthly service and activation charges are estimated
[g]Cost per valve and/or switch.
[h]Cost per individual sensor or sensor system.

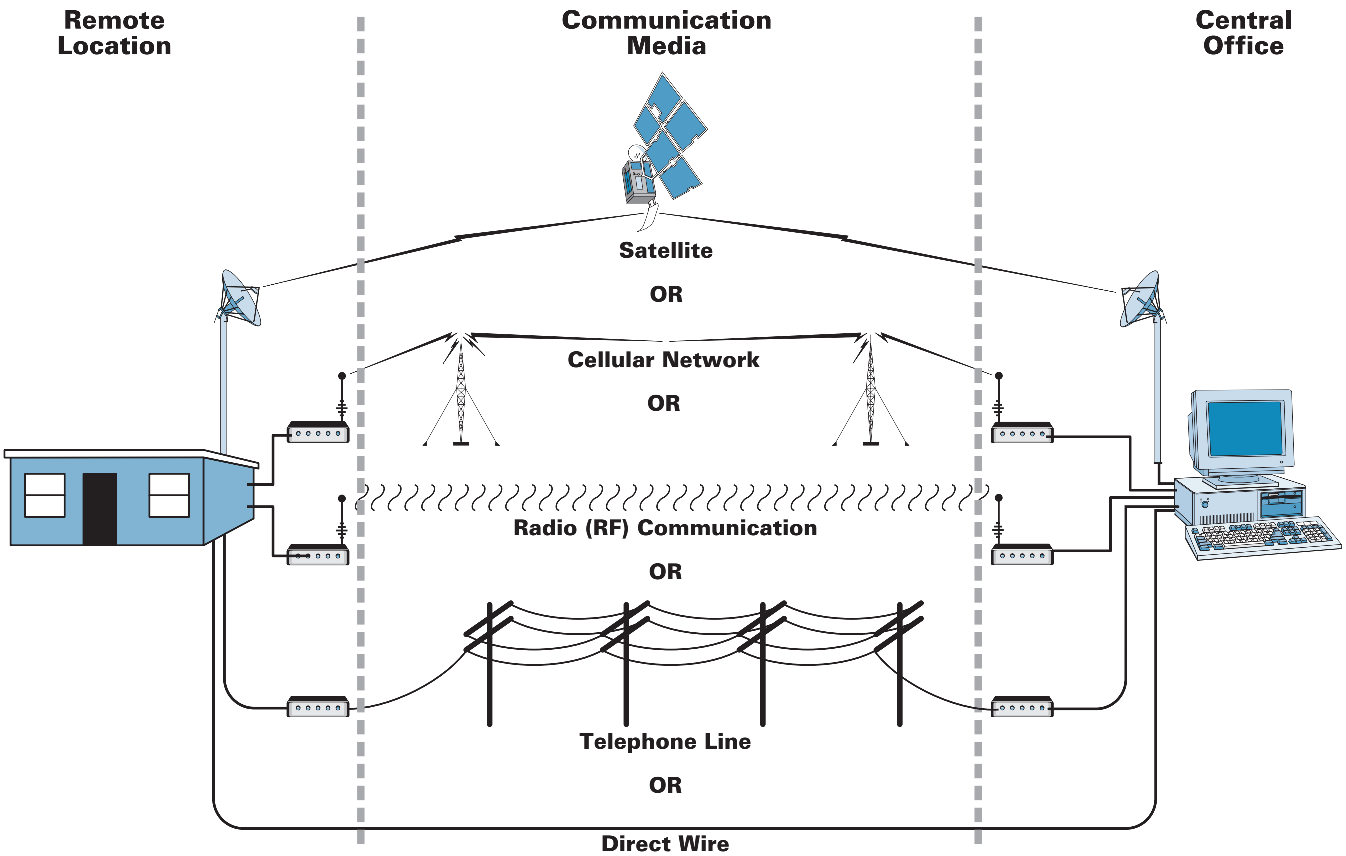


Figure 8-1. Possible layout(s) of a Remote Telemetry System.

9.0 A Real World Packaged Solution

In May 1991, EPA provided funding to support a research project titled "Alternative Low Maintenance Technologies for Small Water Systems in Rural Communities." 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 research was to evaluate the cost-effectiveness of membrane package plant technology in removing microbiological contaminants. The secondary objective of this project was to automate the system and minimize O&M costs.

The EPA test site is located in rural McDowell County, West Virginia. The treatment system is located approximately 12 miles from the McDowell County Public Services Division (MCPSD) office through Appalachian Mountain terrain. Figure 9-1 shows the town MCPSD services. The water source is an abandoned coal mine. The raw water quality parameters are shown in Table 9-1. Prior to 1994, an aerator combined with a slow sand filter was used to treat water at this site (see Figure 9-2). This combined unit had been operational for over 60 years and needed substantial repairs. Water flowed by gravity from the abandoned coal mine to the aeration trays built over a six-foot diameter slow sand filter. A hypochlorinator disinfected the filtered water, which then flowed by gravity through the distribution system to the consumer. The volume of water from the mine was sufficient for the small rural community of approximately 100 people.

Figure 9-1. McDowell County.

The system had several problems. The filtration was not very effective, and the operator used excess chlorine for disinfection. The water quality tests indicated that the residual chlorine content was greater than 4.0 mg/l as received by the consumer. Consumers were being charged $20 per month for water that distinctly tasted and smelled like chlorine.

Table 9-1. Raw Water Quality and Contaminant Specifications

Total Coliform	1,150 CFU/100
Fecal Coliform	650 CFU/100
Hetrotrophic Plate Count (PCA)	900 CFU/mL
Hetrotrophic Plate Count (R2A)	37,000 CFU/mL
Fecal Streptococci	520 CFU/mL
Escherichia coli	100 CFU/ml
TOX	8.2 ug/L
Total Hardness ($CaCO_3$)	180 mg/L
Specific Conductivity (micromhos)	350 micromhos
Ca	60 mg/L
Mg	9 mg/L
Na	4 mg/L
SO_4	12 mg/L
NO_3	1 mg/L

An engineering study conducted by MCPSD estimated the cost of a new conventional water treatment system (to replace the existing treatment system and distribution system) to be $328,000, resulting in a cost of $10,933 per customer. Consumers considered this an impractical and unacceptable solution. It was essential that the replacement technology operate in a rugged environment with minimal maintenance. Also, the treated water quality characteristics were

Figure 9-2. Old treatment system.

required to be consistent with the SWTR and the Total Coliform Rule as described below *[11]*:

- No more than one sample per month may be total coliform positive,
- HPC must be < 500 mL if the chlorine residual value is < 0.2 mg/L
- Turbidity of the treated water must at all times be <5NTU and normally can not be >0.5NTU

Thus, the EPA and MCPSD investigated various alternative economically feasible technologies. Based on a review of available technologies, the EPA determined that a packaged UF system would be ideally suited for this location. In 1992, a packaged UF water treatment system was purchased and installed at this site.

Test Site Treatment Technology Overview—Packaged UF System

The packaged UF system has an overall dimension of 12'10"L x 7'H x 3'W with an approximate empty weight of 800 pounds (see Figure 9-3). The picture shows the front view of the system as purchased and installed in 1992. The main system components of the UF system are as follows:

- Three 8" x 40" spiral-wound UF membrane cartridge elements arranged in series and contained in a fiberglass vessel. The UF elements are polymeric spiral-wound type with a nominal MWCO of 10,000.
- The package UF system includes a control panel, feed pumps, recirculation pumps, 10–25-micron bag pre-filter, 30 gallon cleaning tank, a chlorine monitor, electrically actuated control valves, temperature and pressure gauges, and sight rotometers
- The unit is interconnected with Schedule 80 polyvinyl chloride (PVC) piping. The UF system is designed to produce 10,000 gallons per day (GPD) treated drinking water.

The packaged UF system was installed on a new cement slab and the community constructed a 12' by 24' cinder block building to secure and protect the UF system (see Figure 9-4).

Overview of Remote Monitoring and Control Technology Installed at the Test Site

The packaged UF system as initially installed used a manufacturer provided programmable logic controller (PLC), along with PLC controllable hardware for automation. The UF system also included several instruments and sensors, such as an online pH sensor, online chlorine sensor, pressure gauges, etc. The UF

Figure 9-3. Packaged UF System.

Figure 9-4. New cinder block building.

system operating and water quality parameters were manually logged and recorded from the instrument's analog/digital displays. In 1996, the EPA developed, installed, and tested a RTS at the site. The RTS used commercially available hardware. The RTS software was a MSDOS-based system that was hardware specific, not very user-friendly, and the overall cost of ownership was not practical. Thus, the system operated with proprietary, EPA-developed software.

In 1998, the EPA updated the RTS unit with a commercially available, off-the-shelf, user-friendly, Microsoft® Windows®-based RTS. Figures 9-5 and 9-6 present two operator computer screen shots. The RTS selected was fairly inexpensive, smart, user-friendly and scaleable. The capital cost for the hardware and instrumentation was approximately $12,000, and the total cost (including technical support, training, and set-up) was about $33,000. The EPA worked with MCPSD to remotely monitor the UF system for water quality. The RTS is also being evaluated for its effectiveness in fulfilling the regulatory monitoring and reporting requirements, and its effectiveness in reducing the manpower

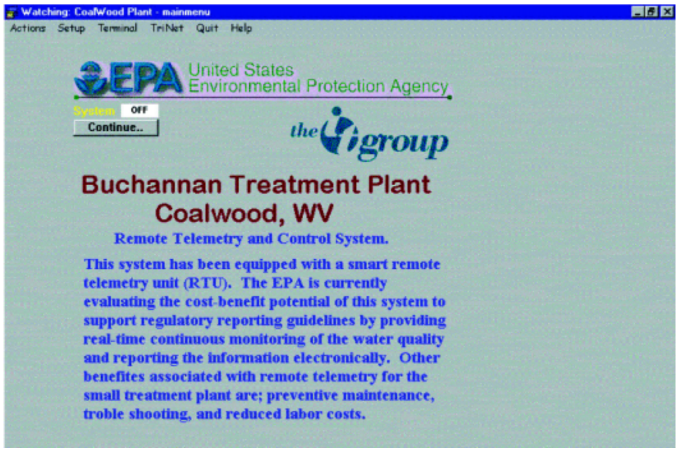


Figure 9-5. Welcome screen.

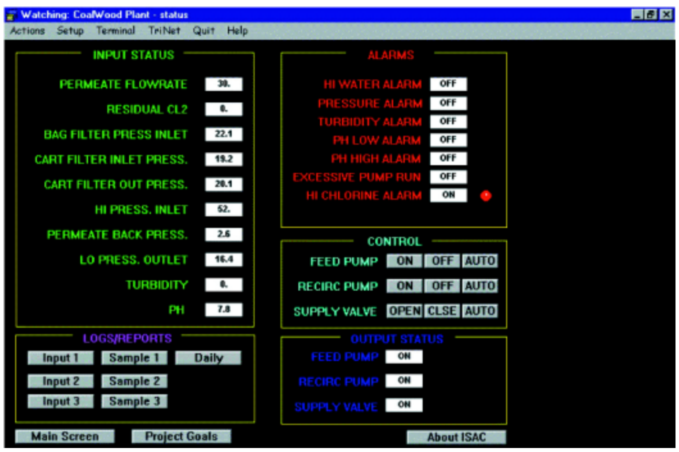


Figure 9-6. System summary (note the high chlorine alarm).

requirements during the operation and maintenance of the UF system.

This RTS can be remotely programmed to optimize treatment system operation based on observed trends. For example, if the monitored trends indicate that during a certain period the storage tank water levels are lower than normally observed during that time, the system can be programmed to automatically increase the water supply to the storage tank. This type of trend-based adjustment can potentially eliminate water supply disruptions. This ability of the RTS unit to adjust treatment and distribution system operating parameters without operator intervention makes the system "smart." This system can also be programmed to dial-out and page the operator during "alarm" conditions. The existing package plant was upgraded and modified as necessary to accommodate RTS functionality. MCPSD currently operates and maintains this system. The RTS has operated trouble free since installation. Based on the initial success, EPA has recently installed similar units at two other locations within McDowell County.

The remote monitoring and control system proved to be a useful tool for troubleshooting. Specifically, MCPSD was able to monitor and download activity logs of the system and monitor system performance over time. This enabled MCPSD personnel to schedule maintenance activities based on observed pressure data. The system also helped MCPSD to monitor the system operation remotely during inclement weather conditions.

10.0 Funding and Technical Resources

Most federally funded water projects are financed by the EPA's Drinking Water State Revolving Fund (DWSRF) and/or the U.S. Department of Agriculture's Rural Utilities Service (RUS) *[33]*. There are also various foundations, bank programs, state programs, other federal programs, and professional organizations that provide grant and loan assistance. This section briefly describes each of these resources.

Capacity development refers to the technical, financial, and managerial capability needed to consistently achieve the public health protection objectives of the Safe Drinking Water Act (SDWA). A key component of the 1996 SDWA Amendments, capacity development ties into the Drinking Water State Revolving Fund (DWSRF) in two important ways. First, states may set aside funds from their DWSRF allotments to develop and implement capacity development programs. Second, the EPA is required to withhold DWSRF funds from states that fail to implement capacity development provisions.

EPA Drinking Water State Revolving Fund (DWSRF)

EPA is aware that the Nation's water systems must make significant investments to install, upgrade, or replace infrastructure to continue providing safe drinking water to their 250 million customers. Installing new treatment facilities can improve the quality of drinking water and better protect public health. Improvements are also needed to help those water systems experiencing a threat of contamination due to aging infrastructure systems. In order to improve small drinking water systems and further the health protection objectives of the SDWA amendments, EPA entered into agreements with "eligible" states to make capitalization grants available through the state programs. The 1996 SDWA Amendments established the DWSRF to make funds available to PWSs to finance infrastructure improvements. The program also emphasizes providing funds to small and disadvantaged communities and to programs that encourage pollution prevention as a tool for ensuring safe drinking water. Section 11.0 of this document identifies the various state agencies and their web locations.

To Find Out More About DWSRF:
www.epa.gov/safewater/dwsrf.html

The DWSRF program required that States develop a priority system for funding infrastructure projects based on three criteria established by the SDWA Amendments. States are also required to solicit and consider public comment when developing their priority systems. Projects are ranked and funding is offered to the highest ranked projects that are ready to proceed. Priority goes to those eligible projects that:

- address the most serious risk to human health;
- are necessary to ensure compliance with the requirements of the SDWA Amendments; and,
- assist systems most in need, on a per household basis, according to State-determined affordability criteria.

In order to qualify for DWSRF funds, states must have an EPA-approved capacity development program and an operator certification program. Funds can be used for loans, loan guarantees, and as a source of reserve and security for other (leveraged) funds. States must also contribute an amount equal to 20% of the total federal contribution. As loans are paid back, the State can re-loan the money to other systems, thus the term "revolving" in DWSRF. Any system that gets a loan must demonstrate that it has the technical, financial, and managerial capacity ("capacity development program") to operate its system for the long-term.

Since 1997, Congress has authorized $9.6 billion for the 50 states and Puerto Rico. Currently, the individual State grants range from $7 million to $80 million per year. Loans can have interest rates

Eligible project categories for DWSRF include:

Treatment – Projects designed to maintain compliance with regulations for contaminants causing health problems.
Transmission and Distribution – Projects related to installing or replacing pipes.
Source – Projects that rehabilitate wells or develop new water sources to replace contaminated sources.
Consolidation – Projects that combine sources or systems if one is unable to maintain technical, financial, or managerial capability.
Creation of New Systems – Projects that establish new systems or projects involving consolidation of multiple systems that have severe problems.

For a state to be "eligible" for DWSRF, it needs to have an EPA-approved operator certification program. Each state has different needs and so programs vary state-to-state. Training and certification program ensures drinking water operator competency, and therefore protects public health. In almost all states, some training is provided by the Rural Water Association and/or the local chapter of AWWA. These classes are generally free or very low cost. But, sometimes small systems simply can't provide the money to cover an operator's travel or lodging costs, even if the tuition is free. EPA has initiated a grant program that will make money available to cover certain training and certification expenses.

As required by SDWA, EPA must reimburse the costs of training for people operating community and nontransient noncommunity public water systems serving 3,300 persons or fewer that are required to undergo training. The reimbursement is to be provided through grants to states. EPA will determine the total amount that each state is to receive to cover the reasonable costs for training and certification for all such operators.

Funding assumptions include money to cover a per diem for unsalaried operators, tuition costs for training classes, fees for initial certification renewal, and mileage. States may apply for and receive the expense reimbursement grant funds once their operator certification program has received EPA approval to apply for and receive its expense reimbursement grant. As part of the grant application, states must submit a work plan and annual progress report outlining how these funds are to be used.

Several financing options are available for communities that seek DWSRF funding, including:
Low-Interest Loans—Loan rates range between zero percent and the current market rate, with a 20-year repayment period.
Refinance or Purchase Local Debt—Helps to reduce a community's cost of borrowing.
Purchase Insurance or Guaranteed Local Debt—Can improve credit market access or reduce interest rates.
Leverage Program Assets—Through issuing bonds to increase the amount of funds available for projects.
Disadvantaged Assistance—Provides help by taking an amount equal to 30 percent of a capitalization grant for loan subsidies or extending the repayment period from 20 to up to 30 years.

between 0% and the market rate. Special help is available for disadvantaged communities. DWSRF guidelines require that at least 15% of the loan fund be used for small PWSs.

U.S. Department of Agriculture Rural Utilities Service (RUS) Loan and Grant Program

The RUS and its predecessor, the Farmers Home Administration, have provided more than $25 billion in loans and grants since 1940. RUS has often been described as the "funder-of-last-resort" for communities that have nowhere else to turn. *[29]* The RUS provides both loans and grants to rural communities for drinking water, wastewater, solid waste, and storm water drainage projects. These are administered locally by state and district Rural Development offices. RUS loans are designed especially for communities unable to obtain money from other sources at reasonable rates and terms. Funds may be used to install, repair, improve, or expand rural water facilities. Expenses for construction, land acquisition, legal fees, engineering fees, interest, and project contingencies can also be covered. The RUS interest rates are set at three levels: the poverty line rate, the intermediate rate, and the market rate, each of which has specific qualification criteria.

State Rural Development offices can provide specific information concerning RUS loan requirements and application procedures. For the phone number of your state Rural Development office, contact the National Drinking Water Clearinghouse at (800) 624-8301 or (304) 293-4191.

The current interest rates (for the second quarter of year 2001 that apply to all loans issued from April 1 through June 30, 2001) are:
poverty line: 4.5 percent (unchanged from the previous quarter);
intermediate: 4.75 percent (down 0.25 percent from the previous quarter); and
market: 5.125 percent (down 0.375 percent from the previous quarter).

Other Financial Assistance

To Find Out More About RUS:
www.usda.gov/rus/water/states/usamap.htm

Programs

The following types of funding tools can also be used to buy equipment. Each offers advantages and disadvantages not only in eligibility and terms, but also in the amount of time and information needed to fill out the application forms.

Loan Programs

Commercial loans are available from banks or other financial institutions and the application process can be relatively quick, but the interest rates are generally higher with less favorable pay-back rules. State programs generally offer better rates and terms for those systems that are ineligible for conventional types of financing.

Grant Programs *[34]*

Grants, which are awarded to a state or local government or nonprofit organization, are sums of money that do not have to be paid pack. They can be awarded by the federal government (e.g., Community Development Block Grants) to state or local governments or by states to local governments. Applying for grants, however, can require a significant commitment of time by utility personnel. In addition, the availability and timing of the grant award may not match the utilities' needs. Most grant programs possess limited funds, and competition for these funds may forestall funding for many projects. Grants also have project eligibility requirements, and some programs may specify that the grantee provide a share of the total project funds.

CoBank, a federally charted financial institution owned and patronized by about 2,400 agricultural cooperatives and rural utilities, provides one popular type of loan program. As customers, these cooperatives and utilities provide capital to the bank by securing equity based on money borrowed. Long-term and interim loans are available for construction and equipment financing if applicants meet the eligibility requirements. PWSs serving a population of fewer than 20,000 that can show an acceptable credit risk are generally eligible.

[34]

To Find Out More About CoBank:
www.cobank.com

The Department of Housing and Urban Development (HUD) provides grants to drinking water utilities through the Community Development Block Grant (CDBG) program. Applications must be filed through the appropriate state government office; states have the authority to administer the distribution of the HUD funds. Grants are targeted to PWSs serving low- and moderate-income households, and drinking water treatment systems are among the types of projects eligible for assistance. On average, the grants cover 50 percent of project costs, although areas experiencing severe economic distress are eligible for grants that cover up to 80% of project costs.

The Department of Commerce provides grants through the Economic Development Administration's Public Works and Development Program. Applications must be submitted to the state economic development agency; states are authorized to administer the funds. The drinking water project must be located in a community or county determined to be economically distressed, and the project must be directly related to future economic development. Some restrictions apply when grants are provided in conjunction with other financial assistance. The combined funding is limited to 80 percent of the total project cost.

Qualifying applicants in designated Appalachian Regions in 13 states can also apply to the Appalachian Regional Commission (ARC) for grants in conjunction with the Tennessee Valley Authority. Local development districts provide assistance in preparing an applicant's proposal. Priority funding is determined each year by the state governors, Appalachian district personnel, and ARC members. All projects that qualify for grant funding must be directly related to economic development, housing development, or downtown revitalization and improvement. Drinking water treatment systems are among the types of projects eligible for assistance.

One restriction of ARC grants is that they are limited to 50% of project costs and require the recipients to provide the other 50%. An exception is made for economically distressed counties, which can receive 80% and must supply only 20%. In 1992, 90 counties out of 398 in the Appalachian region fit within this "distressed" category. However, to raise the remaining 20% of funds, owners of small systems in distressed counties should aggressively seek other innovative sources of funding.

The Indian Health Service (IHS), which is part of the Department of Health and Human Services, provides grants for projects undertaken by American Indians and Alaska Natives. In 1959, Congress passed the Indian Sanitation Facilities Act to provide improved health conditions by improving sanitation, sewer, solid waste, and drinking water facilities. To date, more than $1 billion has been spent on the effort, and more than 182,000 homes have received water, sewer, and solid waste services for the first time. IHS grants support health aspects rather than economic development or environmental preservation and do not include funding for operation and maintenance. No matching funds are necessary, and IHS grants can be consolidated with those from other agencies.

No-interest loans

In 1989, the Rural Electrification Administration (REA) implemented a program to promote projects that "will result in a sustainable increase in the productivity of economic resources in rural areas and thereby lead to higher levels of income for rural citizens." This program is the Rural Economic Development and Grant Program. The program makes no-interest loans available for up to 10 years and grants of as much as $100,000. The local REAs act as sponsors for the actual project owners. Drinking water projects are eligible for these no-interest loans.

Table 10-1 provides a summary of these funding sources. Technical and administrative assistance for applying for these funds can be obtained from various agencies identified in Table 10-2.

Foundations

Private foundations are another possible source of funding for small PWSs. A source of information about foundations that provide grants, The Foundation Directory, provides basic descriptions of foundations that have $1 million or more in assets or that annually award $100,000 or more. Information about smaller foundations can be obtained from the local Internal Revenue Service (IRS) office. The IRS annually collects Form 990-PF (Return on Private Foundations) from foundations of all sizes, and it compiles information about the foundations' interests, restrictions, application procedures, and deadlines.

Information about foundations can also be obtained from Source Book Profiles published by The Foundation Center, which contains information about the thousand largest foundations. Also, the Cooperative Assistance Fund represents foundations that pool their funds to make program-related investments primarily for low-income urban and rural communities. Table 10-3 lists a number of private foundations providing backing to rural economic development programs.

Table 10-1. Federal Funding Programs for Small Public Water Systems

Contact	Telephone
Appalachian Regional Commission (ARC)	(202) 884-7799
Department of Housing and Urban Development (HUD) Community Development Block Grants	(202) 708-2690
Economic Development Administration (EDA)	(202) 482-5081
Indian Health Service (IHS)	(301) 443-1083

Table 10-2. Technical and Administrative Support for Small Public Water Systems

Contact	Telephone
American Water Works Association	(303) 794-7711 ext. 6191
National Rural Water Association	(580) 252-0629
Rural Community Assistance Program	(202) 408-1273
Rural Electrification Administration (private; provides some financial funding)	(202) 720-9540
Rural Information Center	(800) 633-7701
National Drinking Water Clearinghouse	(800) 624-8301

Technical Resources - Environmental Technology Verification (ETV), Drinking Water Systems Center

ETV Program Overview

Historically, the EPA has evaluated technologies to determine their effectiveness in preventing, controlling, and cleaning up pollution. To accelerate the use of environmentally beneficial technologies, the EPA established the Environmental Technology Verification (ETV) program to collect and disseminate quality-assured data on the performance and operation and maintenance issues of specific-model commercial-ready environmental technologies.

Important Principles

The ETV program does not certify product conformance to a standard. There are no pass/fail criteria associated with the ETV process. The ETV program offers an opportunity for characterizing product performance under a predetermined set of test conditions. The ETV program offers flexibility to participating manufacturers and vendors for technology evaluations as either short pre-screening studies on narrowly defined water quality and operating conditions or more comprehensive verification evaluations over multiple seasons of testing and/or multiple testing locations under varying conditions.

ETV testing results become public information. Manufacturers involved in a product evaluation

Table 10-3. Foundation Backing Rural Economic Development Program

Foundation	Telephone	Support Available
Mary Reynolds Babcock Foundation	(336) 748-9222	Grants include operating support for smaller organizations for rural grassroots groups, primarily in North Carolina and the Southeast.
Otto Bremer Foundation	(888) 291-1123 or (651) 227-8036	Grants include some operating support for rural poverty programs and support to strengthen the rural economy of Minnesota, North Dakota, and northwestern Wisconsin.
Ford Foundation	(212) 573-5000	Grants for experimental programs about rural poverty that can inform public opinion
W.K. Kellogg Foundation	(616) 968-1611	Grants for collaborative rural delivery of human services, rural leadership development, and training local government officials
Charles Stewart Mott Foundation	(810) 238-5652	Grants for startup capital and capacity building to create economic opportunities for low-income people
Northwest Area Foundation	(651) 224-9635	Grants for rural development in Idaho, Iowa, Minnesota, Montana, North Dakota, South Dakota, Washington, and Oregon

receive an ETV Verification Report and Verification Statement (a 5- to 6-page summary document) that describes their product and its performance results based on the specified evaluation conditions.

Participation in the ETV program by manufacturers is voluntary. However, ETV reports can be valuable tools for vendors through dissemination of their equipment's performance results, and support toward achieving regulatory and market place acceptance.

Drinking Water Systems Center

On October 1, 2000, the EPA entered a joint venture with NSF International to form the ETV Drinking Water Systems (DWS) Center to provide independent performance evaluations of treatment technologies with the goal of raising awareness for new product applications. The DWS Center efforts include evaluation of a wide range of treatment products from complete package systems to individual treatment modules or components. Direction and prioritization of ETV activities are provided by a stakeholder input/feedback process. DWS Center stakeholders include representatives from State and Federal regulatory agencies, manufacturer-vendor groups, water utility and technology-user organizations, and the scientific-engineering-technology community.

Test Plans and Protocols

The DWS Center has nine contaminant-specific verification testing protocols and 23 technology-specific test plans that outline testing procedure requirements that must be followed in the specific product evaluations. The contaminant-specific protocols cover technologies that inactivate or physically remove microbiological contaminants; particulate material; reduce precursors to disinfection by-products; reduce arsenic, nitrate, organic, and inorganic chemicals; and radionuclides. The test plans and protocols may be used by utilities, state drinking water agencies, and others interested in evaluating technologies. If the testing is coordinated with NSF and its partners, the EPA and independent ETV-qualified field testing organizations, the manufacturer will receive ETV report documents presenting the testing results.

ETV Outputs

The ETV DWS Center has conducted equipment evaluations involving several types of technologies:

- UV and ozone inactivation of microbiological contaminants
- Microfiltration and ultrafiltration membranes for microbial control
- Coagulation/filtration package systems for arsenic and microbials
- Nanofiltration membranes for DBP control
- Reverse osmosis for arsenic removal
- On-site sodium hypochlorite generation for disinfection
- Bag and cartridge filters for microbial control
- Diatomaceous earth filter systems for microbial control

Information about ETV activities, copies of ETV reports, test plan/protocol documents, and mailing lists may be obtained at the ETV web site, www.epa.gov/etv/.

11.0 Additional Information Sources

For more information about small PWSs, funding resources, agency contacts, and other water system related topics mentioned in this document, please contact the following agencies or groups for assistance:

Federal resources

Resource	Contact
Occupational Safety & Health Administration	Web Link: www.osha.gov
U.S. Army Corps of Engineers	Phone: (202) 761-0008 441 G. Street, NW Washington, DC 20314 Web Link: www.usace.army.mil
U.S. Geological Survey	Phone: (888) 275-8747 Web Link: www.usgs.gov
U.S. Dept. of Agriculture Rural Utilities Service	Phone: (202) 720-9583 1400 Independence Ave, SW Washington, DC 20250 Web Link: www.rurdev.usda.gov/rus/index.html
U.S. Environmental Protection Agency (EPA)	Web Link: www.epa.gov
U.S. EPA Office of Groundwater and Drinking Water	Phone: (202) 260-5543 Ariel Rios Building 1200 Pennsylvania Avenue, NW Washington, DC 20460 Web Link: www.epa.gov/OGWDW/
U.S. EPA Office of Research and Development	Web Link: www.epa.gov/ORD/
U.S. EPA OGWDW - Public Drinking Water Systems	Web Link: www.epa.gov/safewater/pws/pwss.html
U.S. EPA OGWDW - Small Systems	Web Link: www.epa.gov/safewater/smallsys.html
U.S. EPA Region 1 (includes: Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont)	Phone: (888) 372-7341 (617) 918-11111 Congress St., Suite 1100 Boston, MA 02114 Web Link: www.epa.gov/region01/
U.S. EPA Region 2 (includes: New Jersey, New York, Puerto Rico, Virgin Islands)	Phone: (212) 637-3000 290 Broadway New York, NY 10007 Web Link: www.epa.gov/region02/
U.S. EPA Region 3 (includes: Delaware, Maryland, Pennsylvania, Virginia, West Virginia, Washington DC)	Phone: (215) 814-5000 1650 Arch Street Philadelphia, PA 19103 Web Link: www.epa.gov/region03/
U.S. EPA Region 4 (includes: Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee)	Phone: (404) 562-9900 61 Forsyth Street, SW Atlanta, GA 30303 Web Link: www.epa.gov/region04/
U.S. EPA Region 5 (includes: Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin)	Phone: (312) 353-2000 77 West Jackson Blvd. Chicago, IL 60604 Web Link: www.epa.gov/region05/
U.S. EPA Region 6 (includes: Arkansas, Louisiana, New Mexico, Oklahoma, Texas)	Phone: (214) 665-6444 Fountain Place 12th Floor, Suite 1200 1445 Ross Avenue Dallas, TX 75202 Web Link: www.epa.gov/region06/
U.S. EPA Region 7 (includes: Iowa, Kansas, Missouri, Nebraska)	Phone: (913) 551-7000 726 Minnesota Avenue Kansas City, KS 66101 Web Link: www.epa.gov/region07/

Resource	Contact
U.S. EPA Region 8 (includes: Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming)	Phone: (303) 312-6312 999-18th St., Suite 300 Denver, CO 80202 Web Link: www.epa.gov/region08/
U.S. EPA Region 9 (includes: Arizona, California, Hawaii, Nevada and Pacific Islands & Tribal Nations subject to U.S. law)	Phone: (415)744-1500 75 Hawthorne San Francisco, CA 94105 Web Link: www.epa.gov/region09/
U.S. EPA Region 10 (includes: Alaska, Idaho, Oregon, Washington)	Phone: (206) 553-1200 1200 6th Avenue Seattle, WA 98101 Web Link: www.epa.gov/region10/

State resources

Resource	Contact
Alabama Water Supply Branch Dept. of Environmental Management	Phone: (334) 271-7773 P.O. Box 301463 1400 Coliseum Blvd. Montgomery, AL 36130-1463 Web Link: www.adem.state.al.us/EnviroProtect/Water/water.htm
Alaska Drinking Water and Wastewater Program Dept. of Environmental Conservation Div. of Environmental Health	Phone: (907) 269-7500 555 Cordova St. Anchorage, AK 99501 Web Link: www.state.ak.us/dec/deh/safewater.htm
American Samoa American Samoa Environmental Protection Agency	Phone: (684) 633-2304 Office of the Governor Pago Pago, AS 96799 Web Link: www.epa.gov/region09/cross_pr/islands/samoa.html
Arizona Drinking Water Monitoring and Assessment Section Water Quality Division Dept. of Environmental Quality	Phone: (602) 207-4644 Room 200 3033 N. Central Ave. Phoenix, AZ 85012-2809 Web Link: www.adeq.state.az.us/environ/water/dw/index.html
Arkansas Div. of Engineering Dept. of Health	Phone: (501) 661-2623 4815 W. Markham St. Mail Slot 37 Little Rock, AR 72205-3867 Web Link: www.healthyarkansas.com/eng/index.html
California Dept. of Health Services Div. of Drinking Water and Environmental Management	Phone: (916)323-6111 Web Link: www.dhs.cahwnet.gov/ps/ddwem/index.htm
Colorado Drinking Water Program Dept. of Public Health & Environment WQCD-DW-B2	Phone: (303) 692-3500 4300 Cherry Creek Dr. S. Denver, CO 80246-1530 Web Link: www.cdphe.state.co.us/wq/wqhom.asp
Connecticut Water Supplies Section Dept. of Public Health MS-51WAT	Phone: (860) 509-7333 P.O. Box 340308 Hartford, CT 06134-0308 Web Link: www.state.ct.us/dph/BRS/WSS/water_supplies.htm
Delaware Div. of Public Health Delaware Health & Social Services	Phone: (302) 739-5410 Blue Hen Corporate Center 655 Bay Rd.Dover, DE 19901 Web Link: www.state.de.us/dhss/dph/index.htm
Florida Drinking Water Section Dept. of Environmental Protection	Phone: (850) 487-1762 Twin Towers Office Building 2600 Blair Stone Rd.Tallahassee, FL 32399-2400 Web Link: www.dep.state.fl.us/water/default.htm
Georgia Water Resources Branch Environmental Protection Div. Dept. of National Resources	Phone: (404) 656-5660 Floyd Towers E, Rm. 1362 205 Butler St., SE Atlanta, GA 30334 Web Link: www.georgianet.org/dnr/environ

Resource	Contact
Guam Guam Environmental Protection Agency	Phone: (671) 475-1658 Government of Guam P.O. Box 22439 GMF Barrigada, GU 96921 Web Link: www.admin.gov.gu/doa/GOVGUAMID/GEPA-ID_1.html
Hawaii Environmental Management Div. Hawaii Dept. of Health	Phone: (808) 586-4258 P.O. Box 3378 Honolulu, HI 96801 Web Link: www.hawaii.gov/health/eh/sdwb/
Idaho Div. of Environmental Quality	Phone: (208) 373-0502 1410 N. Hilton Boise, ID 83706 Web Link: www2.state.id.us/deq//water/water1.htm
Illinois Div. of Public Water Supplies Illinois Environmental Protection Agency	Phone: (217) 785-8653 P.O. Box 19276 Springfield, IL 62794-9276 Web Link: www.epa.state.il.us
Indiana Drinking Water Branch Office of Water Quality Dept. of Environmental Management	Phone: (317) 308-3281 P.O. Box 6015 Indianapolis, IN 46206-6015 Web Link: www.state.in.us/idem/owm/dwb/index.html
Iowa Water Quality Bureau Iowa Dept. of Natural Resources	Phone: (515) 725-0275 401 SW 7th St., Suite "M" 900 E. Grant St. Des Moines, IA 50309 Web Link: www.state.ia.us/government/dnr/organiza/epd/wtrsuply/wtrsup.htm
Kansas Public Water Supply Section Bureau of Water Kansas Dept. of Health & Environment	Phone: (785) 296-5514 1000 SW Jackson, Suite 420 Topeka, KS 66620 Web Link: www.kdhe.state.ks.us/water/pwss.html
Kentucky Drinking Water Branch Div. of Water Dept. for Environmental Protection	Phone: (502) 564-3410 14 Reilly Rd. Frankfort Office Park Frankfort, KY 40601 Web Link: http://water.nr.state.ky.us/dw/
Louisiana Div. of Environmental Health Services Louisiana Dept. of Health & Hospitals Office of Public Health	Phone: (225) 765-5038 6867 Blue Bonnet Blvd. Baton Rouge, LA 70810 Web Link: www.dhh.state.la.us/OPH/safewtr.htm
Maine Div. of Health Engineering Maine Dept. of Human Services	Phone: (207) 287-2070 101 State House Station Augusta, ME 04333 Web Link: http://janus.state.me.us/dhs/eng/water/index.htm
Maryland Public Drinking Water Program Dept. of the Environment	Phone: (410) 631-3702 Point Breeze Bldg. 40, Rm. 8L 2500 Broening Hwy. Baltimore, MD 21224 Web Link: www.mde.state.md.us
Massachusetts Drinking Water Program Dept. of Environmental Protection	Phone: (617) 292-5770 One Winter St., 6th Floor Boston, MA 02108 Web Link: www.state.ma.us/dep/brp/dws/dwshome.htm
Michigan Drinking Water & Radiological Protection Div.Michigan Dept. of Environmental Quality	Phone: (517) 335-9218 Box 30630 Lansing, MI 48909-8130 Web Link: www.deq.state.mi.us/dwr
Minnesota Drinking Water Protection Section Dept. of Health	Phone: (651) 215-0770 121 E. Seventh Place P.O. Box 64975 St. Paul, MN 55164-0975 Web Link: www.health.state.mn.us/divs/eh/eh.html

Resource	Contact
Mississippi Div. of Water Supply Dept. of Health	Phone: (601) 576-7518 P.O. Box 1700 2324 N. State Street Jackson, MS 39215-1700 Web Link: www.msdh.state.ms.us/watersupply/index.htm
Missouri Public Drinking Water Program Div. of Environmental Quality Dept. of Natural Resources	Phone: (573) 751-5331 P.O. Box 176 Jefferson City, MO 65101 Web Link: www.dnr.state.mo.us/deq/pdwp/homepdwp.htm
Montana Public Water Supply Section Dept. of Environmental Quality	Phone: (406) 444-4323 Box 2000901 1520 E. Sixth Ave. Helena, MT 59620-0901 Web Link: www.deq.state.mt.us/wqinfo/index.asp
Nebraska Nebraska Dept. of HHS Regulation & Licensure	Phone: (402) 471-2541 301 Centennial Mall South P.O. Box 95007, 3rd Floor Lincoln, NE 68509-5007 Web Link: www.hhs.state.ne.us/
Nevada Bureau of Health Protection Services Dept. of Human Resources	Phone: (775) 687-4750 1179 Fairview Drive, Suite 101 Carson City, NV 89701-5405 Web Link: www.health2k.state.nv.us
New Hampshire Water Supply Engineering Bureau Dept. of Environmental Services	Phone: (603) 271-3139 P.O. Box 956 Hazen Drive Concord, NH 03302-0095 Web Link: http://www.des.state.nh.us/wseb/
New Jersey Bureau of Safe Drinking Water Environmental Regulation Dept. of Environmental Protection	Phone: (609) 292-5550 P.O. Box CN-426 Trenton, NJ 08625 Web Link: www.state.nj.us/dep/watersupply/
New Mexico Drinking Water Bureau New Mexico Environment Dept.	Phone: (505) 827-7536 (877) 654-8720 525 Camino de los Marquez, Suite 4 Santa Fe, NM 87501 Web Link: www.nmenv.state.nm.us/dwb/dwbtop.html
New York Bureau of Public Water Supply Protection Dept. of Health	Phone: (518) 402-7650 547 River Street Troy, NY 12180-7650 Web Link: www.health.state.ny.us/nysdoh/water/main.htm
North Carolina Public Water Supply Section Dept. of Env. and Natural Resources	Phone: (919) 733-2321 Box 29536 1634 Mail Service Center Raleigh, NC 27699-1634 Web Link: www.deh.enr.state.nc.us/pws/index.htm
North Dakota Div. of Municipal Facilities North Dakota Dept. of Health	Phone: (701) 328-5211 1200 Missouri Avenue, Room 203 P.O. Box 5520 Bismark, ND 58506-5520 Web Link: www.ehs.health.state.nd.us/ndhd/environ/mf/index.htm
Northern Mariana Islands Div. of Environmental Quality Commonwealth of the Northern Mariana Islands	Phone: (670) 664-8500 P.O. Box 1304 Saipan, MP 96950 Web Link: NA
Ohio Div. of Drinking & Ground Water Ohio Environmental Protection Agency	Phone: (614) 644-2769 Lazarus Government Center P.O. Box 1049 Columbus, OH 43216-1049 Web Link: www.epa.state.oh.us/ddagw/
Oklahoma Water Quality Div. Dept. of Environmental Quality	Phone: (405) 271-4000 1000 Northeast 10th St. Oklahoma City, OK 73101-1212 Web Link: www.deq.state.ok.us/water.html

Resource	Contact
Oregon Drinking Water Program Dept. of Human Resources	Phone: (503) 731-4317 P.O. Box 14450 Portland, OR 97293-0450 Web Link: www.ohd.hr.state.or.us/dwp/welcome.htm
Pennsylvania Bureau of Water Supply Management Dept. of Environmental Protection	Phone: (717) 787-9037 P.O. Box 8467 Harrisburg, PA 17105-8467 Web Link: www.dep.state.pa.us/dep/deputate/watermgt/wmw/wmw.htm
Puerto Rico Public Water Supply Supervision Program Dept. of Health	Phone: (787) 754-6010 P.O. Box 70184 San Juan, PR 00936 Web Link: www.epa.gov/region02/cepd/compnum.htm#JCA
Rhode Island Office of Drinking Water Quality Dept. of Health	Phone: (401) 222-6867 3 Capitol Hill, Rm. 209 Providence, RI 02911 Web Link: www.health.state.ri.us/environment/dwq.htm
South Carolina Bureau of Water Dept. of Health & Environmental Control	Phone: (803) 734-5300 2600 Bull Street Columbia, SC 29201 Web Link: www.scdhec.net/water/html/dwater.html
South Dakota Drinking Water Program Div. of Environmental Regulation Dept. of Environmental & Natural Resources	Phone: (605) 773-3754 523 East Capital Ave. Joe Foss Building Pierre, SD 57501 Web Link: www.state.sd.us/denr/des/drinking/dwprg.htm
Tennessee Div. of Water Supply Dept. of Environment & Conservation	Phone: (615) 532-0191 401 Church Street L&C Tower, 6th Floor Nashville, TN 37243 Web Link: www.state.tn.us/environment/dws/index.html
Texas Water Utilities Div. Texas Natural Resource Conservation Commission	Phone: (512) 239-6096 P.O. Box 13087 Austin, TX 78711 Web Link: www.tnrcc.state.tx.us/permitting/waterperm/pdw000.html
Utah Div. of Drinking Water Dept. of Environmental Quality	Phone: (801) 536-4200 P.O. Box 144830 Salt Lake City, UT 84118 Web Link: www.deq.state.ut.us/eqdw/
Vermont Water Supply Div. Dept. of Environmental Conservation	Phone: (802) 241-3400 Old Pantry Bldg 103 South Main Street Waterbury, VT 05671 Web Link: www.anr.state.vt.us/dec/watersup/wsd.htm
Virgin Islands Div. of Environmental Protection Dept. of Planning & Natural Resources	Phone: (340) 774-3320 Wheatley Center 2 St. Thomas, VI 00802 Web Link: NA
Virginia Div. of Water Supply Engineering Dept. of Health	Phone: (804) 786-5566 Room 109-31 1500 East Main Street Richmond, VA 23219 Web Link: www.vdh.state.va.us/owp/water_supply.htm
Washington Drinking Water Div. Dept. of Health	Phone: (360) 236-3100 (800) 521-0323 Washington Industrial Center, Building 3 P.O. Box 47822 Olympia, WA 98504 Web Link: http://www.doh.wa.gov/ehp/dw/
Washington, DC Environmental Health Administration	Phone: (202) 535-2500 51 N Street, NE Washington, DC 20002 Web Link: www.dchealth.com/eha/welcome.htm

Resource	Contact
West Virginia Environmental Engineering Div. Office of Environmental Health Services Bureau for Public Health	Phone: (304) 558-2981 815 Quarrier Street, Suite 401 Charleston, WV 25301 Web Link: www.wvdhhr.org/bph/enviro.htm
Wisconsin Drinking Water & Groundwater Wisconsin Dept. of Natural Resources	Phone: (608) 266-2299 P.O. Box 7921 Madison, WI 53703 Web Link: www.dnr.state.wi.us/org/water/dwg/
Wyoming Wyoming Drinking Water Program EPA Region VIII	Phone: (307) 777-7781 122 W. 25th Street Herschler Building Cheyenne, WY 82002 Web Link: http://deq.state.wy.us/wqd.htm

Other resources

Resource	Contact
American Public Works Association	Phone: (816) 472-6100 2345 Grand Blvd., Suite 500 Kansas City, MO 64108-2641 Web Link: www.apwa.net
American Water Works Association	Phone: (303) 794-7711 6666 W. Quincy Avenue Denver, CO 80235 Web Link: www.awwa.org
American Water Works Association Small Utility Network	Phone: (800) 366-0107 Web Link: www.awwa.org/sun/sunhome.htm
Association of State Drinking Water Administrators	Phone: (202) 293-7655 1025 Connecticut Ave., NW Suite 903 Washington, D.C., 20036 Web Link: www.asdwa.org
National Drinking Water Clearinghouse National Environmental Services Center	Phone: (800) 624-8301 (304) 293-4191 West Virginia University P.O. Box 6064 Morgantown, WV 26506 Web Link: www.ndwc.wvu.edu AND www.nesc.wvu.edu
National Rural Water Association	Phone: (580) 252-0629 2915 South 13th Street Duncan, OK 73533-9086 Web Link: www.nrwa.org
National Small Flows Clearinghouse	Web Link: www.nesc.wvu.edu
NSF International	Phone: (734) 769-8010, (800) NSF-MARK PO Box 130140 789 N. Dixboro Road Ann Arbor, MI 48113-0140 Web Link: http://www.nsf.org/water.html
Rural Community Assistance Corporation	Phone: (916) 376-0507 3120 Freeboard Dr. Suite 201 West Sacramento, CA 95691 Web Link: http://www.rcac.org/
Rural Community Assistance Program	Phone: (202) 408-1273 1522 K Street, NW, Suite 400 Washington, DC 20005 Web Link: www.rcap.org
Safe Drinking Water Foundation	Phone: (306) 934-0389 11 Innovation Blvd. Saskatoon, SK Canada, S7N 3H5 Web Link: www.safewater.org

Resource	Contact
Universities Water Information Network	Phone: (618) 453-6026 UWIN 4436, Faner Hall Southern Illinois University Carbondale, IL 62901 Web Link: www.uwin.siu.edu/index.html
Water Quality Association	Phone: (630) 505-0160 4151 Naperville Road; isle, IL 60532 Web Link: http://www.wqa.org/

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