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Environmental Protection
Agency

GROUND WATER RULE CORRECTIVE ACTIONS GUIDANCE MANUAL

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DISCLAIMER

This manual provides guidance in meeting corrective action requirements under the Ground Water Rule (GWR). Corrective actions are an important part of helping public water systems protect public health.

The statutory provisions and U.S. Environmental Protection Agency (EPA) regulations described in this document contain legally binding requirements. This guidance is not a substitute for applicable legal requirements, nor is it a regulation itself. Thus, it does not impose legally-binding requirements on any party, including EPA, States, or the regulated community. While EPA has made every effort to ensure the accuracy of the discussion in this guidance, the obligations of the regulated community are determined by statutes, regulations, or other legally binding requirements. In the event of a conflict between the discussion in this document and any statute or regulation, the statute or regulation, not this document, would be controlling.

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Although this manual describes suggestions for complying with GWR requirements, the guidance presented here may not be appropriate for all situations, and alternative approaches may provide satisfactory performance.

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EXHIBITS

ACRONYMS

µg/L	micrograms per liter
2D	Twice the Diameter
AG	Air Gap
AOC	Assimilable Organic Carbon
AVB	Atmospheric Vacuum Breaker
AWWA	American Water Works Association
AwwaRF	American Water Works Association Research Foundation
BAT	Best Available Technology
BL	Barometric Loop
BMP	Best Management Practice
CCR	Consumer Confidence Reports
CFR	*Code of Federal Regulations*
CT	Concentration of Residual Disinfectant (in mg/L) multiplied by Time of Water Contact (Detention Time) (in minutes)
CWS	Community Water System
DBP	Disinfection Byproduct
D/DBPR	Disinfectants/Disinfection Byproducts Rule
DCDC	Double Check Detector Check
DCIAV	Double Check Valve with Intermediate Atmospheric Vent
DCV	Double Check Valve
DEP	Department of Environmental Protection
DNA	Deoxyribonucleic Acid
EPA	United States Environmental Protection Agency
EPS	Extracellular Polysaccharides
FDA	United States Food and Drug Administration
GWR	Ground Water Rule
GWS	Public Water Systems that are subject to the requirements of the Ground Water Rule (includes PWSs that also deliver surface water and/or GWUDI)
GWUDI	Ground Water Under the Direct Influence of Surface Water
HAA	Haloacetic Acid
HB	Hose Bib Vacuum Breaker
HPC	Heterotrophic Plate Count
HSA	Hydrogeologic Sensitivity Assessment
HTH	High-test Hypochlorite
IBWA	International Bottled Water Association
ICR	Information Collection Rule
IESWTR	Interim Enhanced Surface Water Treatment Rule
LT1	Long Term 1 Enhanced Surface Water Treatment Rule
LT2	Long Term 2 Enhanced Surface Water Treatment Rule
MCL	Maximum Contaminant Level

MF	Microfiltration
mg/L	milligrams per liter
MWCO	Molecular Weight Cut Off
NCWS	Non-community Water Systems
NDPES	National Pollutant Discharge Elimination System
NF	Nanofiltration
NOM	Natural Organic Matter
NPDW	National Primary Drinking Water
O&M	Operation and Maintenance
PVB	Pressure Vacuum Breaker
PVC	Polyvinyl Chloride
PWS	Public Water System
RCRA	Resource Conservation and Recovery Act
RDC	Residential Dual Check
RO	Reverse Osmosis
RPBA	Reduced Pressure Principle Blackflow Prevention Assembly
SDWIS	Safe Drinking Water Information System – Federal Version
SMCL	Secondary Maximum Contaminant Level
SRF	State Revolving Fund
SWTR	Surface Water Treatment Rule
TCR	Total Coliform Rule
THM	Trihalomethane
TOC	Total Organic Carbon
TOX	Total Organic Halogen
UF	Ultrafiltration
UFTREEO	University of Florida Training, Research, and Education for Environmental Occupations
UIC	Underground Injection Control
USGS	United States Geological Survey
UV	Ultraviolet
UVT	UV Transmittance

1. Introduction to the Ground Water Rule Corrective Actions Guidance Document

The purpose of this guidance manual is to assist States and Public Water Systems (PWSs)[1] to select and implement corrective actions in response to significant deficiencies identified during sanitary surveys or in response to fecal contamination of source water as required under the Ground Water Rule (GWR). Other important aspects of the GWR related to corrective actions are discussed more fully in other guidance manuals, such as:

- The Consecutive Systems Guidance Manual for the Ground Water Rule (USEPA 2007b)
- The Source Water Monitoring Guidance Manual (USEPA 2007c)
- The Ground Water Rule Sanitary Survey Guidance Manual (*to be published*)

This introduction provides an overview of the portions of the GWR that relate specifically to corrective actions.

1.1 The Ground Water Rule (GWR)

The GWR was signed by the United States Environmental Protection Agency (EPA) Administrator on October 11, 2006 and was published in the Federal Register on November 8, 2006 (71 FR 65574). The primary purpose of the GWR is to provide for increased protection against microbial pathogens in PWSs that use ground water as their source.

PWSs that are subject to the requirements of the GWR include systems that use only ground water sources, "mixed systems" that use both ground and surface water sources, and wholesale and consecutive systems that serve ground water[2].

The GWR does not apply to "subpart H" systems that combine all of their ground water with surface water prior to treatment and those systems identified as ground water under the direct influence of surface water (GWUDI). The GWR may apply to all types of PWSs: community water systems (CWSs), non-transient non-community water systems (NCWSs), and transient NCWSs.

EPA has estimated that approximately 147,330 PWSs in the United States, serving over 114 million people, are subject to the requirements of the GWR based on data from the Safe Drinking Water Information System – Federal Version (SDWIS) (USEPA, 2006).

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[1] PWSs are systems that have at least 15 service connections, or regularly serve at least 25 individuals daily at least 60 days out of the year.

[2] These systems are referred to as Ground Water Systems (GWSs) throughout this guidance document.

The GWR established a risk-targeting approach to identify Ground Water Systems (GWSs) subject to the rule that may pose a risk of exposure to microbial pathogens to customers. The key provisions of the risk-targeting approach of the GWR are:

- Periodic sanitary surveys of Ground Water Systems (GWSs) focusing on eight critical elements to identify any significant deficiencies that must be addressed through corrective action. States must complete the first of these periodic sanitary surveys by December 31, 2012 for most CWSs and by December 31, 2014 for CWSs with a history of outstanding performance and for all non-community water systems (NCWSs) (40 CFR 141.401).

- Triggered source water monitoring of GWSs that have a total coliform positive of a routine sample in the distribution system under the Total Coliform Rule (TCR) if that GWS does not currently provide treatment that achieves at least 99.99 percent (4-log) inactivation or removal of viruses. Triggered source water monitoring tests for the presence of a microbial pathogen indicator (*E. coli*, enterococci, or coliphage) as required by the State. A GWS that has microbial pathogen indicator positive identified in the source water may be required by the State to take immediate corrective action or, if not so required, must take five additional source water samples and undertake corrective action if any of those additional samples are positive (40 CFR 141.402(a)).

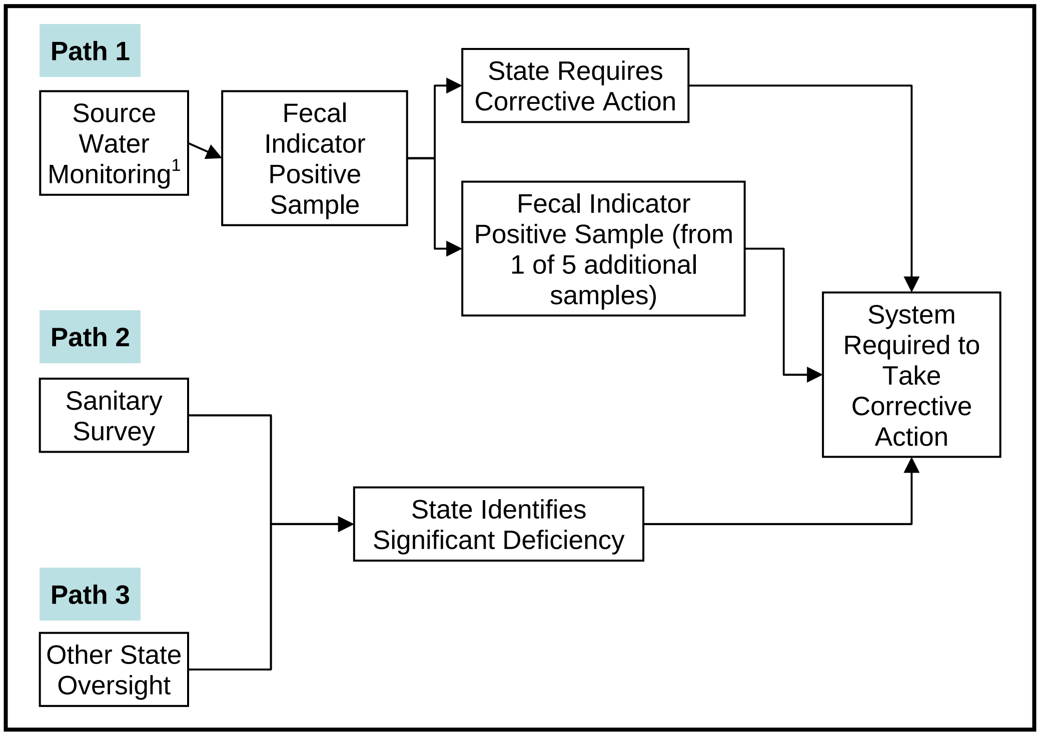
- Assessment source water monitoring may also be required by a State as a complement to triggered monitoring. A State has the ***option*** to require systems, at any time, to conduct source water assessment monitoring for fecal indicators to help identify high risk systems. Hydrogeologic sensitivity assessments (HSAs) can be used as an ***optional*** tool to identify those high risk systems for assessment source water monitoring (40 CFR 141.402(b)).

- Compliance monitoring for GWSs that currently disinfect to ensure that the treatment technology installed reliably achieves at least 99.99 percent (4-log) inactivation or removal of viruses (40 CFR 141.403(b)).

1.2 Overview of the Corrective Action Process under the GWR

Under §141.403(a) the GWR, systems must implement a corrective action if one or more significant deficiencies are identified by the State, or if a fecal indicator positive result is detected in a source water sample collected under §141.402(a)(3) or if directed by the State based on results of monitoring under §141.402(a)(1) or §141.402(b).

Exhibit 1.1 Overview of Corrective Action Process



[1]Source water monitoring is triggered by a total coliform-positive sample in the distribution system. See 40 CFR 141.402(a).

Corrective actions performed under the GWR include one or more of the following alternatives:

- Correct all significant deficiencies;
- Eliminate the source of contamination;
- Provide an alternate source of water; and
- Provide treatment which reliably achieves 99.99 percent (4-log) inactivation or removal of viruses.

The following briefly summarizes the requirements related to corrective actions that States and PWSs must take in response to the identification of significant deficiencies or fecal indicator positives.

1.3 Requirements for States and PWSs Related to Corrective Actions in Response to Significant Deficiencies and Fecal Indicator Positives

1.3.1 State Requirements

The GWR requires States to provide written notice to the PWS describing all significant deficiencies (i.e., those that require corrective action) identified. The notice may be provided on-site at the time the significant deficiency is identified or it may be sent to the PWS within 30 days of identifying the significant deficiency.

In the cases of either the identification of significant deficiencies or the determination of a fecal indicator positive in source water monitoring, the State may specify the corrective actions and deadlines to the affected GWS, or it may work with the affected GWS to determine an appropriate corrective action plan. The State must approve the corrective action plan and schedule (and must also approve any subsequent modifications to it). The State must also verify that corrective actions have been completed through written confirmation or a site visit within 30 days after the PWS has reported to the State that the corrective action has been completed.

1.3.2 PWS Requirements

Within 30 days of receiving written notice from the State of a significant deficiency or written notice from a laboratory of a fecal-indicator positive, the GWS must consult with the State regarding the appropriate corrective action. In some cases, the system may be directed by the State to implement a specific corrective action.

If the State does not specify a corrective action to be taken by the GWS, then within 120 days (or earlier if directed by the State) of receiving written notice from the State of a significant deficiency or written notice from a laboratory of a fecal indicator positive, the GWS must either have completed the appropriate corrective action or be in compliance with a State-approved corrective action plan and schedule.

The GWS must notify the State that a required corrective action has been completed within 30 days of completion.

Also, in addition to other public notification requirements under the GWR, community GWSs must provide a special notice to the public of any significant deficiencies uncorrected at the time of the Consumer Confidence Report (CCR) or any fecal indicator positives, and continue to inform the public annually until the significant deficiency or the fecal contamination has been corrected in accordance with the State approved corrective action plan.

CCRs apply only to community GWSs. Non-community GWSs must provide notice to the public regarding any significant deficiency that has not been corrected within 12 months. Non-community GWSs must repeat notification annually until the significant deficiency is corrected.

1.4 Goal and Organization of the Guidance Manual

The next four chapters of this guidance document provide detailed information on the four different general categories of corrective actions that may be required under the GWR for systems for which States have identified a significant deficiency.

- Chapter 2 - Correcting Significant Deficiencies
- Chapter 3 - Eliminating Sources of Contamination
- Chapter 4 - Providing an Alternate Source of Drinking Water
- Chapter 5 - Installing Treatment

The final chapter, Chapter 6, contains a list of references cited within the guidance manual.

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2. Correcting Significant Deficiencies

The GWR requires States to conduct periodic sanitary surveys at all GWSs, and to identify significant deficiencies during those surveys. Sanitary surveys include reviewing PWS records and monitoring data as well as an onsite evaluation to identify both minor and significant deficiencies. The GWR requires that significant deficiencies identified during sanitary surveys, or during other State field visits or reviews, must be addressed through corrective action.

Significant deficiencies are not explicitly defined or specified in the final GWR. However, 40 CFR 142.16 of the GWR indicates that significant deficiencies would include, though are not limited to, defects in design, operation, or maintenance, or a failure or malfunction of the sources, treatment, storage, or distribution system that the State determines to be causing, or has the potential for causing, the introduction of contamination into the water delivered to consumers. States are required to define and describe in their primacy package at least one specific significant deficiency in each of the eight elements (listed below) that 40 CFR 142.16 specifies must be included in sanitary surveys conducted under the GWR:

1. Source,
2. Treatment,
3. Distribution system,
4. Finished water storage,
5. Pumps, pump facilities, and controls,
6. Monitoring, reporting, and data verification,
7. System management and operation, and
8. Operator compliance with State requirements.

This chapter discusses the eight different elements of a sanitary survey and provides examples of significant deficiencies for each element in the respective sections that follow. It also addresses what States and PWSs should do when a significant deficiency is identified. Correcting significant deficiencies can involve a wide range of technical or managerial changes in the PWS, with a wide range of resource requirements.

The corrective actions that are proposed in this manual vary from actions that can easily be completed to those that will require a significant amount of time and effort on the part of the water system and the State. In order to ensure public health protection while also allowing for the time needed to design and implement the optimal long-term solution, the State should consider creating a two-phased corrective action if the GWS needs an extended period of time (such as six months) to complete the corrective action. The first phase of the corrective action would be designed for the short-term to protect public health while providing the system with the time to implement a permanent solution that finally completes the corrective action. Throughout this manual, you will see short-term and temporary solutions (e.g., providing bottled water, interim disinfection, etc.) as well as long term solutions (e.g., constructing a new well).

EPA expects State drinking water programs to draw on their extensive experience to develop specific criteria for determining which deficiencies are significant and how to correct them in particular cases. This may include the State specifying the corrective action to the PWS or working with the PWS to determine how to correct a particular significant deficiency identified in its sanitary survey. Either way, it is critical that the GWS consult with the State to identify an appropriate corrective action.

2.1 Identifying Significant Deficiencies

As part of a State's primacy package under the GWR, the State must describe the approach it will use to determine if a deficiency is significant. Based on this approach, States will decide on a case-by-case basis whether an identified deficiency is a significant deficiency. There is a wide range of risks associated with significant deficiencies, ranging from those with a small, but not insignificant likelihood of introducing microbial contamination to the finished water, to those where the continued unaltered operation of the system poses a serious imminent health threat to the population. The GWR requires all deficiencies identified by the State as "significant" to be corrected by the water system. Inspectors should be familiar with the approach the State will use to determine if a deficiency is significant.

2.1.1 Sanitary Surveys

Sanitary surveys have been conducted by staff or authorized agents of State drinking water programs for decades. Sanitary surveys provide an opportunity for State drinking water officials, or approved third party inspectors, to visit the water system and educate operators about proper monitoring and sampling procedures, provide technical assistance, and inform them of any changes in regulations. At the same time, sanitary surveys are driven by compliance with existing regulations and by efforts to provide public health protection. EPA believes that periodic sanitary surveys, along with appropriate corrective measures, are indispensable for assuring the long-term safety and quality of drinking water. Currently, all States, except for one, conduct sanitary surveys.

A sound sanitary survey program is an essential element of an effective State drinking water program for PWSs. As required by the GWR, systems must provide all necessary information and assistance requested from States for conducting sanitary surveys. The GWR requires States to conduct sanitary surveys of ground water CWSs every three years (every five years for CWSs that meet performance criteria) and of ground water NCWSs every five years. States are required to complete the initial sanitary survey cycle by December 31, 2012 for CWSs, except those that meet performance criteria (e.g., 4-log treatment or outstanding performance and no TCR violations), and December 31, 2014 for all NCWSs and CWSs that meet performance criteria. States may conduct more frequent sanitary survey cycles for any GWS as appropriate.

The EPA Guidance Manual for Conducting Sanitary Surveys of PWSs Served Solely by Ground Water Sources (*to be published*) contains information on how to perform an onsite inspection and sanitary survey and can be referenced for guidance on the specifics on conducting sanitary surveys under the GWR.

2.1.2 Other Ways of Identifying Significant Deficiencies

While significant deficiencies are often identified during sanitary surveys, other situations may also bring them to the attention of regulators. If a water system reports higher levels of contaminants than normal, even if there has not been a violation, the regulator may take the preventative step of visiting the system to try and identify the source of the contamination. When customers complain to regulators of low water pressure or colored water at their water system, the regulator may follow up with a visit to the system to help identify or investigate the problem. Complaints of illness that may be attributable to waterborne pathogens can also prompt a visit by regulators. It is not unusual for deficiencies to be found during such site visits. Sometimes it's a coincidence that a significant deficiency is found; a regulator may be at the water system for another purpose and notice a significant deficiency during his or her visit.

2.2 Source Deficiencies

A water supply's ground water source can contain contaminants, pathogens, and particles. Preventing source water contamination is an effective way to prevent contaminants from reaching consumers. Source water protection also helps prevent additional, potentially more costly treatment from being necessary for the removal of contaminants. During a sanitary survey, the major components of the well or spring are reviewed to determine reliability, quality, quantity, and vulnerability. The potential for degradation of source water quality is also evaluated.

2.2.1 Examples of Significant Deficiencies

- Well does not meet State-specified setback distances from hazards.
- Well is improperly constructed.
- Well does not have a sanitary seal.
- Spring box is poorly constructed and/or subject to flooding.

2.2.2 Identifying Corrective Actions

- Remove hazards to well or relocate well.
- Address components of well that are not properly constructed (e.g., height of casing above ground, screened vent, grouting).
- Replace or supplement existing well cover with cap that provides a sanitary seal.

2.2.3 Additional Information and Resources[1]

Bloetscher, F., A. Muniz, J. Largey. 2007. Siting, Drilling, and Construction of Water Supply Wells. AWWA. Denver, CO.

Recommended Standards for Water Works. 2007. Great Lakes-Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers. http://10statesstandards.com/waterstandards.html

2.3 Treatment Deficiencies

Water treatment facilities are the primary means of preventing unacceptable drinking water quality from being delivered for public consumption. The treatment facilities and processes should be capable of removing, sequestering, or inactivating physical, chemical, and biological impurities in the source water. Water treatment plants should be designed, operated, maintained, and managed in a way that minimizes existing or potential sanitary risks.

During a sanitary survey, the treatment facilities and processes are evaluated to determine their ability to meet regulatory requirements and to provide an adequate supply of safe drinking water at all times, including periods of high water demand. The distinct parts of the treatment process, including but not limited to disinfection, chemical feed systems, hydraulics, and controls, are inspected. Features of the water treatment process that may pose a sanitary risk, such as inadequate treatment, monitoring, or maintenance, lack of reliability, and cross connections are also identified.

2.3.1 Examples of Significant Deficiencies

- Inadequate application of treatment chemicals and/or no provisions to notify of chemical feed failure.
- Inadequate disinfection contact time.
- No provision to prevent chemical overfeed and/or no provisions to notify of chemical feed failure.
- System delivered untreated or inadequately treated drinking water to customers, when its permit was based on meeting specific treatment requirements.

1 Many States have well standards that need to be met for newly installed wells. Water systems should make sure any actions they take to remediate or install wells are consistent with their State's requirements.

2.3.2 Identifying Corrective Actions

- Written operations and maintenance procedures for water treatment.

- Supplement disinfectant contact time (e.g., additional storage, slower flows, baffling).

- Add controls to notify of chemical feed failure and/or eliminate the possibility of chemical overfeeds (e.g., check valves, day tanks).

- Install and monitor valves or other control measures that allow treatment units to be bypassed; do not serve water to public when bypassing results in inadequately treated water (e.g., does not comply with SDWA requirements).

2.3.3 Additional Information and Resources

AWWA. 2006. Water Chlorination and Chloramination Practices and Principles (M20), Second Edition. Denver, CO.

MWH. 2005. Water Treatment: Principles and Design, Second Edition. John Wiley & Sons.

Recommended Standards for Water Works. 2007. Great Lakes-Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers. http://10statesstandards.com/waterstandards.html

EPA. 2006. Ultraviolet Disinfection Guidance Manual for the Long Term 2 Enhanced Surface Water Treatment Rule. Office of Water. EPA 815-R-06-007.

EPA. 2005. Membrane Filtration Guidance Manual. Office of Water. EPA 815-R-06-009.

2.4 Distribution System Deficiencies

A well maintained and operated distribution system is an important barrier in protecting water quality. During a sanitary survey, the surveyor evaluates the condition (to the extent possible) and maintenance of the distribution system, and one of the eight elements included in the GWR sanitary survey requirements.

All types of ground water systems face the challenge of the introduction of contaminants into finished water in the distribution system. Seasonal ground water systems, in particular, can be at risk. These systems shut down their distribution systems for extended periods of time before starting them up for the next season. During this period of shutdown, the pressure in the pipe can be lower than the pressure outside the pipe (making the distribution system subject to intrusion or structural failure); suspended particulates in the stagnant water settle into pipe sediments, and biofilm can rapidly develop. When the system starts back up, sudden flow increases can cause accumulated biofilm, sediment, and tubercles to be released into the water column. Seasonal systems should work with their State to determine operating procedures for system shut down and start up that minimize the potential for contamination. This could be a combination of disinfecting, flushing the system, and minimizing the magnitude of pressure transients by slowing the rate of opening and closing valves (USEPA, 2006d).

2.4.1 Biofilm Control

Biofilm is a general term used to describe the combination of microorganisms, extra-cellular polymer, organic compounds, and inorganic compounds found on the inside of pipe walls and other surfaces in contact with water. Any microorganism in the bulk water can attach or become enmeshed in biofilm. Organisms of concern for drinking water include coliforms, nitrifying microorganisms (in chloraminated systems), and opportunistic pathogens. Coliform growth in biofilms can lead to detection and possible violations under the Total Coliform Rule. Nitrifying bacteria can reduce chloramine residual concentration and lead to elevated nitrate and nitrite levels. The EPA distribution system issue paper on biofilms (USEPA 2002, see http://www.epa.gov/OGWDW/disinfection/tcr/pdfs/whitepaper_tcr_biofilms.pdf for full reference) includes a list of opportunistic pathogens identified in biofilm, some of which have been associated with waterborne disease outbreaks. Biofilm growth can result in corrosion of metal pipe by suppressing the pH at locations along the pipe wall. This can lead to loss of pipe integrity and aesthetic problems (e.g., red water). For these reasons, it is important to control biofilm growth in wells and distribution systems in order to maintain a potable water supply.

Factors that generally favor biofilm growth include:

- Presence of corroded metal pipe (in particular iron pipe), which provides a protected environment for microorganisms to grow.
- Elevated temperatures (microorganisms generally grow faster at warmer temperatures compared to colder temperatures).
- Low or no disinfectant residual.
- Available nutrients such as carbon, nitrogen, phosphorus (often, assimilable organic carbon is the limiting nutrient with respect to biofilim growth).

In their Total Coliform Rule Distribution System White Paper (2002), EPA lists the following strategies for controlling biofilm growth, citing corrosion control as possibly the most important factor:

- Nutrient control,
- Control of contamination from materials and equipment,
- Control and mitigation of system hydraulic problems,
- Cross-connection control and backflow prevention,
- Disinfectant residuals,

- Corrosion control,
- Infrastructure replacement and repair,
- Security, and
- Storage vessel management and alteration.

The authors caution that biofilm control often requires the use of a variety of tools, rather than a single "best" tool, and the relative effectiveness of a control practice may be site specific. See http://www.epa.gov/OGWDW/disinfection/tcr/pdfs/whitepaper_tcr_biofilms.pdf for additional information.

2.4.2 Cross-Connection Control

Another public health threat that can arise in the distribution system is contamination introduced through cross-connections. A cross-connection is "any unprotected actual or potential connection or structural arrangement between a public or a consumer's potable water system and any other source or system through which it is possible to introduce into any part of the potable system any used water, industrial fluids, gas, or substance other than the intended potable water with which the system is supplied" (AWWA, 1990a). Backflow prevention devices are appropriate on connections between a PWS distribution system and irrigation wells, other irrigation water supplies, or private wells.

Backflow refers to a reverse flow condition created by a difference in water pressures that causes water to flow back into the distribution pipes of a potable water supply from any source or sources other than an intended source (USEPA, 2000). Backflow can occur under two different conditions. The first condition called backpressure exists when a potable system is connected to a non-potable supply operating under a higher pressure by means of a pump, boiler, elevation difference, air or steam pressure, or other means (AWWA, 1990a). The second condition that causes backflow occurs when there is negative or reduced pressure in the supply piping (i.e., the distribution system's pressure is lower than atmospheric pressure) and is known as backsiphonage (AWWA, 1990a).

Distribution systems can lose pressure and even experience a partial vacuum when water is withdrawn at a very high rate, such as during fire fighting or when booster pumps are used. Systems also lose pressure during events like main repairs and line breaks. If the system pressure drops sufficiently, the direction of flow within portions of the system will reverse; if there are cross-connections, contaminants can be siphoned into the distribution system (AWWA, 1990a). For example, fecal contamination can be introduced into the distribution system anytime during a backpressure or backsiphonage event, if the PWS has a cross-connection with a source containing fecal contamination.

This section provides an overview of cross-connection control requirements, equipment, and program elements. Detailed information on cross-connection control is available from the following resources:

- The EPA Distribution System Issue Paper: Potential Contamination Due to Cross-Connections and Backflow and the Associated Health, available online at http://www.epa.gov/OGWDW/disinfection/tcr/regulation_revisions.html

- The EPA Cross-Connection Control Manual (2006), available online at http://www.epa.gov/OGWDW/pdfs/crossconnection/crossconnection.pdf

- The University of Southern California Foundation for Cross Connection Control and Hydraulic Research and associated publications http://www.usc.edu/dept/fccchr/

- The American Water Works Association Recommended Practice for Backflow Prevention and Cross-Connection Control (M14), Third Edition (2004).

2.4.2.1 Existing Requirements

All 50 States require cross-connection control through various means such as plumbing codes, health codes or environmental protection codes. The majority of States require systems or individual localities to implement cross-connection control programs that uphold State regulations; however, other States require individual customers to comply with State regulations that are enforced by a public water supplier.

There are two methods commonly used to control or eliminate backflow hazards due to cross-connections - physically eliminating the cross-connection or installing a backflow preventer. Several States require systems to physically separate the cross-connections rather than install a backflow prevention assembly (Florida DEP, 1996). Some States only allow installation of a backflow prevention assembly when a physical separation is not possible. Systems that physically separate the cross-connection should do so in a manner that the cross-connection cannot be re-established. Additionally, systems should always check State requirements before considering a backflow prevention assembly.

If a cross-connection is implicated as the significant deficiency or source of fecal contamination entering the distribution system, a backflow preventer can be used to eliminate further contamination from entering the distribution system. Backflow prevention used in response to a contamination event can be an effective means of eliminating a source of contamination.

Some jurisdictions regard a cross-connection as a significant deficiency with backflow prevention as the proper corrective action. If the cross-connection is viewed as a significant deficiency, the system is required to correct the significant deficiency as part of the GWR sanitary survey requirements.

2.4.2.2 Choosing a Backflow Preventer

Several types of backflow preventers exist; however, not all types are applicable for all situations. Below is a list of the basic types of backflow preventers (USEPA, 1989).

- Air gap (AG),
- Atmospheric vacuum breaker (AVB),
- Pressure vacuum breaker (PVB),
- Double check valve (DCV),
- Reduced pressure principle backflow prevention assembly (RPBA), and
- Double check valve with intermediate atmospheric vent (DCIAV).

Mechanical backflow preventers should be capable of being tested to determine effectiveness. Several factors should be considered when choosing the right type of backflow prevention assembly. These considerations include the following:

- The degree of hazard protection needed;
- The likelihood that backpressure may result; and
- If the system wants to provide protection inside the customer’s premises (isolation) or at the service connection (containment).

Appendix A presents the applications of various backflow prevention assemblies/methods. Systems deciding to provide backflow prevention against health hazards should use only air gaps, PVBs, AVBs, or RPBAs. Among these, only air gaps and RPBAs should be used to protect against high hazards. Although all backflow prevention assemblies protect against backsiphonage, only AGs, DCVs, and RPBAs should be used to protect against backpressure.

When choosing a backflow preventer, systems should keep in mind that isolation provides protection within premises and containment devices prevent a contaminant from leaving the premises. Backflow preventers that provide isolation are typically more expensive than containment devices since multiple assemblies may be required for a single customer (USEPA, 2003). Because isolation occurs within a customer’s premises, devices can be easily bypassed, eliminating the benefit of the backflow prevention assembly. Alternatively, containment remains under the control of the system, and therefore, bypassing is less of a concern.

2.4.2.3 Installing and Testing Backflow Preventers

Backflow prevention assemblies should only be installed by certified backflow prevention assembly installers and only tested by backflow prevention assembly testers. There are many organizations that provide training for backflow prevention assembly installers and testers such as the following:

- University of Florida Center for Training, Research & Education for Environmental Occupations (UFTREEO);
- American Water Works Association (AWWA); and
- USC Foundation for Cross-Connection Control and Hydraulic Research.

A number of organizations including the UFTREEO Center, USC, and the American Society of Sanitary Engineers (www.asse-plumbing.org) provide certification of backflow prevention assembly installers and/or testers.

2.4.2.4 Cross-Connection Control and Backflow Prevention Programs

Cross-connection control and backflow prevention programs are commonly used as a Best Management Practice (BMP) in many systems to prevent contamination from entering the distribution system. Many States have requirements for cross-connection control and backflow prevention programs for some or all systems or facilities. When a system intends to implement a cross-connection control and backflow prevention program, it is essential to check the specific State regulations to determine what elements may be required in a program.

According to industry experts, a program is considered comprehensive if it contains these five elements (USEPA, 2001)

- Authority to implement the program (e.g., city ordinance);
- Certification of backflow assembly testers;
- Reporting and record keeping;
- Public notification of backflow events; and
- Authority to enforce the program.

Other potential elements could include approval of specific devices, specific testing requirements, what types of premises are required to have protection, and public education.

2.4.3 Examples of Significant Deficiencies

- Negative pressures due to an incident outside of normal operating ranges that could result in the entrance of contaminants.
- Unprotected cross-connections.

2.4.4 Identifying Corrective Actions

- Corrective action for cross-connections and/or cross-connection control program.
- Installation of a backflow protection device to prevent future backflow events.

2.4.5 Additional Information and Resources

Asset Management: A Handbook for Small Water Systems Publication Number EPA 816-R-03-016

American Water Works Association
(800)-926-6142
www.awwa.org

AWWA (American Water Works Association). 1995d. Water Transmission and Distribution. Second edition. Denver, Colo.:

AWWA. Recommended Practice for Backflow Prevention and Cross Connection Control, Manual of Water Supply Practice M14, (AWWA 2004)

Backflow Prevention Theory and Practice. University of Florida, Division of Continuing Education, Center for Training Research and Education for Environmental Occupations. Ritland, Robin L. 1990Kendall/ Hunt Publishing Company, Dubuque, Iowa.

Cross Connection Control Manual (USEPA, 2003b)

Recommended Standards for Water Works, 2007, Great Lakes-Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers.
http://10statesstandards.com/waterstandards.html

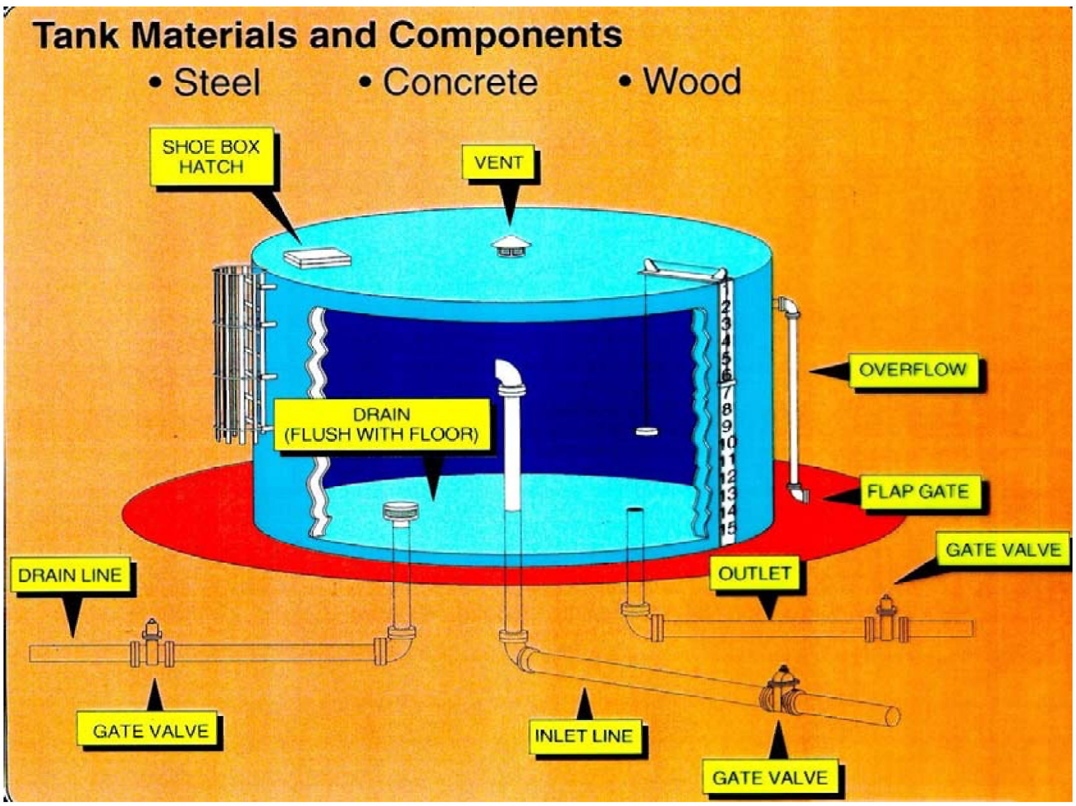
Sacramento State University-Office of Water Programs
(916) 278-6142
http://www.owp.csus.edu/training/onlinecourses.php

University of Florida, Division of Continuing Education, Center for Training Research and Education for Environmental Occupations(TREEO Center)
(352)-392-9570
http://www.treeo.ufl.edu/

2.5 Finished Water Storage

Finished water storage facilities should be maintained and regularly inspected to ensure that distributed water quality is maintained. During a sanitary survey, the surveyor evaluates the condition and maintenance of finished water storage facilities, one of the eight elements included in the GWR sanitary survey requirements. Storage facilities are designed to protect the quality of the finished water while allowing air to enter and escape as the water level changes. They are also designed to allow overflow to occur. There are often penetrations in the tanks to allow access for cleaning and for water level gauging devices. It is important that storage tank integrity be maintained to keep contaminants from entering. Exhibit 2.1 shows a typical ground storage tank. Deficiencies related to a system's water storage facilities may cause water quality and health-related problems for PWSs (NETA, 1998). Such deficiencies can be due to a lack of maintenance on the part of the PWS.

Exhibit 2.1 Typical Ground Storage Tank



Source: (NETA, 1998)

Storage facilities and the grounds surrounding them should be routinely surveyed to prevent water quality problems. It is recommended that water utilities have comprehensive inspections of the structural condition of their storage facilities every 3 to 5 years, including areas of the facility that are not normally accessible from the ground (Kirmeyer, 1999). A comprehensive inspection should include a close evaluation of the condition of interior and exterior coatings, foundation, ladder, vent, hatch, overflow pipe, screens, cathodic protection system, and the depth of the interior sediment.

There are no Federal regulatory requirements for storage tank maintenance or cleaning procedures. Many States recommend adhering to AWWA Standards, NSF Standard 61, and

Recommended Standards for Water Works (2007). AWWA Standards and guidance that apply to finished water storage facilities include:

- C652 Disinfection of Water Storage Facilities;
- D100 Welded Steel Tanks for Water Storage;
- D102 Coating Steel Water-Storage Tanks;
- D103 Factory-Coated Bolted Steel Tanks for Water Storage;
- D120 Thermosetting Fiberglass-Reinforced Plastic Tanks;
- G200 Distribution Systems Operation and Management; and
- AWWA Manual M42 Steel Water Storage Tanks.

When cleaning and maintaining their storage tanks, systems should be aware if their State has environmental regulations that govern discharge of chlorinated water from storage facilities. Dechlorination of the water may be required prior to disposal.

As stated earlier, deficiencies found at storage tanks are frequently associated with insufficient maintenance. Vent screens and flexible sealing materials deteriorate over time and steel eventually corrodes even when properly coated. Each of these problems can cause openings for microbial contaminants to enter the finished water. Often when these defects are found they have progressed to the point where they cannot be quickly and easily corrected in a permanent manner. In these cases, temporary measures should be put in place to minimize public health risk. For example, silicone caulking can sometimes be used to temporarily seal small holes in steel. Noncorrodible screens can be obtained and held in place with stainless steel hose clamps. To accomplish permanent corrective measures, it is advisable to obtain up-to-date construction standards from the primacy agency and bring the storage facility into compliance with those standards. This will often require the use of a licensed professional engineer and submission of plans and specifications for State review and approval.

2.5.1 Correcting Defective Vents

Defective vents should be repaired or replaced according to the Ten States Standards (2007) or State design criteria to prevent the entrance of surface water and rainwater and exclude birds, animals, and, as much as possible, insects and dust. Ground level tanks should be corrected so that vents terminate in an inverted U fashion (see Exhibit 2.1) with the opening 24 - 36 inches above the roof or sod cover with a noncorrodible screen installed within the pipe at a location least susceptible to vandalism. The vent should also be protected from ice formation. Vents should not be replaced by overflows because a storage tank should have both a vent and an overflow pipe; an overflow pipe is not a reliable way to ventilate a tank because the overflow pipe might be in use at the same time that ventilation is needed. (Ten States Standards, 2007).

2.5.2 Correcting Inadequate Access Hatches

In some cases, the State may find defective access hatches that allow insects and dust to enter the storage tank or allow the storage tank to be vandalized. Exhibit 2.2 shows a finished water storage area with an access hatch designed to allow entry for cleaning and maintenance. Systems should refer to State design criteria or other accepted engineering standards for details.

Exhibit 2.2 Raised Sill Appropriate for a Hatch

2.5.3 Correcting Insufficient Overflows

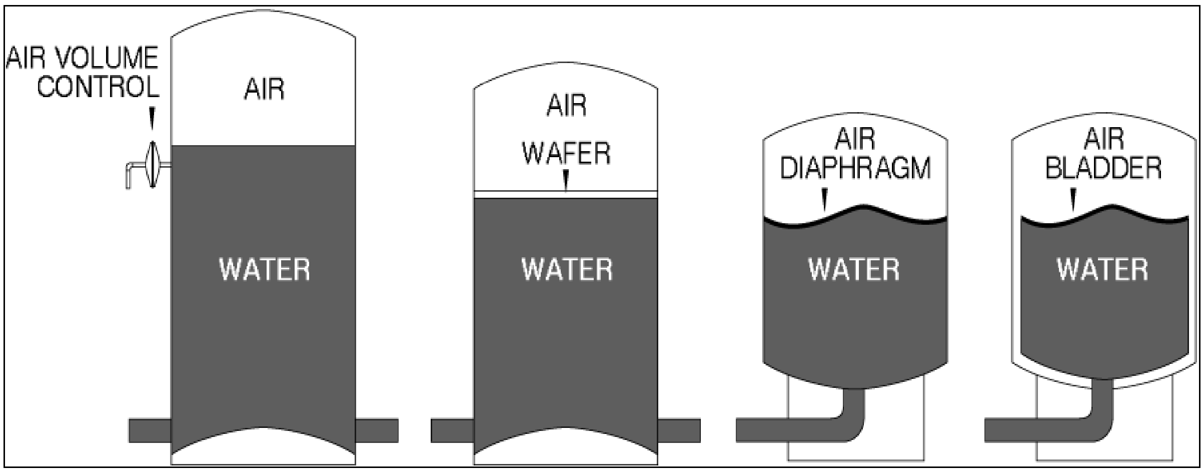
Insufficient overflows may also pose a problem for PWSs. PWSs should ensure that all finished water storage facilities have an overflow that is brought down to an elevation between 12 and 24 inches above the ground surface and discharges over a drainage structure or splash pad. The PWSs should make sure that the discharge point is visible and cannot be connected to any waste water structure. The discharge pipe should also be screened with 24-mesh noncorrodible screen (Ten States Standards, 2007). There are also additional standards available for reference (e.g., AWWA standards).

2.5.4 Hydropneumatic Tanks

Hydropneumatic pressure tanks are commonly used by smaller systems or to serve small pressure zones. The main purpose of hydropneumatic tanks is to prevent excessive cycling of pumps. They contain a fixed volume of air that becomes compressed as water enters the tank. Once the pressure in the tank has reached a predetermined level (i.e., the cut-out pressure) the pump stops and the compressed air starts to expand while it pushes the water into the distribution system. As the water leaves the tank, the pressure in the tank decreases until it reaches a point where the pump will be triggered to start again (i.e., the pump-on level) and the cycle is repeated. The cycle rate is the number of times the pump starts and stops in one hour (typically 10 to 15 cycles per hour).

Hydropneumatic tank systems can use any of several types of pressure storage tanks. Exhibit 2.3 depicts the various types of pressure tanks available. Most small ground water systems use vertical tanks like the two on the right side of the exhibit.

Exhibit 2.3 Types of Pressure Tanks



Source: ©Arasmith Consulting Resources

Suggested minimum design components for hydropneumatic tanks include:

- Tank is located completely above ground.
- Tank meets American Society of Mechanical Engineers (ASME) standards with an ASME name plate attached.
- Access port is available for periodic inspections.
- Tank is fitted with a pressure relief device with a pressure gauge.
- There is a control system to maintain proper air/water ratio for the air/interface.
- Air injection lines are equipped with filters to remove contaminants from the air line.
- Sight glass can provide a visual determination of the water level for proper air/water ratio.
- Tank should have slow closing valves and time delay pump controls to prevent water hammer.

2.5.5 Examples of Significant Deficiencies

- Inspection and cleaning of storage tanks not included in system operation and maintenance (O&M) plan or failure to inspect and clean storage tanks.
- Lack of screening of overflow pipes, drains or vents.
- Storage tanks roofs or covers need repairs (e.g., holes, hatch damage or improper construction, failing floating cover).

2.5.6 Identifying Corrective Actions

- Corrective action plan for cleaning and maintenance.
- Corrective action schedule for repairs.
- Repair screens.

2.5.7 Additional Information and Resources

Asset Management: A Handbook for Small Water Systems Publication Number EPA 816-R-03-016

American Water Works Association
(800)-926-6142
www.awwa.org

AWWA (American Water Works Association). 1987b. *AWWA Standard for Factory-Coated Bolted Steel Tanks for Water Storage.* AWWA D103-87. Denver, Colo.: AWWA.

AWWA (American Water Works Association). 1995a. AWWA *Standard for Circular Prestressed Concrete Water Tanks with Circumferential Tendons,* AWWA D115-95. Denver,Colo: AWWA.

AWWA (American Water Works Association). 1995b. *AWWA Standard for Wire- and Strand-Wound Circular Prestressed-Concrete Water Tanks*. AWWA D110-95. Denver, Colo: AWWA.

AWWA (American Water Works Association). 1996a. *AWWA Standard for Flexible-Membrane Lining and Floating-Cover Materials for Potable-Water Storage*. AWWA D130. Denver, Colo.:AWWA.

AWWA (American Water Works Association). 1996. *AWWA Standard for Welded Steel Tanks for Water Storage.* AWWA D100-96. Denver, Colo.: AWWA.

AWWA (American Water Works Association). 1998. *AWWA Manual M42—Steel Water-Storage Tanks*. Denver, Colo.: AWWA.

Kirmeyer, G.J., L. Kirby, B.M. Murphy, P.F. Noran, K.D. Martel, T.W. Lund, J.L. Anderson, and R. Medhurst. 1999. *Maintaining and Operating Finished Water Storage Facilities*. Denver, Colo.: AWWA and AWWARF.

Recommended Standards for Water Works, 2007, Great Lakes-Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers. http://10statesstandards.com/waterstandards.html

2.6 Pumps

For many public water systems, pumps are a critical component of the distribution system. During a sanitary survey, the conditions of pumps/pump facilities and controls should be reviewed. The surveyor should evaluate the operation and maintenance as well as safety practices to determine that water supply pumping facilities are reliable.

2.6.1 Examples of Significant Deficiencies

- Lack of adequate pumping capacity or emergency power at critical facilities.
- Cross connections to auxiliary supplies or cooling water.
- Pump inspection and maintenance not included in system O&M plan; system does not comply with plan.

2.6.2 Identifying Corrective Actions

- Corrective action plan for installation of required pumping capacity or emergency power.
- Remove cross connection or install backflow protection.
- Include pump inspection and maintenance in O&M plan; perform as required.

2.6.3 Additional Information and Resources

Asset Management: A Handbook for Small Water Systems
Publication Number EPA 816-R-03-016

American Water Works Association
(800)-926-6142
www.awwa.org

Recommended Standards for Water Works, 2007, Great Lakes-Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers. http://10statesstandards.com/waterstandards.html

2.7 Monitoring, Reporting and Data Verification

All PWSs are required to perform water quality monitoring to determine compliance with drinking water standards. The constituents monitored and the monitoring frequency vary with system size and source. Compliance with National Primary Drinking Water (NPDW) standards is based on self-monitoring and reporting and the sanitary survey provides an opportunity to review these procedures.

2.7.1 Examples of Significant Deficiencies

- Failure to monitor water quality or treatment.
- Failure to monitor water quality in accordance with required monitoring plans.
- Failure to report water quality monitoring.
- Operators are using improper procedures and/or methods when collecting samples or conducting onsite analyses.
- Falsification of sampling records, laboratory, or other data.

2.7.2 Identifying Corrective Actions

- Monitoring plans or revisions to monitoring plans.
- Training plan for system staff.
- Contracts with certified laboratories.

2.7.3 Additional Information and Resources

The Standardized Monitoring Framework: A Quick Reference Guide, Publication Number EPA 816-F-04-010. www.epa.gov/safewwater/regs.html

Lead and Copper Rule: A Quick Reference Guide, Publication Number EPA 816-F-04-009. www.epa.gov/safewwater/regs.html

Analytical Methods for Drinking Water http://www.epa.gov/safewater/methods/methods.html

EPA's Interactive Sampling Guide for Drinking Water System Operators, Publication Number EPA 816-C-06-001. http://yosemite.epa.gov/water/owrccatalog.nsf/

A Small System Guide to the Total Coliform Rule, Publication Number EPA 816-R01-017A. http://yosemite.epa.gov/water/owrccatalog.nsf/

2.8 System Management and Operations

PWSs need access to technical managerial and financial resources to provide a reliable supply of drinking water meeting State and Federal standards and to maintain public health protection. Smaller systems, many of which are groundwater systems, face unique challenges in providing drinking that meets standards and in operating and maintaining treatment and distribution systems.

2.8.1 Identifying Financial Resources

Small communities may be unable to maintain even low-cost ground water technologies without adequate management and revenues. Fee structures should take into account operating funds and revenues for capital improvements. In some communities, insufficient funding is the result of a small population and very low average per capita income. Unfortunately, without adequate funding, small systems have difficulty hiring skilled managers who could increase revenues and ensure effective business planning.

State and local governments, as well as Technical Assistance Centers, Environmental Finance Centers, Rural Water Associations, Rural Community Assistance Partnerships, and other technical assistance providers, may be available to assist small systems with identifying and overcoming these deficiencies. Some States have performance appraisal programs that require each regulated water system to assess its short-and long-term ability to:

- Provide adequate quantities of water;
- Meet water quality standards; and
- Operate and maintain the plant.

States can also require PWSs to achieve levels of performance prior to issuing operating permits. The performance appraisal by either the State or PWS may include evaluating the following:

- The system's record of responses to previous significant deficiencies, orders, or outbreaks.
- Compliance with water quality standards, including monitoring requirements.

Regulators historically have considered waterborne disease outbreaks, compliance with drinking water standards, operator certification, and sanitary surveys when evaluating small systems. According to the National Research Council (1997), an area that has been overlooked is comprehensive short-term (less than 5 years) and long-term financial planning (20 years). PWSs should engage local governments to provide information on future trends in the service area, population, land use policies, and water demands to evaluate the need for system improvements. Costs for future improvements can be compared to current and future budgets enabling the GWS to project the future rates that would be needed to sustain these budgets.

If funding problems affecting a system's future fiscal viability are discovered, the system should restructure on its own or involve outside entities such as regional water authorities, local government, or private water systems to plan for and solve the problems. Financial restructuring fits one of four categories (National Academy Press, 1997):

- Direct ownership where the PWS agrees with another authority to take over system ownership or to join with another system to form a regional water authority or agency.

- A regulatory takeover where the State takes responsibility for transferring management of a failing utility to another entity, or where the owner does not voluntarily relinquish control of the PWS.

- Contract service where O&M, monitoring, emergency assistance, and routine administration are handled by a contractor.

- Support from another utility in the form of training, or purchasing supplies or water to receive high volume discounts.

Each of these options should be designed to control consumer costs by consolidating one or more PWS responsibility within a larger agency or system while improving operations, reliability, quantity, or quality as needed. The unwillingness of an entity to take over a PWS with problems because of the potential for financial burdens for system improvements, or the fear of liability for water quality standards violations can become a barrier to financial restructuring. States should develop incentives for consolidation or restructuring where appropriate, and limit the use of State Revolving Funds (SRFs) to circumstances where all other possibilities have been exhausted (as determined from State performance appraisals). American Water Works Association Research Foundation (AwwaRF) project #4075 (expected to be finalized in 2008) and AwwaRF Report 91146 should present benefits of system consolidation and other regional solutions to water services, including case studies.

2.8.2 Security Measures

Systems have areas that are potentially susceptible to security breaches such as at a system's wells, storage facilities, and pumping stations. During a sanitary survey, the surveyor should assess the site security of the water system to determine the potential for intruder access. If the water system is permitted, there may be provisions related to security in the permit that will be checked. Vulnerable areas include un-manned or temporarily un-manned areas with finished water. If a system is notified of potential areas for vandalism, it should install appropriate security measures. Helpful references, such as *Guidelines for Physical Security of Water Utilities* (AWWA, 2006), should be used for guidance. Any potable water storage tank should be enclosed by an intruder-resistant fence with a lockable access gate. Systems should also ensure that all buildings such as well houses and pump stations are locked with secure locking systems. Facility staff should remove ladders to storage facilities and/or lock the ladder access opening. Systems should padlock access hatches, ensure that vents are secure, and include an internal or in-line check valve for design overflows to prevent the introduction of contaminants. In the rare cases where vandalism is a real problem and presents a significant risk, the system may need to provide a security staff.

2.8.3 Examples of Significant Deficiencies

- Failure to meet water supply demands/interruptions in service.
- Inadequate technical, managerial and financial resources to continue to reliably operate the system.
- Inadequate resources for emergency response or lack of emergency response plan.
- Inadequate staffing to ensure proper operation and system control.

2.8.4 Identifying Corrective Actions

- Additional source of supply, new service limits, interconnections or cooperative agreements with nearby systems.
- TMF capacity development improvement plan.
- Asset management plan, operations plan, and/or business plan.
- Emergency response plans, cooperative agreements.

2.8.5 Additional Information and Resources

AWWA

Effective Utility Management Primer for Water and Wastewater Utilities: http://www.awwa.org/files/Resources/EffectiveUtilityManagement4color.pdf

Regional Solutions to Water Supply Provision. AwwaRF Report 91146. http://www.awwarf.org/

EPA

Technical: http://www.epa.gov/safewater/smallsystems/technical_help.html
Managerial: http://www.epa.gov/safewater/smallsystems/managementhelp.html
Financial: http://www.epa.gov/safewater/smallsystems/financialhelp.html

Compliance: http://www.epa.gov/safewater/smallsystems/compliancehelp.html
Emergency/Response Planning: http://cfpub.epa.gov/safewater/watersecurity

Sources of Technical and Financial Assistance for Small Drinking Water Systems, Publication number EPA 816-K-02-005

Asset Management: A Handbook for Small Water Systems, Publication Number EPA 816-R-03-016

Strategic Planning; A Handbook for Small Water Systems, Publication Number EPA 816-R-03-015

Drinking Water State Revolving Fund-http://www.epa.gov/safewater/dwsrf/

2.9 Operator Compliance with Certification Requirements

Operator certification programs establish minimum professional standards for the operation and maintenance of public water systems. In 1999, EPA issued operator certification program guidelines specifying minimum standards for certification and recertification of the operators of community and nontransient noncommunity public water systems. While the specific requirements vary from State to State, operator certification programs generally set minimum certification requirements based on criteria such as system size and the type of treatment provided.

All States have operator training programs for PWS operators through workshops, informal instruction, equipment vendors, and technical schools and universities. Management and administration of the system are essential to system sustainability, but many training programs do not address these areas, even though many operators of small systems are responsible for them (National Academy Press, 1997). Recommended training areas for running a small water system include the following:

- Metering,
- Customer service,
- Financing,
- Administration,
- Budget management (unless another entity is responsible for it),
- Water treatment,
- Water distribution, and
- Public health.

Several types of training should be part of an on-going and coordinated effort to meet the needs of small systems. A PWS design may be very advanced even in a small system. Therefore it is recommended that small system operators receive system-specific training from either the equipment manufacturer or other sources on how to operate their treatment processes to ensure that they are thoroughly educated.

2.9.1 Examples of Significant Deficiencies

- No certified operator where one is required by the State.
- Operator is not certified at the level required by the State.

2.9.2 Identifying Corrective Actions

- Corrective action plan or compliance plan/agreement for certification.
- Assistance from other PWSs.
- Contracts or other formal arrangement for certified operator support.

2.9.3 Additional Information and Resources

Association of Boards of Certification (ABC) http://www.abccert.org/certificationrecip.html

EPA Operator Certification Information www.epa.gov/safewater/operatorcertification/index.html

AWWA Operator Certification Information
(800)-926-6142
http://www.awwa.org

University of Florida TREEO Center
(352) 392-9570
http://www.treeo.ufl.edu/

Sacramento State University-Office of Water Programs
(916) 278-6142
http://www.owp.csus.edu/

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3. Eliminating Sources of Contamination

This chapter presents some of the corrective actions a PWS can employ to eliminate, remove, or remediate causes and sources of contamination. The purpose of these corrective actions is to eliminate existing potential sources of microbial contamination within water supply sources, distribution systems, and storage tanks; to minimize the impact of flooding; and to eliminate cross-connections that can contaminate a PWS. This chapter will discuss the following corrective actions:

- Source Water Rehabilitation
  - Identifying contamination causes,
  - Preventing contamination from an abandoned well,
  - Rehabilitating an existing well, and
  - Minimizing contamination after a flood.

3.1 Source Water Rehabilitation

3.1.1 Identifying Contamination Causes

Salvato (1998) identified five probable causes of fecal contamination of ground water used as a source for drinking water:

1. Lack of proper disinfection of a well following repair or construction;
2. Failure or lack of a sanitary seal at the place where the pump line goes through the casing;
3. Failure to seal the annular space between the drilled hole and the outside of the casing; and
4. Contamination by surface water or wastewater from the surrounding soil or the aquifer.
5. Cracked or separated well casing that allows ground water from the surface or a contaminated strata to enter.

For situations where the appropriate corrective action is not obvious, or where the sanitary survey does not provide enough information, the State should work with the system to fill in the information gaps as necessary to identify effective actions that can be taken quickly and at a low cost. Where needed, extra time may be required to determine the direction of ground water flow under static and pumping conditions. Federal and State records should be reviewed to determine potential underground sources of contamination. County or local health department records may also have to be reviewed and local land and business owners interviewed to identify all possible underground sources of contamination.

Additionally, multiple contamination sources may complicate identification or elimination of the contaminant sources. Even if a source of contamination is eliminated, there may be a period of time that a well will continue to be contaminated. Therefore, systems should decontaminate any contaminated wells and verify results of corrective actions with further source water microbial monitoring.

Additional detail about item one (the lack of proper disinfection) is provided in Section 3.1.3.4; the remaining items are discussed in more detail in this section.

Failure or lack of a sanitary seal at the place where the pump line goes through the casing

If the suspected cause of contamination is an underground leak where a pump line goes through the casing, a dye or salt solution can be poured around the casing, and samples taken for visual or chemical analysis. The seal can also be excavated to visually inspect for damage. If contamination is through holes in the casing or if there are channels leading to the casing from a source of contamination, dyes can be used to trace the flow path. A light source or mirror can be lowered into the casing to see if light coming through cracks in the casing is visible outside the casing (Salvato, 1998).

Failure to seal the annular space between the drilled hole and the outside of the casing

Depending on the results of dye tests and other investigation, some sources can be remediated with simple repairs. Other deficiencies, such as an unsealed annular space, are more difficult to correct. An experienced well-driller should be contacted to investigate the possibility of grouting the annular space and installing a new casing or inner casing in rock or other tight sealing material (Salvato, 1998). If the casing is not a problem, then pollutants are most likely flowing to the well through the aquifer. In some cases, although this is costly, the well casing could be sealed at some depth to seal off the polluted stratum, or drilled deeper to a new water-bearing layer. Unless the polluted layer of water-bearing material is effectively sealed off, future contamination cannot be prevented.

Contamination by surface water or wastewater from surrounding soil or the aquifer

Shallow wells and wells near a surface water body in an aquifer that is loosely consolidated can experience contamination from surface water. If a ground water source is experiencing contamination from surface water, then it should be evaluated to determine if it is GWUDI. If classified as GWUDI, the system would be considered a subpart H system and must provide treatment and meet the other requirements of the SWTRs. If not classified as GWUDI or an underground aquifer is contaminated by leaking septic tanks or other contamination sources and the source of contamination cannot be eliminated, the system may need to replace, rehabilitate, or abandon the well.

Systems replacing or abandoning a well should check with their State to determine the State-specific closure requirements to ensure that the well is properly disconnected and filled. Wells that are not properly abandoned can create pathways that allow contamination to enter an otherwise protected aquifer. An abandoned well should be sealed in a manner that restores geological conditions that existed before the well was installed (Recommended Standards for Water Works. 2007). The well should be filled, preferably with cement grout or concrete, and sealed to prevent any water from passing into the aquifer (or in accordance with State or local requirements).

Cracked or separated casing of a well that allows ground water from the surface or a contaminated strata to enter.

If a well casing becomes cracked or separated it may allow ground water from the surface or a contaminated strata to enter into the well. This and other problems occurring below grade may be diagnosed by completing a video inspection of the interior of the well. If a crack or separation is identified during the inspection, the system may need to rehabilitate, replace, or properly abandon the well.

3.1.2 Preventing Contamination from an Abandoned Well

Abandoned wells can offer a near-perfect conduit for contaminants from the surface (i.e., runoff water, waste disposal) or below-grade (i.e., septic systems, Class 5 shallow injection wells, overlaying contaminated aquifers) to migrate into underground sources of drinking water. Some abandoned wells have had the casing removed leaving the entire bore hole open for passage of fluids. Larger, open wells also pose safety hazards for small children and animals. Often these abandoned wells are old and poorly constructed with no grout seal around the casing and/or no cap on the casing. This allows water and contaminants to move down the casing through the annular opening or casing and contaminate the aquifer that supplies drinking water to the nearby PWS.

When a system has concluded that an abandoned well is the source of contamination it should contact the State primacy agency to obtain information on the correct procedures for proper abandonment. Currently, the majority of States have detailed construction standards for well abandonment that are crafted to keep water and contaminants from migrating up or down the bore hole. In most cases, when a well is to be permanently abandoned, the State will require it to be completely filled in such a manner that vertical movement of water within the well bore, including vertical movement of water within the annular space surrounding the well casing, is effectively and permanently blocked. All fluids within the well should be confined to the specific strata that they were originally encountered in and the controlling geologic conditions restored to those of pre-well construction.

Artesian wells, free-flowing artesian wells, and gravel pack wells can present special abandonment problems. Often States have specific standards for abandoning these kinds of wells. If the State does not have such standards, the system should seek advice from an engineer, well driller, hydrologist, or other professional.

When installing a new well, or rehabilitating a current well, it is important to comply with State standards and requirements. Many States may also have certification or other approval requirements for contractors working on well installation or maintenance.

3.1.3 Remediating an Existing Well

A well's structure should be in good operational condition to ensure a dependable supply of high quality source water is available at all times. Good operational condition means the piping is not leaking or corroded, the valves and controls are operable, and the electrical system is protected from the elements and is not corroded. In some cases, the transport of microorganisms occurs due to improper well seals or casings that can result in conduits for fecal contamination to pass into the water supply. This is particularly true of small systems and older systems that were not originally constructed in accordance with their respective State's design and construction standards (Linsley et al., 1992). Prior to making significant investments in well remediation, systems should consider hiring a qualified contractor to assess the well integrity and condition. Remediating an existing well that is at the end of its useful life may not be cost-effective.

If a system must remediate a well, it may need to repair or replace the well screen, well casing, well seal, or even the well pump. The system should consult with applicable State or local standards when repairing or replacing well components. Systems should also carefully adhere to any applicable standards required during the well's reparation (e.g., NSF/ANSI Standard 61 for drinking water system components) and for disinfecting and flushing after the well has been serviced (e.g., ANSI/AWWA Standard C654-03 for disinfection of wells).

Surface runoff can migrate down the annular space along the outside of the well casing and contaminate the aquifer. Therefore, all sources of leakage should be plugged to prevent contamination. The most visible point of leakage is the encasement at the surface. The construction of the well above the surface should prevent leakage down the outside of the well casing as well as through the casing cap located on top of the casing. By extending the casing at least 18 inches above the well slab, surface runoff should not be able to enter the casing. The well slab should be concrete and sloped away from the casing. The well site should be graded to prevent ponding of surface water and to direct drainage away from the wellhead. The well casing cap should be a watertight sanitary seal to prevent water from entering through it. In addition, the casing vent through the cap should extend above flood level to preclude surface runoff from entering the well directly, and the end of the vent should be terminated with a downward turned gooseneck and screen to prevent rain and bugs from entering.

Valves and meters should be fully functional and well maintained to keep out contamination. Personnel should have sufficient access to these valves for cleaning. The electrical system should be protected from lightning since the sudden electrical surge caused by lightning striking the wellhead or nearby may cause the electrical components to burn out. Ground fault protection is important to protect the operator.

Wells with submersible pumps should be capped and the cap should be sealed so no water or contamination can enter the well. Seals should fit properly to accommodate all well appurtenances. If the well is not housed, the well cap should be locked and lightning protection should be provided. Exhibit 3.1 provides an example of a properly sealed well that is not housed. Wells with a lineshaft turbine pump mounted on top of the casing should have a metal support plate on which a rubber gasket is mounted to provide a sanitary seal. The motor, along with an attached column and discharge head, is mounted on top of the gasket and support plate. The rubber gasket should be checked periodically to ensure it is in good condition and providing a sanitary seal.

Exhibit 3.1 Sealed Well that is Not Housed

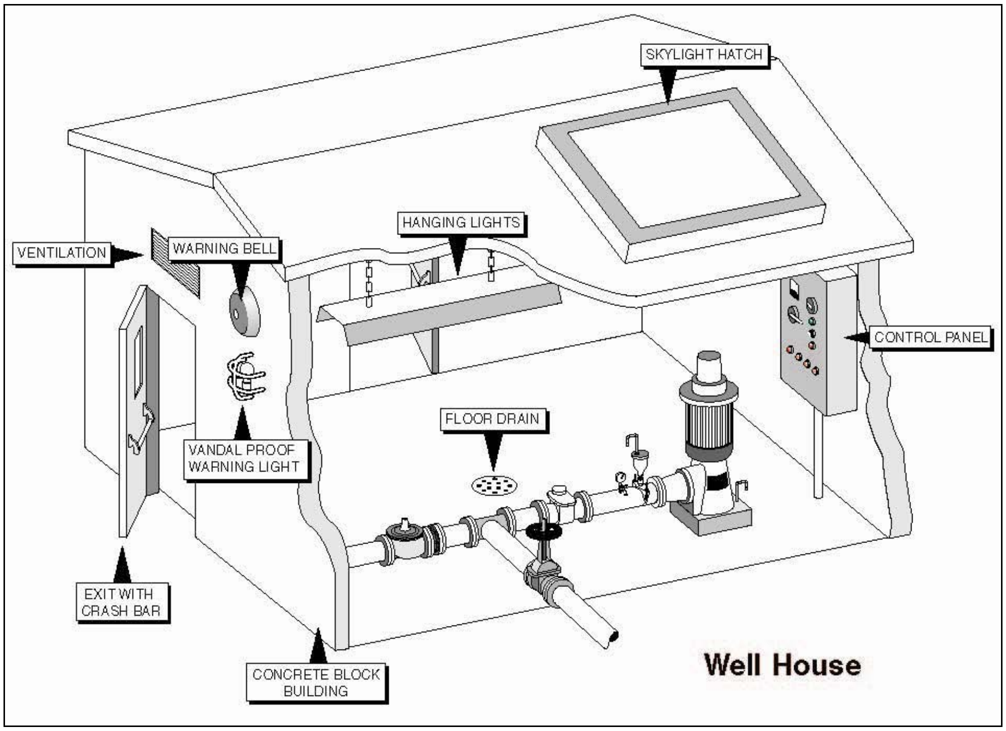
Well casings should be vented to the atmosphere. For wells with submersible pumps, the vent should terminate in a downward "U" position, and should be located at or above the top of the casing. The vent's opening should be screened with a 24 mesh corrosion resistant screen. Wells with turbine pumps mounted on top of the casing frequently are vented to the side of the casing. These vents should be located high enough to prevent water from entering them and should also be properly screened (Recommended Standards for Water Works, 2007).

The discharge from the well should have a sample tap with a smooth nozzle to allow for sampling before the addition of any chemicals or disinfectants and before any treatment step. A sample of the raw water will allow the water system to test for contaminants that might be present or any changes in source water quality.

Wells that are housed should be located in a properly constructed and maintained building. Exhibit 3.2 shows an example of a properly constructed pump house and its appurtenances. The discharge piping of housed wells and wells in the open is often located below ground. In such cases, the well is usually fitted with a pitless unit or pitless adaptor. Water systems should check with their States to see if there are restrictions on the use of pitless adaptors. Exhibit 3.3 shows an example of a submersible pump with pitless adapter.

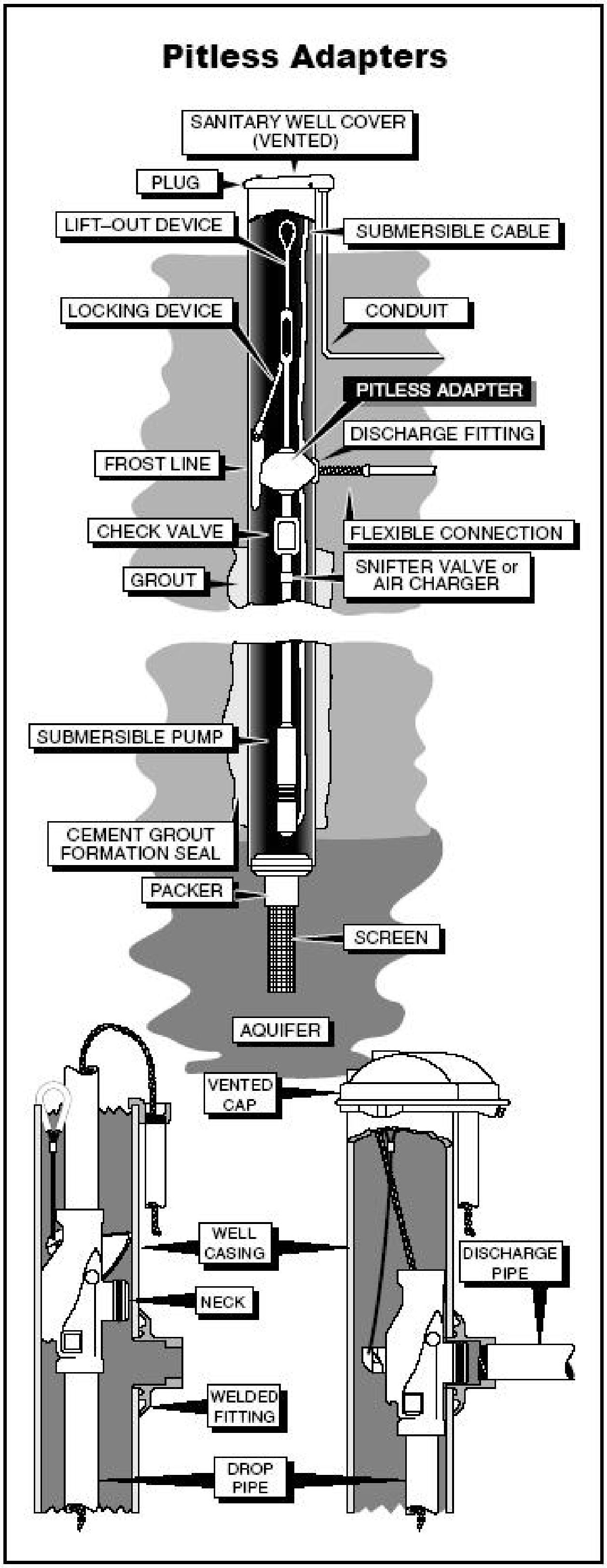
The pump room floor should be watertight, preferably made of concrete and should slope away from the well casing in all directions (Ten States Standards, 2007). It is unnecessary to use an underground discharge connection if an insulated, heated pump house is provided. If the pump room is not continuously manned, it is not necessary to maintain the temperature at typical room conditions, only warm enough to prevent freezing. For individual installations in rural areas, a thermostatically controlled electric heater will generally provide adequate protection for the equipment when the pump house is properly insulated.

Exhibit 3.2 Pump House and Well Appurtenances



Source: USEPA, 2003

Exhibit 3.3 Submersible Pump with Pitless Adapter



Source: USEPA, 2003

In some cases, the transport of microorganisms occurs due to improper well seals or casings that can result in large, open conduits for fecal contamination to pass unimpeded into the water supply. This is particularly true of small systems and older systems that were not originally constructed in accordance with their respective State's design and construction standards (Linsley et al., 1992).

If a system must remediate a well, it may need to repair or replace the well screen, well casing, well seal, or even the well pump. The well casing should extend above ground, and the system should grade the ground surface at the well site to drain away from the well. If a new well casing is needed, the system should consult with applicable State or local standards, or where no regulations exist, consult with other national criteria such as the AWWA Standards (1997) or the Ten States Standards (2007) (Chapter 3.2).

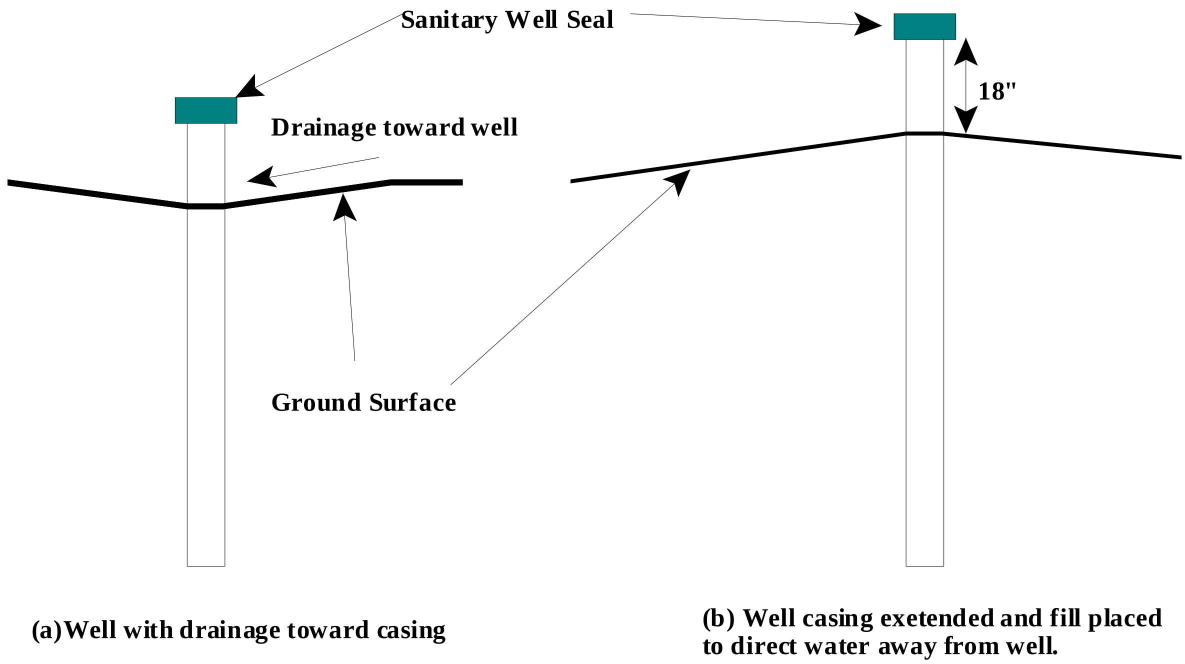
The following subsections contain information regarding well rehabilitation, including correcting drainage problems, replacing a sanitary well seal, eliminating a well pit, and disinfecting wells and applying shock chlorination.

3.1.3.1 Correcting Drainage Problems

Wells should be located in areas with good drainage to prevent surface water runoff from entering the well casing where it may find its way into the ground water via the annular opening around the casing. Drilling in an area of low elevation allows the driller to penetrate the aquifer at a shallower depth from ground surface and reduces drilling costs. Unfortunately, it can also make the well subject to contamination from surface runoff.

Exhibit 3.4 depicts how a drainage problem can be corrected by placing fill material around the well casing, compacting the fill, and grading it away from the casing. In some cases the well casing may need to be extended to ensure that it terminates a minimum of 18 inches above the final ground surface (Ten States Standard, 2007). EPA recommends that systems pour a concrete pad around the casing to ensure drainage away from the well.

Exhibit 3.4 Example of Correcting Drainage Problems



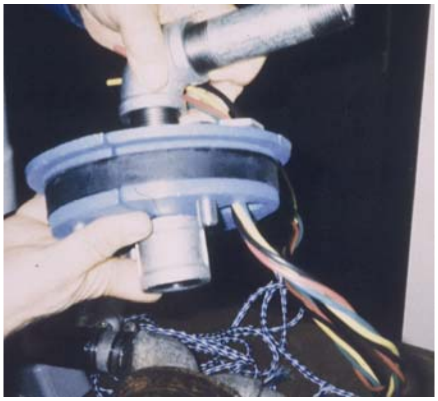
3.1.3.2 Replacing a Sanitary Well Seal

Well seals are used to cover the top of a well casing pipe to prevent surface runoff from entering the casing (Purdue, 1997). In some cases sanitary well seals must be replaced to prevent additional contamination from entering the well through the top of the casing.

Well seals are provided with vents to allow air movement in and out of the casing as the water level fluctuates with pumping. The vents are screened to exclude insects and have openings turned downward in order to keep out dust. Systems should check seals and vents regularly, however, because insects and mice may enter in the event that a power cable opening is unprotected, a vent is unscreened, or a well cap overlaps with, but does not completely seal, the well casing.

The sanitary well seal pictured in Exhibit 3.4 is designed for use on wells that are terminated within well houses. As the bolts are tightened, the two plates are pulled together, expanding the gasket material located between the plates. This seals the openings around the casing, the pump drop pipe, the inverted U-type screened vent, and the electrical conduit.

Exhibit 3.5 Sanitary Well Seal with Expandable Gasket



The well seal shown in Exhibit 3.5 is more commonly used in outdoor applications with submersible pumps and pitless adapter units. This seal has no openings on its top and is sloped so that rainwater will run off. The vents are located on the underside of the lip surrounding the casing, and gasket material seals all openings around the casing and conduit.

Exhibit 3.6 Overlapping Exterior Well Seal

The replacement well seal must be of the proper size and type to fit the casing and accommodate other well appurtenances. Systems should coordinate with the State to make sure that the type of replacement well seal chosen is approved by the State.

3.1.3.3 Eliminating a Well Pit / Buried Well

In the northern parts of the United States, many older wells were terminated within pits in order to keep them from freezing during colder months. Such pits are dangerous to enter because of confined space safety issues, and are subject to flooding that can cause loss of service and contamination of the aquifer. Well pits are not considered a method of sanitary construction.

To eliminate the well pit, the system should extend the casing so that it will terminate at least 18 inches above the finished grade or 12 inches above the pump house slab (Ten States Standards, 2007). The pit then should be backfilled with suitable material and compacted. Bentonite or other grout material should be placed around the casing as backfilling occurs in order to keep water from moving down the casing. A pump house should be constructed around the well if the original pit well was constructed to keep the top of the well below the frost line.

3.1.3.4 Temporary Disinfection of Wells by Applying Shock Chlorination

If a system is found to have a serious deficiency or fecal contamination, it may take time for the system to design and install a corrective action. In the meantime, the system cannot serve the contaminated water to its customers. The primacy agency may require the system, as part of its corrective action, to apply chlorination until the contamination is eliminated or a corrective action is put in place. Hypochlorination will generally be used because it is easier to install and operate than gaseous chlorination or other disinfection methods and is the least costly of the treatment methods.

It is important to note that temporary disinfection is meant to deal with a single contamination event, such as a flood, or maintenance on a well. Shock chlorination is not intended to deal with a chronic problem, such as a cracked casing or a well next to a failed septic system.

Shock chlorination can be effectively used to treat iron- and sulfate-reducing bacteria in PWSs and to treat PWSs contaminated with high levels of heterotrophic plate counts (HPC) or coliform bacteria (Alberta, 1999). Disinfection should occur promptly in order to reduce the possibility of growth of undesirable biofilms within the well and reduce the potential for migration of the microbial contaminants.

It is essential to make sure that the disinfecting agent comes in contact with all portions of the well, pumping equipment, and plumbing during shock chlorination. To be effective, shock chlorination must disinfect the following (Alberta, 1999):

- The entire well depth;
- The formation around the bottom of the well;
- The pressure system;
- Some water treatment equipment; and
- The distribution system, if needed.

Disinfection with Calcium Hypochlorite

Calcium hypochlorite solution (approximately 65 percent available chlorine by weight) is an effective and widely used method of disinfecting wells (USEPA, 1982). Calcium hypochlorite is available in tablet and powder form. Exhibit 3.7 shows quantities of calcium hypochlorite to be used in treating wells of different diameters and water depths.

When disinfecting newly constructed wells or disinfecting wells after maintenance, calcium hypochlorite is added to provide a dosage of at least 100 milligrams per liter (mg/L) of available chlorine in the well water. For wells with chronic biofouling problems, much higher concentrations of chlorine and repeated applications may be necessary. Additional chemicals and treatment techniques may be needed if biological growth has caused encrustation of the well (see Borch, et al., 1993 for details). While preparing a stock solution of calcium hypochlorite, the percent available of chlorine by weight must be taken into account during the weighing of the chemicals. It is useful to prepare a stock solution first (e.g., mixing 2 ounces of hypochlorite with 2 quarts of water).

Exhibit 3.7 Quantities of Calcium Hypochlorite, 70% to Provide a Chlorine Dosage of at Least 100 mg/L

Well Diam.Inches	2	3	4	5	6	8	10	12	16	20	24	28	32	42	48
Depth(feet)															
5	1T	1T	1T	1T	1T	1T	2T	3T	5T	6T	3 oz.	4 oz	5 oz	7 oz	9 oz
10	1T	1T	1T	1T	1T	2T	3T	5T	8 T	4 oz	6 oz	8 oz	10	13 oz	1.5 lb
15	1T	1T	1T	1T	2T	3T	5T	8 T	4 oz	6 oz	9 oz	12 oz	1 lb.	1.5 lb.	1.5 lb
20	1T	1T	1T	2T	3 T	4 T	6 T	3 oz	5 oz	8 oz					
30	1T	1T	2T	3T	4 T	6 T	3 oz	4 oz	8 oz	12 oz					
40	1T	1T	2T	4 T	6T	8 T	4 oz	6 oz	10 oz	1 lb					
60	1T	2T	3 T	5T	8 T	4 oz	6 oz	9 oz							
80	1T	3 T	4 T	7 T	9 T	5 oz	8 oz	12 oz							
100	2T	3 T	5 T	8 T	4 oz	7 oz	10 oz	1 lb							
150	3T	5 T	8 T	4 oz	6 oz	10 oz	1 lb	1.5 lb							

Source: (USEPA, 1982)
Notes: Quantities are T = tablespoons; oz = ounces (by weight); lb = pounds.
Values corresponding are solid calcium chloride required.

Exhibit 3.8 Liquid Chlorine Bleach* (5.25%) to Provide a Chlorine Dosage of at Least 100 mg/L

Well Diam.Inches	2	3	4	5	6	8	10	12	16	20	24	28	32	42	48
Depth(feet)															
5	1C	1C	1C	1C	1C	1C	1C	1C	2C	4C	1 Q	2 Q	3 Q	3Q	3 Q
10	1C	1C	1C	1C	1C	1C	2C	2 C	1 Q	2 Q	3 Q	4 Q	4 Q	6 Q	8 Q
15	1C	1C	1C	1C	1C	2C	3C	4 C	2 C	2.5 Q	4 Q	5 Q	6 Q	2 G	3 G
20	1C	1C	1C	1C	1C	2 C	4C	1 Q	2.5 Q	3.5 Q					
30	1C	1C	1C	1C	2C	4C	1.5 Q	2 Q	4 Q	5 Q					
40	1C	1C	1C	2C	2 C	1 Q	2 Q	2.5 Q	4.5 Q	7 Q					
60	1C	1C	2 C	3C	4 C	2 Q	3 Q	4 Q							
80	1C	1C	2C	4 C	1 Q	2 Q	3.5 Q	5 Q							
100	1C	2C	3 C	1 Q	1.5 Q	2.5 Q	4 Q	6 Q							
150	2C	2C	4 C	2Q	2.5 Q	4 Q	6 Q	2.5 G							

* That meets NSF Standard 60.
Notes: Quantities are C = cups; Q = quarts; G = gallons.
Values corresponding are amounts of liquid household bleach.

Operators of systems using calcium hypochlorite should be cautious when handling and storing the chemical and should always carefully read and follow all safety and storage instructions. Calcium hypochlorite should always be added to water (i.e., water should never be added to calcium hypochlorite). Calcium hypochlorite will release chlorine gas on contact with acids and should be stored separately. Also, since the chemical exhibits caustic and corrosive properties, operators should wear goggles, gloves, and respirators when working with calcium hypochlorite, and should only work in areas with suitable ventilation.

Protocols for disinfecting new or recently repaired wells can be found in American Water Works Association (AWWA) C654-03. A simpler procedure that can be used for smaller wells is as follows (USEPA, 1982):

- Determine the volume of water in the well based on the casing diameter, static water level, and depth of casing. Calculate the amount of chlorine solution or granular chlorine necessary to bring that volume of water, and the water in the plumbing, to the required concentration (see Exhibit 3.7 and 3.8). Before disinfection, the well must be purged of any accumulated sediment and debris and be free of turbidity for disinfection to be effective.

- Add the correct amount of chlorine to 5 - 10 gallons of fresh water and pour the water down the casing. Try to make sure the chlorinated water contacts the inside of the casing and outside of the drop pipe as it enters the well so it can clean and disinfect those surfaces.

- Operate the pump until the odor of chlorine can be detected or use a DPD test kit (a kit which uses test reagents and color charts) to measure the chlorine residual in addition to detecting chlorine odor.

- Shut off the pump and allow the chlorinated water to remain in the well and plumbing for 24 hours.

- After 24 hours, turn on the pump and flush the chlorinated water from the well and plumbing equipment. Make sure the chlorinated water is not discharged to surface water or to any other area where the chlorine could cause damage or violations of the Clean Water Act. Continue flushing for at least one hour after the odor of chlorine has dissipated.

- Collect one coliform sample at the well head for three consecutive days. If any of the three samples are coliform positive, repeat the process.

Once the source water is tested free of chlorine residual, the operator should collect a few samples of water for water quality analysis from a clean non-leaking tap. Water should be flushed from the tap for a few minutes before sampling. The number of bacteriological samples collected depends on State guidelines; samples are sent to a State-approved laboratory for analysis.

Make sure to contact the laboratory for the proper sample collection and storage procedures. Analyses can be run on several chemical, physical, and biological parameters such as nitrogen, lead, manganese and other metals, sulfates, cyanide, pH, and/or coliforms. Most States designate the specific parameters required for analyses.

One of the concerns with disinfecting a newly developed or rehabilitated well is the potential risk of discharging chlorinated waters directly into surface water bodies. Since high levels of chlorine (prior to discharge) can be harmful to aquatic life, chlorinated waters may need to be dechlorinated to reduce the chlorine in the water to acceptable levels. Dechlorination can be achieved by applying dechlorination chemicals such as thiosulfate or ascorbic acid. If the amount of water to be dechlorinated is small, passive techniques such as discharge through hay bales or other natural structures and detention in holding ponds can be used (Tikkanen et al., 2001). These approaches may also be used to treat superchlorinated water pumped from a well.

In some cases, the discharge may be regulated by a National Pollutant Discharge Elimination System (NPDES) or a State permit. PWSs should contact their primacy agency for more information about applying for an NPDES or a State permit. Some utilities may be allowed to inject the chlorinated water and other waste streams into the ground by underground injection wells. The underground injection control (UIC) program regulates the discharge of such units and ensures that the water is discharged below the lowest level of any aquifer serving as a source of potable water and that the migration of the injectate into pristine ground waters is avoided.

3.1.4 Minimizing Contamination after a Flood

After a flood, PWSs should inspect, clean, and pump wells, and then disinfect wells that have been flooded and test the water prior to use. Flood precautions issued by the State and local health department should be followed in addition to EPA guidelines (USEPA, 2005a). Additionally, a PWS should address why the flooding occurred and determine whether the cause of flooding can be eliminated, mitigated, and/or minimized. A system is much better off preventing the contamination by managing the risk of flooding rather than responding to contamination from a flood after the fact.

Floods may cause some wells to collapse; therefore, conditions at the wellhead should be checked. Swiftly moving flood water can carry large debris that could loosen well hardware, dislodge well construction materials, or distort casing. Coarse sediment in flood waters could erode pump components. If the well is not tightly capped, sediment and flood water could enter the well and contaminate it.

Electrical systems should not be turned on until after flood waters have receded and the pump and electrical system have dried. The wiring system should be checked by a qualified electrician, well contractor, or pump contractor. If the pump's control box was submerged during the flood, all electrical components must be dry before electrical service can be restored. Pumps and their electrical components can be damaged by sediment and floodwater. The pump, including the valves and gears, should be cleaned of silt and sand.

To avoid damage to drilled, driven, or bored wells, remove mud, silt and other debris from around the top of the well. If excessive mud, silt or sediment has entered the well, the pump may need to be removed or bailers used to remove mud and silt from the bottom of the well. It is not recommended to attempt to disinfect or use a dug well after it has been flooded.

To minimize contamination after a flood, pump the well until the water runs clear to rid the well of flood water. Depending on the size and depth of the well and extent of contamination, pumping times will vary. If the water does not run clear, further investigation into the cause of the problem is necessary before attempting to disinfect.

Emergency disinfection after a flood should be performed according to the shock chlorination procedures described in Section 3.1.3.4. Wells can remain contaminated even after disinfection procedures are followed, so sampling and testing the water may be necessary to ensure safe drinking water. In extensive flood areas, the speed and direction of ground water flow can cause wells to remain contaminated for months. Septic systems should not be used immediately after floods because drain fields will only work once the ground is no longer saturated. Additionally, water systems should avoid pumping of a septic tank when the soil is saturated to prevent the tank from collapsing due to a static pressure differential. In such cases, long range precautions such as testing should be used to protect drinking water.

Since well disinfection does not provide protection from pesticides, metals, or other types of non-biological contamination, further cleanup and analyses may be necessary when such contamination is suspected. Also, if drums or barrels are moved by the flood within the wellhead protection area, special treatment may be required. For specific questions on various contaminants, the EPA Safe Drinking Water Hotline (1-800-426-4791) or the Superfund Hotline (1-800-424-9346) can be contacted.

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4. Providing an Alternative Source of Drinking Water

If remediating an existing source of drinking water is not an option, the next step is to consider alternative sources of drinking water. If a well is contaminated, abandoning the well and connecting to another public water supply, or consolidating with another utility are options for providing safe drinking water. In some cases bottled water can be used as a short-term solution. Another choice is to install a new well that is properly constructed, cased, and sealed to prevent ground water contamination. This chapter provides detailed descriptions of the types of new wells and well characteristics to consider when installing a new well. The alternative source options addressed in this chapter are:

- Providing bottled water *(Section 4.1)*;
- Consolidating/purchasing water from another utility *(Section 4.2)*;
- Installing a new well *(Section 4.3)*; and
- Switching to a surface water source *(Section 4.4)*.

4.1 Providing Bottled Water (Short Term)

One option for a utility to ensure safe drinking water to its customers is to provide them with bottled water. The use of bottled water in lieu of piped water for direct consumption and cooking purposes is used only as a short-term solution to a contamination problem while other permanent solutions are being implemented for the following reasons (40 CFR 141.101):

- Relative expense of bottled water;
- Demanding logistics of distribution; and
- Does not provide safe water for other household uses.

Bottled water is regulated by the United States Food and Drug Administration (FDA) under the Federal Food, Drug, and Cosmetic Act (21 U.S.C. 301 et seq.) if sold in interstate commerce and by some States when it is sold in those States. Water systems that are distributing bottled water to their users should be sure the bottled water they are distributing meets all applicable State and Federal standards. Systems may elect to require bottled water vendors to conduct or arrange for testing of the bottled water provided to assure consumers of its quality.

If a water system provides its users with bottled water, it should issue a “do not use” or “do not drink” public notice, as appropriate, so the tap water is not consumed. The system should work closely with its drinking water regulators to ensure proper notification is made. The water being provided should be made as readily available as possible to all of the system’s usual users, and special consideration should be given to housebound and immobile people. Systems may consider preparing a brief fact sheet about details of the short-term situation, the bottled water being used, and how it can be obtained. Alternatively, the water system could include such information in its public notice if the State agrees and the system is required to make public notice. Community water systems may consider providing a phone number consumers can call for additional information.

4.2 Consolidating/Purchasing Water from Another Utility

Consolidating with another public water utility may be the only option for a utility with extremely limited financial and technical resources. Such utilities may not be able to invest in new infrastructure for providing their customers with an alternate source of drinking water. Consolidating with a utility that has greater resources at its disposal can help ensure a safe and alternative drinking water supply source to customers.

Purchasing water from another PWS may be a sound economical solution to providing an alternate source of safe drinking water. There are many benefits to purchasing water from a nearby utility including a reduction in the regulatory burden (i.e., monitoring and reporting) that comes from eliminating the source(s) as well as more simplified operations and maintenance. However, the purchasing utility may have to disinfect the water before bringing the purchased water into the distribution system. Deciding to disinfect depends on whether the purchased water has an adequate disinfectant residual to control microbial re-growth in the distribution system and whether disinfection is necessary at all. If disinfection is needed, the purchasing utility may need to install or modify existing contactor and/or clearwell capacity to post-disinfect the water. Whether the purchasing utility adds a chemical disinfectant or the wholesale system adds a chemical disinfectant, the purchasing water system will have to comply with the Disinfection and Disinfection Byproducts Rules (Stage 1 and/or Stage 2) and should work with the State in doing so.

4.3 Installing a New Well

In many cases, the primacy agency and ground water system may find the best corrective action for a contaminated well or significantly deficient well is to install a new well. There are many types of wells –bored, driven, jetted, drilled – which are discussed in this section. In addition, there are basic construction components to wells, such as the well casing (typically steel, plastic, or PVC), grout (typically cement, concrete, or clay), surface seal, and screens. Well siting factors should be considered for the proposed location, including any contamination sources nearby. The proposed well's location in relation to other wells and surface water bodies, its relative size and draw down influences, as well as accessibility to the well site and power sources should also be considered. This section provides an overview of some of the issues that the primacy agency and system should discuss when considering installing a new well as part of a corrective action. The specific standards for design, testing, and installation vary from State to State. When considering installation of a new well, the system should ensure that all relevant issues (e.g., siting, hydraulics, costs, financing, security, etc.) are considered.

4.3.1 Critical Factors in Well Construction

If a decision has been made to install a new well, the availability of adequate quantity and quality of water is the first critical factor. Other critical factors controlling well suitability include well casing and grouting, surface seals, and the potential for flooding (Jorgenson, et al., 1998). These assumptions regarding what constitutes an acceptable well are shown in Exhibit 4.1. Section 4.3.3 provides additional information on sanitary construction of wells.

Exhibit 4.1 Well Construction and Condition

Acceptable	Unacceptable
The well is cased and grouted to the confining layer or production zone	The casing, grouting, or surface seal is damaged or leaking
The casing is steel, plastic, PVC, or other non-porous material	The well is subject to periodic flooding
The well has a surface seal	Shallow well or well under the direct influence of surface water
Well should be of adequate depth and distance from a body of surface water and in an appropriate geology to prevent it from being classified as a GWUDI	

Source: Jorgenson, et al./USEPA, 1998

Casing

All wells should be cased and grouted or otherwise sealed. The casing should extend from the surface through a confining layer (if there is one) or to the production zone in the aquifer. The casing should be composed of a nonporous material such as steel or plastic (Ten States Standards, 2007).

All wells should be constructed in accordance with State and local requirements; common State standards are shown in Exhibit 4.2.

Exhibit 4.2 Ten State Standards (2007) Recommendations for Casing

Steel Casing	Nonferrous Casing
• Temporary steel casing used for construction must be capable of withstanding the structural load imposed during its installation and removal. • Permanent steel casing pipe should: o Be a new single steel casing pipe meeting AWWA Standard A-100, ASTM, or API specifications for water well construction; o Have specified minimum weights and thickness; o Have additional thickness and weight if minimum thickness is not considered sufficient to assure reasonable life expectancy of a well; o Be capable of withstanding forces to which it is subjected; o Be equipped with a drive shoe when driven; and o Have full circumferential welds or threaded coupling joints.	• The following guidelines are for nonferrous casing materials: o Approval of any nonferrous well-casing material is subject to special determination by the reviewing authority before submissions of plans and specifications; and o Nonferrous well-casing material must be resistant to: - Water corrosivity, - Stresses of installation, and - Grouting and operation.

Surface Seal

The surface seal should be installed around the well to protect it from contamination that could enter between the casing and the borehole wall. The seal should fill the space between the casing and borehole wall and extend to a depth at least below the frost line. In some cases, the cement grout can be extended to the surface to form the surface seal (Massachusetts DEP, 2004).

Protection from Flooding

The well should be protected from flooding. A well located in a periodic floodplain or in a topographic depression that collects surface runoff can become contaminated by either direct flow or seepage around the seal. To prevent flooding, the casing can be extended to a height above the expected flood level and surface seals and grout can be used to seal it (Ten States Standards, 2007).

4.3.2 Types of Wells

This section describes different types of wells and how each is constructed. Most wells constructed today are drilled wells. However, bored wells may also be installed or constructed.

According to Ten State Standards (2007), drilling fluids and additives should not impart any toxic substances to the water or promote bacterial contamination. Minimum protected depths of drilled wells provide watertight construction to such depths as may be required by the State to exclude contamination and seal off formations that are or may be contaminated. The system's State may require minimum protected depths for drilled wells in order to exclude contamination and seal off surficial aquifers that may be contaminated. Exhibit 4.3 describes general soil characteristics suitable to different types of wells. Systems installing new wells should be careful to adhere to State well standards.

Exhibit 4.3 Suitability of Well Construction Methods with Different Geological Conditions

Characteristics	Bored	Driven	Jetted
Range of practical depths	0-100 ft	0-50 ft	0-100 ft
Diameter	2-30 inches	1.25-2 inches	2-12 inches
Type of geologic formation			
Clay	Yes	Yes	Yes
Silt	Yes	Yes	Yes
Sand	Yes	Yes	Yes
Gravel	Yes	Fine	¼" pea gravel
Cemented gravel	No	No	No
Boulders	Yes, if less than well diameter	No	No
Sandstone	Yes, if soft and/or fractured	Thin layers	No
Limestone	Yes, if soft and/or fractured	No	No
Dense igneous and metamorphic rock	No	No	No

Characteristics	Drilled		
	Percussion	Rotary Hydraulic	Rotary Air
Range of practical depths	0-1,000 ft	0-1,000 ft	0-750 ft
Diameter	4-18 inches	4-24 inches	4-10 inches
Type of geologic formation			
Clay	Yes	Yes	No
Silt	Yes	Yes	No
Sand	Yes	Yes	No
Gravel	Yes	Yes	No
Cemented gravel	Yes	Yes	No
Boulders	Yes, when in firm bedding	Difficult	No
Sandstone	Yes	Yes	Yes
Limestone	Yes	Yes	Yes
Dense igneous and metamorphic rock	Yes	Yes	Yes

Source: Grundfos, 2007

4.3.2.1 Bored Wells

Bored wells are usually constructed with earth augers turned by hand or power equipment (USEPA, 1973). These wells can be constructed to a depth of up to 100 feet if the water requirement is low and the overlying material contains few large boulders and has non-caving properties (Purdue Research Foundation, 2001). Because the bore holes for these wells must remain open until the casing is installed, the construction of bored wells is most successful in fine-textured soils (Purdue, 1997).

Once the well is bored, casing should be inserted into the hole. Bored wells are cased with vitrified tile, concrete pipe, standard wrought iron pipe, steel casing, or other suitable materials capable of sustaining imposed loads (Purdue Research Foundation, 2001). The well is usually completed by installing well screens or perforated casing in the water bearing strata. A gravel layer (approximately 4 inches) is placed around the casing from 10 feet below the land surface to the well bottom. Cement grouting up to adequate depth is necessary to protect the well from surface drainage. The upper 10 feet of the well should be protected from surface contamination by approved construction methods (Purdue, 1997).

4.3.2.2 Driven Wells

The simplest and often least expensive method of well construction is to drive a drive-well point that is fitted to the end of a series of pipe sections (USEPA, 2006a). Drive-well points come in a variety of designs and materials. Drive points are usually 1.25 inches or 2 inches in diameter and are driven with the aid of a maul, or a special drive weight. For deeper wells, the well points are sometimes driven into the water bearing strata from the bottom of a bored well (Kansas Geological Survey, 2004). If they can be driven to an appreciable depth below the water table, they are no more likely than bored wells to be seriously affected by water table fluctuations. The most suitable locations for driven wells are areas containing alluvial deposits of high permeability.

When driving a well, it is common practice to use a hand auger slightly larger than the well point to prepare a pilot hole that extends to the maximum practical depth. The assembled point and pipe are then lowered into the hole. The pipe is driven by directly striking the drive cap that is threaded to the top of the protruding section of the pipe. A maul, a sledge, or a “special driver” may be used to hand drive the pipe. The “special driver” may consist of a weight and sleeve arrangement that slides over the drive cap as the weight is lifted and dropped in the driving process (Department of the Army, 1994)

4.3.2.3 Jetted Wells

The jetted well technique is a rapid and efficient method of sinking well points (USEPA, 1973). A source of water and a pressure pump are needed to use this technique.

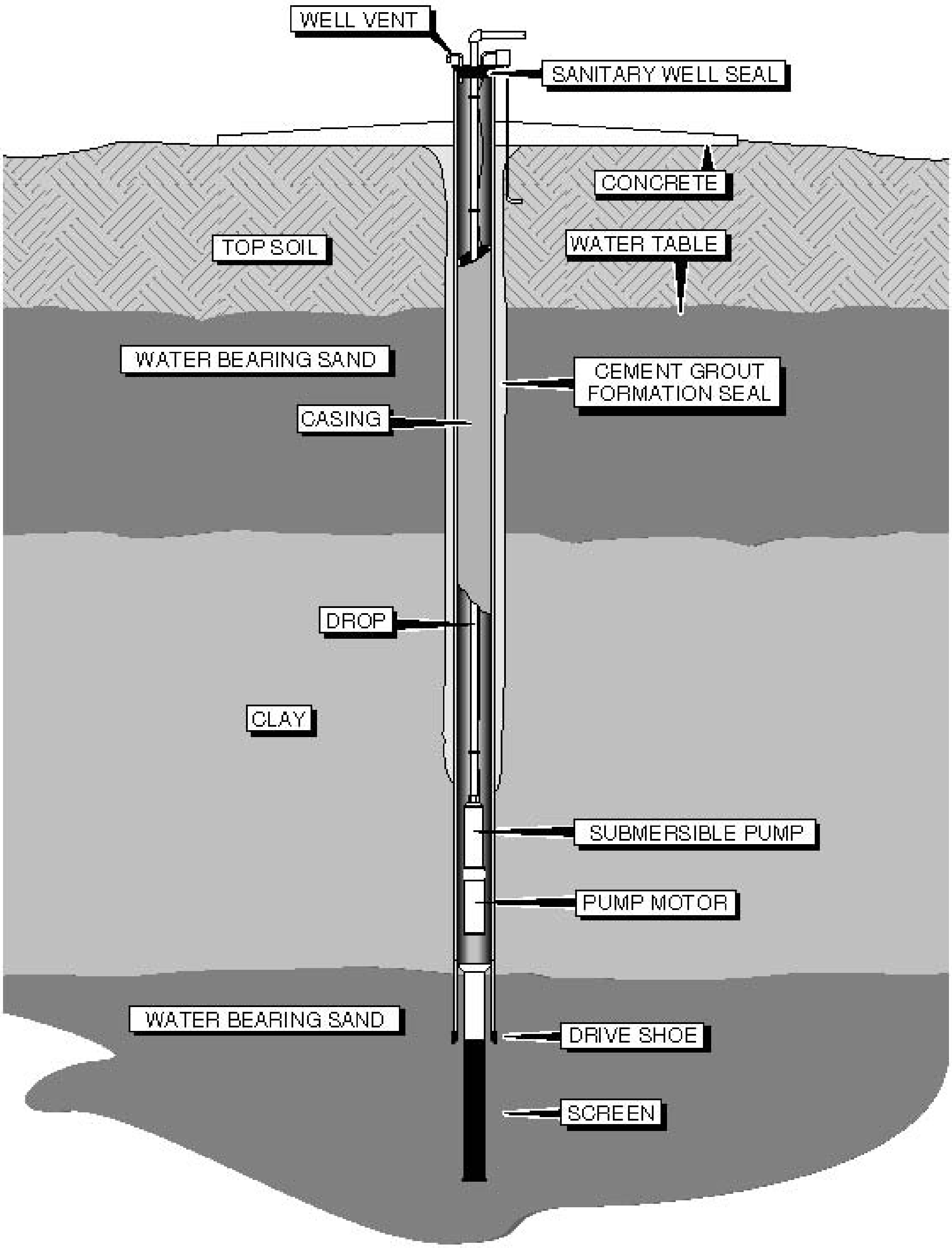
Water is first forced under pressure down the riser and comes out of a special washing point. The well point and pipe are then lowered as material is loosened by the impact of the water jet. Often the riser pipe is used as the suction pipe for the pump. In such cases, surface water may be drawn into the well if the pipe develops holes. An outside protective casing may have to be installed to an adequate depth to ensure protection from the possible entry of contaminated surface water run-off. The space between the casings is also filled with cement grout. It is recommended that the system install the protective casing as an auger hole and to drive the point inside it.

4.3.2.4 Drilled Wells

Exhibit 4.4 shows the layout of a drilled well with a submersible pump. Exhibit 4.5 shows a typical wellhead design for submersible pumps. Construction of drilled wells is accomplished by either percussion or rotary drilling.

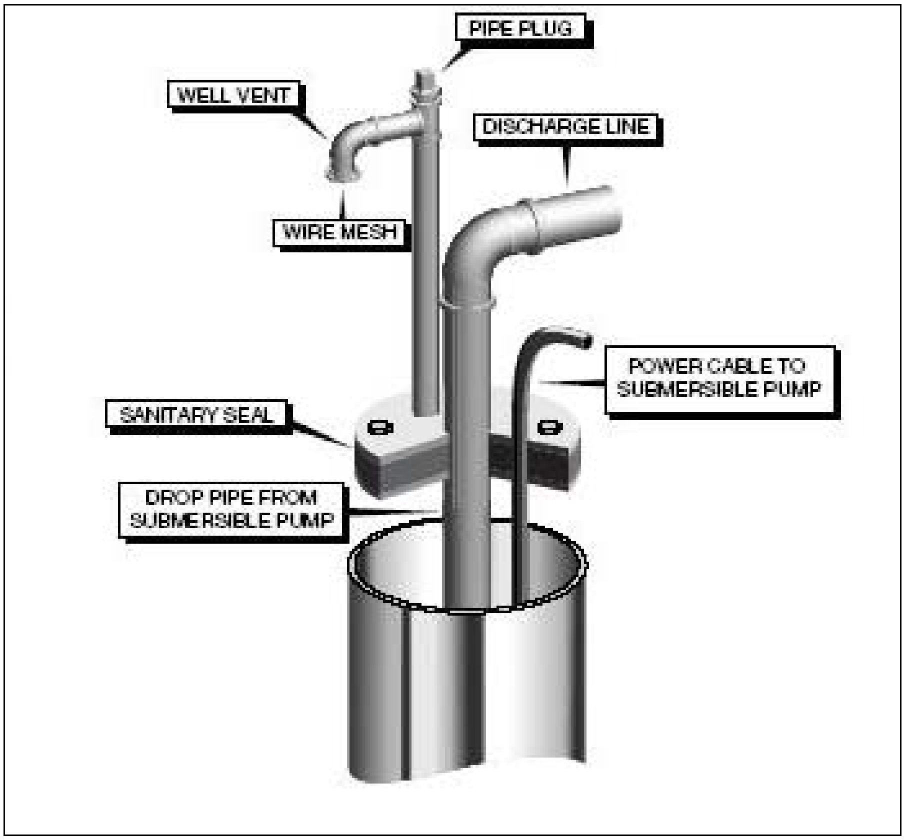
Percussion (Cable-tool) Method: This method is accomplished by raising and dropping a heavy drill bit and stem. The impact of the bit crushes and dislodges pieces of the formation. The reciprocating motion of the drill tools mixes the drill cuttings with water into a slurry at the bottom of the hole. This is periodically brought to the surface with a bailer (a 10-20 foot long pipe equipped with a valve at the lower end). Caving is prevented as drilling progresses by driving or sinking a casing slightly larger in diameter than the bit. When good drilling practices are followed, water-bearing beds are readily detected in cable holes because the slurry does not tend to seal off the water bearing formation. A rise or fall in the water level in the hole during drilling or increased recovery water during bailing indicates that the well has entered a permeable bed.

Exhibit 4.4 Drilled Well with Submersible Pump



Source: USEPA, 2003b

Exhibit 4.5 Typical Wellhead Design for Submersible Pumps



Source: USEPA, 2003a

Hydraulic Rotary Drilling Method

The hydraulic rotary drilling may be used in almost all formations. The drilling equipment consists of the following:

- Derrick,
- Hoist,
- Revolving table through which the drill pipe passes,
- Series of drill pipe sections,
- Cutting bit at the lower end of the drill pipe, and
- Pump for circulating the drilling fluid and a power source.

The bit breaks up the material as it rotates and advances while the drilling fluid (mud) that is pumped down the drill pipe picks up the drill cuttings and carries them up the space between the rotating pipe and the wall of the hole. The mixture of mud and cuttings is discharged to a settling pit where the cuttings decant to the bottom and the mud is recirculated to the drill pipe. Once the hole is completed the drill pipe is withdrawn and the casing is placed. The drilling mud is usually left in place and pumped out after the casing and screen are positioned. The space between the hole wall and the casing is generally filled with cement grout in non-water bearing sections, but may be enlarged and filled with gravel at the level of the water-bearing strata (NGWA, 2007).

Air Rotary Drilling Method

The air rotary drilling method uses similar equipment to that used for the hydraulic rotary drilling method. The major difference between the two methods is that the air rotary method uses air and the hydraulic rotary drilling method uses mud and water.

The air rotary method is well adapted to rapid penetration of consolidated formations and is especially popular in regions with limestone aquifers. Penetration rates of 20-30 feet per hour are usually achieved in very hard rock formations. To remove cuttings, upward velocities of at least 3000 feet per minute are required. The air rotary method usually is not suitable for unconsolidated formations where careful sampling of rock materials is required for well-screen installation.

4.3.3 Characteristics of Wells

4.3.3.1 Yields of Different Types of Wells

Driven wells can be sunk to 30 feet or more below the static water level. Because of their small diameters (2 to 12 inches) they can have relatively small yields. Combining several driven wells can offset the small yield of a single well. Deeper wells with large available drawdowns tend to have higher yields. Drilled and jetted wells can usually be sunk to such depths that the available drawdown can be hundreds of feet (Purdue Research Foundation, 2001).

Exhibit 4.3 provides details about penetrating various types of geological formations using different well drilling methods.

4.3.3.2 Sanitary Construction of Wells

When a well penetrates a water-bearing formation, it provides a direct route for potential contamination at the source. To prevent contamination from reaching the ground water, the following basic sanitary guidelines should always be followed during the construction of wells (USEPA, 1992).

- Fill the open space outside the casing with a watertight cement grout from a point just below the frost line (or deepest level of excavation near the well) to as deep as necessary to prevent entry of surface water. See Section 4.3.3.3 for a detailed description of grouting requirements.

- For artesian basins, seal the casing into the overlying impermeable formations to retain artesian pressure.

- When a water-bearing formation containing poor quality water is penetrated, seal off the formation to prevent infiltration of water into the well and aquifer.

- Install a sanitary well seal with an approved vent at the top of the well casing to prevent the entrance of contaminated water or other objectionable material.

- It is difficult to provide a sanitary seal for large diameter wells. Therefore, a reinforced concrete slab should be installed that overlaps the casing and seals to it with a flexible sealant or rubber gasket.

4.3.3.3 Grouting Requirements

According to Ten State Standards (2007), all permanent well casing, except driven Schedule 40 steel casing with the approval of the reviewing authority, shall be surrounded by a minimum of 1.5 inches of grout to a depth required by the reviewing authority. Temporary construction casings should be removed. If it is not possible or practicable to remove the temporary construction casing, it should be withdrawn by at least 5 feet to ensure grout contact with the native formation.

The following types of grout mixes are recommended by Ten State Standards (2007):

- Neat cement grout

    - Consists of cement (conforming to ASTM standard C150) and water.

    - No more than six gallons of water per sack of cement are to be added.

    - Additives may be used to increase the fluidity of the grout, subject to approval by the reviewing authority.

    - Can be used for only 1.5 inch openings and not for larger openings.

- Concrete grout

    - Equal parts of cement (conforming to AWWA A100 Section 7) and sand with no more than six gallons of water per sack of cement may be used for openings larger than 1.5 inches.

    - When an annular opening larger than four inches is available, gravel not larger than 0.5 inch in size may be added.

- Clay seal
  - Where an annular opening of greater than six inches is available, a clay seal of local clay mixed with at least 10 percent swelling bentonite may be used when approved by the reviewing authority.

Ten State Standards (2007) also stipulates that the following requirements should be met prior to or during the application of the grout mix:

- Sufficient annular space should be provided to permit a minimum of 1.5 inches of grout around permanent casings.

- Bentonite or similar materials may be added to the annular opening prior to grouting through fractured geological formations.

- Grout should be installed under pressure using a grout pump. When the annular opening is less than four inches, the annular opening should be filled in one continuous operation.

- Gravity placement can be performed using a grout pipe installed at the bottom of the annular opening, in one continuous operation when:
  - The annular opening is four or more inches and less than 100 feet deep, and
  - Concrete grout mix is being used.

- A clay seal placed by gravity may be employed when the annular opening is greater than six inches and less than 100 feet deep.

- Work on the well should be discontinued until the cement or concrete grout sets properly with no air pockets.

4.3.3.4 Well Screens

Screens (slotted casings) are installed in wells to permit sand-free water flow into wells and to prevent unstable formations from caving in. The slot size for screens is based on a sieve analysis of carefully selected samples of the water bearing formation. If the slots are too large, the well may pump significant quantities of sand. If the slots are too small, they become easily plugged with fines, which results in reduced yield. In a drilled well, the screens are normally placed after the casing has been installed. However, in a driven well, the screen is a part of the drive assembly and is sunk to its final position as the well is driven.

Well screen manufacturers provide tables of capacities and other information to aid in selecting the most economical screen size. According to the Ten State Standards, the following minimum standards are applicable to well screens:

- They should be constructed of materials that are resistant to damage by the chemical action of ground water or those of cleaning operations.

- Their installation should ensure that the pumping water level remains under the screen for all operating conditions.

- Where applicable, they should be designed and installed to allow easy removal and replacement without adversely impacting water-tight construction of the well.

- They should be provided with a bottom plate or washdown bottom fitting of the same materials as the screen.

4.3.3.5 Well Development

Before a well becomes operational, it is essential to remove all the silt and fine sand next to the well screen by employing a process called "well development." Development unplugs the formation and produces a natural filter of coarser and more uniform particles of high permeability surrounding the well screen (Purdue Research Foundation, 2001). After development is completed, a well-graded, stabilized layer of coarse material will enclose the entire well screen and facilitate the flow of water into the well. Surging and high-velocity hydraulic jetting are two common methods for conducting well development and are described below.

Surging

This process agitates the silt and sand grains by a series of rapid reversals in the direction of water flow, which cause the silt and sand grains to be drawn toward the screen through larger pore openings. One method of surging a well is to move a plunger up and down the well, resulting in water moving in and out of the formation alternately. When water containing the fines flows into the well the particles settle into the bottom of the screen and are then removed by pumping or bailing. (Purdue Research Foundation, 2001)

High-Velocity Hydraulic Jetting

Water under high pressure is ejected through the slot openings and violently agitates the aquifer material. Sand grains finer than the slots move through the screen and either settle at the bottom or are washed out to the top. Water pressures in the vicinity of 150 psi are required. High-velocity jetting is most useful for screens having continuous horizontal slot design. It is also effective in washing out drilling mud and crevice cuttings in hard-rock wells. However, it is less useful for slotted or perforated pipes.

4.3.3.6 Testing Wells for Yield and Drawdown

A pumping test should be performed on a developed well to determine its yield and drawdown. The results of a pumping test can help select what type of pumping equipment should be used. The pumping test should include the following (Purdue Research Foundation, 2001):

- Volume of water pumped per minute or hour;
- Depth to the pumping level as determined over a period of time at one or more constant rates of pumping;
- Recovery of water level after pumping is stopped; and
- Length of time the well is pumped at each rate during the test procedure.

According to Ten State Standards (2007), yield and drawdown tests need to be performed on every production well after construction and prior to the placement of the permanent pump. Test methods should be clearly indicated in the project specifications. The test pump capacity at maximum anticipated drawdown should be at least 1.5 times the quantity anticipated. The yield and drawdown tests should provide for continuous pumping for at least 24 hours at the design pumping rate or until stabilized drawdown has continued for at least six hours when pumped at 1.5 times the design pumping rate. There may also be State requirements for testing and stabilization. Ten State Standards (2007) recommends that the following data be provided by any yield/drawdown test:

- Test pump capacity-head characteristics;
- Static water level;
- Depth of test pump setting;
- Start and end time of each test cycle; and
- Zone of influence of the well.

The test should also provide hourly readings of the following parameters:

- Pumping rate,
- Pumping water level,
- Drawdown, and
- Water recovery rate and levels.

When testing a well for yield and drawdown, it is best to test it near the end of the dry season. When this cannot be done it is important to estimate the additional seasonal decline in water levels from wells tapping the same formations. This additional drawdown should be added to the drawdown determined by the pumping test in order to arrive at the maximum pumping water level. Additional information regarding testing wells for yield and drawdown can be obtained from the United States Geological Survey (USGS), the State health department, and manufacturers of well screens and pumping equipment.

4.3.4 Disinfection of Newly Constructed Wells

All newly constructed wells should promptly be disinfected to destroy disease-causing microorganisms that may have been introduced into the well during construction, hookup, maintenance, or as a result of faulty well construction. The system should follow all applicable State requirements and can also consult AWWA standard C-654-03 for well disinfection.

All elements of the well should be disinfected including the gravel pack, casing, and pump. Disinfection can be performed using liquid chlorine, sodium hypochlorite, or calcium hypochlorite. If liquid chlorine is used, it should conform to ANSI/AWWA standard B301. If hypochlorite is used, it should conform to ANSI/AWWA standard B300.

Similar to the shock chlorination procedures discussed in Chapter 3 (section 3.1.3.4), the following procedures for disinfecting newly constructed wells (AWWA 2003) can be followed to disinfect the well and its components. Individual States may have standards which deviate from these and should be consulted prior to performing any disinfection.

To disinfect the gravel pack, one quarter to one half a pound of calcium hypochlorite tablets can be mixed per ton of gravel prior to the gravel being placed. Care should be taken to ensure that the gravel is free from organic material. Alternatively, chlorinated water can be added to the well after the gravel is in place and the drilling mud has been displaced. Chlorinated water should be added until the concentration is 50 mg/L or greater throughout the entire volume of the well.

Equipment such as pumps, meters, and valves should be disinfected just prior to installation by spraying with a solution containing at least 200 mg/L of chlorine.

The procedure to disinfect the well after all the components have been installed is as follows (AWWA, 2003):

- Add chlorine until the water throughout the well volume is 50 mg/L or greater. If calcium hypochlorite is used, it can be dribbled down the casing vent. Sodium hypochlorite should be pumped using a tube down the casing vent to the bottom of the well.

- Surge the well at least 3 times to provide mixing.

- Leave the chlorine solution in contact with the well for 12 to 24 hours.

- Establish at least a 2 inch pressure tight connection from the pump discharge piping to the casing vent.

- Operate the pump against a throttled discharge valve to return several hundred gallons per minute flow to the casing vent, not to exceed one half the well's capacity, while the rest is discharged to waste. Be sure the throttle is not so extensive as to cause damage to the well or piping.

- Continue the discharge until no chlorine residual is detected for at least 15 minutes.

- After there is no detectable residual, the well should be tested for coliform bacteria. If coliform bacteria are detected, the well should be pumped for another 15 minutes and re-sampled. If still positive for bacteria, it must be re-disinfected or undergo corrective action to correct the contamination source.

The discharge of chlorinated water is a potential problem and is discussed in Section 3.1.3.4.

4.4 Switching to a Surface Water Source

It may become necessary for a utility to switch to a surface water source if alternate reliable and safe ground water sources are not available. Surface waters are generally more susceptible to chemical and microbial contamination and are therefore usually treated more extensively than ground water sources before serving the public. Ground water systems switching to a surface water source often require large investments to modify their treatment trains and set up additional unit processes (along with the necessary instrumentation, controls, and monitoring systems). In addition to surface water systems having more extensive treatment requirements, they also have more elaborate reporting requirements and usually require more highly trained operators.

Systems switching to surface water sources are often required to obtain a permit from the State for drawing water from the surface water body. This may be a more challenging prospect in areas where water rights are an important factor, especially in areas of the country threatened by drought.

Surface water intakes on streams or rivers should be located upstream of sewer outlets and other sources of contamination. If a lake or reservoir is used, the intake should be set away from discharges with the potential to contaminate the source water being drawn and used. Systems should check with their States to see what intake setback distance requirements may apply. Utilities should also be aware of the nature and locations of any activities in the watershed that may introduce contamination.

5. Installing Treatment

Ground water systems that choose to install treatment to correct significant deficiencies or fecal contamination must provide at least 99.99 percent (4-log) inactivation (disinfection) or removal (filtration) of viruses. EPA has determined that the treatment technologies or combination of technologies that have demonstrated the ability to achieve 4-log inactivation of viruses are chlorine (chlorine gas or hypochlorite), chlorine dioxide, ozone, ultraviolet (UV) radiation, anodic oxidation, reverse osmosis (RO), and nanofiltration (NF). Though these last two, RO and NF, are filtration methods that have demonstrated the ability to remove 4-log of viruses (AWWA, 1990b; USEPA, 2006b; USEPA, 2006c), these technologies will have different impacts on cost, operation, maintenance, and reporting requirements for systems. Selecting the most appropriate treatment technology (or combination of technologies) to achieve 4-log treatment is a site-specific decision best left to utility personnel and State agencies.

Americans expect tap water to be available at reasonable costs, with minimal to no associated health risks. In some cases, however, those served by small systems may face significantly higher per capita costs both to install and operate new treatment and to employ qualified operators needed to ensure compliance with drinking water standards than the per capita costs for those served by larger systems.

Small systems should exhaust all possible options (including switching to higher quality source water such as another ground water well) before installing new technologies. Purchasing water from another system is another potentially lower cost option for small systems. If full water treatment is necessary, a package treatment plant may be a lower-cost option. While disinfection technology designs are readily available without need for pilot studies prior to installation systems may find pilot studies useful in minimizing DBP formation and in lowering costs to meet pathogen inactivation requirements. The effectiveness of disinfection systems is based on laboratory results that are applicable to all systems.

This chapter describes the types of treatment that can be used to achieve 4-log inactivation or removal of viruses. It is organized in three main sections:

- Chemical disinfection *(Section 5.1)*;
- UV light disinfection *(Section 5.2)*; and
- Membrane technologies-filtration *(Section 5.3)*.

This chapter provides an overview discussion of each treatment technology along with advantages and disadvantages of each to help systems and States with the selection process. In addition, Section 5.4 provides a list of additional references where systems and States can find more detailed information.

GWSs that install disinfection or filtration treatment must demonstrate (through compliance monitoring as specified in 40 CFR 141.403(b) of the GWR), that their treatment reliably and effectively achieves 4-log virus inactivation, removal, or a State-approved combination of inactivation and removal before or at the first customer. Existing GWSs that provide such 4-log treatment and want to avoid triggered source water monitoring must notify the State in writing of their treatment status by December 1, 2009, and include engineering, operational, or other information requested by the State to evaluate the submission. GWSs with a new ground water source going into service after November 30, 2009, that provide 4-log treatment must also notify the State in writing to that effect (and also include engineering, operational, or other information requested by the State to evaluate the submission). GWSs with new ground water sources that are disinfected must initiate compliance monitoring within 30 days of placing the source in service.

The requirements for systems choosing to conduct compliance monitoring or required to conduct compliance monitoring vary depending on the type of treatment provided and, for those systems using chemical disinfection, the size of the system. In addition, the exact treatment technique standards (e.g., disinfectant concentration level) will be defined by each State and may differ significantly from State to State.

GWSs using chemical disinfection must maintain the State-determined residual disinfectant concentration every day the system serves water from the ground water source to the public. Disinfectant residual monitoring must be conducted in accordance with 40 CFR 141.74 (a)(2):

- GWSs serving more than 3,300 people and using chemical disinfection must monitor the residual disinfectant concentration continuously at a location approved by the State. Systems doing continuous monitoring must record the lowest residual disinfectant concentration each day. If there is a failure in the continuous monitoring equipment, the system must conduct grab sampling every four hours until the equipment is returned to service. Continuous monitoring must resume within 14 days.

- GWSs serving 3,300 or fewer people and using chemical disinfection must either take a daily grab sample during the hour of peak flow (or at another time specified by the State) or monitor the residual disinfectant concentration continuously. For systems taking grab samples, if a daily grab sample is below the State-determined residual disinfectant concentration, the system must take follow-up samples every four hours until the residual disinfectant concentration is restored to the State-determined level.

A GWS that uses membrane filtration to achieve 4-log virus removal must monitor and operate the membrane process in accordance with all State-specified requirements. The system is in compliance if:

1. The membrane has an absolute molecular weight cut-off (MWCO) (or an alternate parameter describing the membrane's exclusion characteristics) that can reliably achieve 4-log removal of viruses;

2. The membrane process is operated in accordance with State-Specified compliance requirements; and

3. The integrity of the membrane is intact.

A GWS that uses an alternative State-approved treatment (i.e., other than chemical disinfection or membrane filtration) must monitor and operate the alternative treatment in accordance with State-specified requirements that the State determines are necessary to achieve at least 4-log virus inactivation, removal, or a combination of inactivation and removal before or at the first customer.

5.1 Chemical Disinfection

Chemical disinfection of viruses involves maintaining a certain disinfectant concentration for a period of time. Desirable properties for a chemical disinfectant include:

- Inactivates pathogens of concern,
- Stability,
- Solubility,
- Low toxicity to humans and other animals that are exposed during normal operation (or ability to control exposure),
- Dependability,
- Residual effect,
- Ease of use and measurement,
- Availability, and
- Low cost.

In general, the level of inactivation depends on site-specific water quality parameters such as temperature, pH, and TOC.

The CT value is the residual disinfectant concentration (in milligrams per liter (mg/L)) multiplied by the contact time (the time in minutes it takes the water to move between the point of disinfectant application and a point downstream before or at the first customer during peak hourly flow) (USEPA 1991). The system compares the CT value achieved to the published CT value for a given level of treatment to determine the level of treatment attained. As long as the CT value achieved by the system meets or exceeds the CT value needed for 4-log inactivation or removal of viruses, the system meets the treatment technique requirement of the GWR. Exhibit 5.1 presents the required CT values identified by the SWTR that achieve 2-, 3-, and 4-log inactivation of viruses with chlorine. Note that much higher CTs are required to achieve 4-log inactivation at pH 10 than at pH 6 to 9. The contact time (the “T” in “CT”) is affected by baffling factors; in addition not all processes receive credit for the full “time” that it can take for water to go through the process.

Exhibit 5.1 CT Values for Inactivation of Viruses by Free Chlorine (mg-min/L)

Temperature (°C)	Log Inactivation[1]					
	2.0		3.0		4.0	
	pH 6-9	pH 10	pH 6-9	pH 10	pH 6-9	pH 10
0.5	6	45	9	66	12	90
5	4	30	6	44	8	60
10	3	22	4	33	6	45
15	2	15	3	22	4	30
20	1	11	2	16	3	22
25	1	7	1	11	2	15

Source: EPA, 1991

1. Presents data for inactivation of Hepatitis A virus (HAV) at pH = 6 - 9, and 10 and temperature = 0.5, 5, 10, 15, 20, and 25 degrees centigrade (°C). CT values include a safety factor of 3. To adjust for other temperatures, simply double the CT value for each 10°C drop in temperature.

The *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* (EPA 1991) presents a detailed description of the application of the CT concepts to disinfection practices.

Contact time, contact tank design, and baffling are all interrelated in the area of disinfection treatment of the finished water supply. All of these areas of scenario design are important in ensuring that the disinfectant is allowed adequate contact time with the contaminated water in order to inactivate viruses and other microorganisms. When a disinfectant like chlorine is added to the water supply, it reacts with other chemicals in the water (e.g., iron, manganese, hydrogen sulfide, and ammonia) and is not fully available for disinfection. The amount of disinfectant that reacts with the other chemicals plus the amount required to achieve disinfection represents the disinfectant demand of the water. Disinfectant demand may change with dosage, time, temperature, pH, and nature and amount of the impurities in the water.

For instance, chlorine is the most commonly used chemical disinfectant. The chlorine dose (in mg/L) is the amount of chlorine added to satisfy the chlorine demand and provide a free chlorine residual up to the end of the contact period:

Chlorine dose = chlorine demand + free available residual chlorine (the "C" in "CT")

Within the distribution system, free chlorine residuals range from 0.2 mg/L to as high as 3-3.5 mg/L in some systems. Most US systems maintain a chlorine residual above 0.2 mg/L in the distribution system (AWWA, 1990b). EPA has established maximum residual disinfectant levels (MRDLs) that cannot be exceeded without incurring a violation. Systems experiencing high levels of disinfection byproducts (DBPs) in their distribution systems should work with the State or their engineer to identify compliance options. See the Simultaneous Compliance Guidance Manual (USEPA, 2007a) for more information.

In addition to inactivation of viruses and harmful microbes, chemical disinfection serves other useful purposes in water treatment including:

- Taste and odor control;
- Prevention of algal growths;
- Maintenance of clean filter media;
- Removal of iron and manganese;
- Destruction of hydrogen sulfide;
- Bleaching of certain organic colors;
- Maintenance of distribution system water quality;
- Restoration and preservation of pipeline capacity; and
- Restoration of well capacity, water main sterilization.

Some of the above list apply more generally to surface water systems, while others apply to all systems. Chemical disinfection technologies discussed in this chapter include chlorine (applied in the form of chlorine gas or hypochlorite solution), chlorine dioxide, and ozone. The most commonly used disinfectants in small systems are chlorine gas or hypochlorite solution. Chloramines are not addressed, as they are ineffective for virus inactivation, but they may be used as a secondary disinfectant.

5.1.1 Temporary Hypochlorination

If a system is found to have a significant deficiency or fecal contamination, it may take time for the system to design and install a corrective action. In the meantime, the system should not serve the contaminated water to its customers. The Primacy Agency may require the system to apply 4-log virus disinfection until the contamination is eliminated or a corrective action is put in place. For most applications, hypochlorination should be used because it is easier to install and operate than gaseous chlorination or other disinfection methods and is the least costly of the treatment methods. Although hypochlorination may be a viable temporary solution, systems should remember that there is an ongoing cost of operation, maintenance, and reporting for water that remains unsafe, so eliminating contamination or completing a corrective action as soon as possible is recommended.

5.1.2 Chlorine Gas

5.1.2.1 Background

Disinfection using chlorine gas is less common at water utilities than in the past, but is still widely used. This process involves the addition of elemental chlorine (Cl_2) to the water supply at one or more locations within the treatment train. Elemental chlorine is typically supplied as a liquefied gas. It comes in high-pressure containers that typically weigh between 100-2000 lbs.

Although it is extensively used for many purposes, there are some safety and security issues associated with the use of chlorine gas. Facilities storing more than 1,500 pounds of chlorine are subject to the Process Safety Management standards regulated by the Occupational Safety and Health Administration under 29 CFR 1910 and the Risk Management Program Rule administered by EPA under Section 112(r) of the Clean Air Act. All of these regulations (as well as local and State codes and regulations) should be considered during the design and operation of chlorination facilities at a water treatment plant. Systems should develop appropriate safety and security plans when installing chlorine gas. Systems should also have their own safety equipment and operators should take the following precautions when using or handling chlorine gas:

- Chlorine gas is poisonous and corrosive; therefore, adequate exhaust and ventilation should be used when applying chlorine for water treatment. The ventilation should be positive at the floor level because chlorine gas is heavier than air. Operators should wear proper personal protective equipment including goggles, gloves, and respirators. Each operator should also have access to a self-contained breathing apparatus.

- Liquid and gaseous chlorine should be delivered using rubber lined or polyvinyl chloride (PVC) piping with hard rubber (using rubber lined or PVC piping will increase the life of the piping system and decrease maintenance costs).

- Cylinders should be placed on platform scales that are flush with the floor and continuously monitored for leaks. Loss of weight of the cylinders should be directly recorded as chlorine dosage.

5.1.2.2 System Design

The design criteria for chlorine disinfection usually encompass a variety of factors to ensure proper chlorine dose application. Some of these factors are chlorine gas application (gas delivery), contact time, contact tank design, contact tank baffling, and residual effluent water concentrations.

The chlorinator is a supply-metering device for chlorine gas controlled by regulated pressure and/or variable orifices. The chlorine feed rate can be manually or automatically regulated. It is also convenient to use an electronic or mechanical scale to measure the chlorine gas usage. A scale will allow the system to determine a cylinder's content level. Scales are intended for use in chlorination and other gas feeding applications and can be used to measure liquefied chlorine, sulfur dioxide, ammonia, hydrogen chloride, or carbon dioxide packaged in cylinders. Small systems may choose to use manual chlorination to control chlorine dosage.

Contact time, contact tank design, and baffling are all interrelated in the area of chlorine gas treatment of the finished water supply. All of these areas of scenario design are important in ensuring that the chlorine gas is allowed adequate contact time with the contaminated water in order to inactivate viruses and other microorganisms. When chlorine is added to the water supply, it reacts with other chemicals in the water (e.g., iron, manganese, hydrogen sulfide, and ammonia) and is not fully available for disinfection. The amount of chlorine that reacts with the other chemicals plus the amount required to achieve disinfection represents the chlorine demand of the water. Since chlorine is hazardous and corrosive, systems should store chlorination equipment away from other treatment facilities and chemicals. Chlorine can also react with natural organic matter in drinking water and form harmful byproducts. Systems experiencing high levels of disinfection byproducts (DBPs) in their distribution systems should work with the State or their engineer to identify compliance options. See the Simultaneous Compliance Guidance Manual (USEPA, 2007a) for more information.

5.1.2.3 Operation and Maintenance

Normal operation of gas chlorination includes both routine observation and preventive maintenance. On a daily basis the operator should:

- Read the chlorination rotameter;
- Record the reading time, date, and initial entries;
- Read flow meters and record the number of gallons of water pumped;
- Check the chlorine residual and increase or decrease the chemical feed rate of the chlorine gas mixture based on the residual concentration; and
- Calculate and record the chlorine usage.

On a weekly basis the operator should:

- Clean all of the equipment and the chlorine storage and housing area; and
- Perform any necessary preventive maintenance on the application equipment and piping.

Individual States may have additional or more stringent requirements for routine observations and preventative maintenance. Systems should consult the State for specific requirements.

5.1.2.4 Advantages and Disadvantages

Chlorine has many attractive features that contribute to its wide use in the industry. The use of chlorine gas is highly advantageous because it is readily available. There is an abundance of chlorine gas for continuous plant operation without any significant chemical mixing, which makes the process much easier to apply. Chlorine leaves a residual that is easily measured and controlled. Chlorine is also economical and has an excellent track record of successful use in improving water treatment operations.

There are also disadvantages in using chlorine as a disinfectant. The use of chlorine promotes the formation of chlorinated organic compounds, such as trihalomethanes (THMs), which are potentially harmful to humans. CWSs and non-transient non-community water systems (NTNCWSs) must comply with DBP MCLs and monitoring requirements if chlorine or other disinfectants are used. In addition, high chlorine doses can cause taste and odor problems.

Chlorine gas has specific hazards associated with its use or misuse and requires special handling and response programs. Chlorine gas combines with the mucous membranes in the nose and throat, as well as the fluids in the eyes and lungs, irritating and inflaming those areas. Therefore, a very small percentage of chlorine gas in the air can irritate the lungs and cause severe coughing; heavy exposure can be fatal (White, 1999). Systems should ensure that safety equipment (e.g., eye wash, shower, chlorine gas detectors) is routinely available, routinely check for leaks in the chlorine cylinders, and routinely clean interior parts of the gas chlorination system. For emergency purposes, self-contained breathing apparatuses should be available outside the chlorine gas cylinder storage area.

5.1.3 Hypochlorite

5.1.3.1 Background

Many properties of hypochlorite are similar to those of chlorine gas as far as oxidizing principles and corrosiveness of the substance; however, since storage of hypochlorite is generally safer than storage of chlorine gas, many small systems choose to use hypochlorination instead of gaseous chlorination to treat their drinking water. Hypochlorite compounds are non-flammable; however, they can cause fires when they come in contact with certain organic compounds or easily oxidizable substances. If a spill occurs, then it should be washed with a large amount of water and cleaned up immediately. Skin contact with hypochlorite can burn the skin and may cause damage to the eyes.

Systems typically use either sodium hypochlorite (NaHOCl) or calcium hypochlorite (CaHOCl). Sodium hypochlorite, which is produced when chlorine gas is dissolved in a sodium hydroxide solution, is most commonly used in aqueous form. Calcium hypochlorite, which is formed from the precipitate that results from dissolving chlorine gas in a solution of calcium oxide (lime) and sodium hydroxide, is more commonly used in dry solid form (White, 1999).

Sodium hypochlorite is available in concentrations of 5 to 15 percent, and typically contains 12.5 percent available chlorine (White, 1999). One gallon of 12.5 percent sodium hypochlorite solution typically contains the equivalent of one pound of chlorine. Sodium hypochlorite (commonly referred to as liquid bleach or Javelle water) can be purchased in bulk quantities ranging from 55-gallon drums to 4,500-gallon truckloads. Bulk loads can be stored in fiberglass or plastic tanks. The stability of the sodium hypochlorite solution depends on hypochlorite concentration, storage temperature and duration, impurities of the solution, and exposure to light. Decomposition of hypochlorite over time can affect the feed rate and dosage, as well as produce undesirable byproducts such as chlorite ions or chlorate (Gordon et al., 1995). Because of these storage problems and high transport cost, many systems are investigating onsite generation of hypochlorite instead of purchasing it from a manufacturer or vendor (USEPA, 1998).

Calcium hypochlorite has a high oxidizing potential and typically comes in the powdered form of high-test hypochlorite (HTH). Calcium hypochlorite also comes in tabular and granular forms containing at least 65 percent available chlorine and dissolves easily in water (USEPA, 1991). This means that 1.5 pounds of calcium hypochlorite contains the equivalent of one pound of chlorine. Similar to sodium hypochlorite solution, the addition of calcium hypochlorite to water yields hydroxyl ions that will increase the pH of the water. One option for continuous chlorination is the use of HTH tablet erosion feeders. These are devices containing HTH tablets. As water feeds through the device, the HTH erodes and dissolves it into solution, which is then reintroduced to the raw water.

Calcium hypochlorite is stable under proper storage and is therefore favored for most hypochlorite disinfection schemes. Calcium hypochlorite should be stored in a cool dry location in corrosion-resistant containers away from heat sources or organic materials such as wood, cloth, and petroleum products (USEPA, 1998).

5.1.3.2 System Design

The application of hypochlorite in potable water achieves the same result as chlorine gas. Therefore, similar contact times and concentrations are used in design (White, 1999). Systems apply hypochlorite by injecting a stock solution into the water supply using chemical metering pumps (hypochlorinators). Systems should ensure that mixing occurs to have adequate disinfection. Typically, positive displacement meters and pumps are employed as feed mechanisms for hypochlorite. These types of hypochlorinators are designed to pump an aqueous chlorine solution into the water being pumped and treated and are usually available at a modest price. These pumps are typically designed to operate against pressures up to 100 psi but can also be used to inject chlorine on the suction side of the pump. These pumps are quite accurate and have been found to maintain a constant dose as long as the water flow is relatively constant. If this is not the case, a metering device is placed on the pump to vary the dosage in conjunction with the flow rate of the water being treated.

5.1.3.3 Operation and Maintenance

In general, hypochlorination facilities are easier to operate than gas chlorination facilities. Operation and maintenance (O&M) costs include daily, weekly, and monthly operations, preventive maintenance, and personnel training and certification. Activities regularly conducted at hypochlorination facilities are listed below.

On a daily basis the operator should:

- Read and record the level of the solution tank at approximately the same time everyday;

- Read meters and record the amount of water pumped;

- Check the free chlorine residual and adjust as necessary; and

- Observe chemical pump operation by reading the dial that indicates chlorine feed rate. The pump should be operated in the upper ranges of the dial for optimum performance. Also, frequency of piston or diaphragm strokes should be such that hypochlorite is constantly being supplied to the water that is being treated.

On a weekly basis the operator should:

- Clean the building and all application equipment; and

- Replace chemicals and wash all chemical storage equipment.

On a monthly basis the operator should:

- Check the operation of all delivery equipment and examine all safety devices such as check valves and backup power devices; and

- Perform all preventive maintenance on system, and check for leaks and corrosion.

Small system hypochlorinators typically have a limited number of repairable parts. Therefore, it is often advisable to replace all essential parts at the time of any single part failure. Minor maintenance, such as oil changes and lubrication of all moving parts, can significantly increase the life span of small system hypochlorinators.

5.1.3.4 Advantages and Disadvantages

Hypochlorite has many of the same advantages and disadvantages of gaseous chlorine as described in Section 5.1.2.4, including DBP compliance requirements for CWSs and NTNCWSs. However, hypochlorite may be more advantageous than chlorine for small systems because spills and leaks of hypochlorite can be more easily managed and contained than chlorine gas leaks. Additional advantages and disadvantages associated with the use of hypochlorite are discussed below.

Sodium hypochlorite is easier to handle than chlorine gas or calcium hypochlorite, however, it is very corrosive and should be stored with care and kept away from equipment that can be damaged by corrosion. It also should be stored in a cool, dark, and dry area and cannot be stored longer than one month.

Calcium hypochlorite is very stable when properly packaged and can be stored up to a one year. Since it is a corrosive material with a strong odor, it should be properly handled and stored. Reactions with organic material can generate enough heat to cause an explosion. Since it readily absorbs moisture, forming chlorine gas, shipping containers should be emptied completely or carefully resealed. Also, using calcium hypochlorite in dust form requires dust control practices to guard against breathing the dust and minimizing skin exposure.

5.1.4 Chlorine Dioxide (ClO_2) Disinfection

5.1.4.1 Background

Chlorine dioxide is one of the most powerful oxidizing agents used for water treatment. It is also used to control taste and odor, iron, manganese, hydrogen sulfide, and phenolic compounds. The SWTR Guidance Manual (AWWA, 1991) provides CT values for inactivation of viruses as shown in Exhibit 5.2.

Exhibit 5.2 CT Values (mg-min/L) for Inactivation of Viruses[1] by Chlorine Dioxide for pH 6 to 9

Inactivation	Temperature					
	≤ 1°C	5°C	10°C	15°C	20°C	25°C
2-Log	8.4	5.6	4.2	2.8	2.1	1.4
3-Log	25.6	17.1	12.8	8.6	6.4	4.3
4-Log	50.1	33.4	25.1	16.7	12.5	8.4

Source: EPA, 1991
1. Studies pertain to the Hepatitis A virus.

Chlorine dioxide is a highly unstable material and is typically generated onsite for the disinfection of water. Chlorine dioxide gas is yellow/red, has a noticeable odor, and is more explosive than in the liquid form.

It exists in solution without the need for hydrolysis and disinfects by oxidation, not by chlorination. Since free chlorine species are not the reactants, the production of THMs in the distribution system are highly unlikely; however, total organic halogen (TOX) may be produced. Waters with high alkalinity reduce the yield and effectiveness of chlorine dioxide by reducing the oxidation-reduction potential and give rise to potentially harmful byproducts.

5.1.4.2 System Design

Chlorine dioxide is most frequently generated using aqueous sodium chlorite solution (White 1999). Sodium chlorite is used in the liquid or solid form along with a high level acid mixture to create chlorine dioxide that is used to treat the influent water. The formation reaction for chlorine dioxide is more effective at a lower pH.

If mixed properly, the production of chlorine dioxide will generate a 95 percent yield with no more than 5 percent excess chlorine in the effluent. If this is the case, there is minimal potential for THM and haloacetic acid (HAA) formation in the effluent plant flow.

5.1.4.3 Operation and Maintenance

O&M of a chlorine dioxide generation system requires significant knowledge of the system. Therefore, it is important to have highly trained personnel operating and maintaining sodium chlorite storage and feed systems and chlorine dioxide generator and feed equipment. Compared to other disinfectants, chlorine dioxide has a low MRDL; exceeding the MRDL is considered an acute health risk and requires immediate response. Chlorine dioxide generation requires constant monitoring and tweaking of the chlorine dioxide production amount, based on any changes in the original amount of water being treated and the flow rate of the water being treated. Also, the volatility of the chlorine dioxide generation process, which can create a risk of explosion, must be taken into account when working with chlorine dioxide generation.

On a daily basis, operators should adjust flow meters and rotameters that control all gas flow within the plant. Also, constant monitoring of all delivery equipment should take place to ensure the highest amount of chlorine dioxide yield efficiency. For example, operators should take measures to prevent crystallization (that can go through the pipes and plug valves and generator equipment) or stratification (i.e., more dense material shifts to the bottom of the bulk (storage) tank causing an inappropriate level of feed) of sodium chlorite. Operators should be trained in the areas of equipment calibration as well as start-up and shut-down procedures for the plant in the event of an emergency. Proper calibration of all application equipment keeps the cost of operation down as well.

5.1.4.4 Advantages and Disadvantages

Systems have found that there are many advantages to using chlorine dioxide to disinfect water supplies. Chlorine dioxide is more effective than chlorine for inactivation of *Giardia* and *Cryptosporidium*. Also, it does not react with ammonia or nitrogen to form unpleasant tastes and odors or react with any oxidizable materials that aid in the formation of THMs and HAAs. In fact, chlorine dioxide destroys as much as 30 percent of all DBP precursors allowing free residual chlorination to be used without the production of unwanted THMs and HAAs within the distribution system (Lagerquist et al., 2004). Chlorine dioxide is also advantageous because its biocidal properties are not affected by the pH at levels from 6 to 9. Chlorine dioxide is also superior to chlorine in the oxidation of iron and manganese from water, and it provides a residual, although the residual is limited with high levels of total organic carbon (TOC).

There are several disadvantages to chlorine dioxide use. Chlorine dioxide is not as cost-effective as chlorination since the chemical cost of chlorine dioxide is several times that of chlorine (White, 1999). It is generally less effective than chlorine for inactivation of viruses. Chlorine dioxide also forms chlorite, a regulated DBP. The MCL for chlorite was set at 1.0 mg/L and the MRDL was set at 0.8 mg/L by the Stage 1 Disinfection/Disinfectants Byproducts Rule (D/DBPR). All systems (including transient systems) using chlorine dioxide must comply with an intensive compliance monitoring schedule that includes monitoring daily at the entrance to the distribution system for both chlorine dioxide and chlorite. If either exceeds the federal standard, the system must collect 3 follow-up samples the next day in the distribution system. They must also collect 3 chlorite samples per month in the distribution system. As much as 70 percent of the chlorine dioxide added to water can break down to form chlorite. This limits the dose of chlorine dioxide that can be used and therefore the amount of inactivation that can be achieved.

Due to its high volatility and explosive nature, chlorine dioxide should be generated on-site and cannot be transported. There are also high costs associated with containing the compound and proper operator and maintenance training. Storage of the compound should be monitored very carefully since chlorine dioxide decomposes in sunlight.

Additional information on advantages and disadvantages of chlorine dioxide are available in the Simultaneous Compliance Guidance Manual (USEPA 2007a) and the Alternative Disinfectants Guidance Manual (USEPA 1999b).

5.1.5 Ozone (O_3) Disinfection

5.1.5.1 Background

Ozone is used to inactivate bacteria and viruses and oxidize organic compounds in water treatment plants. Ozone treatment is known to reduce problems with taste, odor, and color in drinking water. Ozone is injected into the flow of the water being treated by mechanical mixing devices, counter-current and co-current flow columns, porous diffusers, or jet injectors. Typical ozone dosages range from 3–10 mg/L (AWWA, 1990b).

Ozone forms highly reactive and highly potent free radicals such as OH-, which are very strong oxidizing species. These act quickly to inactivate bacteria and viruses. Because of its quick germicidal action, ozone needs relatively short contact time to disinfect most waters, provided the initial turbidity of the water being treated is low at the time of ozone addition (as is generally the case with ground waters). Exhibit 5.3 provides CT values for virus inactivation by ozone.

Exhibit 5.3 CT Values (mg of O_3-min/L) for Virus Inactivation by Ozone

Inactivation	Temperature					
	$\leq$ 1°C	5°C	10°C	15°C	20°C	25°C
2-Log	0.9	0.6	0.5	0.3	0.25	0.15
3-Log	1.4	0.9	0.8	0.5	0.4	0.25
4-Log	1.8	1.2	1.0	0.6	0.5	0.3

Source: EPA, 1991

Ozone is a powerful oxidant of organic materials, breaking them into smaller chain organic molecules. These smaller chain particles, sometimes measured as AOC are an easily degradable food source for microorganisms in the distribution system. While biological filtration following ozonation can effectively remove these materials to create biologically stable finished water and reduce the occurrence of microbial growth in the distribution system, it may not be necessary for ground waters with low TOC (USEPA 2007a).

5.1.5.2 Operation and Maintenance

The general O&M needs for an ozonation facility are labor, energy, and materials. The three O&M cost categories are daily operation, preventive maintenance, and personnel training. The time spent on operation activities varies by the size of the facility. Although ozone generators are complex, they use complete automation and require modest amounts of time for routine maintenance. Technicians require training in preventive maintenance and repair to operate the ozone generator. This includes checking the generator and keeping system parts clean. Ozone is a strong oxidizer; therefore, the system parts require cleaning to prevent corrosion. Parts requiring occasional cleaning are the ozone contacting unit and the ozone exhaust gas destruction unit. Other parts for the dehumidifying process also require cleaning and maintenance. In addition, users should clean the air preparation or oxygen feed and dehumidify the saturated desiccant.

Ozone leaks in and around the ozone generation facility may create a health hazard to operators of the treatment plant and may destroy or enhance the wear of other equipment materials. Therefore, facilities should apply strict safety measures, install an ozone gas detector, and periodically check alarms.

The materials needed to ensure the equipment functions adequately comprise the final O&M component of the ozonation facility. Materials include cleaning chemicals, replacement parts, and additional necessary supplies for periodic maintenance, system cleaning, and unanticipated breakdowns.

5.1.5.3 Advantages and Disadvantages

Ozone has powerful disinfection capabilities. Its high diffusion characteristics make it one of the most efficient chemical disinfectants, with its contact time of only a few minutes. Ozone inactivates microbes without forming chlorinated DBPs. Ozone also oxidizes iron and manganese and improves the taste, odor, and color of raw water. It enhances the biodegradability of natural and synthetic organic compounds and destroys many organic compounds. Due to its relatively short half-life and safety issues, ozone requires on-site production. Due to the difficulty in determining an adequate dose, ozone is most beneficial to systems with a constant demand or little demand fluctuation, such as ground water systems.

Disadvantages of ozone include its relatively high cost and complexity in its use (AWWA, 1990b). Relative to other treatment technologies, ozone also requires more highly skilled operators. Ozone decomposes quickly in water with high pH levels (about 8-9) and therefore does not provide an adequate residual to protect against recontamination in distribution or water storage systems (USEPA, 1999b). Therefore, secondary disinfection may be required. If the source water has a high bromide concentration, ozone can react with bromide to form bromate, a regulated DBP. CWSs and NTNCWs using ozone are required to comply with a 10 microgram per liter (µg/L) MCL for bromate. Ozonation in conjunction with chlorination could result in high concentrations of brominated DBPs.

Water containing large amounts of organic matter and bromide may increase ozone demand and the potential for byproduct formation. However, high natural organic matter (NOM) content in raw waters is generally not an issue for most ground water systems.

5.2 UV Radiation Disinfection

5.2.1 Background

UV disinfection continues to grow in popularity as a microbial treatment strategy. UV light is generated artificially through a wide variety of arcs and incandescent lamps. Low pressure mercury-vapor lamps produce UV light as a result of an electron flow between the electrodes in an ionized mercury vapor. The principle behind inactivating microorganisms is based on photochemical reactions that result in nucleic acid and pyrimidine and/or thymine dimerization, disrupting the reproductive system. UV light has proven to be effective in the inactivation of several waterborne organisms such as *Giardia*, *E.coli*, some viruses, and most recently, *Cryptosporidium* (USEPA, 2006b).

Unlike chemical disinfection, UV leaves no residual that can be monitored to determine UV dose and inactivation credit. The UV dose depends on the UV intensity (measured by UV sensors), the flow rate, and the UV transmittance (UVT). As described further in Section 5.2.5, the very high dose requirements for 3- and 4-log virus inactivation present challenges for validation testing of UV reactors (USEPA, 2006b). Exhibit 5.4 presents UV dose requirements for virus inactivation.

Exhibit 5.4 UV Dose Requirements for Virus Inactivation (mJ/cm^2)

	Log Inactivation			
	1.0	2.0	3.0	4.0
UV Dose	58	100	143	186

Source: 40 CFR 141.720 (d)(1)

The doses in Exhibit 5.4 are based on the inactivation of adenoviruses, which are particularly resistant to UV light. EPA is concerned that fecally-contaminated ground water may contain adenoviruses and/or other UV resistant viruses that present a human health risk. The UV doses in Exhibit 5.4 are significantly higher than those considered for the proposed GWR (USEPA, 2000). When developing the proposed rule, EPA considered only the UV inactivation of Hepatitis A virus (HAV), which is much less resistant to UV light than adenovirus. Based on HAV inactivation alone, EPA included UV light in the GWR proposal regulatory text as a stand-alone treatment technology that could provide 4-log virus inactivation. However, data published subsequent to the GWR proposal indicated that some viruses, particularly adenoviruses, are much more resistant to UV light than HAV. EPA believes that the UV doses in Exhibit 5.4 are sufficient to achieve the designated level of inactivation of all waterborne pathogenic viruses that have been studied.

5.2.2 Inactivation Mechanism and Effectiveness

Proteins and nucleic acids absorb invisible shortwave UV light. The photochemical changes induced by molecular absorption are very harmful to living cells. The most effective spectral region corresponding to maximum absorption by nucleic acids is around 254 nm (USEPA, 2006b). UV affects the cell replication process by promoting the dimerization reaction of pyrimidine nucleotides. Inhibition of replication results in inactivation and the death of cells.

5.2.3 System Design

Detailed guidance on UV system design can be found in *Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule* (EPA 815-R-06-007) (USEPA, 2006b). The guidance manual is available on line at http://www.epa.gov/safewater/disinfection/lt2/compliance.html. The design should include a UV reactor with accessible banks of lamps so that maintenance of the lamps can be accomplished. This maintenance includes cleaning of quartz sleeves and replacement of sensors and ballasts. Access to the critical parts of the UV reactor minimizes off-line operation of the UV disinfection portion of the treatment scheme. Also, the design of a UV disinfection system should always include redundancy to ensure continuous microbial inactivation.

UV lamps emit UV light that passes through the quartz sleeve and into the water to be treated. The microorganisms are inactivated by the UV light that transmits through the water, into the cell, and is partially absorbed by the microorganism's DNA. As a result, the water's turbidity, turbulence and the presence of UV absorbing substances are the principle factors that affect the UV transmittance through the water.

For design purposes, it is important that turbulence occurs (to allow all elements of fluid to come sufficiently close to the lamp surfaces), but short circuiting should be minimized. In some cases, within the chamber, there are baffles that force the flowing water being treated to travel tangentially through the chamber in a spinning motion around the quartz sleeves. This increases the light versus water contact time and therefore increases the level of disinfection achieved.

UV has been employed in a variety of physical configurations. Lamp placement may be horizontal (perpendicular to the flow) or vertical (parallel to the flow).

Important considerations in evaluating UV as a treatment strategy include:

- Existing and emergency power supply–A reliable power supply and emergency power with adequate capacity (and fuel supply) to support the demand of the UV system and provide continuous disinfection.

- UV equipment availability–What is available for the system size and configuration?

- UV doses needed-Is it feasible to provide the necessary UV doses to the water being treated, or does the current system configuration or operation require other consideration of other disinfection or removal strategies?

- Cost–Are total suspended solids, color, and turbidity a problem in the supply? These factors may require additional treatment processes and increase capital and/or operating costs.

5.2.4 Operation and Maintenance

Accumulation of solids onto the surface of UV sleeves can reduce the applied UV intensity and, consequently, disinfection efficacy (USEPA, 1999b). If the water being treated contains biofilms and/or buildup of inorganics, the lamps are susceptible to scaling. In addition, the quartz sleeves can be fouled by organic and inorganic debris in the water. Scaling and fouling reduce the amount of UV light reaching the water. Therefore, it is important to minimize inorganic and dissolved organics upstream, preventing scaling and increasing UV efficacy.

The lamps should be maintained by cleaning the quartz sleeves to prevent fouling. If the source water is fairly clean, the lamps need not be cleaned as often, and vice versa. Approaches for cleaning include on-line mechanical cleaning, on-line mechanical/chemical cleaning, and off-line chemical cleaning. On-line systems usually use wipers to remove scale from the sleeves. For off-line systems, the reactor is shut down, drained, and flushed with a cleaning solution (USEPA, 2006b).

One of the main operational concerns involving UV disinfection is the need for a constant and reliable power source to power the ballasts. It is imperative that an alternate, dependable power source be supplied to provide continuous disinfection of the water supply.

The life expectancy of a typical UV lamp varies in the range of 4,000 to 12,000 hours (USEPA, 2006b). Because lamp output decays over time, UV lamps should be replaced regularly. The replacement schedule should be based on lamp decay characteristics and the guaranteed lamp life (USEPA, 2006b). Because lamps contain mercury, they are often considered a hazardous waste under Subtitle C of the Resource Conservation and Recovery Act (RCRA) and should be disposed of accordingly.

UV reactors should undergo validation testing to determine the operating conditions under which the reactor delivers the UV dose required for the necessary virus inactivation level. In general, the operating conditions determined in validation testing should include flow rate, UV intensity as measured by a UV sensor, and UV lamp status. These operating conditions, as well as any State-specified monitoring or operating conditions, would be both a part of State approval of an alternative treatment process that meets the requirement of the GWR and part of compliance monitoring for an alternative treatment process for GWR compliance. The *Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule* (EPA 815-R-06-007) (USEPA, 2006b) provides additional information on UV disinfection, planning and design of UV facilities, validation of UV reactors, and start-up and operation of UV facilities.

5.2.5 Advantages and Disadvantages

UV has many advantages for primary disinfection. Since there is no chemical consumption, there is no need for large-scale storage facilities, transportation, or chemical handling. UV requires low contact time to inactivate most microorganisms, and forms no known harmful byproducts. UV disinfection is not dependent upon temperature or pH. Finally, low doses of UV are effective against *Giardia* and *Cryptosporidium*.

There are, however, disadvantages to using UV light for ground water disinfection. A UV treatment system can lose power in the event of a power interruption, voltage fluctuation, or power quality anomaly. Source water quality can reduce UV transmittance and cleaning costs can be significantly increased with poor source water quality. Since UV light does not provide a residual disinfectant in the distribution system, a secondary disinfectant may be required. Also, very high UV doses are needed for 4-log inactivation of viruses.

At present, EPA is unaware of available testing protocols that can validate the performance of UV reactors at the dose of 186 mJ/cm^2 needed for a 4-log virus inactivation credit. However, UV reactors validated at lower doses can be used in a series configuration or in combination with other inactivation or removal technologies to provide a total 4-log treatment of viruses to meet GWR requirements. The GWR allows States to approve and set compliance monitoring and performance parameters for any alternative treatment, including UV light or UV light in combination with another treatment technology, which will ensure that systems continuously meet the 4-log virus treatment requirements. Further, a UV reactor validation protocol for 4-log inactivation of viruses may be developed in the future.

The UV dose requirements shown in Exhibit 5.4 were derived exclusively from studies with low pressure (LP) UV lamps. UV dose is well defined and can be determined accurately for this type of lamp. However, a recent bench scale study has observed that medium pressure (MP) and pulsed UV (PUV) lamps may inactivate viruses, particularly adenovirus, at lower UV doses than LP UV lamps (Linden et al., 2007). A recent full scale study also found that MP UV lamps may inactivate adenovirus at lower doses than LP UV lamps (Linden et al., 2008). MP and PUV lamps emit UV light at many wavelengths (polychromatic), while LP UV lamps primarily emit light at a single wavelength.

If future studies support the finding that MP and PUV lamps inactivate adenoviruses at lower UV doses than LP lamps, then the identification of alternative UV doses for virus inactivation credit with MP and PUV lamps may be warranted. Such development of UV dose requirements for specific polychromatic lamp types would potentially also require the use of specialized validation and monitoring approaches to account fully for the effects of different light wavelengths.

5.3 Membrane Filtration Technologies

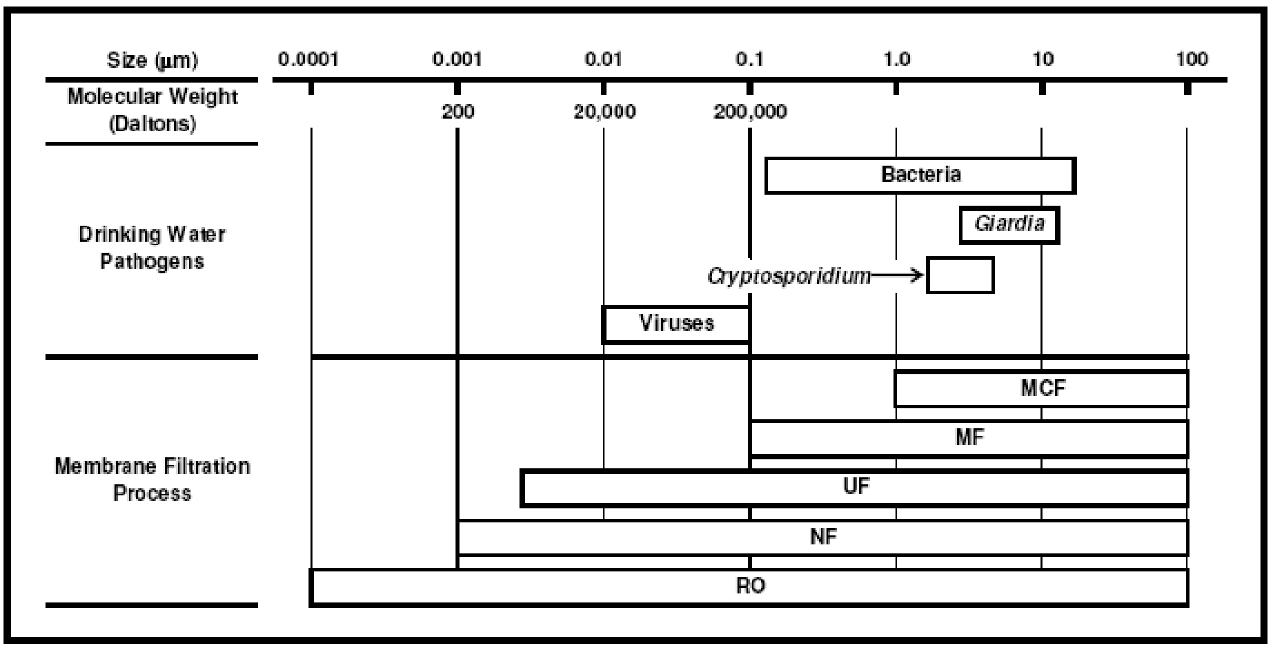
Generally, only ultrafiltration, nanofiltration, and reverse osmosis membranes provide virus removal. While microfiltration has been shown to achieve partial virus removal in some cases, removal is typically attributable to the formation of a time-dependant cake layer on the membrane surface, thus microfiltration is generally considered to be unreliable for high levels of virus removal, such as those required by the GWR (USEPA, 2005). Also, bag and cartridge filters have not been shown to achieve the necessary virus removal.

All membrane filtration technologies employ similar filtration mechanisms (including sieving, repulsion due to like charges at the membrane/liquid interface, etc.), similar materials, and similar module configurations. Their difference lies in their ability to separate particles and ions of different sizes and molecular weights. Exhibit 5.5 illustrates the ability of each type of membrane process to remove various drinking water contaminants based on size.

The factors affecting membrane performance include pore size, molecular weight cutoff (MWCO), material and geometry, removal of targeted materials, and the quantity (and quality) of the treated water. Membrane pore sizes vary with differing technologies; RO systems have a smaller pore size than that of NF systems. Membrane performance is measured by recovery. Recovery represents the percentage of feed converted to product:

$$\textit{Recovery Rate} = \frac{\textit{feed rate - brine rate}}{\textit{feed rate}} \; x\ 100$$

Exhibit 5.5 Particle Size Removal for Various Membrane Technologies



Source: USEPA, 2005

Generally, the higher the recovery rate, the greater the product water yield from the feed water. Factors that determine the recovery rate are water quality and the saturation percentage of critical membrane foulants such as calcium and barium sulfates in the concentrate.

A number of different types of membrane materials, modules, and systems are used by different classes of membrane filtration systems. In general, MF and UF systems use hollow-fiber membranes, while NF and RO systems use spiral-wound membranes (USEPA, 2005). A spiral wound membrane consists of two flat sheets of membrane separated by a porous support.

5.3.1 Background

In drinking water applications, RO is usually employed by systems to reduce the salinity of brackish ground water. However, it is also very effective in removing organic and dissolved solids, bacteria, and viruses.

In RO, the water to be treated is forced by high pressure through the membrane (usually cellulose acetate or aromatic polyamide) into the product water. Operation pressures vary between 300 and 1500 psi, with a typical range of 600-800 psi (Viessman, 1998).

NF units operate under pressures between 70-150 psi and use thin film membranes to filter particles of sizes greater than 1 nm. Typical NF systems employ an MWCO of approximately 200 to 800 daltons, but NF membranes used for potable water applications use MWCOs of 200 to 400 daltons (USEPA, 2005). NF systems are typically used for water softening and removal of NOM. Because of its very small pore size, NF can remove exceptionally high levels of microorganisms, including viruses.

Under the GWR, membrane technologies used to provide 4-log removal of viruses to meet GWR requirements must have an absolute molecular weight cut off (MWCO), or an alternate parameter that describes the exclusion characteristics of the membrane, which reliably achieves at least 4-log removal of viruses.

Manufacturers of membrane technologies may have performed challenge or demonstration studies according to State or other protocols to demonstrate virus removal performance. Manufacturers may have also participated in treatment device certification programs such as the National Sanitation Foundation (NSF) (http://www.nsf.org) or EPA's Environmental Technology Verification (ETV) Program (http://www.epa.gov/etv).

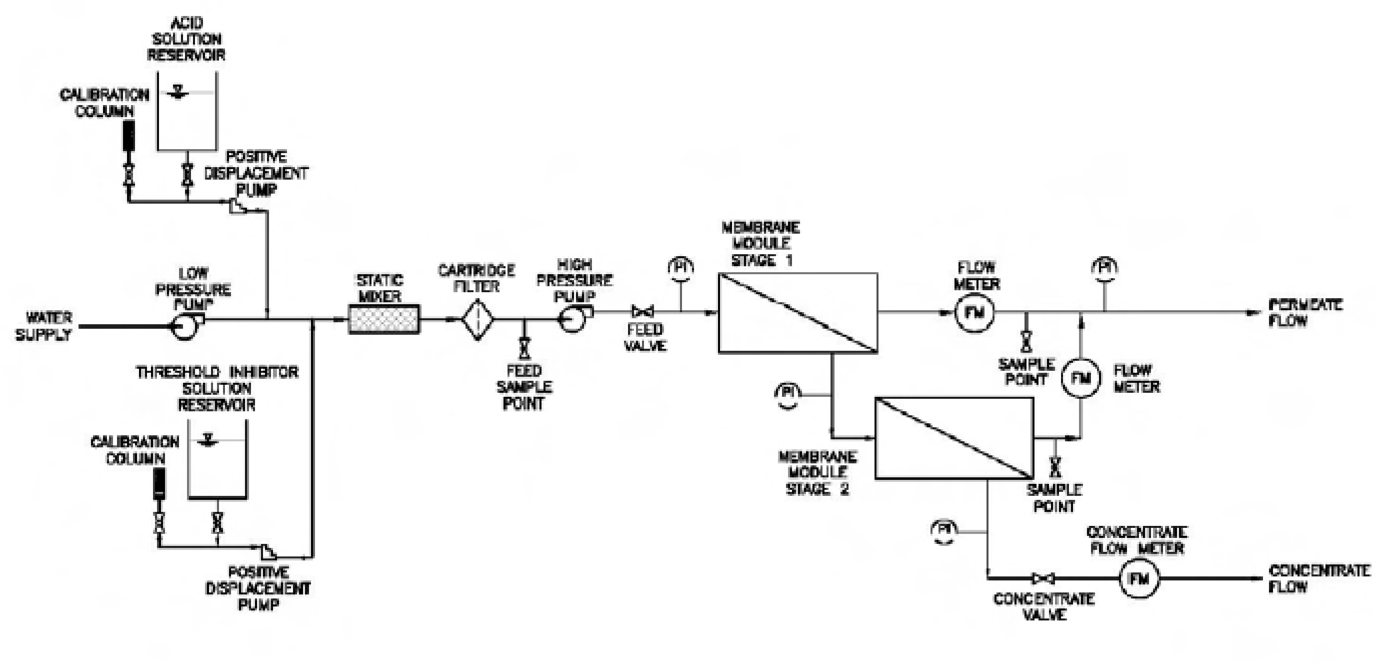
5.3.2 System Design

The key components of an RO or NF plant include:

- Chemical feed system for pretreatment and pH adjustment;
- Cartridge filter to remove large particles (greater than 1 micron) that could potentially foul the membrane;
- Medium to high pressure booster pumps for the feed-water;
- Membrane vessels; and
- Disposal system for concentrate.

Exhibit 5.6 shows a schematic for a typical RO/NF treatment system.

Exhibit 5.6 Schematic of a Typical RO/NF Treatment System



Source: USEPA, 2005

5.3.3 Operation and Maintenance

The feed-water supply should be checked routinely for changes in water quality (e.g., increased concentration of chemical ions like calcium that can cause scaling). Water quality parameters, both chemical and biological, should be monitored and the trends charted. Silt and iron oxides are common ground water contaminants. The acid injection system consisting of bulk storage tanks, chemical feeders, ratio controllers, and injection lines should be routinely checked for maintenance and safety related conditions. Acid quality should be verified on the shipments and certified analyses reviewed. Operators should routinely calibrate and check pH controllers and clean pH probes weekly.

Cartridge filter vessel drains should be flushed daily, and the pressure drop across the filters should be checked and recorded. Upon filter changeout, proper seating of the cartridges should be ensured (USEPA, 2005). Residual particulate matter inside the cartridge filter vessel should not be allowed to enter downstream piping during filter cartridge changeout. Maximum flow rates per individual cartridge should not be exceeded. Membrane block feed-water, brine and product conductivity, flows, pH, and pressure should be logged daily. Any unusual changes in preset membrane block operating conditions may require adjustment to the system. High-pressure pumps and motors require routine maintenance as recommended by the manufacturer.

All instrument systems associated with fail-safe or shutdown conditions should be kept operational. Minimum spare parts inventory recommended by the manufacturer should be kept at hand. The degasifier packed tower or tray aeration system should be inspected and cleaned periodically. Slime buildups occur in degasifiers and require cleaning. Degasifier blowers and motors require routine maintenance.

The GWR also requires that membrane technologies used to provide 4-log removal of viruses to meet GWR requirement be operated in accordance with State-specified performance requirements and show that the integrity of the membrane is intact. The most accurate method of demonstrating membrane integrity currently available is direct integrity testing. The most commonly applied direct integrity test is the pressure decay test, but other tests such as the vacuum decay test are used in some applications. Three important attributes of a direct integrity test are defined in the *Membrane Filtration Guidance Manual* (USEPA, 2005): sensitivity, resolution, and frequency. Available direct integrity tests are capable of demonstrating integrity capable of achieving 4-log removal, however, site-specific conditions may result in direct integrity test sensitivity lower than 4-log removal. Thus it is important to demonstrate the sensitivity of a direct integrity test in each application of the technology. States may choose to limit the virus removal credit awarded to a membrane process based on the demonstrated sensitivity of the direct integrity test.

Operation of a membrane treatment system requires disinfecting and cleaning the membranes to prevent fouling. Depending on the influent water quality, systems should clean the membrane every few days to every few months. Membrane concentrates are usually discharged to:

- Surface waters such as lakes, rivers, or oceans (requiring a NPDES permit);
- Injection wells (under the UIC program);
- Sanitary sewers (possibly requiring State or Local Permits); or
- Evaporation ponds.

Federal, State, and local authorities, regulations, and permitting requirements regulate disposal methods.

5.3.4 Advantages and Disadvantages

RO and NF systems are advantageous because they are extremely efficient in removing viruses, bacteria, and DBP precursors.

There are several disadvantages associated with the use of RO and NF, including the high cost of the process. Both processes are highly energy-intensive and require a large amount of power to sustain proper removal levels of viruses and bacteria. They also require highly skilled personnel to operate and maintain the filters and to ensure that proper cleaning of the filters is conducted. RO and NF do not provide any residual to control microbial regrowth in the distribution system. A disadvantage of RO is that the feedwater may be wasted as brine when the goal is to lower ion concentrations by reducing the permeate recovery. This is especially significant in areas with limited water supplies.

As described previously, the most accurate method of demonstrating membrane integrity currently available is direct integrity testing. Resolution is the smallest integrity breach that contributes to the response from a direct integrity test. EPA is not aware of any commonly used, pressure-based direct integrity test that can achieve a resolution consistent with the size of a virus particle. The required test pressure is beyond the pressure tolerances of most membrane technologies in use today and pressure-based direct integrity tests applied at lower pressures may not detect small integrity breaches that could pass viruses and thus compromise the log-removal capability of the system. Appendix E of the *Membrane Filtration Guidance Manual* (USEPA, 2005) provides additional information on the application of direct integrity tests to membrane processes used for virus removal.

Continuous indirect integrity monitoring, using turbidity, particle counts or other surrogate water quality parameters, may be used to assess membrane integrity on a continuous basis and establish performance criteria. Some methods of indirect integrity monitoring may not have sufficient accuracy to serve as more than gross measures of membrane integrity for virus removal (USEPA, 2005). For most ground water sources, turbidity and particles are not likely to be present at levels high enough to set performance criteria or use in continuous monitoring, and States may need to use other water quality parameters (e.g., TDS, conductivity) or operating parameters (e.g., transmembrane pressure, flux rate) as performance indicators. Monitoring of some parameters may require laboratory analysis or additional monitoring equipment. It is important to note that the continuous indirect integrity monitoring techniques discussed here are significantly less sensitive than direct integrity tests, and do not provide verification that membrane integrity is sufficient to meet virus log removal requirements. Rather, continuous indirect integrity monitoring is used to monitor for major integrity problems, such as a failed seal or end-cap.

As with other treatment technologies, membranes may be combined with another treatment technology to provide a total of 4-log treatment of viruses. The combination of a membrane technology with chlorine disinfection, which easily inactivates viruses at low doses, would provide multiple virus barriers with a level of redundancy.

5.4 Additional Resources

More detailed guidelines can be found in other publications, including but not limited to:

- Alternative Disinfectants Guidance Manual (USEPA, 1999b)
- Handbook of Chlorination and Alternative Disinfectants (White, 1999)
- Ultraviolet Disinfection Guidance Manual for the Long Term 2 Enhanced Surface Water Treatment Rule (USEPA, 2006b)
- Water Quality and Treatment (AWWA, 1990b)

- Membrane Filtration Guidance Manual (USEPA, 2005)
- Simultaneous Compliance Guidance Manual (USEPA 2007a)

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Appendix A

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Appendix A. Applications of Various Backflow Prevention Assemblies or Methods

Description	Advantages/Disadvantages	Protects Against Backpressure	Protects Against Backsiphonage	Hazard Type	High Hazard[1]	Containment/ Isolation
- A physical separation between the free flowing outlet of a potable water pipe and an unpressurized receptacle (USCFCCCHR, 1993). - Physical separation should be at least twice the diameter (2D) of the outlet pipe and no less than one inch (USEPA, 2003). - The only means of absolute separation between plumbing systems, and should be used whenever possible and not bypassed (USPHS, 1966). - Well-designed and properly maintained air gaps are AWWA's recommended method of protection against backflow for extremely hazardous installations (AWWA, 1990a). - Mainly used at the end of a service line (USEPA, 2003), an air gap is the recommended protection for sewage pumps and ejectors, sewer pipe connections, trap primers, and swimming pools.	**Advantages** -Non-mechanical -Highly effective and easy to integrate into a current system -Provides maximum protection **Disadvantages** - Pressure loss can lead to the need for secondary pumping requirements in continuous piping systems (USEPA, 1989). - Frequent inspection is needed to maintain 2D physical separation and prevent backsplash (USEPA, 2003). - Water exposure to the surrounding atmosphere can lead to contamination by airborne contaminants and can allow disinfectant residuals to escape (USEPA, 1989).	Yes	Yes	Health	Yes	Isolation

Description	Advantages/Disadvantages	Protects Against Backpressure	Protects Against Backsiphonage	Hazard Type	High Hazard[1]	Containment/ Isolation
Pressure Type Vacuum Breaker						
- Under normal flow conditions, the inlet water pressure opens the check valve allowing flow to continue, while pushing the PVB's air inlet valve against the air inlet canopy preventing air from entering. However, when normal flow is interrupted due to at least a partial vacuum, the check valve closes preventing backflow. If the check valve is fouled and does not close, the air inlet valve acts as a second check and opens, allowing air to enter the system (AWWA, 1990a). - Must be installed only in a vertical position, above grade with a minimum of 12 inches of vertical clearance above the highest point in the downstream piping, and must be accessible for testing and repair (BMI, 1996). - PVBs are available for piping ranging from one-half to 10 inches in diameter and are widely used in agricultural and industrial applications (USEPA, 1989).	**Advantages** - Can be used under constant pressure and can be tested in line (USEPA, 2003). - Available in sizes ranging from one-half to ten inches (USEPA, 2003) **Disadvantages** - Some manufacturers may have pressure or temperature limitations placed on their assemblies (BMI, 1996).	No	Yes	Health/Non-Health	No	Either

Description	Advantages/Disadvantages	Protects Against Backpressure	Protects Against Backsiphonage	Hazard Type	High Hazard[1]	Containment/ Isolation
Double check valve						
- Consists of two check valves in one body located between two tightly closing gate valves. The check valves are spring-loaded and require approximately one pound of pressure to open (USEPA, 2003). - Under normal flow conditions in excess of one pound of pressure, the water pressure will hold the check valves open allowing water to flow through the assembly. When backflow conditions occur, the check valves close and prevent backflow. **Modified DCVs** - Double check detector check (DCDC), is commonly used for fireline installations. DCDC differs from the DCV in that it has a metered bypass line for low flow situations (USEPA, 1989). - Residential dual check (RDC) that differs from the DCV in that it has no test cocks or gate valves. RDCs were designed to provide inexpensive protection against backpressure and backsiphonage from household hazards (USEPA, 1989). They are available in sizes ranging from one-half to one inch (USEPA, 1989).	**Advantages** - Can be installed in pits or vaults, and, in some cases can be installed vertically (BMI, 1996). - The internal loading or weighting allows the check valve to seal even in the presence of small debris (USEPA, 2003). -Ability to be used under constant pressure(USEPA, 2003) **Disadvantages** -should only be used for low to medium hazard situations	Yes	Yes	Non-health	No	Either

Description	Advantages/Disadvantages	Protects Against Backpressure	Protects Against Backsiphonage	Hazard Type	High Hazard[1]	Containment/ Isolation
Reduced pressure principle backflow prevention device						
- Consist of two independent check valves - one is a differential relief valve between the two check valves and the other is located below the first check valve (AWWA, 1990a). Both valves are equipped with gate valves and test cocks. - Under normal flow conditions, water pressure forces both check valves open. When the water passes through the first check valve a slight predetermined pressure drop results (USEPA, 1989). The space between the first and second check valves is normally maintained at two psi lower than the inlet pressure. The second check valve is lightly loaded to allow the water pressure to hold it open and results in a pressure drop of one psi. When reduced pressure from the inlet, or increased pressure downstream occurs, the check valves close and the pressure differential between the inlet and the space between the two check valves forces the flow out of the differential relief valve (USEPA, 1989). - RPBAs are available for service lines ranging from three-fourths to 10 inches and can be installed in pits or vaults.	**Advantages** - Provides maximum protection (USEPA, 2003). - Discharge of flow out of the differential relief valve also acts as an indication of a backflow event. - The differential relief valve also provides backflow protection in the event that the second check valve becomes fouled. **Disadvantages** - Some models can only be installed horizontally and have temperature and pressure limitations (BMI, 1996). - More expensive than the other backflow preventers.	Yes	Yes	Health	Yes	Either

Description	Advantages/Disadvantages	Protects Against Backpressure	Protects Against Backsiphonage	Hazard Type	High Hazard[1]	Containment/ Isolation
Double check valve with intermediate atmospheric vent						
- Similar in construction and function to a DCV in that it has double check valves within a single body. However, it also has an atmospheric vent located between the two check valves, which adds extra protection (USEPA, 2003).	**<u>Advantages</u>** - Compact with protection for moderate hazards -Can be used under constant pressure - Available in sizes ranging from one-half to three-fourths of an inch (USEPA,2003).	Yes	Yes	Non-health	No	Either

[1] A high hazard is when a cross connection endangers human health. Low hazards may result in contamination but generally not affect human health