

# **CLASS III/IV WATER OPERATOR COURSE MANUAL**

WEST VIRGINIA  
Department of



**2016**

## **CLASS III/IV WATER OPERATOR COURSE MANUAL**

### **Overview/Preface**

This manual is designed for operators taking the voluntary Class III/IV water operator course and exam. This tool, along with your operating experience and review of the Office of Water Programs California State University Sacramento manuals, will help you prepare for the certification exams.

Originally, this manual was written as a “need to know” study guide for individuals taking the water operator certification exam. However, it was decided this manual should be a stand alone resource to assist operators in their overall understanding of the treatment process at any Class III or IV system. With the great diversity and dynamics present in the water treatment industry, it is important for operators to be resourceful – at least know enough to ask the right questions to the right people.

Information contained within this manual should give you a basic understanding of any water system you may work with. Operators should use however, this manual as a catalyst or springboard for further research and inquiry into your individual system(s). We strongly encourage your continued educational growth.

#### ***Disclaimer***

*All reasonable precautions have been taken in the preparation of this document, including both technical and non-technical proofing. The West Virginia Department of Health and Human Resources and West Virginia Rural Water Association and all staff assume no responsibility for any errors or omissions.*

*Should the summarized information in this document be inconsistent with a governing rule or statute, the language of the rule or statute shall prevail.*

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## INTRODUCTION

The **U.S. Environmental Protection Agency (EPA)** or sometimes **USEPA**) is federal agency charged with protecting human health and with safeguarding the natural environment: air, water, and land. On July 9, 1970, Richard Nixon transmitted Reorganization Plan No. 3 to the U.S. Congress by executive order, creating the EPA as a single, independent, agency from a number of smaller arms of different federal agencies. Prior to the establishment of the EPA, the federal government was not structured to make a coordinated attack on the pollutants which harm human health and degrade the environment. The EPA was assigned the task of repairing the damage already done to the natural environment and to establish new criteria to guide Americans in making a cleaner, safer America.

The agency conducts environmental assessment, research, and education. It has the primary responsibility for setting and enforcing national standards under a variety of environmental laws, in consultation with state, tribal, and local governments. It delegates some permitting, monitoring, and enforcement responsibility to U.S. states and Native American tribes. EPA enforcement powers include fines, sanctions, and other measures.

EPA headquarters in Washington, D.C. EPA comprises 17,000 people in headquarters program offices, 10 regional offices, and 27 laboratories across the country. More than half of its staff are engineers, scientists, and environmental protection specialists; other groups include legal, public affairs, financial, and computer specialists.

Each EPA regional office is responsible within its states for implementing the Agency's programs, except those programs that have been specifically delegated to states.

- Region 1 - responsible within the states of Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont.
- Region 2 - responsible within the states of New Jersey and New York in addition it's also responsible for the US territories of Puerto Rico, and the U.S. Virgin Islands.
- **Region 3 - responsible within the states of Delaware, Maryland, Pennsylvania, Virginia, West Virginia, and the District of Columbia.**
- Region 4 - responsible within the states of Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee.
- Region 5 - responsible within the states of Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin.
- Region 6 - responsible within the states of Arkansas, Louisiana, New Mexico, Oklahoma, and Texas.
- Region 7 - responsible within the states of Iowa, Kansas, Missouri, and Nebraska.
- Region 8 - responsible within the states of Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming.
- Region 9 - responsible within the states of Arizona, California, Hawaii, Nevada, and the territories of Guam and American Samoa.
- Region 10 - responsible within the states of Alaska, Idaho, Oregon, and Washington.

## **Office of Groundwater and Drinking Water**

The Environmental Protection Agency's **Office of Groundwater and Drinking Water (OGWDW)**, together with states, tribes, and its many partners, protects public health by ensuring safe drinking water and protecting groundwater. OGWDW, along with EPA's ten regional drinking water programs, oversees implementation of the **Safe Drinking Water Act (SDWA)**, which is the national law safeguarding tap water in America. The SDWA requires **public water systems (PWSs)** to provide drinking water that meets safety standards and protects sources of drinking water, including rivers, lakes, reservoirs, springs, or groundwater wells. Approximately 90% of Americans rely on PWSs for their drinking water at home; the other 10% have private wells, which are not federally regulated. Almost everyone drinks water from a public system at some point: while at school, at work, in a restaurant, or on vacation.

OGWDW develops and helps implement national drinking water standards; oversees, assists and helps fund state drinking water programs and source water protection programs; helps small drinking water systems; protects underground sources of drinking water through the Underground Injection Control Program; and provides information to the public. OGWDW also works in cooperation with states, tribes, and EPA's Office of Enforcement and Compliance Assurance to guarantee that water systems meet these protective standards.

## **Setting National Drinking Water Standards**

OGWDW sets national standards for drinking water, which either limit the amount of a particular contaminant in drinking water or require a certain treatment to remove or inactivate a contaminant. Both types of standards protect public health. When setting these standards, OGWDW uses sound data and peer-reviewed science to focus on the contaminants which present the greatest public health risk and which appear most frequently in drinking water. OGWDW also identifies sub-populations most vulnerable to drinking water contaminants, such as infants, children, pregnant women, the elderly, and the immunocompromised, and considers the risk to these sensitive sub-populations when setting safety standards. As part of the standard-setting process, OGWDW relies on input from all interested parties, looks at whether drinking water regulations are cost effective, determines appropriate procedures for analyzing samples of drinking water, and identifies affordable ways to treat drinking water.

## **Working with States and Tribes to Implement the Drinking Water Program**

States and tribes work directly with water systems to implement the national drinking water program. To implement the drinking water program, each state or tribe must establish a drinking water program that is at least as stringent as the federal program (some states have stricter programs), assure that water systems meet safety standards, and adopt and implement adequate enforcement procedures (called primacy). If a state or tribe is unable to meet the requirements for primacy, or is simply unwilling, EPA's regional offices will directly implement the drinking water program in that jurisdiction. OGWDW provides grants, training, and technical assistance to help states and tribes successfully carry out the provisions of the SDWA. OGWDW also administers the drinking water state revolving loan fund, and grants funds to states, that loan money to water systems to install or upgrade facilities and to replace aging pipes and other infrastructure. The fund's policy is to support all water systems in need, including assisting small and disadvantaged communities, and protecting sources of drinking water from contamination.

## **Assistance for Small Drinking Water Systems**

The vast majority of PWSs in the U.S. serve fewer than 3,300 people. Small water systems incur greater costs per household because they must spread the cost of infrastructure improvement

over a smaller customer base. In fact, small systems could incur three times as much cost per household to continue to provide safe drinking water in the future as compared to that of larger systems. OGWDW assists small systems by identifying affordable and effective ways for small systems to treat water for their customers and providing technical and financial assistance.

### **Voluntary Programs with Water Systems: The Partnership for Safe Water**

The Partnership for Safe Water is a unique cooperative effort between OGWDW and over 100 large water systems that join the partnership to provide protection beyond what is currently required by federal law to their customers from *Cryptosporidium*, *Giardia lamblia* (herein referred to as *Giardia*) and other microbial contaminants.

### **Protecting Drinking Water at its Source and Protecting Groundwater**

OGWDW is working with states so that they can determine how susceptible drinking water sources are to contamination. States and water suppliers will share this information (compiled into source water assessments) with the public so that communities can protect their drinking water sources. OGWDW also oversees programs that protect aquifers which serve as the primary source of drinking water for one or more communities (sole source aquifers), and works with states to implement wellhead protection programs, under which states protect the land around wells from contaminants. Through the Underground Injection Control program, OGWDW protects underground sources of drinking water. Injection deep into the earth is a common way of disposing of hazardous waste. If not injected properly, these wastes can contaminate sources of drinking water. OGWDW sets standards for safe injection practices, and bans certain types of injection altogether. A number of other EPA programs also protect drinking water from potential sources of contamination. For instance, the Superfund program cleans-up hazardous waste sites, while other programs regulate landfills, discharges to water, underground storage tanks, and chemicals used on farms and lawns. OGWDW works with other EPA offices to support efforts to coordinate these and many other programs to provide comprehensive protection of the nation's groundwater resource.

### **Collecting and Providing Information to the Public**

Public information and public involvement are critically important to the successful implementation of the drinking water program. OGWDW works through an advisory committee, the National Drinking Water Advisory Council, and solicits other input through public meetings with states, tribes, water systems, environmental and other groups, and the public. OGWDW is working with these partners and others to provide information to citizens and communities on the quality of their local drinking water. OGWDW collects information on every PWS, such as how many people each system serves and whether each is meeting drinking water standards. This information is stored in the Safe Drinking Water Information System, and is used to help OGWDW understand whether systems are complying with drinking water safety standards. OGWDW is also collecting information on the occurrence of contaminants which may need to be regulated in the future, and storing this information in the National Contaminant Occurrence Database. OGWDW is providing materials to help water systems prepare annual water quality reports (consumer confidence reports) and notify consumers of water emergencies, and is helping consumers use this information to make decisions.

OGWDW maintains a web site (<http://www.epa.gov/safewater/>) and the **Safe Drinking Water Hotline (1-800-426-4791)** to make drinking water information easily available, and has also recently established the Drinking Water Academy to provide further training.

## **DRINKING WATER REGULATIONS**

Prior to 1976, water quality was regulated by individual state standards. In many cases, these standards were only recommendations rather than enforceable regulations. In December 1974, the Federal **Safe Drinking Water Act (SDWA)** (P.L. 93-523) was passed by Congress. The SDWA was amended in 1986 and 1996. The SDWA establishes a Federal program to monitor and increase the safety of the nation's drinking water supply. The SDWA authorizes the EPA to set and implement health-based standards to protect against both naturally occurring and man-made contaminants in drinking water. The EPA is also responsible for assessing and protecting drinking water sources; protecting wells and collection systems; making sure water is treated by qualified operators; ensuring the integrity of distribution systems; and making information available to the public on the quality of their drinking water. The EPA works closely with each state to establish public drinking water standards and enforce the requirements of the SDWA. In West Virginia, the state government agency with primacy authority is the **WV Department of Health and Human Resources (WVDHHR), Bureau for Public Health (BPH), Office of Environmental Health Services (OEHS)**. Therefore, OEHS has the same primary drinking water regulation enforcement authority over PWSs within the state as EPA. Local governments should be aware that while secondary drinking water standards are not federally enforceable, individual states may adopt any of the secondary standards as part of their own regulations, thus making them enforceable at the state level.

### **Implementing the SDWA**

The EPA establishes and implements the SDWA and its amendments through Title 40 **Code of Federal Regulations (CFR)** Parts 141-142, "**National Primary Drinking Water Regulations (NPDWR)**" and Title 40 CFR Part 143 "**National Secondary Drinking Water Regulations (NSDWR)**." These regulations allow the EPA to enforce federally established drinking water standards by setting goals to ensure the highest quality of drinking water, from the source to the tap.

The EPA establishes health goals based on risk and sets a legal limit, or **maximum contaminant level (MCL)**, to help ensure consistent quality of the water supply. MCLs are established based on known or anticipated adverse health effects, the ability of available technology to remove contaminants, their effectiveness, and the cost of treatment. The limit is based on lifetime exposure and represents the highest permissible level of a contaminant in water that is delivered to any user of a PWS. MCLs have been set for over 90 potential drinking water contaminants, seven of which are new standards enforceable as of January 1, 2002. The NPDWR also codifies other specific requirements of the SDWA, including monitoring and analytical requirements, reporting and record keeping, maximum contaminant level goals (MCLG), filtration and disinfection, control of lead and copper, treatment techniques, and information collection requirements for PWSs. This regulation also provides **best available treatment technologies (BAT)**.

Secondary drinking water standards under the NSDWR are established for contaminants that primarily affect aesthetic qualities relating to public acceptance of drinking water. These secondary standards are not federally enforceable, but rather serve as guidelines for state use.

### **EPA's Next Steps**

The EPA has drinking water regulations for more than 90 contaminants. The SDWA includes a process the EPA must follow to identify new contaminants which may require regulation in the

future. The EPA must periodically release a **Contaminant Candidate List (CCL)**. The EPA uses this list of unregulated contaminants to prioritize research and data collection efforts to help determine whether specific contaminants should be regulated.

In February 2005, the EPA published the second CCL of 51 contaminants and provided an update on the efforts to improve the CCL process for the future that is based, in part, on recommendations from the National Research Council and the National Drinking Water Advisory Council. In addition to making the process used for selecting contaminants easier to understand, the EPA goals for the future are to:

- Evaluate a wider range of information;
- Screen contaminants more systematically; and,
- Develop a more comprehensive CCL by expanding the number of contaminants being reviewed for inclusion on the next CCL.

## WEST VIRGINIA DRINKING WATER REGULATIONS

West Virginia has received approval from EPA to have primacy authority for enforcing public drinking water regulations at the state level. In other words, OEHS ensures all federal and state drinking water requirements are met. These state regulations can be accessed online at the West Virginia Legislature web site at [www.legis.state.wv.us](http://www.legis.state.wv.us). The OEHS **Environmental Engineering Division (EED)** Director, Walter Ivey, oversees several programs that make up the WV drinking water program. The following programs function as the multiple barrier approach in West Virginia:

- The **Source Water Assessment & Wellhead Protection (SWAP)** Program's mission is to assess, preserve, and protect the state's source waters which are used to supply water for the state's PWSs.
- The **Certification & Training (C&T)** Program provides training and/or testing to PWS operators, wastewater treatment works operators, backflow prevention assembly installers/testers, water well drillers, and monitoring well drillers to administer certifications.
- The **Infrastructure & Capacity Development (I&CD)** Program helps PWSs improve their finances, management, infrastructure, and operations so they can provide safe drinking water consistently, reliably, and cost-effectively.
- The **Compliance & Enforcement (C&E)** Program determines whether a PWS is in compliance with all state rules and federal regulations pertaining to the SDWA. Such determination is based on results of the chemical/contaminant monitoring required for each PWS. If a system is out of compliance, a violation is then issued requiring the PWS to do public notification activities to inform the public that there was a problem, what happened, and what they are doing to fix it.
- The Data Management Program enters all data received from the **Monthly Operational Reports (MORs)**, bacteriological reports, and chemical reports into a specialized database called **Safe Drinking Water Information System (SDWIS)**. Each PWS monitors and samples their water for various chemicals and contaminants that have the potential to be a public health risk.

All of the WV drinking water program is based in the OEHS central office located at 350 Capitol Street, Room 313 in Charleston, WV 25301-3713. The OEHS central office phone number is (304) 558-2981 and fax number is (304) 558-0139. The OEHS website is <http://www.wvdhhr.org/oehs/eed>. OEHS also has 5 district offices to provide technical and administrative support locally to PWSs across the state:

- **Wheeling District Office** (304) 238-1145
- **Philippi District Office** (304) 457-2296
- **Kearneysville District Office** (304) 725-0348
- **Beckley District Office** (304) 256-6666
- **St. Albans District Office** (304) 722-0611

The OEHS not only enforces drinking water standards, such as those in the SDWA, but it is also responsible for establishing and enforcing standards and regulations for water system design, construction, operation and maintenance, well construction and placement, pumps, treatment processes, chemical addition, well abandonment, lab certification, and wellhead protection. To ensure PWSs meet these state requirements, water system owners are responsible for obtaining plan approvals from the OEHS for well construction, pump installation, well rehabilitation,

chemical addition to water, water treatment, and new system capacity. Plan approvals help ensure that water suppliers provide a safe and dependable supply of water to their customers.

OEHS personnel enforce compliance with all appropriate codes and regulations by performing periodic on-site inspections of each system. These inspections are called sanitary surveys and their frequency depends upon the size and classification of the water system. During the sanitary survey, the OEHS representative will review the system's compliance and monitoring records and inspect the water system facilities. Following the inspection, the system owner will receive a written report listing any deficiencies or violations found. A PWS must respond within 45 days and establish time frames to correct the problem(s).

## SAFE DRINKING WATER ACT

The SDWA sets permissible levels of substances found in water which could be hazardous to public health. These regulations include MCLs for inorganic and organic chemicals, radioactivity, turbidity and microbiological levels. Testing and monitoring requirements, reporting and record keeping schedules, and public notification are enforced by OEHS.

The SDWA gives the EPA the authority to set drinking water standards. Drinking water standards are regulations the EPA sets to control the level of contaminants in the nation's drinking water. There are two categories of water standards: the Primary Drinking Water Regulations and the Secondary Drinking Water Regulations. A **National Primary Drinking Water Regulation (NPDWR)** is a legally-enforceable standard that applies to PWSs. Primary standards protect drinking water quality by limiting the levels of specific contaminants that can adversely affect public health and are known or anticipated to occur in water. They take the form of MCLs or **Treatment Techniques (TT's)**. A **National Secondary Drinking Water Regulation (NSDWR)** is a non-enforceable guideline regarding contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste and odor) in drinking water. EPA recommends secondary standards to PWSs but does not require systems to comply.

### **Maximum Contaminant Level (MCL) and Maximum Contaminant Level Goal (MCLG)**

A MCL is the highest level of a contaminant that is allowed in drinking water. Before setting a MCL for any health related drinking water contaminant, the SDWA requires EPA to set what are called MCLGs. The MCLG is the level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety. MCLs are set as close to the MCLGs as feasible using the best available treatment technology. Realizing that, in some cases, it is not technologically or financially feasible to achieve the MCLG for all contaminants, EPA establishes MCLs for all regulated contaminants in drinking water. In doing so, they take into account such factors as health risk assessments, cost-benefit analysis, and BATs, in establishing acceptable levels. BAT refers to the technology currently available to detect and treat the contaminant of concern. MCLs are the "drinking water standards" that all PWSs must meet. It is important to remember that MCLs are not set in stone. As new health effects data becomes available, MCLs are adjusted either up or down, depending on what the latest data shows.

### **Treatment Technique (TT) Requirement**

For some contaminants, establishing a specific MCL is either not possible or too costly to mandate. For such contaminants, EPA may also choose to require a specific water treatment process intended to reduce the level of a contaminant in drinking water, called a **Treatment Technique (TT)**, which, when implemented by the water system, would reasonably protect public health. Examples of TTs are corrosion control for reduction of lead and copper, and filtration for removal of particulates in surface water.

**Secondary Maximum Contaminant Levels (SMCLs)** which apply to public water systems and which, in the judgment of the Administrator, are requisite to protect the public welfare. The SMCL means the maximum permissible level of a contaminant in water which is delivered to the free flowing outlet of the ultimate user of public water system. Contaminants added to the water under circumstances controlled by the user, except those resulting from corrosion of piping and plumbing caused by water quality, are excluded from this definition.

## **WATER SYSTEM RECORDS RETENTION**

At times, owning, operating, and maintaining a PWS can seem a daunting challenge. The paperwork requirements alone can feel overwhelming. Keeping complete, well organized records can greatly simplify the task of running a water public system. Records prove compliance, track system trends, and assist in the overall planning, operation, maintenance, and management of the water system. You cannot effectively run a water system and keep it in compliance without keeping and maintaining good records.

Records should be kept in a safe secure place and readily available for use by the system operator or to be provided to a state or federal inspector upon request. If the ownership, management, or the operator of your system changes, all records are required to be transferred to the new responsible party.

The following is a general listing of the types of records and the length of time they must be kept:

### **Recordkeeping Time Lines**

2 years	Copies of Backflow Testing Results
3 years	Records of action to correct violation
3 years	Copies of Public Notices
5 years	Monthly Operational Reports & Bacteria Analysis
5 years	Records concerning a variance or exemption
10 years	Copies of written reports, summaries, or communications relating to sanitary surveys
10 years	Radiological, chemical and turbidity analysis
12 years	Lead and copper results and reports
Indefinitely	Disinfection Benchmark and Profiling results

## SAFE DRINKING WATER RULES AND REGULATIONS

SDWA Rule	Risk Type	Coverage	Overview	Monitoring
Total Coliform Rule	Microbial	All PWS	Monitoring for coliform as indicator of potential contamination.	Sampling based on population; requires confirmation for positive coliform.
Surface Water Treatment Rule	Microbial	All PWS that use SW or GWUDI*	Establishes criteria when filtration is required. Systems must filter and disinfect or apply for reduced monitoring.	1. Inactivation Ratios 2. Residual Disinfectant Concentration (RDC) 3. Turbidity
Phase I, II, V Rule	Chemical and Radiological	CWS and NTNCWS	Establishes MCLs or treatment for 66 chemicals (IOC, VOC and SOC)	Nine year compliance cycle with 3 year compliance period
Nitrate and Nitrite only	Chemical and Radiological	All PSW	Establishes MCLS or treatment	Once per year
Lead and Copper Rule	Chemical and Radiological	CWS and NTNCWS	Establishes treatment techniques for corrosion control, source water, and lead service line replacement and public education triggered by levels at consumer taps.	Consumer taps during each 6-month period. Two consecutive periods triggers corrosion control, or reduced monitoring.
Stage 1 Disinfection Byproducts Rule	Chemical and Radiological	CWS and NTNCWS	Reduce levels of disinfectants and DBPs. Sets MCLs for HAA5s, chlorite, bromate, and TTHMs and MRDL and MRDLG**	1. Monitoring for DBP. 2. For surface water and GWUDI, TOC and alkalinity.
Filter Backwash Recycling Rule (FBRR)	Microbial	PWS or GWUDI that use conventional or direct filtration	Requires systems to return backwash for filtration.	Complete upgrades by 6/8/06
Consumer Confidence Reports		All CWS	CCR to customers about the quality and health implications of community water supply.	Monitoring and results and violations must be reported.
Public Notification		All PWS	Divides Notification to Public for violations into 3 tiers: Tier 1-Serious Health Effect-within 12 hours Tier 2-Health Potential-within 30 days Tier 3-Not immediate health impact-one year	Tier monitoring results must be reported to public in timely manner.
Arsenic and New Source Contaminants	Chemical and Radiological	CWS and NTNCWS	Sets MCL and monitoring requirements for arsenic at 0.010 mg/L	Places arsenic monitoring with other IOCs***
Radionuclides Rule	Chemical and Radiological	CWS	MCL for monitoring at each entry point and reporting, sets public notification requirements	Places monitoring for gross alpha and Radium 226 and 228 and Uranium in standard framework. Also beta if affected.

SDWA Rule	Risk Type	Coverage	Overview	Monitoring
Interim Enhanced Surface Water Treatment Rule	Microbial	PWS and GWUDI that serves more than 10,000 persons	Sets requirements for microbial contamination including 2 log reduction of <i>Cryptosporidium</i> and prevents risk associated with DBP requirements	Grab samples of combined filter effluent every for 4 hours; Continuous turbidity monitoring on each filter every 15 minutes; NTU $\leq$ 0.3 95% of time, Maximum level of 1 NTU Disinfection Profiling each week
Long Term 1 Enhanced Surface Water Treatment Rule	Microbial	PWS and GWUDI that serves less than 10,000 persons	Sets requirements for microbial contamination including 2 log reduction of <i>Cryptosporidium</i> and prevents risk associated with DBP requirements	Grab samples of combined filter effluent every for 4 hours; Continuous turbidity monitoring on each filter every 15 minutes; NTU $\leq$ 0.3 95% of time, Maximum level of 1 NTU Disinfection Profiling each week
Groundwater Rule	Microbial	PWS that use GW	Sets requirements for viruses and bacteria	Sets inactivation levels for viruses
Radon Rule	Chemical and Radiological	CWS that use GW, mixed GW or intermittently use GW	Regulates exposure to radon	Results trigger additional or reduced monitoring
Stage 2 Disinfection Byproduct (DBP) Rule	Microbial	CWS and NTNCWS that do not use UV	Works in combination with Long Term Enhanced Surface Water Treatment Rule	Initial Distribution System Evaluation to determine monitoring sites
Long Term 2 Enhanced Surface Water Treatment Rule	Microbial	PWS that use surface water and GWUDI	Regulates treatment for source water	For systems serving under 10,000; <i>Cryptosporidium</i> and <i>E. coli</i> monitoring

## WHAT ARE SECONDARY STANDARDS

The EPA has established National Primary Drinking Water Regulations that set mandatory water quality standards for drinking water contaminants. These are enforceable standards called "maximum contaminant levels" or "MCLs", which are established to protect the public against consumption of drinking water contaminants that present a risk to human health. An MCL is the maximum allowable amount of a contaminant in drinking water which is delivered to the consumer .

In addition, EPA has established National Secondary Drinking Water Regulations that set non-mandatory water quality standards for 15 contaminants. EPA does not enforce these "secondary maximum contaminant levels" or "SMCLs." They are established only as guidelines to assist public water systems in managing their drinking water for aesthetic considerations, such as taste, color and odor. These contaminants are not considered to present a risk to human health at the SMCL.

Since these contaminants are not health threatening at the SMCL, and public water systems only need test for them on a *voluntary* basis, then why it is necessary to set secondary standards? EPA believes that if these contaminants are present in your water at levels above these standards, the contaminants may cause the water to appear cloudy or colored, or to taste or smell bad. This may cause a great number of people to stop using water from their public water system even though the water is actually safe to drink. Secondary standards are set to give public water systems some guidance on removing these chemicals to levels that are below what most people will find to be noticeable.

There are a wide variety of problems related to secondary contaminants. These problems can be grouped into three categories: *Aesthetic effects* -- undesirable tastes or odors; *Cosmetic effects* -- effects which do not damage the body but are still undesirable; and *Technical effects* -- damage to water equipment or reduced effectiveness of treatment for other contaminants. The secondary MCLs related to each of these effects are given in Table 1.

### **Aesthetic Effects**

*Odor and Taste* are useful indicators of water quality even though odor-free water is not necessarily safe to drink. Odor is also an indicator of the effectiveness of different kinds of treatment. However, present methods of measuring taste and odor are still fairly subjective and the task of identifying an unacceptable level for each chemical in different waters requires more study. Also, some contaminant odors are noticeable even when present in extremely small amounts. It is usually very expensive and often impossible to identify, much less remove, the odor-producing substance.

- **Standards related to odor and taste:** Chloride, Copper, Foaming Agents, Iron, Manganese pH, Sulfate, Threshold Odor Number (TON), Total Dissolved Solids, Zinc.

*Color* may be indicative of dissolved organic material, inadequate treatment, high disinfectant demand and the potential for the production of excess amounts of disinfectant by-products. Inorganic contaminants such as metals are also common causes of color. In general, the point of consumer complaint is variable over a range from 5 to 30 color units, though most people find color objectionable over 15 color units. Rapid changes in color levels may provoke more citizens complaints than a relatively high, constant color level.

- **Standards related to color:** Aluminum, Color, Copper, Foaming Agents, Iron, Manganese, Total Dissolved Solids.

*Foaming* is usually caused by detergents and similar substances when water has been agitated or aerated as in many faucets. An off-taste described as oily, fishy, or perfume-like is commonly associated with foaming. However, these tastes and odors may be due to the breakdown of waste products rather than the detergents themselves.

- **Standards related to foaming:** Foaming Agents.

### **Cosmetic Effects**

*Skin discoloration* is a cosmetic effect related to silver ingestion. This effect, called argyria, does not impair body function, and has never been found to be caused by drinking water in the United States. A standard has been set, however, because silver is used as an antibacterial agent in many home water treatment devices, and so presents a potential problem which deserves attention.

- **Standard related to this effect:** Silver.

*Tooth discoloration* and/or pitting is caused by excess fluoride exposures during the formative period prior to eruption of the teeth in children. The secondary standard of 2.0 mg/L is intended as a guideline for an upper boundary level in areas which have high levels of *naturally occurring* fluoride. It is *not* intended as a substitute for the lower concentrations (0.7 to 1.2 mg/L) which have been recommended for systems which *add* fluoride to their water. The level of the SMCL was set based upon a balancing of the beneficial effects of protection from tooth decay and the undesirable effects of excessive exposures leading to discoloration.

- **Standard related to this effect:** Fluoride.

### **Technical Effects**

*Corrosivity*, and *staining* related to corrosion, not only affect the aesthetic quality of water, but may also have significant economic implications. Other effects of corrosive water, such as the corrosion of iron and copper, may stain household fixtures, and impart objectionable metallic taste and red or blue-green color to the water supply as well. Corrosion of distribution system pipes can reduce water flow.

- **Standards related to corrosion and staining:** Chloride, Copper, Corrosivity, Iron, Manganese, pH, Total Dissolved Solids, Zinc.

*Scaling* and *sedimentation* are other processes which have economic impacts. Scale is a mineral deposit which builds up on the insides of hot water pipes, boilers, and heat exchangers, restricting or even blocking water flow. Sediments are loose deposits in the distribution system or home plumbing.

- **Standards related to scale and sediments:** Iron, pH, Total Dissolved Solids, Aluminum.

## **EMERGING CONTAMINANTS**

Improved analytical methods have made it possible to analyze for contaminants that occur within our environment, and possibly our drinking water. Additional research is needed to understand potential health effects, along with the occurrence and cost of treatment to remove these contaminants from our drinking water.

### **UNREGULATED CONTAMINANT MONITORING RULE**

The Unregulated Contaminant Monitoring Rule (UCMR) collects data for potential contaminants. The program monitors selected large and small water systems for as many as 30 contaminants in a five year cycle. UCMR 1 (2001-2005) monitored 35 contaminants, which included:

- Acetochlor
- MTBE
- Nitrobenzene
- Perchlorate
- Aeromonas
- AlachlorESA
- Lead-210
- Polonium-210
- Cyanobacteria
- Echoviruses
- Helicobacterpylori
- Microsporidia
- Adenoviruses

UCMR 2 (2008-2010) is monitoring contaminants in these categories:

- Insecticide and Insecticide Degradates
- Flame Retardants
- Explosives
- Acetanilide Herbicides and Herbicide Degradates
- Nitrosamines (often resulting from nitrate-reducing bacteria)

UCMR monitoring is based on availability of analytical methods and contaminant prioritization, with known and/or suspected health effects as top priority. Results from each cycle of the UCMR are used to develop the Candidate Contaminant Lists (CCLs) and future regulated contaminants.

### **PHARMACEUTICALS AND PERSONAL CARE PRODUCTS**

Pharmaceuticals and Personal Care Products (PPCPs), including Endocrine Disruptors (EDs), typically refer to any product used by individuals for personal health or cosmetic reasons or used by agribusiness to enhance growth or health of livestock. PPCPs represent a diverse collection of thousands of chemical substances, including, but not limited to:

- Prescription drugs
- Estrogenic steroids
- Insect repellent
- Detergent metabolites
- Plasticizers
- Fire retardants

- Antibiotics
- Genotoxic drugs
- Insecticides
- Hormones
- Antibiotics
- Antimicrobials
- Fragrances
- Solvents
- Veterinary drugs
- Sunscreen products
- Antidepressants
- Caffeine
- Antiepileptic drugs
- Nonprescription drugs

While research is being done to more fully determine potential health effects related to PPCPs, the best and most cost-effective way to ensure safe drinking water is to protect our drinking water at the source. The federal Office of National Drug Control Policy recommends not flushing prescription drugs down the toilet, unless the accompanying patient information specifically instructs it is safe to do so.

### **PERFLUOROCHEMICALS**

Perfluorochemicals (PFCs) are a family of man-made chemicals that have been used for decades to make products that resist heat, oil, stains, grease, and water. Common uses include nonstick cookware, stain-resistant carpets and fabrics, as components of fire-fighting foam, and other industrial applications.

Some of the chemicals in the PFC group are perfluorooctane sulfonate (PFOS; C<sub>8</sub>F<sub>17</sub>SO<sub>3</sub>), perfluorooctanoic acid (PFOA; C<sub>8</sub>F<sub>15</sub>O<sub>2</sub>H), and perfluorobutanoic acid (PFBA; C<sub>4</sub>F<sub>7</sub>O<sub>2</sub>H). The chemical structures of PFCs make them extremely resistant to breakdown in the environment. PFCs are manmade chemicals and do not occur naturally.

PFCs are very stable chemicals that do not change or break down in the environment. As a result, they may be found in soil, sediments, water, or in other places. There are a few studies indicating that PFCs easily enter groundwater and move long distances. Some experts suggest that PFCs can also travel long distances in air, deposit on soil, and leach into groundwater.

Studies show that nearly all people have some PFCs in their blood, regardless of age. The way PFCs get into human blood is not known at this time. People could be exposed through food, water, use of commercial products, or from the environment. Some PFCs stay in the human body for many years.

The PFC family of chemicals is relatively new and is the focus of active scientific research. In laboratory animal studies, high concentrations of PFCs cause harmful changes in the liver and other organs. Developmental problems (e.g., delays in growth and maturation) have been seen in the offspring of rats and mice exposed to PFCs while pregnant. Both PFOA and PFOS in high concentrations over a long period of time also cause cancer in laboratory animals. PFBA is not suspected of causing cancer in animals.

USEPA is engaged in a major effort with companies that have made or used PFCs to investigate the ways that PFCs enter the environment, and ultimately how people and animals are exposed to them. In addition, the EPA has announced an initiative to phase out 95% of the uses of PFOA by 2010 and entirely by 2015.

## **PUBLIC NOTIFICATION**

In addition to monitoring requirements, the federal government realizes that an important element of public safety is keeping the customer informed about the quality of their drinking water. Two regulations that were enacted to accomplish this goal are the **Public Notification Rule** and the **Consumer Confidence Report**.

Whereas the **Consumer Confidence Report (CCR)** is designed to provide information to customers on an annual basis (due July 1<sup>st</sup>), the Public Notification Rule specifies how water suppliers must inform their customers in the event of a MCL violation or emergency situation. This rule went into effect in May 2000 and established specific language, actions, time frames, and methods that must be used to notify the public in these situations. The Public Notification Rule establishes **Tiers** for each contaminant and the type of situation that resulted in the violation.

**Public notification (PN)** is intended to ensure that consumers will always know if there is a problem with their drinking water. PWSs must notify the people who drink their water if the level of a contaminant in the water exceeds EPA and State drinking water regulations, if there is a waterborne disease outbreak or any other situation that may pose a risk to public health, if the water system fails to test its water as required, or if the system has a variance or exemption from the regulations. Depending on the severity of the situation, water suppliers have from 24 hours to one year to notify their customers. PN is provided in addition to the CCR to provide customers with a more complete picture of drinking water quality and system operations.

EPA sets strict requirements on the form, manner, content, and frequency of public notices. Notices must contain:

- A description of the violation that occurred, including the potential health effects
- The population at risk and if alternate water supplies need to be used
- What the water system is doing to correct the problem
- Actions consumers can take
- When the violation occurred and when the system expects it to be resolved
- How to contact the water system for more information
- Language encouraging broader distribution of the notice

EPA specifies three categories, or tiers, of public notification. Depending on what tier a violation or situation falls into, PWSs have different amounts of time to distribute the notice and different ways to deliver the notice:

### **Tier 1 Public Notice - Required Within 12 Hours**

Any time a violation and situation with significant potential to have serious adverse effect on human health as a result of short-term exposure, water suppliers have 12 hours to notify people who may drink the water of the situation. Water suppliers must use media outlets such as television, radio, and newspapers, post their notice in public places, or personally deliver a notice to their customers in these situations.

### **Examples of Tier 1 Violations:**

- Violation of the MCL for total coliform, when fecal coliform or **Escherichia coli** (herein referred to as *E. coli*) are present in the water distribution system, or

failure to test for fecal coliform or *E. coli* when any repeat sample tests positive for coliform;

- Violation of the MCL for nitrate, nitrite, or total nitrate and nitrite; or when a confirmation sample is not taken within 24 hours of the system's receipt of the first sample showing exceedance of the nitrate or nitrite MCL;
- Exceedance of the nitrate **MCL (10 milligrams per liter (mg/L))** by non-community water systems, where permitted to exceed the MCL (up to 20 mg/L) by the primacy agency;
- Violations of the **maximum residual disinfection level (MRDL)** for chlorine dioxide when one or more of the samples taken in the distribution system on the day after exceeding the MRDL at the entrance of the distribution system or when required samples are not taken in the distribution system;
- Violation of the turbidity MCL of 1 **nephelometric turbidity unit (NTU)**, where the primacy agency determines after consultation that a Tier 1 notice is required or where consultation does not occur in 12 hours after the system learns of violation;
- Violation of the TT requirement resulting from a single exceedance of the maximum allowable turbidity limit, where the primacy agency determines after consultation that a Tier 1 notice is required or where consultation does not take place in 12 hours after the system learns of violation;
- Occurrence of a waterborne disease outbreak, as defined in 40 CFR 141.2, or other waterborne emergency; and
- Other violations or situations with significant potential for serious adverse effects on human health as a result of short term exposure, as determined by the OEHS either in its regulations or on a case-by-case basis.

\* If your system has any of these violations or situations, in addition to issuing public notice, you must initiate consultation with your primacy agency as soon as practical but within 12 hours after you learn of the violation or situation.

### **Tier 2 Public Notice - Required Within 30 Days (unless extended to 90 days by State)**

Any time a violation and situation with potential to have serious, but not immediate, adverse effects on human health, water suppliers must supply notices within 30 days, or as soon as possible, with extension of up to three months for resolved violations at the discretion of the OEHS. Notice may be provided via the media, posting, or through the mail.

#### **Examples of Tier 2 Violations:**

- All violations of the MCL, MRDL, and TT requirements except where Tier 1 notice is required.
- Violations of monitoring requirements where OEHS determines that a Tier 2 public notice is required, taking into account potential health impacts and persistence of the violation.
- Failure to comply with the terms and conditions of any variance or exemption in place.

### **Tier 3 Public Notice - Required Within 1 Year**

When PWSs violate a drinking water standard that does not have a direct impact on human health, for all other violations not included in Tier 1 or Tier 2, the water supplier has up to a year

to provide a notice of this situation to its customers. The extra time gives water suppliers the opportunity to consolidate these notices and send them with annual water quality reports (CCRs).

### **Examples of Tier 3 Violations:**

- Monitoring violations, except where Tier 1 notice is required or the primacy agency determines that the violation requires a Tier 2 notice.
- Failure to comply with an established testing procedure, except where Tier 1 notice is required or the primacy agency determines that the violation requires a Tier 2 notice.
- Operation under a variance granted under §1415 or exemption granted under §1416 of the SDWA.
- Availability of unregulated contaminant monitoring results.
- Exceedance of the secondary maximum contaminant level for fluoride.

### **Tier Determination**

In any of the above situations, the water supplier must notify OEHS as soon as possible for a determination of what Tier applies to a given situation. OEHS will make a determination and work with you to provide the appropriate language and steps you must take to notify the public. **“When in doubt, call the OEHS and find out.”**

### **What information must be included in a notice?**

Your public notice must include specific information in order to be considered complete. Each notice must contain information addressing ten elements, including use of standard health effects language for MCL and treatment technique violations and standard language for monitoring violations. PWSs serving a large proportion of non-English speaking consumers are also required to include information in the notice in languages other than English.

For each violation and situation requiring notice (except for fluoride **secondary maximum contaminant level (SMCL)** exceedances, availability of unregulated contaminant monitoring data, and operation under a variance or exemption), you must provide a clear and easy-to-understand explanation of the following:

1. The violation or situation, including the contaminant(s) of concern, and (as applicable) the contaminant level(s);
2. When the violation or situation occurred;
3. Any potential adverse health effects from drinking the water, using mandatory language;
4. The population at risk, including subpopulations that may be particularly vulnerable if exposed to the contaminant in their drinking water;
5. Whether alternate water supplies should be used;
6. Actions consumers should take, including when they should seek medical help, if known;
7. What you are doing to correct the violation or situation;
8. When you expect to return to compliance or resolve the situation;
9. Your name, business address, and phone number or those of a designee of the PWS as a source of additional information concerning the notice; and
10. A statement encouraging notice recipients to distribute the notice to others, where applicable, using the standard language.

Some required elements may not apply to every violation or situation. However, you must still address these elements in your notice. For example, if it is unnecessary for consumers to boil their water or drink bottled water, you should tell them they do not need to do so. This is especially important for Tier 2 notices, where a violation may have been resolved by the time the notice is issued or may not be an immediate health risk.

### **Certification of Compliance**

After you provide the notice to your consumers, you must, within 7 days, send OEHS a copy of each type of notice you distribute (e.g., newspaper article, press release to TV/radio, mail notices) and a certification that you have met all the public notification requirements

**NOTE:** Be sure to obtain a copy of the OEHS Environmental Health Procedures Manual Memorandum DW-37 on Public Notice when it becomes final (ETA 2009).

## **BOIL WATER NOTICE**

Water treatment professionals must regard public health protection as the highest priority. Although every water treatment plant operator strives to produce high quality water, if a test result or a condition exists that may threaten public health, a boil water notice (BWN) must be considered.

Therefore, water professionals must develop BWN criteria and action plans **before** there is a problem, not during a crisis. BWNs require a considerable amount of thought if they are to be carried out in timely fashion. One of the most important aspects of BWN's is determining what circumstances will trigger the event, a few examples are:

- A violation of the total coliform rule;
- Loss of disinfection residuals at the point of entry;
- High filter effluent turbidities;
- Loss of pressure in the distribution system;
- Cross-connection/backflow incidents;
- Major water main breaks; or,
- Breaches in the integrity of water storage facilities.

There is no single perfect action plan for all utilities: each must be tailored to the specific system and situation. It is essential that plant staff focus on the challenge of fixing the problem that prompted the BWA thus protecting public health. Text of the public notification regulation can be found in the EPA Public Notification Handbook, on the OEHS website or by contacting your OEHS district office engineer.

Professional judgment and discretion are necessary in making decisions on the issuance of a notice. The water supplier is advised to consult with the local primacy agency to discuss the criteria for issuing public notices or BWNs. These discussions should include the actual wording and conditions for issuing the advisory.

**DO NOT DRINK THE WATER WITHOUT BOILING IT FIRST.** Bring all water to a boil, let it boil for one minute, and let it cool before using, or use bottled water. Boiled or bottled water should be used for drinking, making ice, brushing teeth, washing dishes, bathing, and food preparation **until further notice**. Boiling kills bacteria and other organisms in the water.

Once the criteria to issue a BWN have been met, prompt action is necessary. Failure to issue a timely BWN could lead to serious public health, financial, and public relations consequences. Customer confidence may be eroded or elevated depending on the timeliness and accuracy of the information they require. BWNs erode public confidence if they are not issued in time or issued too often.

On July 8, 1998, OEHS Environmental Health Procedures Manual Memorandum DW-23 addressed Boil Water Orders at PWSs. Recently, June 2009, DW-23 was reviewed and revised to improve consistent, proper handling of situations requiring boil water orders. Be sure to obtain a copy of the new DW-23.

## **OPERATOR CERTIFICATION**

Operator certification helps protect human health and the environment by establishing minimum professional standards for the operation and maintenance of PWSs. In 1999, EPA issued operator certification program guidelines specifying minimum standards for certification and recertification of the operators of community and nontransient noncommunity PWSs. While the specific requirements vary from state to state, the goal of all operator certification programs is to ensure that skilled professionals are overseeing the treatment and distribution of safe drinking water. Operator certification is an important step in promoting compliance with the SDWA.

The West Virginia Operator Certification Program was approved by EPA on February 20, 2002. West Virginia requires all PWSs to have a certified operator to effectively operate the system. Certified operators play a crucial role in protecting the health and welfare of West Virginia citizens, which can be jeopardized if persons not properly qualified are allowed to operate water supply systems. There are many disease-causing organisms and chemicals that may enter a system through the source water or through problems in the distribution system. Most contaminants cannot be seen or smelled, so proper system maintenance and monitoring is required to ensure the protection of public health. Water users expect a safe and adequate water supply and rely on the system operator to notify them if problems occur.

The need for responsible water system operators is enormous. Competent water system operations require someone with skill, knowledge and experience in operating, maintaining and troubleshooting water sources, and treatment and distribution systems. Even if the operator will not be the one to repair or replace broken equipment, he/she must be able to recognize potential problems and take action to have problems corrected. Any individual making process control/system integrity decisions about water quality or quantity must be certified.

### **West Virginia's Operator Certification Program:**

- Provides applications and informational resources to prospective operators;
- Administers the examination process;
- Evaluates applicant experience and education;
- Evaluates training for continuing education; and,
- Tracks continuing education obtained by each operator.

### **To become a certified operator, an individual must:**

1. Submit an application;
2. Attend any required training courses;
3. Pass a written examination specific for the size and type of system to be operated; and,
4. Meet minimum experience and education requirements;

### **Maintaining certification requires:**

1. Applying for new renewal by submitting an application every 2 years;
2. Documented attendance at sufficient OEHS-approved continuing education courses (CEHs); and,
3. Continued employment as an operator in a PWS.

### **Continuing Education Hours**

Our understanding of drinking water quality and chemical and biological contaminants in water is changing almost daily. Similarly, better laboratory methods to find small amounts of

chemicals, and improvements in diagnosing and tracking disease, more clearly define water that is truly safe to consume. Along with increased knowledge of health threats, which may be in drinking water, we have also increased our ability to prevent their occurrence, and to detect and remove them. Special sample collection methods, monitoring schedules and treatment options exist for a variety of possible contaminants. All certified operators, as well as system owners and managers, have a responsibility to keep up with changes in monitoring and reporting requirements. Also, it is important you are aware of new information on water quality and treatment and they maintain a basic level of knowledge.

West Virginia requires all certified operators, except 1Ds, to obtain **continuing education hours (CEHs)**. Continuing education is essential to keeping up to date with water supply, treatment, maintenance, and monitoring information. The amount of continuing education that must be obtained depends on your certification classification.

- **Operators-in-Training (OITs) and Water Distribution (WD) operators are required to obtain 6 CEHs every 2 years.**
- **Class WD operators are required to obtain 6 CEHs every 2 years.**
- **Class I operators are required to obtain 12 CEHs every 2 years.**
- **Classes II-IV are required to obtain 24 CEHs every 2 years.**

Operators are required to notify the OEHS in the event they are no longer the operator for a specific system. This is to emphasize the importance of having a certified operator at all times. A 30 day notice is required for voluntary terminations. Please complete and submit form ES-74 at least 30 days prior to quitting to stay in compliance with operator requirements and keep your certification. If you are fired, contact Certification & Training so they are aware your employment status has changed and provided them with your new or anticipated employment information.

Certification is personal. Each individual operator is responsible for keeping his/her certification current and ensuring all requirements are met. Please contact the Certification and Training Program at (304) 558-2981 or WVRWA at (304) 201-1689 if you have any questions concerning your responsibilities as a certified PWS operator. The Certification and Training Program currently oversees information on more than 2,300 certified water operators (as of May 2007) in addition to wastewater operators, backflow prevention & assembly inspector testers, water well drillers, and monitoring well driller training in West Virginia. It is essential we work together and openly communicate.

### **Responsibilities of the PWS and OEHS**

The PWS owner and operator, along with OEHS, work together to make sure that safe drinking water is provided to water system users and that all regulatory requirements are met. Providing safe drinking water requires a team effort from systems, operators, and OEHS.

### **Responsibilities of the Owner and Operator**

The owner of a PWS is responsible for meeting all of the legal requirements that apply to the water supply. An operator is a person who conducts day-to-day operational and technical activities related to the operation of a water supply. Although the owner may designate an operator, the owner is ultimately responsible for providing safe drinking water and meeting regulatory requirements. It is important that both the owner and operator work together to ensure

that the water system provides safe drinking water and meets all applicable requirements. **The ultimate goal for both the owner and operator is to provide safe drinking water to the public.**

The owners of PWSs shall:

- Employ a Chief Operator with a certification equal to or higher than the system classification and an adequate number of certified operators to operate the system;
- Not employ more OITs than the number of employed certified operators, unless written permission is granted by the Commissioner;
- Apply to the Commissioner for OIT Certification, on behalf of OIT applicants, within thirty (30) days of their hire at the PWS. Experience gained for certification starts only upon the issued date of the OIT certificate;
- Notify the Commissioner within ten (10) days, in a manner and form approved by the Commissioner, of any employment status changes, except termination, of the system's certified operators, OITs, and intended certified operators and OITs, including their reassignment;
- Notify the Commissioner within twenty-four (24) hours if a certified operator or OIT terminates employment for any reason;
- Renew the OIT Certification every two (2) years or until all requirements for Class I certification are met. Submit the renewal application at least thirty (30) days prior to expiration date, in a manner and form approved by the Commissioner. The OIT shall attempt to pass the Class I or WD examination at least once during each two (2) year renewal;
- Require in the case of Class II, III, and IV PWSs, that a certified operator with certification equal to or greater than the system classification, be present at all times when the plant is operational, unless the Commissioner grants a written exception to this requirement in response to a written request by the owner of the PWS.
- Require in the case of Class III and IV PWSs, that a certified operator with certification no lower than one (1) class below the system classification, be present at all times when the plant is operational.
- Submit a personnel status report by July 15 every year. The report is to be in a manner and form approved by the Commissioner and required information includes, at a minimum: a list of all certified operators, the operator in charge of each shift (if applicable), the Chief Operator, and any OIT's currently employed; and,
- Post a copy of the current certification of all certified operators employed at the PWS and a copy of the certified operators' renewal card, if applicable, in a conspicuous location in the water treatment plant, or, if there is no water treatment plant, the office of the PWS.

### **Operator's Responsibilities**

An operator is the person who is, in whole or part, responsible for the operation of a water system. At times, he/she may be a manager, laboratory technician, mechanic, meter reader, and a public relations specialist. To become a competent operator one must have a strong interest and desire for the job. Becoming a competent operator means; being accountable, having the will to learn, and to work without supervision. Even though many aspects of a water system can be "out of sight", they should not be "out of mind" for the water operator. By properly

maintaining the system, a competent operator provides a large degree of protection for a community's great investment in infrastructure. The operator also protects the health and well being of customers by producing a safe finished product, free of harmful bacteria and toxic materials.

A certified operator shall:

- Notify the Commissioner at least thirty (30) days prior to voluntarily terminating employment with a PWS in a manner and form approved by the Commissioner (EW-74);
- Obtain the necessary amount of CEHs and retain documentation of attendance required for his or her renewal application;
- Ensure that the renewal applications are submitted at least thirty (30) days before the required date and no earlier than sixty (60) days prior to expiration, in a manner and form approved by the Commissioner;
- Have the original personal certification card issued by the Commissioner upon his or her person at all times the operator is operating the PWS; and,
- Not work in a PWS under the certification of another; only the person whose name appears on the operator certification is certified by that document.

The Commissioner may suspend or revoke the certification of an operator if the operator:

- Fraudulently obtained certification;
- Performed the duties of an operator in a grossly negligent or incompetent manner;
- Knowingly or negligently submitted misleading, inaccurate, or false reports to the Commissioner;
- Violated, or caused to be violated, any portion of the Division of Health rule, "Public Water Systems," 64CSR3 or the Division of Health rule, "Cross-Connection Control and Backflow Prevention," 64CSR15; or
- Failed to notify the Commissioner of voluntary termination of employment in accordance with subdivision 5.2.a. of 64CSR4, even though the failure shall not subject the certified operator to the penalties of Section 10 of 64CSR4.

## **PWS OPERATOR REGULATIONS**

Title 64 Legislative Rule Bureau for Public Health Series 4 *Public Water Systems Operator Regulations* (64CSR4) governs the examination and certification of operators of PWSs. OEHS recently reviewed and revised 64CSR4, which became effective April 18, 2007.

OEHS revised the current regulations to:

- Meet new needs identified by the committee;
- Improve compliance with minimum federal operator requirements; and,
- Clarify ‘gray’ areas of existing regulations that often required internal interpretation and handling within the Certification and Training Program.

So what does this mean to operators? Please do not panic. No one likes change but it is necessary to improve and move forward. Overall, the content has changed minimally. The changes are mostly associated with needed clarifications of existing definitions, rules, and responsibilities.

The new regulations will enable operators and systems to do their job better through improved communication and preparation. OEHS recognizes the importance of professionals in the drinking water industry and looks forward to working with each and every individual operator and system to successfully implement these new requirements on a reasonable timeframe.

Please note that the following sections are a summary of the regulation and does not contain all the details of the new requirements. Reading these sections is not a substitute for reading the 64 CSR4 entirely. You can contact our office at 304-558-2981 to discuss these rules or if you would like a copy, please contact the WV Secretary of State or download from <http://www.wvsos.com/csr/verify.asp?TitleSeries=64-04>

The new regulation is an amendment to the existing PWS operator rule (April 18, 2007) intended to increase clarity and maintain compliance with changes in federal rules and requirements. Periodic rule review and revision enable West Virginia to retain primary enforcement for the Safe Drinking Water Act. Without the PWS operator regulations administered by the operator certification program, one of the important barriers to preventing contamination of PWS’ has been compromised.

## **NEW RENEWAL & CERTIFICATION REQUIREMENTS**

All operator certifications now require renewal every 2 years. Although this is not new for all certifications, it adds clarification that OITs are also renewable. The experience requirements for all certifications are now measured in hours instead of years to help improve proper credit with a variety of employment schedules. For example, instead of 1 year (assuming full time) experience, it is listed as 2,000 hours for a Class I operator.

There are new renewal requirements for OITs and WD operators. Both OITs and WD operators are now required to obtain 6 CEHs for renewal. The intent of the new OIT CEH requirement is that if the OIT cannot pass the exam, CEHs may help them pass the next time around.

OITs are also required to attempt the Class I or WD exam at least once during each 2 year renewal cycle. Federal guidelines require continuing education for all certified operators. The new regulations will require all certified operators (except 1D) continue to receive training related to water treatment and distribution to promote continued learning and professionalism, more efficient operation, and a better understanding of emerging technologies and trends.

OIT minimum education requirements can now be waived by the Commissioner, in writing, to a minimum age of 16 and completion of the 10th grade with a current school transcript and 2.0/4.0 grade point average. The intent of this change is to allow interested students to receive water treatment related training earlier in their academic career paths and help promote awareness of the water treatment field.

The regulations also clarify that it is the duty of each certified operator to obtain the necessary amount of appropriate CEHs and retain documentation of attendance required for the renewal application. All certified operators must now ensure renewal applications are submitted no earlier than 60 days prior to expiration, in addition to the previous requirements, to facilitate proper data management and timely processing.

All continuing education units (CEUs) must now be preapproved by the Commissioner for relevancy so that the applicant knows beforehand the courses are enough, or if additional course work will be needed. 100% credit will be awarded to CEUs deemed directly related to water treatment and distribution otherwise 50% credit will be awarded.

## **CHIEF OPERATOR REQUIREMENTS & RESPONSIBILITIES**

The current version of the 64CSR4 dated April 18, 2007 includes the following definition for chief operator that is more descriptive of responsibility:

**The certified operator whom the owner designates who is responsible for managing the daily operational activities of an entire PWS or a water treatment facility, or a distribution system in a manner that ensures meeting state and federal safe drinking water rules and regulations.**

Every PWS owner must employ a chief operator with certification equal to or higher than the system classification. Therefore, all PWS', excluding 1D systems and systems with only 1 certified operator, must designate a chief operator. A certified operator in a system with 1 certified operator is automatically designated as the chief operator. Class 1D systems are exempt from the requirements of this subsection.

To better support and prepare chief operators for their great responsibilities, the new regulation requires:

**All new and current chief operators attend a course approved by OEHS for training as a chief operator.**

Attendance of the designated course is also applicable for 6 CEHs for the renewal cycle. Current chief operators must fulfill this training requirement by attending the next available class. New chief operators are required to take the next available class unless waived in writing. OEHS will develop a list of approved courses and make arrangements for additional course offerings.

A certified chief operator is responsible for the day to day operation of the PWS to ensure the delivery of safe water at all times by complying with all state and federal regulations. The way this is accomplished is by the completing the following tasks. These tasks may vary depending on the size of your system, the type of water source and the complexity of treatment.

- Attend training to meet state primacy agency's continuing education requirements;
- Attend training programs and workshops to keep current of technical improvements;
- Be aware of all changes in regulations regarding water treatment;
- Be available to accompany regulatory officials for on-site inspections when given adequate notice;
- Collect or oversee the collection of water samples as specified by OEHS;
- Communicate with the owner, manager, or board about technical and financial needs of your system;
- Conduct frequent system and security inspections;
- Develop and maintain a plan for monitoring system process controls and meet all related goals;
- Educate other staff on emergency procedures and keep contact information up to date;
- Ensure that all samples are tested by a WVBPH certified lab;
- Ensure that all treatment equipment is maintained and operated properly according to the manufacturers' specifications and recommendations;
- Ensure that daily chemical analyses are properly measured and recorded;

- Ensure that OEHS approval has been obtained prior to starting treatment or changing chemical types and/or manufacturers;
- Inspect critical facilities and components, including door locks and fencing, as part of daily inspections;
- Inspect, flush, clean and disinfect the water distribution system as needed per OEHS regulations;
- Investigate water quality and quantity problems and take corrective measures as needed in a timely manner;
- Keep accurate operational records;
- Keep accurate records of repairs and routine maintenance performed on the treatment equipment;
- Keep accurate records of water analyses, repairs, maintenance and correspondence;
- Make all chemical adjustments and add all chemicals when necessary;
- Measure and record all chemical dosage rates as needed;
- Maintain a consumer complaint log, including how complaints are resolved;
- Oversee and monitor all repairs performed on the PWS;
- Review all water quality analyses for completeness prior to submission to OEHS;
- Report all violations to OEHS and issue public notices when needed;
- Update system maps when a significant change to the distribution system has been made; and,
- Utilize appropriate safety equipment.

Chief operators are also responsible for training of any Operators-in-Training (OITs) at their system. The Chief Operator must review and sign the OIT application (EW-102E) within 30 days of new employee hire as well as document in writing when the OIT has sufficient work experience to upgrade to a WD or Class I operator. Certified experience is the only experience counted towards upgrade so it is important to ensure all operators or individuals employed by the system conducting operator duties are currently certified. PWSs may not employ more OITs than the number of currently employed certified operators, unless written permission is granted by OEHS.

## **WATER DISTRIBUTION CERTIFICATION**

US Environmental Protection Agency (EPA) guidelines require all PWS operating personnel making process control/system integrity decisions about water quality or quantity that affect public health be done under the direction of a qualified, certified operator. This potential exists in both the treatment facility and distribution system. Therefore, a Water Distribution (WD) operator certification has been added.

Some water utilities have “split” responsibilities, where the water treatment plant may be under the direction of a certified PWS operator but the distribution system is not. This is no longer allowable under 64CSR4. The WD certification will allow two “chief operators” to be assigned under the above scenario and still meet the federal guidelines. Although a WD system is defined as a PWS that obtains all of its water from another PWS (also known as a purchase system), and is not owned or operated by the supplying PWS, an individual working in the distribution portion of any PWS must hold a WD or higher certification to ensure properly certified operator coverage.

Since WD operators collect water quality samples at the distribution system but not provide any treatment, much of the current Class I (and higher) operator certification training is not needed for distribution only systems or related work. Development of a WD training course and exam where only distribution activities are taught and tested, will eliminate the problem of a person having to study unneeded and unnecessary material in order to proficiently perform their job functions.

WD certification requires:

- a completed EW-102C application;
- a high school diploma or equivalent;
- attendance at a WD training course approved by OEHS;
- 70% on the WD certification exam;
- 1,000 hours of experience at a WD or higher classification PWS; and,
- 6 CEHs for renewal every 2 years.

All of these new requirements for WD operator certification are based on current EPA guidelines related to operator education, examination, experience, and continued training. Any current 1D operator may apply to be reclassified as a WD operator by passing the WD exam and meeting the minimum educational and experience requirements within 2 years from the effective date of the new rule (by April 18, 2009). Any operator collecting samples at a WD or higher system must hold a 1D or higher certification. This provision was added to give existing WD operators a chance to upgrade without going through the Operator-in-Training (OIT) process.

Prior to April 18, 2007, all water operator certifications were sequential – in other words, they built upon each other with no dual certifications allowed. With the new WD certification, Class I-IV certified operator may choose to be WD certified in addition to their higher classifications, however, it is not required. If both certifications are held, all requirements for both must be met in accordance with 64CSR4. For example, a Class IV operator who wants to be additionally certified as a WD must complete a total of 30 CEHs every 2 years. The Water Distribution Operator Certification Course is approved for 23 CEHs (CEH2008-052) so it may be taken for continued learning purposes instead of certification if the individual chooses.

## **PWS OWNER REQUIREMENTS**

PWS owners must notify the OEHS:

- within 10 days of any employment status changes;
- within 24 hours if any operator terminates employment for any reason; and,
- by July 15th every year with a personnel status report on an approved form which includes a list of all certified operators, the operator in charge of each shift (if applicable), the Chief Operator, and any OITs currently employed.

These more specific reporting requirements will increase enforceability and enable the OEHS to have more current information. Previously, employment status changes were often discovered during site visits but not necessarily soon after changes occurred.

Additional owner requirements in the new regulation include applying for and renewing OIT certification on behalf of OIT applicants and operators, and posting a copy of the certified operators' renewal card, in addition to the current certification, in a conspicuous location at the system. Although this has been OEHS policy, it was not written previously in the regulation.

## OPERATOR FORMS

Remember all forms must be complete, legible, signed and dated, and timely with all required documents attached (copy of diploma, CEH certificates, etc.) for processing. Also remember to use the most current version of each form. All forms are available on the OEHS website at <http://www.wvdhhr.org/oehs/eed/swap/training&certification/forms.asp> or by phone request from the Certification and Training Program at (304) 558-2981.

**EW-74 Voluntary Resignation:** Use this form when voluntarily terminating employment to ensure proper notification.

**EW-75 Application for Certification as a Backflow Prevention Assembly Inspector/Tester (BPAIT):** Use this form when applying for initial, reinstatement, or renewal of BPAIT certification.

**EW-102C Application for WD and Class I-IV Certification and Examination:** Use this form when applying for examination or certification as a WD or Class I-IV operator.

**EW-102D Application for Renewal of WD and Class I-IV Certification:** Use this form for renewal of WD or Class I-IV operator certifications.

**EW-102E Operator-In-Training Certification (OIT):** Use this form when applying for initial certification or renewal of OIT certification. OIT renewal requires 6 CEHs and taking the WD or Class I Exam.

**EW-102F 1D Application:** Use this form when applying for examination, initial certification or renewal of 1D operator certification.

**EW-104 Public Water System Personnel Status Report:** All PWS' must submit this form by July 15<sup>th</sup> every year to facilitate accurate information on all certified personnel currently employed.

**EW-107 Certified Operator Requirement Waiver:** Use this form when applying for a certified operator requirement waiver, in accordance with 64CSR4 5.1.g and h.

**EW-108 Reciprocity Application:** Use this form when you are certified by another jurisdiction outside of WV and seeking certification as a WV PWS operator to document your competency (64CSR4 8.1).

**EW-111 Public Water System Employee Status Changes:** Use this form to ensure reporting within 10 days of any employment status change (except termination) of PWS certified operators for compliance with 64CSR4 Section 5.1.d. Terminations of certified operators must be reported to OEHS within 24 hours (64CSR4 5.1.e).

## **COMPLIANCE AND ENFORCEMENT METHODS**

The operator regulations are specific on the definitions of suspension and revocation. Suspension is effective for an initial period of less than 1 year and revocation is effective for a period of more than 1 year. Both actions result in operator's certification being invalid. Revocation requires reexamination at the former certification level and fulfillment of CEH requirements. The process for compliance and enforcement actions is also more clearly defined as notification via certified mail with the action proposed, effective date, reasons and length of time of the proposed action. The new regulations also enable the Commissioner to establish an Advisory Board consisting of at least 5 certified operators and a designated chairman.

## **PWS CLASSIFICATION**

The classification of PWS has been changed from a point rating table to a descriptive definition based on source, population served, and treatment requirements. In general, the system complexity will continue to determine the required operator classification. All PWS will be reviewed as part of the sanitary survey conducted by District Office staff. This timeframe enables existing staff to reevaluate each system. Exceptions to this schedule will be made if requested in writing or if other problems arise. If reclassification occurs, systems must communicate with OEHS to ensure proper operator coverage. OEHS recommends operators at systems likely to change to start training and working towards the appropriate classification.

### **Class 1D**

All transient non-community water systems that have ground water only as a source, and do not use gaseous chlorine or chlorine dioxide as a means of disinfection, and do not treat for the removal of nitrate or nitrite, or both. Ground water sources that use gaseous chlorine, chlorine dioxide as a means of disinfection or have treatment for removal of nitrate or nitrite, or both, are considered a Class I PWS.

### **Class WD**

A PWS that obtains all of its water from another PWS, and is not owned or operated by the supplying PWS. The system does not have any other source of water other than water from the supplying PWS. A WD system may apply chlorine for supplemental disinfection.

### **Class I**

Community and non-transient non-community PWSs that use ground water only, serve a population of less than 10,000 (including consecutive connection population), and do not treat for a primary contaminant.

### **Class II**

All PWSs that use a surface source or a ground water under the direct influence of a surface water source, serve a population of less than 10,000 (including consecutive connection population), and do not have any additional treatment units within the treatment plant for identified primary contaminants in the source water. Treatment installed for removal of Cryptosporidium is considered an additional treatment unit. Class II also includes all PWSs that use ground water only, serve less than 10,000 population, use at least one radial water collector well as a source, or treat for at least one primary contaminant identified in the source water, or both.

### **Class III**

All PWSs that use surface or a ground water under the direct influence of a surface water source, serve a population of at least 10,000 (including consecutive connection population), and do not have any additional treatment plant for identified primary contaminants in the source water. Class III also includes all PWSs that use ground water only, serve a population of at least 10,000 and use at least one radial water collector well as a source.

**Class IV**

A PWS that uses a surface or a ground water under the direct influence of a surface water source and serves a population of at least 20,000 (including consecutive connection population).

## **OPERATOR CERTIFICATION CHECKLIST**

Since certified operators are a key component of any water system, it is important to understand what all goes into becoming a certified water operator. The Certification and Training Program is commonly asked how quickly an individual can become a certified water operator. The summary below was comprised to address this good question in writing. Feel free to use it as a checklist in the future.

### **1D Water Operator:**

- employed with a PWS;
- completed EW-102F, which includes proof of 8th grade completion;
- attended 1-day OEHS course; and,
- passed the 1D certification exam with a 70% or higher.

### **Water Operator-in-Training (OIT):**

- employed with a PWS; and,
- completed EW-102E, which includes proof of high school or GED diploma and PWS Chief Operator signing-off on responsibility for individual's training experience.

### **Water Distribution (WD) Operator:**

- employed with a PWS;
- completed EW-102C;
- attended OEHS-approved week long WD training course;
- passed WD certification exam with a 70% or higher; and,
- documented proof of 1,000 hours (~6 months full-time) OIT or PWS certified experience at a WD or higher PWS.

### **Class I Water Operator:**

- employed with a PWS;
- completed EW-102C;
- attended OEHS-approved week long Class I training course;
- passed Class I certification exam with a 70% or higher; and,
- documented proof of 2,000 hours (~1 year full-time) OIT or PWS experience.

Note: Experience gained in WD or 1D counts for no more than 600 hours.

### **Class II Water Operator:**

- employed with a PWS;
- completed EW-102C;
- attended OEHS-approved week long Class II training course;
- passed Class II certification exam with a 70% or higher; and,
- documented proof of 6,000 hours (~3 years full-time) PWS experience with 2,000 of those at a Class II or higher PWS.

Note: Can substitute up to half of the required experience (~1.5 years full-time or 3,000 hours) with OEHS approved education continuing education units (CEUs), but still will need 3,000 hours (~1.5 years full-time) experience minimum. A CEU is 10 CEHs or any higher education approved by OEHS. C&T reviews each course for relevancy and assigns CEUs on a case-by-case basis. The rules specify courses relevant to water treatment will count 100% towards CEUs. However, a course not directly related will receive 50% credit towards CEUs. Thus, a 3 credit hour Music Appreciation course taken at WVU will only be granted 1.5 CEUs. Also, keep in mind you cannot use your education for both minimum education requirements and experience substitution. Therefore, a person with a 4-year degree would be well advised to consider NOT using their degree for experience substitution if

they plan to eventually become a Class III or IV operator.

Note: 1,000 hours experience (or approved alternative) in a surface source water treatment plant prior to being allowed to operate unsupervised in a Class II or III surface water source water treatment plant.

### **Class III Water Operator:**

- employed with a PWS;
- completed EW-102C;
- passed Class III certification exam with a 70% or higher;
- documented proof of 10,000 hours (~5 years full-time) PWS experience with 2,000 of those at a Class II or higher PWS; and,

Note: Can substitute up to half of required experience (5,000 hours or ~2.5 years full-time) with OEHS approved education (CEUs), but will still need 5,000 hours (~2.5 years full-time) experience minimum.

- documented completion of 90 CEUs.

Note: Can substitute all required education (up to 90 CEUs) with 4,000 hours (~2 years full-time) experience.

### **Class IV Water Operator:**

- employed with a PWS;
- completed EW-102C;
- passed Class IV certification exam with a 70% or higher;
- documented proof of 12,000 hours (~6 years full-time) PWS experience with 2,000 of those at a Class III or higher PWS; and,

Note: Can substitute up to half of required experience (3 years full-time or 6,000 hours) with OEHS approved education (CEUs), but will still need 6,000 hours (~3 years full-time) experience minimum.

- documented completion of 180 CEUs.

Note: Can substitute up to half of the required education (90 CEUs) with 2 years full-time or 4,000 hours experience but would still need 90 CEUs.

Applying the above information, the fastest an individual *without* prior certification or higher education beyond high school/GED could become a Class IV water operator is with 6 years full-time experience and 180 CEUs. Keep in mind, **all operator certification requirements are based on federal and state regulations to ultimately protect public health.** Each certified PWS operator is responsible in providing adequate supply of safe, potable drinking water to consumers who are confident their water is safe to drink. It is essential these operators not only achieve these minimum requirements for certification but continue to gain knowledge and acknowledge the public health foundation of their career choice in the drinking water industry. Please contact the Certification and Training Program at any time to discuss any aspect of the operator certification program at 304-558-2981.

## **GUIDANCE FOR CERTIFIED WATER OPERATORS**

OEHS Certification and Training (C&T) Program staff takes pride in reviewing and processing each operator application based on quality, timeliness, and fulfillment of all current certification regulation requirements. However, if applications are incomplete or required information is not submitted or is illegible, our job is more difficult and timeliness of your certification is reduced. By adhering to the following guidelines, initial certification or renewal will proceed more effectively.

1. Know the rules and regulations for your profession and how to receive and maintain your certification(s). This includes knowledge of education and experience requirements and associated timelines. West Virginia Administrative Rules, Title 64 Series 4, *Public Water Systems Operator Regulations* are available online from the Secretary of State website at <http://www.wvsos.com/csr/verify.asp?TitleSeries=64-04>. If you have any questions on these regulations, contact C&T for clarification.

2. Know the proper forms required to initially become certified and renew your certification (if required). Knowing what forms to use and having them available in your work area will facilitate meeting the required timelines. All current forms are available on our website at [www.wvdhhr.org/oehs/eed/swap/training&certification/forms.asp](http://www.wvdhhr.org/oehs/eed/swap/training&certification/forms.asp) or by calling us at (304) 558-6988 or (304) 558-6991. Always read carefully and complete the forms in their entirety, which includes a signature and date for proper documentation.

3. Make sure any classes you take toward certification upgrade or renewal are already approved by OEHS. All classes must be approved by the Commissioner and attendance documented by the operator before OEHS will accept the continuing education hours (CEHs) for operator renewal requirements. A list of approved classes is available on our website at [www.wvdhhr.org/oehs/eed/i&cd/education\\_index.asp](http://www.wvdhhr.org/oehs/eed/i&cd/education_index.asp) or by calling C&T at (304) 558-6988. All approved CEHs have a unique, 7-digit CEH number. Taking unapproved classes and failing to provide class certificates upon completion may result in the need for you to take additional classes and delay processing your application. **Contact the instructor or their supervisor if you have not received appropriate certificates with the corresponding approved CEH number and course title for all of your training.**

4. Do not procrastinate on taking classes for renewal. Hundreds of classes have been approved, some indefinitely. By waiting until the last few months before your renewal, you increase the chance of the class being full, cancelled, possible sickness on your part, having to stay at work due to problems, etc. There are two (2) years in between certification renewals for water plant operators and three (3) years between certification renewals for Class III and IV wastewater operators. Requesting extensions for more time to obtain required continuing education is unacceptable and indicates poor career management on your part.

5. Share good information. The articles you are reading often contain valuable information. Please ensure it is reviewed by staff and coworkers.

In Short:

1. Know the rules and regulations for your profession.
2. Use the correct form (s) and make sure they are complete and timely.

3. Take approved CEH classes and contact the instructor(s) for appropriate certificates.
4. Do not procrastinate on obtaining your renewal training.
5. Information is out there for all of you, take advantage of it and manage your careers appropriately.

By following the above guidance, C&T can provide timely certifications and renewals for everyone. Please contact us with any questions or concerns at any time. We oversee approximately 4,000 individual certifications, which are each unique, personal, and very important. Open communication is essential in facilitating all operator certification needs and ultimately protecting drinking water.

## WAIVERS AND VARIANCES

Operator waivers and system variances, or in other words exceptions to the certified operator requirements, do exist. However, they are the exception, not the norm, and have strict guidelines.

Upon first glance, sections 5.1.g and h of 64CSR4 sound contradicting and may need revised for clarity in the next version. In general, 5.1.h limits the exceptions granted under 5.1.g. The intent of the current rule is:

- All Class II PWSs must have a Class II operator or higher present at all times plant operational, unless a written exception is made by OEHS based on a written request received.
- All Class III PWSs must have a Class III operator or higher present at all times plant operational, unless a written exception is made by OEHS based on a written request received.
- A written exception may be granted by OEHS for a Class II operator to be present at all times plant is operational at a Class III system based on written request received. A class I operator alone cannot provide adequate operator coverage at a Class III PWSs.
- All Class IV PWSs must have a Class IV operator present at all times plant operational, unless a written exception is made based on a written request received.
- Written exceptions at Class IV PWSs are limited to Class III operators. A Class I or II operator alone cannot provide adequate operator coverage at Class IV PWSs.

OEHS's decision to issue an operator waiver has several steps. First, a written request from the system explaining the situation(s) creating a need for the waiver is received by OEHS Certification and Training Program or district office. PWS must document effort(s) made on their part to address the situation. For example, the vacancy was posted and no qualified candidates applied or an emergency occurred involving one of our certified operators. A waiver should be a last resort, **not** a safety net for poor planning and management. Once the written request is received, OEHS will seek recommendation from the appropriate district office engineer. Generally, they will state whether or not the system is in need, and if the proposed operator can adequately performs the required functions. OEHS will also make sure the requesting PWS chief operator recommends approval of the waiver request, if it did not originate from he or she. The written request will then receive a written response from the OEHS EED Director with specifics on the decision and with copies provided to all involved individuals. Operator waivers are situation, operator, system, and time specific to ensure consistency in implementation of regulations.

There are also PWS operator variances. On April 12, 1993 OEHS Environmental Health Procedures Manual Memorandum DW-36 outlined Operator Variance Permits (OVP) for qualifying and OEHS approved PWSs who automate their systems (automatic dialers and automatic equipment shut down). In general, an OVP requires: a minimum one (1) year continuous operation before we would consider issuing and a PWS classification level of Class II or higher. Up until early 2009, these types of PWS variances were handled by OEHS IC&D. However, OEHS intends to revise DW-36 with OEHS C&T lead. Be sure to obtain a copy of the new DW-36 when it becomes final.

Even with any waivers or variances, all PWSs still must have a Chief Operator with certification equal to or greater than the PWS classification **and adequate number of certified operators to operate the system** (to comply with 5.1.b,g&h). OEHS Environmental Health Procedures Manual Memorandum DW-29 specifies adequate operator coverage at PWSs. Although initially developed in December 1993 and revised again in May 2001, the DW-29 is currently under revision to further clarify the intent of 64CSR4 and support consistent implementation statewide. Be sure to obtain a copy of the new DW-29 when it becomes final.

## PWSs IN WEST VIRGINIA

The jurisdiction of the drinking water program at the OEHS applies only to PWSs, those that service water to the public. This includes municipal water systems as well as facilities, such as mobile home parks or factories, that have their own source of water and that serve it to the public. Whether the system is privately owned or not, if it serves water to more than 25 people, it is considered a PWS and subject to the regulations of the SDWA.

West Virginia has over 1,100 active PWSs. This number constantly changes and varies year to year. Approximately 90% of all PWSs use groundwater, while only 10% use a surface water or groundwater under the direct influence of surface water source. However, this low number of surface water source PWSs serve large population centers such as the cities of Charleston, Morgantown, Huntington, and Clarksburg.

### **Water System Types**

**Public Water Systems (PWSs)** provide piped water for human consumption to 15 or more service connections or an average of at least 25 individuals each day for at least 60 days each year. The system includes the source water intake (such as a well), treatment, storage, and distribution piping. Human consumption of water includes drinking water and water used for cooking, food preparation, hand washing, bathrooms and bathing. A private home served by its own well is not a public water supply system since it serves only a single service outlet.

There are three categories of PWSs: **Community Water System (CWS); Non Transient Non Community Water System (NTNCWS); and, Transient Non Community Water System (TNCWS)**. A **Community Water System (CWS)** is defined as a PWS which serves at least 15 service connections used by year-round residents or it regularly serves at least 25 year-round residents. A public system that is not a community water system is a **Non-Community Water System (NCWS)**.

There are two types of non-community water systems, **Non-Community Non-Transient Systems (NTNCWS)** and **(TNCWS) Transient Non-Community Water Systems**.

**Non-Community Non-Transient Water Systems (NTNCWS)** are non-community PWSs that regularly serve at least 25 of the same people over 6 months of the year. Schools with their own groundwater supply are a good example of this type of system.

**Transient Non-Community Water Systems (TWS)** do not serve at least 25 of the same people on a regular basis over a 6 month period in a year. This category covers bars, restaurants, rest stops and campgrounds, to name a few.

PWSs are further classified into 6 distinct categories (1D, WD, or Class I, II, III or IV) to ensure each is regulated according to its population served, source water, and treatment complexity.

### **Purpose of PWSs**

The main purpose of PWSs is to provide water safe for human consumption. Other important purposes are to provide an adequate quantity of water of acceptable taste, odor and appearance; and meet the needs of fire protection. Providing water service places owners and operators of PWSs under an ethical and legal obligation to meet these needs.

Most people in the U.S. take safe, inexpensive drinking water for granted. We assume all water that comes from a tap is okay to drink, whether in a restroom, a gas station or a friend's home. Few of us realize the planning, monitoring, repair and maintenance required to obtain and protect adequate amounts of safe water.

### **Acute and Chronic Health Effects**

These requirements are meant to protect the public from contaminants that may cause acute or chronic health effects.

Contaminants that may have an immediate impact on health after drinking small amounts of water must be dealt with in all PWSs. These are contaminants that cause acute health effects. Examples are disease-causing organisms and nitrates.

Contaminants that cause health effects if consumed over long periods of time must be dealt with in systems where the same residential or non-residential consumers have access to the water on a long-term basis. These are contaminants that cause chronic health effects. Examples include cancer-causing chemicals and chemicals affecting the nervous system or kidneys.

### **Responsibilities of PWSs**

Today with increasing regulatory requirements brought about with the 1996 Amendments to the SDWA, PWSs in West Virginia are finding themselves facing many challenges. Along with the increasing responsibilities in the area of treatment and compliance, there is also the issue of source water protection. Achieving and maintaining financial, technical, and managerial capacity is critical for PWSs. Capacity Development is a concept stated in the 1996 SDWA Amendments that pertains to the successful management and operation of a PWS. This concept illustrates the overlapping influence that each of these areas has upon the other. Capacity Development further implies that there is no static endpoint to success. That is, PWSs must strive daily to do the best possible job in technical, financial, and managerial endeavors.

Given the increasing regulatory requirements and scarcity of resources that often exist with small systems, it is more important than ever to make certain that individuals directing and operating these systems have a thorough understanding of their system's operation. The basic responsibility of a water system is to furnish customers with potable drinking water that meets or exceeds customer demands. This responsibility is shared by every member of the utility's work force, from managers to operators and from clerical staff to field employees. Every member of the team should be aware of their duties and report any condition to the next in command that has the potential to adversely effect the system's ability to produce safe clean drinking water.

## **MULTIPLE-BARRIER APPROACH**

Capacity development — the development of a system’s technical, managerial, and financial ability to provide safe and adequate drinking water to its customers — is the foundation of a successful multiple barrier approach for any system.

Safe drinking water is essential to our physical health and to the economic health of our communities. However, drinking water is vulnerable to contamination from many potential threats. The 1996 Safe Drinking Water Act Amendments created a coordinated set of programs and requirements to help PWSs make sure they have a safe supply of drinking water. These programs and requirements form a Multiple Barrier Approach complete with technical and managerial barriers that help prevent contamination at the source, enhance treatment, and ensure a safe supply of drinking water for consumers.

By placing integrated barriers from the source to the consumer at the tap, PWSs can help protect communities from the risk of contamination and waterborne disease. A successful multiple barrier approach includes:

### **Barriers between potential threats and the consumer:**

- Source water protection activities such as identifying and reducing contamination in watersheds.
- Appropriate source water treatment.
- Properly trained, certified operators.
- Properly designed and constructed facilities.

### **Programs and activities to make sure the barriers are in place and operational:**

- Sanitary surveys to evaluate the adequacy of a water system’s facilities for producing and distributing safe drinking water.
- Comprehensive Performance Evaluations to identify potential cost-effective improvements in system performance.
- Standards for the design and construction of a system’s components.
- Continuing education and training of managers and certified operators.
- Strategic and emergency response planning to make sure a system is prepared for the future and for potential crises or disasters.

### **1. Risk Prevention**

The first barrier in a water system’s multiple barrier approach is risk prevention. Risk prevention focuses on the selection and protection of drinking water sources. Systems should be aware of potential contamination caused by agricultural drainage, urban runoff, organic materials, and other factors. When selecting sources, systems should examine:

- The quality of the raw water (e.g., does it contain pathogens, chemicals, radionuclides, nitrates, or high turbidity?).
- The risk of contamination (e.g., will development encroach on the water source?).
- The ability of the supply to meet current and future needs.

PWSs, unless they are new systems, rarely have the opportunity to select their water source. But existing systems can and should take steps to protect their water sources, including:

- Identifying sources of contamination in watersheds and recharge areas.
- Identifying the conditions under which the risks increase.
- Developing and implementing source water protection strategies.

By properly selecting and protecting its water source, a system can reduce its need for and reliance on treatment and increase the reliability of its water quality and quantity.

The financial incentive for systems to prevent risks is significant. It is almost always more cost-effective for a water system to protect its source water from contamination than to remove or inactivate contamination with treatment.

## **2. Risk Management**

Risk management barriers focus on the protection provided by water treatment and system operations. PWSs traditionally have relied on treatment to prevent waterborne disease. Treatment continues to play a central role in protecting public health.

Water treatment:

- Removes and inactivates contaminants present in source water.
- Leads to improved finished water quality.

No single treatment technology or process can solve every water quality problem, so a water system should consider using a combination of treatment technologies and processes if necessary. To provide adequate protection of public health, a water system:

- Must meet the state's minimum design and construction standards.
- Should develop asset management plans that help provide sound infrastructure.
- Must meet federal and state drinking water standards.

In addition to using the appropriate treatment, PWSs should make sure their operators are properly certified and know how to apply treatment concepts to the specific circumstances facing their system. PWSs should also test the treatment process that they are using to be certain that the treatment is working correctly.

The risk management barrier also includes developing and putting in place appropriate security arrangements and comprehensive plans to respond to emergencies, thus reducing the risk of serious consequences from a security breach or other emergency.

A wide range of financial assistance and incentives are available to help systems fund upgrades or replacement of their treatment components. Contact information for some key providers of financial assistance is listed on the last page of this brochure.

## **3. Monitoring & Compliance**

Under the monitoring and compliance barrier, systems aim to detect and fix problems in the source and/or distribution system as early as possible. They accomplish this by collecting information about:

- The presence of contaminants.
- The effectiveness of current treatment processes.
- Any deterioration in the quality of source or treated water.

Monitoring the quality of water at the source and throughout the distribution system is very important. Even if water from an extremely clean source is adequately treated, breakdowns in the distribution system can lead to waterborne illnesses. In particular, the contamination of treated water can result from:

- Line breaks.
- Inadequate water pressure.
- Deficiencies in storage tanks.
- Inadequate separation of water supply lines and sewers.

As part of your multiple barrier approach to protection, include a cross-connection detection and control program as well as efforts to make sure that all distribution system components are properly sized and maintained. PWSs must also monitor water in the distribution system for the formation of byproducts from disinfection and for the leaching of lead and copper from household plumbing.

Monitoring programs should be developed around the needs and characteristics of individual PWSs, and they should comply with all regulatory requirements. The monitoring and compliance barrier helps a system maintain the physical integrity of its components and make adjustments as necessary to provide a consistent, safe supply of water.

From a financial perspective, operators who have data on the performance and condition of their system's components (as part of an asset management plan) can increase the useful life of system components and quickly identify and respond to small problems before they become large and expensive.

#### **4. Individual Action**

Consumer awareness and participation are key components in the multiple barrier approach. A community water system is required to prepare and provide to their customers, at least annually, Consumer Confidence Reports (Annual Water Quality Reports) that discuss:

- The condition of the system's source water.
- The level of contaminants in the system's drinking water.

The reports are a way to raise consumer awareness about drinking water, and they can be used as a tool to encourage dialogue between consumers and the water system.

PWSs are also required to notify the public of any violations of national drinking water standards. Public notification makes sure that:

- Consumers are informed of any health risks in a timely manner.
- PWSs build trust with consumers by sharing information.

Beyond information sharing, systems can benefit greatly from involving the public in a variety of activities. For example:

- Systems can further their source water protection efforts by helping the public form watershed associations.
- Systems can encourage the public to notice and report activities that could represent contamination or sabotage threats to the water system.

Informed and involved consumers can become advocates for improvements in their water system's operations. Public education and participation can also help consumers become more aware of the true cost and value of water.

From a financial perspective, customers who have a better understanding of their water system, the true cost and value of water, and the role they play will be more likely to support rate increases and bond issues needed to fund multiple barrier approach activities.

## WATER SUPPLIES

The total amount of water in the world is almost constant. It is estimated to be 370,000 quadrillion gallons, 97% of which is the water in the oceans, which is salty and unfit for human consumption without an expensive treatment. The remaining 3% is known as fresh water, but 2% of that is the glacier ice trapped at the North and South Poles. Only 1% is available for drinking water.

Pure water is a colorless, odorless, and tasteless liquid. The depth and light give it a blue or bluish-green tint. Tastes and odors in water are due to dissolved gases, such as sulfur dioxide and chlorine, and minerals. Water exists in nature simultaneously as a solid (ice), liquid (water) and a gas (vapor). Its density is 1 g/mL or cubic centimeter (cm<sup>3</sup>). It freezes at 0°C and boils at 100°C. When frozen, water expands by one ninth of its original volume.

A majority of U.S. drinking water systems use ground water compared to surface water (147,000 vs. 14,500), however more people drink from surface water systems (195 million vs. 101,400). Water that is taken from lakes, rivers, or impoundments is known as surface water. Many large systems make use of surface supplies because these rivers and lakes offer storage of large amounts of water. The chemical characteristics of surface water differ from groundwater in several ways and generally require a greater degree of treatment to meet the Drinking Water standards. The minimum treatment required for surface water in West Virginia is filtration and disinfection.

These water bodies are formed of water from direct rain, runoffs, and springs. A runoff is the part of rain water that does not infiltrate the ground or evaporate. It flows by gravity into the water body from the surrounding land. This drainage area is known as the watershed. One inch of runoff rain/acre is equal to 27,000 gallons. Watershed characteristics affect the water quality, therefore protection of these watersheds is very important.

Water exists in different forms and locations. The source of drinking water refers to where it comes from. There are three main sources of drinking water: surface water, groundwater, and “groundwater under the influence” of surface water. Surface water supplies about seventy-five percent of the water consumed by people in the United States. Even though a larger number of water systems in the United States use a groundwater source, on the average, they are smaller and serve fewer people. Surface water is a more likely source for large cities.

Usually, the source of water will determine the type of treatment necessary. In most circumstances, groundwater requires little treatment. Groundwater quality problems include minerals, hardness, and dissolved gasses. Surface water and groundwater-under-the-influence quality issues are turbidity, taste, odor, and color. Surface water and “groundwater under the influence” usually require chemical treatment and filtration.

### **Surface Water**

Surface water accumulates mainly as a result of direct runoff from precipitation (rain or snow) or recharge from groundwater. Therefore, surface waters are very susceptible to contamination. You name it - manure, gasoline, pesticides, fertilizers, industrial chemicals, bacteria, air pollution – it can enter surface waters. Because of their high susceptibility to contaminants, surface water

sources must meet strict monitoring and treatment requirements for filtration and disinfection. While there are relatively few surface water systems in the world, they provide more water to more people than any other type of system. These systems are typically used by large cities that need a large volume of water to meet their needs.

Surface waters can be classified into lentic (calm waters) and lotic (the running waters). Lentic waters are the natural lakes and impoundments or reservoirs. Natural lakes of good quality water are very good sources of water. Impoundments are useful, as they eliminate seasonal flow fluctuations and store water for adequate water supply, even under high consumer demand periods, such as drought in summer. Impounding also helps in the pretreatment of water by reducing turbidity by sedimentation and reducing coliform bacteria and waterborne pathogens through exposure to sunlight. Algal growth and other planktons, drifters formed of free-floating algae, protozoans and rotifers, can cause taste and odor problems.

Normally, a natural lake goes through an aging process called eutrophication. There are three stages of a lake: oligotrophic, mesotrophic, and eutrophic. Oligotrophic lakes are young, deep, and clear, with few nutrients. They have a few types of organisms with low populations. Mesotrophic lakes are middle aged due to nutrients and sediments being continuously added. There is a great variety of organism species, with low populations at first. As time increases the populations increase. At an advanced mesotrophic stage a lake may have undesirable odors and colors in certain parts. Turbidity and bacterial densities increase. Eutrophic lakes, due to further addition of nutrients, have large algal blooms and become shallower, with fish types changing from sensitive to more pollution-tolerant ones. Over a period of time, a lake becomes a swamp and finally a piece of land.

Lakes and reservoirs are calm water supplies. Factors affecting these water supplies include several factors, such as temperature, sunlight, turbidity, dissolved gases and nutrients.

- **Temperature and stratification.** Water has a maximum density ( $1 \text{ g/cm}^3$ ) at  $4^\circ\text{C}$ . Above and below this temperature water is lighter. Temperature changes in water cause stratification, or layering, of water in lakes and reservoirs. During the summer, the top water becomes warmer than the bottom and forms two layers, with the top one warmer and lighter and the bottom one cooler and heavier. During the fall as the temperature drops and the top water reaches  $4^\circ\text{C}$ , it sinks to the bottom and the bottom water moves to the top. This is known as fall turnover. This condition stirs the bottom mud and releases the anaerobic decomposition products such as sulfur dioxide and other odor-causing chemicals that cause severe taste and odor problems. In the winter too much snow cover for longer time periods can cause oxygen depletion by reducing light penetration, thus the lower rate of photosynthesis. This condition can cause winter fish kill. In spring, as the ice melts, and the temperature at the surface reaches  $4^\circ\text{C}$  water sinks once again to the bottom and results in the spring turnover, which, like fall turnover, can cause taste and odor problems.
- **Light.** Light, the source of energy for photosynthesis, is important. The rate of photosynthesis depends on the light intensity and light hours per day. The amount of biomass and oxygen production corresponds to the rate of photosynthesis. The amount of dissolved oxygen (DO) in the lakes is maximum at 2 p.m. and minimum at 2 a.m.

- **Turbidity.** Turbidity affects the rate of the penetration of sunlight, and thus, photosynthesis. The more turbidity, the less sunlight can penetrate, which lowers the rate of photosynthesis and consequently less DO.
- **Dissolved gases.** These are mainly carbon dioxide (CO<sub>2</sub>) and oxygen (O<sub>2</sub>). Carbon dioxide is produced during respiration and is used in photosynthesis; oxygen is produced during photosynthesis and is needed for respiration. DO is consumed by the microorganisms for the aerobic decomposition of biodegradable organic matter. This oxygen demand of the water is known as biochemical oxygen demand (BOD). The more the BOD, the less DO in the water. The more the DO, the better the quality of water. The minimum amount of DO to maintain normal aquatic life, such as fish, is 5 mg/L.

Rivers, streams and springs are running water supplies. Factors affecting these water supplies are much smaller than those affecting lakes and reservoirs. The only factors affecting running water is current and nutrients.

- **Current.** It is the velocity or rate of flow of water. The faster the current, the better it is. Current mixes the oxygen from the atmosphere and keeps the bottom of the stream clean by washing away the settleable solids. There is more DO and less natural organic matter that would otherwise decompose in the bottom. Thus, due to the current, streams and rivers seldom go anaerobic.
- **Nutrients.** Main sources of nutrients are drainage from the watershed. Heavy rains and drought conditions can also cause serious problems, such as high turbidity and more nutrients.

Surface water supply is the most contaminated supply, mainly due to discharge of sewage, used water, which is the source of waterborne pathogens, runoffs from farmland, which are the source of Cryptosporidium, pesticides, and fertilizers; and industrial discharges, which are the source of a variety of contaminants. Surface water, therefore, needs the maximum treatment for potability (satisfactory for drinking).

## **WATER TURNOVER**

Operators often have difficulty understanding the causes of “water turnover” in reservoirs and the reasons for the fish kills which may occur following these events. Fish kills are frequently caused by low dissolved oxygen concentrations in the water.

Most reservoirs mix or circulate their waters during the winter months. Generally, the reservoir surfaces only freeze for short durations, or do not freeze at all. However, little or no mixing of the reservoir’s water volume may occur during the hottest months of summer. Large populations called “blooms” composed of microscopic algae decreases sunlight penetration into the reservoir to a depth of about 6 feet. Suspended clay particles in the water may also decrease sunlight penetration. This deeper water cools due to the absence of sunlight to warm it. Cooler water has a greater density than warmer water. A “layering effect” of water occurs throughout the reservoir when the cooler, more dense water remains near the reservoir bottom, and warmer water resides near the surface. During daylight hours, plants and algae release oxygen into the water while producing glucose, their sugar-like food. Little or no oxygen is produced in these cool layers of water, due to the absence of sunlight which prohibits plant and algae growth. Eventually, the dissolved oxygen is consumed from the cool waters by decomposing organic matter. This is caused by plants and animals that have died and sunk to the reservoir bottom.

During winter when water temperatures reach 32°F, ice forms at the water’s surface and not the reservoir bottom. Water reaches its maximum density at 39.4°F. Colder or warmer waters will always be found closer to the reservoir’s surface. Reservoir turnovers often occur during summer after cold, hard rains, windy weather or following the first cold weather of fall. When air and surface water temperatures cool during the fall, surface waters will “sink” when they become more dense than the waters near the reservoir bottom. Warmer, less dense bottom waters are forced to the surface creating a mix or a “turnover.” If large volumes of oxygen deficient bottom waters are present in the reservoir, the entire reservoir may be depleted of dissolved oxygen as the waters mix. Low concentrations of dissolved oxygen are responsible for most fish kills.

Abrupt changes in weather conditions and air and water temperatures can rapidly affect the reservoir environment. Typically, reservoirs that are older, have greater depth, or are sheltered from prevailing winds, may be affected more severely from water turnovers. Shallow reservoirs, which have a maximum depth of 6 to 8 feet and are located in sites subject to prevailing winds, are less likely to have fish kills associated with water turnovers. Similarly, those reservoirs that contain less organic matter such as leaves, manure, and aquatic plants are less likely to experience fish kills as a result of water turnover. The type of vegetation in the watershed (wooded or pasture) will influence the amount of oxygen consuming organic matter which enters the reservoir. Human activities such as livestock pasturing, over-fertilizing lawns, and drainage from septic systems will encourage aquatic plant growth which will eventually die and consume dissolved oxygen.

Unless the reservoir has dense aquatic plant growth, microscopic algae “blooms” generally produce most of the dissolved oxygen in reservoirs and lakes. Algae and plants produce oxygen during daylight hours, but consume oxygen during the night.

Due to the dying algae bloom, the water color may change from green to black or gray with black streaks.

Low oxygen conditions may occur in reservoirs with prolonged ice and snow cover. Snow covered ice will prevent sunlight penetration to the algae blooms and aquatic plants, and if prolonged, will eventually cause their death. Under these conditions, dissolved oxygen cannot be produced, but is consumed by the algae blooms and plants. The water beneath the ice has no access to air at the surface. Decaying algae blooms and plant material will further lower dissolved oxygen concentrations, and eventually a fish kill may occur.

Proper aeration, water circulation and water quality management will reduce the severity of “water turnover” and prevent dissolved oxygen-related fish kills. Avoiding excessive depths (greater than 8 feet deep when possible) and shallow areas when constructing reservoirs can help reduce the severity of dissolved oxygen depletions. Constructing minimum reservoir depths of 3 feet will help prevent the growth of aquatic plants and filamentous algae.

To a lesser extent, oxygen is also absorbed from the atmosphere at the water’s surface. Wave action or other disturbances will increase the water’s dissolved oxygen concentration by expanding its surface area for oxygen to enter. Healthy algae blooms and aquatic plant populations will produce enough dissolved oxygen to support life in a reservoir throughout a 24 hour period. However, dying populations may consume more dissolved oxygen at night than they produce during the day. When algae blooms or aquatic plants release less dissolved oxygen during cloudy days than they consume at night, low dissolved oxygen conditions may occur. The oxygen consumed by the constant decay of algae, vegetation and other organic matter will further deplete dissolved oxygen concentrations in the reservoir. Low dissolved oxygen conditions often occur during the night or just before dawn, particularly when water temperatures are warm. Warm water holds less oxygen than cold water. Increases in altitude and salinity will also lessen the ability of water to hold dissolved oxygen.

## ALGAE BLOOMS

During photosynthesis, algae consume carbon dioxide from the water. The series of chemical reactions that convert bicarbonate and carbonate into carbon dioxide result in the production of hydroxide ions, which can significantly increase the pH of the water. Algae can result in fluctuations of pH over the course of a day, with pH values generally higher during the day and lower at night. The amount of direct sunlight directly impacts the algae lifecycle and impacts source water pH.

Algae convert inorganic carbon in the water into organic carbon compounds. This process can lead to detectable increases in TOC and DOC in the surface water body during algal blooms. Algal blooms also result in the production of organic matter that is generally more hydrophobic than hydrophilic.

Algal blooms can result in a variety of water quality problems including tastes and odors, shortened filter runs, increased chlorine demand, increased turbidity, pH fluctuations, and, in some cases, increased organic DBP precursors. There are several techniques including aeration, destratification, dredging, and aquatic weed harvesting that have been used with some success for managing eutrophication. However, it is uncertain whether any of these techniques significantly reduce organic DBP precursors. Many water systems that use lakes or reservoirs for their surface water supply have been practicing algae control through the use of toxic chemicals, such as copper sulfate.

It is generally possible for water systems to detect the early stages of an algal bloom through an aggressive source water quality monitoring program and at that time, use copper sulfate to control algal growth. However, copper sulfate should be used cautiously for algae control because indiscriminant use may result in a greater likelihood of copper-resistant algae growing in the lake or reservoir. Systems that are considering using copper sulfate should first consult with the State to determine if it will be allowed. In many States, copper sulfate application requires a pesticide permit application or certified pesticide applicator. Directly applying chlorine to a reservoir undergoing an algal bloom will very likely result in an increase in TTHM or HAA5 concentrations. Another alternative algae control method is using submerged straw bales that release a natural algicide to control the algal bloom. Although this method may not be successful in every application, it is an inexpensive alternative that may be worth investigating.

Of the above choices, copper sulfate pentahydrate,  $\text{CuSO}_4 \cdot 5 \text{H}_2\text{O}$ , also called “bluestone”, either by itself or in conjunction with certain other chemicals is the only algicide in common use in domestic water reservoirs at the present time. Copper sulfate is toxic to many species of algae at relatively low concentrations. It does not present a health hazard to either the workers applying it or to domestic water users if proper application and safety procedures are followed. However, copper sulfate may be a hazard to trout at levels below those necessary to control some algae. Copper sulfate may cause toxins to be released by algae.

Water that contains even very low concentrations of copper has been found to cause significant corrosion problems in water distribution systems, particularly those with galvanized piping. The problem appears to be most severe in newer systems where no buildup of calcium or other compounds has occurred. This problem is more severe in systems supplied with highly mineralized water. Copper residuals in water entering the distribution system must be monitored closely following copper sulfate treatments in order to compile a record for copper

concentrations for future reference. The action level for copper at the consumer's tap is 1.3 mg/L.

In reservoirs where algae are a potential problem, the operator must have a monitoring program capable of anticipating a possible algal bloom. When the data reveal that a bloom is likely, the operator must take the necessary treatment action to prevent the bloom. After a bloom occurs it is more difficult, if not almost impossible, to control the bloom and correct the bad effects on water quality.

Whenever a chemical algae control program is started, monitoring should be carried out before, during, and after use of chemicals. Before and for several days after the chemical application, data on type of algae, amount of algae, and where they are located should be collected in order to evaluate the effectiveness of treatment at the dosage applied. Careful evaluation must be made to determine if algae die-offs actually occur as a result of the chemical application or if they simply die off due to natural circumstances. This can best be accomplished by monitoring bloom/die-off cycles under natural conditions when no chemical treatment is carried out. Careful monitoring of algicide residual concentrations should be practiced during and following treatment in order to determine if the desired dose is obtained and the extent of the algicide distribution. Accurate data should be kept on the actual algicide concentration in the reservoir or water supply in case legal questions regarding causes of fish die-off or system corrosion arise.

Full and accurate recordkeeping is an important part of any chemical algae control program. These records are valuable when evaluating current and historical treatment programs, for designing new or revising existing programs, and for showing compliance with federal, state, or local regulations.

## **CYANOBACTERIAL BLOOMS**

Harmful algal blooms (HABs) can occur anytime water use is impaired due to excessive accumulations of algae. In freshwater, the majority of HABs are caused by cyanobacteria (also called blue-green algae). Cyanobacteria cause a multitude of water-quality concerns, including the potential to produce taste-and-odor causing compounds and toxins that are potent enough to poison animals and humans. Taste-and-odor compounds and toxins are of particular concern in lakes, reservoirs, and rivers that are used for either drinking water supplies. Taste-and-odor compounds cause malodorous or unpalatable drinking water resulting in increased treatment costs. Cyanobacterial toxins (cyanotoxins) have been implicated in human and animal illness and death in over fifty countries worldwide, including at least 35 U.S. States.

The cyanobacterial compounds most commonly associated with taste-and-odor episodes are geosmin and 2-methylisoborneol (MIB). Cyanobacteria also produce a chemically and bioactively diverse group of toxins, all targeting fundamental cellular processes and thereby affecting a wide range of organisms. Cyanotoxins implicated in human illness include microcystin, cylindrospermopsin, anatoxin, saxitoxin, and  $\beta$ -methylamino alanine (BMAA). Because of potential human health risks, cyanotoxins are currently on the U.S. Environmental Protection Agency drinking water contaminant candidate list (CCL).

Although anecdotal reports are common, few studies have documented the distribution, occurrence, and concentration of taste-and-odor compounds and toxins in cyanobacterial blooms throughout the United States. In addition, while the general factors influencing cyanobacterial bloom formation are well known, the specific factors driving particular occurrences of taste-and-odor compounds and toxins remain unclear. Taste-and-odor compounds and cyanotoxins represent both economic and public-health concerns for water treatment plant operators. Understanding the environmental factors associated with the occurrence and concentration of taste-and-odor compounds and cyanotoxins is key to lake management and drinking water treatment decisions and minimization of human health risks.

The taste-and-odor compound geosmin, probably produced by the cyanobacterial genera *Anabaena*, is the likely cause of taste-and-odor episodes. Continuously monitored variables, such as light, temperature, conductivity, and turbidity have been used to successfully predict when geosmin concentrations will exceed the human detection limit of 10 nanograms per liter.

## COPPER SULFATE FOR ALGAE CONTROL

Alkalinity, suspended matter, and water temperature are the three major water quality indicators that affect the efficiency of using copper sulfate as an algicide. Alkalinity of the water is the principle factor that reduces the effectiveness of copper sulfate. In alkaline waters, the copper ions react with bicarbonate and carbonate ions to form insoluble complexes that precipitate from solution and reduce the amount of biologically active copper. Once the copper is removed from the ionized form, it is no longer effective as an algicide.

Copper sulfate is fully effective as an algicide when the alkalinity is 0 to 50 mg/L. For alkalinity concentrations ranging from 50 to 150 mg/L, copper sulfate dosages must be increased as the alkalinity increases. When the alkalinity exceeds 150 mg/L, the use of copper sulfate by itself as an algicide would not normally be recommended because of its very low effectiveness. Mixing of algicide chemicals into solution is a good method when citric acid is combined with the copper sulfate to prevent the precipitation of copper in alkaline water.

pH of the water is important for two reasons. The effectiveness of copper sulfate as an algicide depends on the pH. Also the pH level influences the precipitation of copper whose presence is essential to control algae.

Suspended matter in the reservoir or lake being treated with copper sulfate can reduce the effectiveness of copper as an algicide. Such suspended matter provides sites or masses other than algae bodies where the copper is adsorbed. Organic matter, both living and dead, adsorbs the copper. Suspended inorganic sediment is also a significant factor including the loss of copper available to kill the algae.

Water temperature plays a major role in how well the copper sulfate kills the algae. When the water temperature drops to the 50°F level, algae do not respond to treatment as they do at higher temperatures. Higher rates of copper sulfate application will generally be required when water temperature drops below 50°F. In many reservoirs, major blooms of algae do not occur in colder waters with temperatures below 50°F. In the majority of cases, the problem blooms take place after surface water temperatures have warmed during spring and summer months.

The amount of copper sulfate required for effective control of algae is also influenced by the species to be treated. Not all algae are alike in their reaction to copper sulfate. Several tiny planktonic green algae, some of the green flagellates, and filamentous blue-green algae are somewhat resistant to the toxic effects of copper sulfate. Most diatoms are quite susceptible to treatment, though they often bloom in large numbers following copper sulfate treatment for other algae. Many of the major taste- and odor-producing algae and filter clogging algae are controlled effectively with low rates of application.

## **WATERSHEDS**

By definition, a watershed is an area where all rainfall collects into a common location. The common location could be a stream, a pond, a river, etc. Smaller watersheds flow into increasingly larger watersheds. For example, the Kanawha River contains three small watersheds. All three watersheds, the Elk River, Coal River and Pocatalico River eventually flow into the Kanawha River, so they are all part of the Kanawha River watershed. The Kanawha River is part of the Ohio River watershed, which in turn is part of the Mississippi River watershed and is also the Gulf of Mexico's watershed.

The headwaters of a river are made up of first order streams. The watershed of a first order stream cannot be broken down into smaller watersheds because water feeding first order streams flows directly into the streams. The water may originate as runoff from rainfall or as groundwater welling up from below the earth's surface.

Each watershed has its own unique characteristics. Size, permeability of the soil, vegetation type, soil type, slope, microorganisms, pH, DO (Dissolved Oxygen), and temperature all affect the water in a watershed. Each watershed also presents its own problems for the water treatment operator.

### **Sources of Contamination**

We're interested in defining an area's watershed so that we can find potential sources of contamination to our facilities. When considering sources of contamination in the watershed, keep in mind the effect of distance on the concentration of the contaminant in the water.

For example, contamination in the Kanawha River will be more dilute than it was in the source stream. The further we go from the source of contamination, the less concentrated the contamination will become until it is an insignificant component of the water running into the Gulf of Mexico. The total amount of contamination in the water is about the same when it reaches the Gulf of Mexico as it was when it left the source stream. But there is so much water in the Gulf of Mexico that the contamination becomes very diluted.

There are many possible sources of contamination in a watershed. Septic tanks, airports, automobiles, industrial facilities, mining operations, and agricultural lands all contribute to the contamination. In addition, various other sources and processes contaminate the water supply.

### **Point Source Pollution**

When a single source of pollution at a specific location can be identified, it is called point source pollution. Illegal drains from a factory discharging contaminants or an overflow pipe from a sewer system are examples of point source pollution. Many communities across the U.S. are attempting to reduce or eliminate sewer overflows, especially during heavy rain events. These discharges pollute waterways and adversely affect animal life within these surface waters. The pollution also presents health threats to humans who may drink the water or enjoy it for recreational purposes. Point sources of pollution often can be easily identified, but are very difficult (and usually expensive) to correct.

### **Non-point Source Pollution**

Non-point sources of pollution include farm runoff of chemicals such as fertilizers, animal wastes and pesticides. During periods of rain, these pollutants will drain from higher land levels into waterways and, also, adversely affect animal life within the surface water. High levels of pesticides and herbicides may also threaten humans and animals that may be exposed to the water.

Microbial contamination of the water supply is not as much of a concern as other types of contamination. Bacteria are killed or removed during the water treatment processes: coagulation, flocculation, sedimentation, filtration, and disinfection. But knowing the amount and type of contamination in the treatment plant's watershed can influence how much chemical treatment necessary to produce potable water.

Every watershed has different characteristics - different colloids, different pH, and so forth. The only thing that is common in water treatment with respect to a watershed is that every watershed is unique.

### **Responding to Contamination**

As a water plant operator, you need to have an understanding of what potential sources of contamination are contained within your watershed. Without this knowledge, you won't be able to respond adequately to problems as they arise.

### **Example**

The watershed that feeds Huntington, West Virginia, goes through an industrial area that had an acid spill. A hose carrying sulfuric acid burst and emptied the contents of the tank car into the river. The water operator that was on duty noticed the pH of the water coming into the plant was dropping. The first thing the operator did was to shut the plant down. He/she was able to guess that the acid came from a spill in the industrial area even though no one at the company there had noticed the problem. So the operator called the other water treatment plants downstream of the spill area to let them know about the contamination.

You never know when your watershed will become contaminated. Usually the amount of time that you will have to respond to such a situation is not what you would like it to be. What is a reasonable amount of time to be able to respond to a problem? Enough time to prevent irreversible damage or expensive correction. The people who are responsible for water treatment facilities want an operator who is on his/her toes to catch problems as they come down the stream, an operator who will take appropriate action or shut the plant down, if necessary. This prevents cleanup cost and problems with treated water.

## **SOURCE WATER ASSESSMENT AND PROTECTION**

Virtually every stream, lake, river and aquifer in this country is used as a drinking water source. Protecting these source waters from contaminants is a major national priority in protecting public health through ensuring a clean, safe drinking water supply. Reducing the threat of waterborne illnesses helps save hundreds of millions of dollars annually by eliminating costly health care expenses, lost wages, work absences, decreased job productivity, and additional treatment costs incurred by PWSs required to meet federal drinking water quality standards. The Source Water Assessment and Protection Program (SWAP), authorized by the 1996 Amendments to the SDWA, outlines a comprehensive plan to achieve maximum public health protection.

Source Water Assessment and Protection Plans:

- Are an integral part of the multiple-barrier approach for public health protection.
- Are a preventive effort designed to eliminate unnecessary risk of contamination to the source of water used by a public water supply system.
- Are a community-based approach to protecting drinking water through a process that identifies the origins of certain contaminants and then determines the best way to manage them at the community level.
- Are achieved through the development and implementation of a SWAP plan.
- Can work very well with existing environmental programs by serving as a basis for prioritization for permitting, inspections, and enforcement.

The general concepts of SWAP are applied to public water supply systems using surface water, ground water (also known as Wellhead Protection), or water from a source with significant surface water / ground water interaction. Source water protection is an extension of the wellhead protection concept and includes systems using water from any type of source. Source water protection plan development is designed to manage a specific land area identified or delineated according to the local hydrology (for surface water systems) or hydrogeology (for ground water systems) to prevent ground or surface water contamination. According to the source water assessment and protection plan, it is essential that every community take these six steps:

### **Step 1- Delineate**

Delineating the source water protection area (SWPA) shows the area to be protected and prescribes the boundaries of the area from which drinking water supplies are drawn. This step also designates the area within which contaminant source inventories are conducted, identifying substances or activities that may pose potential risks to the drinking water supplies within that area. Delineations may be performed using a variety of accepted methods (e.g., calculated fixed radius; computer modeling, etc.), and are most protective when they include all sources of water and potential contaminants and activities affecting them within the prescribed area.

### **Step 2- Inventory**

The source inventory lists all documented and potential contaminant sources or activities of concern that may be potential threats to drinking water supplies. The source inventory indicates the level of concern assigned to each potential risk by ranking, rating, or prioritizing management measures to reduce or eliminate them.

### **Step 3- Determine the Susceptibility**

Determining susceptibility of the public water supply (PWS) to inventoried threats relates the nature and severity of the threat to the likelihood of source waters serving that system being

contaminated. Mitigating factors taken into account when determining susceptibility include potency or toxicity of the contaminant, volume of discharge or release, distance from wells or intakes, and the likelihood of entry of the contaminant into the source waters.

#### **Step 4- Notify and Involve the Public**

To ensure that the public has information necessary to control and modify their own actions to prevent contamination and to participate effectively in community activities to protect drinking water.

- Use plain English in reports
- Provide maps of the SWPA
- List, show or indicate potential sources/threats to the PWS identified within the SWPA
- List, rank, or otherwise prioritize importance of threats identified to the individual PWS and explains what it means to your water supply
- Reports are unique to each individual PWS
- Public meetings are effective methods of involving the community.

#### **Step 5-Implement Management Measures**

Using the information gathered from the assessments allows specific management measures to be formulated and put in place. By examining the results of the contaminant source inventory and the susceptibility determination for each PWS, these measures can be tailored to address each threat or array of risks specific to each PWS. A successful drinking water contamination prevention plan is tailored to the unique concerns and circumstances of the local community. Effective involvement is a critical component to a successful public health plan. Every PWS's source water is unique. Management measures need to tailor local actions to address threats to your water supplies. Early involvement in the source water protection process and consensus on need for action is essential — you can help!

#### **Step 6-Develop Contingency Planning Strategies**

In the event of short- or long-term water drinking water supply disruption as a result of natural causes (e.g., biological contamination or floods) or intentional destruction (e.g., vandalism or terrorism), water supply replacement strategies that coordinate all available efforts to restore service to single or multiple PWSs are an indispensable part of any drinking water protection program.

- Outline emergency plans for short or long-term drinking water supply replacement
- Direct plan towards water supply interruption due to contamination or physical damage to supply system
- Coordinate the efforts of water supply managers with those of civil defense, local emergency response, hazmat/spill cleanup, and local area disaster response networks

An initial SWAP report has been developed for every PWS in the state. Additional guidance and assistance for setting up a SWAP plan is available from OEHS, but local effort and initiative are key to developing a useful plan.

## **SANITARY SURVEY**

A comprehensive sanitary survey is an important element in helping water systems protect public health. Sanitary surveys are carried out to evaluate: (1) the capability of a drinking water system to consistently and reliably deliver an adequate quality and quantity of safe drinking water to the consumer, and (2) the system's compliance with federal drinking water regulations. Much of the information generated by a sanitary survey helps identify existing and potential sanitary risks.

Conducting sanitary surveys on a routine basis is an important element in preventing contamination of drinking water supplies. EPA recognizes the importance of sound sanitary surveys in helping PWSs protect public health. Sanitary surveys are an opportunity to work and communicate with PWSs in a preventative mode.

Sanitary surveys also aid in the process of evaluating a PWS's progress in complying with federal and state regulations which require the improvement of the capabilities of the system to provide safe drinking water. Sanitary surveys provide the water system with technical and management information regarding the operation of the system from the water source, through the treatment facilities and the distribution system.

Sanitary surveys are a means by which a comprehensive inspection of the entire water delivery system and its operations and maintenance (O&M) can be performed. These surveys are structured to determine whether a system's source, facilities, equipment, operation, maintenance, and management are effective in producing safe drinking water. Sanitary surveys also evaluate a system's compliance with federal drinking water regulations, as well as state regulations and operational requirements. In addition, a sanitary survey evaluates water quality data and administrative issues and draws conclusions about the system's integrity and its capability for consistently and reliably delivering an adequate supply of safe drinking water to consumers. Conducting sanitary surveys on a regular basis is the best means of identifying potential problems and possible reasons for trends in finished water quality and demand that may need to be addressed by enhanced O&M or a system upgrade. Sanitary surveys play a fundamental role in ensuring that reliable and safe drinking water is provided to the public by PWSs.

### **Benefits of a Sanitary Survey**

EPA believes that periodic sanitary surveys, along with appropriate corrective measures, are indispensable for assuring the long-term quality and safety of drinking water. Properly conducted sanitary surveys help PWSs protect public health. Sanitary surveys have many benefits for the operation and management of PWSs. Sanitary surveys may also provide support to enforcement actions by establishing a record of conditions and operations at a point in time.

EPA lists the following specific benefits of conducting sanitary surveys:

- Operator education;
- Source protection;
- Risk evaluation;
- Technical assistance and training;
- Independent, third party system review;
- Information for monitoring waiver programs;
- Identification of factors limiting a system's ability to continually provide safe drinking water;
- Reduction of monitoring requirements;

- Reduction of formal enforcement actions in favor of more informal action;
- Reduction of oversight by state monitoring and enforcement personnel;
- Increased communication between state drinking water personnel and PWS operators;
- Provision of contact personnel to notify in case of emergencies or for technical assistance;
- Improvement of system compliance with state drinking water regulations;
- Identification of candidate systems for enforcement action;
- Identification of candidates for Comprehensive Performance Evaluations;
- Verification of data validity;
- Validation of test equipment and procedures;
- Reduced risk of waterborne disease outbreaks;
- Encouragement of disaster response planning; and
- Improved system security.

## COMPONENTS OF A SANITARY SURVEY

In the EPA Guidance Manual, Sanitary Surveys are broken into eight sections: Source, Treatment, Distribution, Storage, Pump Facilities, Monitoring/Reporting/Data Verification, Management/Operation, and Operator Certification. The following further defines the eight elements of the Sanitary Survey and provides the major topics within each element that will be evaluated.

### **1. Source**

The system's source will be evaluated for quality, quantity, reliability, and vulnerability. The major items of concern are: does the source have adequate storage (even during a drought); is the source water being impaired by a discharge upstream; and does the source have extreme changes in water quality. A review of the system's Source Water Assessment may be necessary to identify possible problems in the system's watershed.

### **2. Treatment**

In evaluating the treatment of a surface source or GWUDI source, the condition and capacity of treatment facilities will be evaluated. In evaluating treatment capacity, each stage of the treatment will be assessed for size, chemical addition (type of chemical, application point and application rate), and operational condition. The treatment plant will also be evaluated for its handling of washwater to determine if there is any adverse impact on the treatment plant caused by recycling this water. Slowly recycling filter backwash water back to the head of the plant will reduce the need for the operator to make changes in chemical dosages.

### **3. Distribution**

An improperly maintained or designed distribution system can adversely impact public health just as a poorly operated water treatment plant. These conditions could lead to contamination of the distribution system through backflow from a cross connection or improperly maintaining a chlorine residual. The following will be evaluated during the survey:

1. sampling plans/maps (are samples representative of entire system);
2. field sampling/measurement (chlorine residual and pressures);
3. water line repair practices;
4. system flushing procedures;
5. cross connection control program;
6. water loss control program;
7. distribution maps; and
8. adequacy of properly certified distribution system operators.

### **4. Storage**

Adequate above ground storage is an essential part of any distribution system. If a system does not have adequate storage that provides satisfactory pressure (one day's average usage and a minimum of 20 psi at the customer's meter) contamination through backflow could result. will be evaluated for location, capacity (correct size for service area), condition (inspected within last 3-5 years), and security.

### **5. Pump Facilities**

Pumping facilities are essential to many PWSs and especially those with large distribution systems. They provide the means for moving water from one section of the distribution system to another via storage tanks. Without pumping facilities to maintain adequate tank levels, water

quality could become compromised if pressures fluctuate radically or drop below 20 psi. Evaluation will include pump facility capacity (with largest pump out of service), condition, chemical addition (if any), and security.

#### **6. Monitoring/Reporting/Data Verification**

Quality control is important in any industry that produces a product. A water system's product is potable water. Improperly treated water can directly impact public health, so it is vital that a water system closely monitor its water quality. To ensure that the system is supplying water that meets or exceeds standards, the inspector will review all records submitted to the Department, all chemical monitoring within the past several years, verify that correct water quality data is being submitted to the Department (comparison of monthly reports with daily logs), and ensure that correct testing procedures are being followed by the system's certified operator.

#### **7. System Management/Operation**

Water system management has a major effect on water system performance. Management provides direction for the system, sets specific quality goals and ensures adequate funding and support is available to enable the system to provide safe, reliable drinking water. This element focuses on water system management and operation. The inspector will review system funding, goals set by management, staffing requirements/staffing needs, O&M documents and SOP's to be used by system operators.

#### **8. Operator Certification**

The inspector will determine if the system has enough certified operators of sufficient grade to operate and maintain the water system. Surface water treatment plants are required to have an onsite operator of appropriate grade (III or IV) at all times during plant operation. Distribution systems need enough supervisory certified operators to ensure that any work performed by non-certified operators is in accordance with accepted water practices and AWWA guidance documents.

These eight elements, when combined, form the basis of the Sanitary Survey. When the Sanitary Survey is completed the system will be provided with a letter which details the results of the Sanitary Survey and whether the system was viewed as satisfactory or unsatisfactory. If the water system is found to be unsatisfactory, a detailed list of deficiencies will be provided along with specific date by which the system must correct or respond to the named deficiencies. If necessary, the District Engineer may schedule a follow-up visit to ensure that the system is properly correcting the deficiencies.

Should a water system desire additional information on what is to be expected during a Sanitary Survey, EPA's Guidance Manual titled "*Conducting Sanitary Surveys of Public Water Systems-Surface Water and Ground Water Under the Direct Influence (GWUDI) of Surface Water* (April 1999)" should be obtained by contacting EPA through their website at [www.epa.gov](http://www.epa.gov).

## **COMMON DEFICIENCIES FROM SANITARY SURVEYS**

Listed below are deficiencies that routinely come up during the sanitary survey inspection.

1. Insufficient staffing (this typically becomes a significant deficiency).
  - Not enough operators.
  - Operators without the proper license classification.
  - No operator for distribution system.
2. Records not kept for the required times.
3. Raw water meter not calibrated.
4. Filter backwash flow rate is not measured.
5. Insufficiently sized spent filter backwash holding tanks/lagoons.
6. No day tanks for bulk liquid chemical feed processes.
7. No containment around bulk chemical feed processes.
8. Lack of a process for identifying cross-connections.
9. No formal flushing schedule or written flushing program.
10. Screens or flappers missing from distribution storage tank overflow piping.
11. Distribution storage tank overflow piping not located 10 horizontal feet from the base of the tank.
12. Lack of measurable chlorine residual in a part of the distribution system (this can be made a significant deficiency upon the recommendation of the inspectors).
13. Operation and Maintenance (O and M) manuals are not updated annually (only updated as needed).
14. Air intakes in the chlorine rooms located at the floor or someplace other than the ceiling.
15. Chlorine alarms visual but not audible or vice versa.

## **WATER QUALITY CHARACTERISTICS**

Water acquires certain characteristics from its surroundings – from the soils, rocks, minerals, and air that the water contacts, and from animals and people that contact and influence the water. Water quality and characteristics are important to consider when choosing a water source. The quality of water is determined by the measuring the concentrations of impurities in it. Water quality characteristics are classified into four broad categories:

- Physical
- Chemical
- Biological
- Radiological

### **Physical Characteristics**

There are a number of physical characteristics of water that consumers notice because they can be seen, smelled or tasted. Generally, these physical characteristics are important only from an aesthetic standpoint, but are typically the basis for many consumer complaints. Interestingly, complaints regarding the aesthetic quality of the water are generally the driving force behind the installation of water treatment devices. If drinking water looks, smells or tastes bad, it may be rejected in favor of an unsafe source that does look, smell or taste good.

#### **1. Temperature**

Water temperature will dictate how it tastes, how easily it dissolves things, and whether it's effective for other uses such as cooling. Generally, surface water sources are warmer than groundwater sources. Groundwater sources typically have constant temperatures, although some may be warmer than others. Temperature is a useful tool for determining if groundwater is directly influenced by surface water.

#### **2. Turbidity**

Turbidity is caused by very small particles such as clay and silt that are suspended in the water. When water is cloudy, it is said to be turbid or have a high turbidity. Consumers will object to water that is highly turbid, even though it may be perfectly safe to drink. Removal of turbidity not only makes the water more pleasing from an aesthetic standpoint, but it also has public health implications.

High turbidity in finished water is a potential health risk, because viruses and bacteria can hide, within the turbidity-causing particulates making disinfection difficult. Removal/inactivation of these particulates reduces the chance of pathogenic microorganisms in finished water.

#### **3. Color**

If water is colored, it is less pleasing to the consumer and may be rejected in favor of a drinking water source that is less safe. Color occurs most frequently in surface water due to the decay of organic material. Color can be measured in the laboratory and, generally, a measurement of 15 color units or higher is objectionable.

#### **4. Taste and Odor**

The taste and odor of water are determined by the physical and chemical characteristics of water. Taste and odors can be caused by temperature, chemicals, minerals, decaying matter, or dissolved gases. The most common cause of odor in drinking water is the presence of hydrogen

sulfide, iron, or sulfur-reducing bacteria. However, most contaminants do not impart either and cannot be detected by just smelling or looking at a glass of water.

In a distribution system, the corrosion of pipe materials can also cause taste and odor. Even though taste and odor are more of an aesthetic concern than a health related one, their presence may be indicative of other contaminants harmful to public health.

### **Chemical Characteristics**

Although the physical characteristics exhibited by the source water are readily discernable by sight, smell and taste, the chemical composition of water can, with a few exceptions, be determined only through chemical analysis. Consequently, laboratory testing is necessary. The importance of each chemical substance depends on the kind and amount of that substance found in the water and on the use for which the water is intended. The strictest standards apply to surface water used as a public drinking water supply. Chemical characteristics are broken down into three areas: inorganics, organics and minerals.

- Inorganics chemicals (IOC) include metals such as arsenic, lead and copper.
- Organic chemicals (OC) include: volatile organics (VOC) such as trichloroethylene and benzene; and synthetic organics (SOC) such as pesticides and aldicarb.
- Mineral constituents include alkalinity, calcium, chloride, copper, foaming agents, iron, magnesium, manganese, pH, sodium, sulfate, zinc, specific conductance, total dissolved solids, and hardness (calcium and magnesium).

Some of the more troublesome naturally occurring chemical constituents found in source waters are: calcium and magnesium (hardness), iron and manganese, hydrogen sulfide, nitrate, arsenic, sulfate and radiological contaminants.

### **Biological Characteristics**

A variety of aquatic organisms are routinely found in raw water sources. These include tiny microorganisms, such as bacteria, protozoa, and viruses, and a variety of visible organisms, such as algae, fresh water shrimp, and snails.

Although most do not pose a health risk, the presence of some microorganisms in drinking water can be devastating. In fact, providing drinking water that is microbiologically safe is the primary goal of all water providers.

As a general rule, surface water sources are more likely to contain greater numbers and more diverse populations of microorganisms than groundwater sources. This is because surface water can easily pick up microorganisms from contaminated areas as it flows across the earth's surface. On the other hand, the filtering action of aquifer material results in fewer microorganisms in groundwater. However, shallow wells and unprotected wellheads can provide an opportunity for contaminated surface water to enter the groundwater. Consequently, groundwater cannot be assumed to be free of microorganisms. Disease-causing organisms are called **pathogens**. Water-borne pathogens include bacteria, protozoa and viruses. These pathogens can be transmitted from person to person through fecal contamination of drinking water. Consequently, disinfection is generally required for surface water sources and may be necessary for groundwater sources if they become contaminated.

### **Radiological Characteristics**

Although the presence of radiological elements, or **radionuclides**, in drinking water may be attributed to human activities, they are most often a result of dissolution of naturally occurring radioactive elements in rock formations such as granites. Examples of radionuclides found in drinking water include radium 226, radium 228, uranium, and radon. When consumed at high levels, these radioactive contaminants are known to cause cancer in humans.

## **APPLIED MICROBIOLOGY**

A variety of aquatic organisms are routinely found in raw water sources. These include tiny microorganisms, such as bacteria, protozoa, and viruses, and a variety of visible organisms, such as algae and zebra mussels.

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### **Coliform Bacteria**

Coliform bacteria live in soil or vegetation and in the gastrointestinal tract of animals. Coliforms enter water supplies from the direct disposal of waste into streams and lakes or from runoff from wooded areas, pastures, feedlots, septic tanks, and sewage plants into streams or groundwater. In addition, coliforms can enter an individual house via backflow of water from a contaminated source or carbon filters.

Coliforms are not a single type of bacteria, but a grouping of bacteria that includes many strains, such as *E. coli*. They are ubiquitous in nature, and many types are harmless. Therefore, it is not definitive that coliform bacteria will cause sickness. Many variables such as the specific type of bacteria present, and someone's own immune system's effectiveness will determine if there will be a sickness. In fact, many people become immune to bacteria that are present in their own water. Guests on the other hand, may not have developed an immunity to the water and may experience some gastrointestinal distress such as diarrhea or gastroenteritis.

Total coliforms are the standard by which microbial contamination is measured. Coliforms will be one of the first bacteria present in the water should contamination occur, and they will be in much larger quantities than some pathogenic microbes that may be present. Therefore, coliforms act as indicators of possible contamination. The presence of coliform bacteria does not necessarily mean that pathogenic microbes are also present. However, if large coliform quantities are detected, the presence of other microbes should be checked for.

Most bacterial pathogens are easily controlled with normal disinfection processes.

### ***Giardia Lamblia***

*Giardia* has become more prevalent in the past few years as a waterborne disease, and a few large outbreaks that have occurred in the U.S. *Giardia* are flagellated protozoa that are parasitic

in the intestines of humans and animals. They have two stages, one of which is a cyst form that can be ingested from contaminated water. Once the cyst enters the stomach, the organism is released into the gastrointestinal tract where it will adhere to the intestinal wall. Eventually the protozoa will move into the large intestine where they encyst again and are excreted in the feces and back into the environment.

Once in the body, the *Giardia* causes giardiasis, a disease characterized by symptoms such as diarrhea, abdominal cramps, nausea, weight loss, and general gastrointestinal distress. These symptoms last for about a week, however some people can undergo a more chronic infection with similar symptoms and an even greater degree of weight loss. Giardiasis is rarely fatal and can be treated medicinally by quinacrine, metronidazole, and furazolidone.

*Giardia* enters the water supply via contamination by fecal material. The fecal material can enter the water from:

- Sewage discharged into the water via cross contamination of sewage and water lines;
- Sewage directly discharged from small sewage plants into lakes or streams;
- Sewage discharged into lakes or streams from cabin toilets;
- Animals carrying the cysts, depositing their fecal material directly into the water; and,
- Rainfall moving the cysts deposited from animals on the soil into a body of water.

Once in the water, unsuspecting hikers or campers may drink infected water, exposing themselves to the cysts. Water from these lakes or streams may also be transported to municipal water supplies. If the municipal system uses filtration in addition to chlorination, the cysts should be removed. If chlorination is used without filtration, the chance for a *Giardia* infection increases. It is estimated that 20-65 million Americans are at risk due to this lack of filtration of surface water. It has been suggested that 40-45% of *Giardia* cases are associated with exposure to unfiltered water. Other sources of exposure include unsanitary conditions at day care facilities, exposure while traveling in developing countries, hikers or campers drinking infected surface water, and sexual practices involving fecal exposure.

### ***Cryptosporidium***

*Cryptosporidium parvum* is a protozoan parasite that causes cryptosporidiosis, which has gained notoriety in the past years. In 1993, over 400,000 people in Milwaukee, Wisconsin became ill with it after drinking contaminated water. Since this outbreak, there has been a greater impetus to remove the *Cryptosporidium* from municipal water supplies.

*Cryptosporidium* is spread by the transmission of oocysts via drinking water which has been contaminated with infected fecal material. Oocysts from humans are infective to humans and many other mammals, and many animals act as reservoirs of oocysts which can infect humans. Once inside of its host, the oocyst breaks, releasing four movable spores that attach to the walls of the gastrointestinal tract, and eventually form oocysts again that can be excreted. Symptoms occur 2 to 10 days after infection. These symptoms include diarrhea, headache, abdominal cramps, nausea, vomiting, and a low fever. There is no treatment against the protozoa, although it is possible to treat the symptoms. After about 1-2 weeks, the symptoms subside as the immune system stops the infection. However, for persons with a compromised immune system such as infants, seniors, those with AIDS, or transplant patients, cryptosporidiosis may become life threatening.

Cryptosporidium infected fecal material enters the water supply either from cross contamination of sewage lines with water lines, or surface water infected with contaminated animal waste. Water treatment processes that utilize coagulation, sedimentation, filtration, and chlorination may remove it. However, due to its small size and its resistance to chlorination, these treatments may not work.

### **Protozoa**

Protozoan go through a life cycle, one phase of which results in an extremely resistant form that makes them very difficult to control with normal disinfection.

### **Hepatitis A**

Hepatitis A is an enteric virus that is very small. It can be transferred through contaminated water, causing outbreaks. The virus is excreted by a person carrying it, and if the sewage contaminates the water supply, then the virus is carried in the water until it is consumed by a host. Symptoms such as an inflamed liver, accompanied by lassitude, anorexia, weakness, nausea, fever and jaundice are common. A mild case may only require a week or two of rest, while a severe case can result in liver damage and possible death. Generally, water systems utilize chlorination, preceded by coagulation, flocculation, settling and filtration to remove the virus.

### **Algae**

Algae, small aquatic, plant-like organisms are frequently found in surface water supplies but not in groundwater because they require sunlight to survive. Algae contribute to taste and odor problems in finished drinking water. These problems are caused by natural chemicals produced by the algae and by chemicals released when algae cells die.

The earthy, musty taste and smell of the drinking water is related to two naturally occurring compounds, geosmin and 2-methylisoborneol. Research shows two commonly encountered microorganisms, actinomycetes (bacteria) and cyanophytes (bluegreen algae) produce these compounds as metabolic byproducts. An increase in these organisms will have a consequential increase in the taste and odor complaints.

The problem results from a build-up during the warm summer months of blue-green algae which contains a naturally occurring compound called geosmin. In the past, the algal problem has been of short duration and is usually dispersed by a sudden drop in water temperature resulting in replacement of surface water. It can last longer if the weather is particularly dry and sunny.

### **Iron Bacteria**

One special group of bacteria, iron bacteria, causes problems with water supplies. If iron is present, it will promote the growth of these bacteria. Iron bacteria metabolize iron and will flourish when iron levels are high. During this metabolic process the bacteria will produce byproducts that give the water a metallic taste. Iron bacteria can also cause red water, clog well screens and reduce water production. If reddish or green slime builds up in your toilet flush tank you probably have an iron bacteria problem. Iron bacteria problems are very hard to eliminate. High dosages of chlorine must be used throughout the plumbing system to kill all of the bacteria. It may be necessary to feed chlorine continuously to prevent regrowth. A filter alone will not solve this problem.

### **Sulfur Bacteria**

Once this mat of iron bacteria is established on steel pipes, such as the well casing, it may provide a haven for sulfur bacteria, another troublesome microorganism. Some sulfur bacteria convert sulfides to elemental sulfur, which combines with bacterial filaments to clog pipes. Another group of sulfur bacteria generate hydrogen sulfide gas, which is corrosive to pipes and has a foul smell like rotten eggs. Certain sulfur bacteria may produce sulfuric acid that can also cause corrosion of pipes. As mentioned above, the slime mat produced by the iron bacteria provides a favorable environment for the sulfur bacteria. This slime mat also encloses and supports sites of corrosion, which may be the cause of the odor, taste, and staining problems commonly encountered with well water.

### **Zebra Mussels**

Zebra Mussels (*Dreissena polymorpha*) are small clam shells (1/2 - 2 inches) which attach to any solid object with tufts of fiber called "byssal threads." They are native to the Caspian Sea region of Asia, and were introduced into North America in the mid 1980's via transoceanic ships that discharged ballast water into Lake St. Claire, near Detroit. Tolerant of a wide range of environmental conditions, zebra mussels have extended their range to parts of all the Great Lakes and the much of the Mississippi River, and are beginning to infest inland lakes as well.

Water treatment plants are experiencing reductions in their pumping ability due to zebra mussels clogging the intake pipes. Since the mussels filter water so effectively, they increase the water's clarity. This in turn results in enhanced growth of aquatic weeds, which has led to taste and odor problems in drinking water supplies. This has necessitated in more expensive and aggressive water treatment procedures. They are also known to increase the rate of corrosion of iron and steel structures at the point of attachment.

Water plants are trying to control zebra mussels by certain types of chemical treatment, such as chlorine (Cl<sub>2</sub>), potassium permanganate (KMnO<sub>4</sub>), and ozone (O<sub>3</sub>).

## CHEMISTRY

### **pH**

pH is defined as the "negative log of the hydrogen ion concentration." This is actually a mathematical determination and is expressed as  $\text{pH} = -\log_{10} [\text{H}^+]$ . More simply, pH is a measure of the hydrogen ion concentration in water and can be considered as an "Index" of the amount of hydrogen ions present in a substance. This "Index" is important because it can be used quickly to determine if a substance is acidic, basic or neutral.

The pH scale is a numerical scale from 0 to 14, with 7 considered neutral. At a pH below 7, the water is acidic. An acidic solution is one that has a greater concentration of hydrogen ions than hydroxyl ions. At a pH above 7, the water is basic. A basic solution is one that has a greater concentration of hydroxyl ions than hydrogen ions.

Since pH is measured as a logarithm, a change of one (1) pH unit means a ten-fold increase or decrease in the hydrogen ion concentration. For example, pH 8.0 is ten times more basic than pH 7.0; pH 9.0 is ten times more basic than a pH 8.0 and pH 9.0 is 100 times more basic than pH 7.0. We see that as the pH increases, the number of hydrogen ions DECREASES.

Natural waters rarely have a pH less than 6.0 or greater than 9.0. Treated water is usually between pH 6.5 and 8.5.

The table below gives some common acids and bases and their pH values.

I. Acids	pH	Bases	pH
Hydrochloric acid	1.0	Sodium bicarbonate	8.4
Sulfuric acid	1.2	Ammonium hydroxide	9.2
Acetic acid	2.9	Sodium carbonate	11.4
Alum	3.2	Lime	12.3
		Sodium hydroxide	13.0

### **pH Control**

There are a number of pH increase treatment options available to small systems to increase pH.

#### **1. Lime**

Lime or limestone is calcium carbonate ( $\text{CaCO}_3$ ) and can be used to raise pH. As the lime is added to the water, it dissolves the  $\text{CaCO}_3$ . Through a chemical reaction, similar to the  $\text{CO}_2/\text{H}_2\text{CO}_3$  resulting in a higher pH..

A possible drawback to the use of a lime is that calcium ions are also released into the water which increases hardness and scaling.

#### **2. Soda Ash**

Soda ash ( $\text{Na}_2\text{CO}_3$ ) can also be used to raise the pH. The chemistry is similar to the use of lime and causes a higher pH. Soda ash is normally fed into the water system as a solution using a liquid chemical feed pump. The feed equipment is almost the same as that used to feed hypochlorites.

### 3. Sodium Hydroxide

Sodium hydroxide (NaOH), commonly called caustic soda, is readily soluble in water and a very strong base. It can be used to raise pH in water systems, but it is extremely corrosive and can be very dangerous if mishandled. It is critical that workers who handle NaOH be well trained.

Diluted NaOH (30% or 50%) is normally fed into the water system using a liquid chemical feed pump similar to ones used to feed hypochlorites.

### HARDNESS

The hardness of water relates to the amount of calcium, magnesium and sometimes iron in the water. The more minerals present, the harder the water. Soft water may contain sodium and other minerals or chemicals; however, it contains very little calcium, magnesium or iron.

Many people prefer soft water because it makes soap lather better, gets clothes cleaner and leaves less of a ring around the tub. Some municipalities and individuals remove calcium and magnesium, both essential nutrients, and add sodium in an ion-exchange process to soften their water.

### ALKALINITY

Alkalinity is the capacity of water to neutralize acids. Alkalinity is the result of the water's content of carbonate, bicarbonate, and hydroxide. It is expressed as milligrams per liter equivalent calcium carbonate. Alkalinity is measured by titrating the sample to a pH of 4.5.

#### Influences of treatment

##### Lowers Alkalinity

Aluminum sulfate (alum)  
Carbon dioxide  
Chlorine gas  
Ferric chloride  
Ferric sulfate  
Sulfuric acid

##### Increases Alkalinity

Calcium hypochlorite (HTH)  
Caustic soda (sodium hydroxide)  
Hydrated lime (calcium hydroxide)  
Soda ash (sodium carbonate)

### NITRATE

High levels are usually caused by concentrated sources of nitrogen such as animal feedlots, septic systems, or heavily fertilized cropland. Nitrates are the only chemical contaminant that represents an immediate health risk. High nitrate-containing water is a serious health concern for pregnant women and infants under the age of 6 months. Infants that consume water high in nitrates are susceptible to a life-threatening disease called **methemoglobinemia** or "**blue baby**" **syndrome**. Babies with this condition become oxygen starved because their red blood cells are unable to carry oxygen properly. This reduction of oxygen uptake in the bloodstream gives the skin a blue tint. Infants become less susceptible to the effects of nitrates after six months of age.

The MCL for nitrate nitrogen is 10.0 mg/L and the MCL for nitrite is 1 mg/L. Public water systems that exceed this level are required to obtain a new water source or treat their water.

### HYDROGEN SULFIDE

Water containing hydrogen sulfide, commonly called sulfur water, has a distinctive "rotten egg" or swampy odor. Hydrogen sulfide is a gas formed by the decay of organic matter such as plant material. It is typically found in groundwater containing low levels of dissolved oxygen and a pH

less than 6.0. Sulfur problems occur less frequently in surface waters because flowing water is aerated naturally so that the hydrogen sulfide reacts with oxygen and escapes as a gas or settles as a solid.

Sulfur bacteria are also found in many drinking water wells and household distribution systems. These harmless bacteria use natural sulfur compounds in water as a food source, thereby producing hydrogen sulfide. Although sulfur bacteria pose no health risk to humans, their presence in drinking water may cause objectionable tastes and odors.

A water heater may also produce a sulfur odor. The magnesium rod present in many water heaters can chemically change naturally occurring sulfates in water to hydrogen sulfide. If this occurs, the magnesium rod can be replaced with an aluminum rod or simply removed, although removing the rod may nullify the warranty on the water heater.

Hydrogen sulfide is not regulated, however, because it is considered a nuisance chemical and does not pose a health risk at concentrations typically present in household water. Concentrations high enough to be a health risk also make the water unpalatable. Conversely, concentrations as low as 0.5 milligrams per liter (mg/L) can add objectionable taste and a rotten egg odor to drinking water.

Continuous chlorination is a very common and effective method for oxidizing hydrogen sulfide, especially if the water pH is 6.0-8.0. Chlorine has the secondary advantage of being lethal to bacteria so it typically follows other treatment options to maintain a chlorine residual and prevent bacterial activity. Chlorine is usually administered as sodium hypochlorite, which reacts with sulfide, hydrogen sulfide, and bisulfide to form compounds that do not cause foul taste or odors in drinking water.

Another common treatment for sulfur water is aeration. Hydrogen sulfide is physically removed by agitating the water via bubbling or cascading and then separating or "stripping" the hydrogen sulfide in a container. The undesired hydrogen sulfide is removed as a volatile gas by venting it into a waste pipe or to the outdoors. Aeration is most effective when hydrogen sulfide concentrations are lower than 2.0 mg/L. At higher concentrations, this method may not remove all of the offensive odor unless the air is used to oxidize hydrogen sulfide chemically into solid sulfur, which is then filtered.

## **LEAD and COPPER**

### **Copper**

Although copper is an essential micronutrient and is required by the body in very small amounts, excess copper in the human body can cause stomach and intestinal distress such as nausea, vomiting, diarrhea and stomach cramps. People with Wilson's disease, a rare genetic disorder, are more sensitive to the effects of copper.

### **Lead**

Lead is a cumulative poison, meaning it accumulates in the body until it reaches toxic levels. Chronic exposure to low levels of lead over an extended period of time can have severe effects. Excess lead in the human body can cause serious damage to the brain, kidneys, nervous system and red blood cells. Young children, infants and fetuses are particularly vulnerable to lead poisoning. Since lead is accumulated and stored in the bones, continued exposure will allow

blood lead levels to affect nerve tissue. This can then irreversibly impair a child's mental and physical development, resulting in learning disabilities or stunted growth.

### **Limits**

The current enforceable action levels for copper is 1.3 mg/L (or 1.3 ppm) and for lead is 0.015 mg/L or 15 parts per billion (ppb).

### **Lead and Copper Removal Treatment**

Each public water system must now target high-risk households (based on materials used in the delivery system and other factors) and analyze tap water samples from these households for lead and copper.

### **Lead and Copper Corrosion Control Options**

EPA has identified three acceptable treatment approaches for corrosion control:

1. pH adjustment
2. Addition of calcium
3. Addition of corrosion inhibitors

## APPLIED CHEMISTRY

This section is a brief overview of chemistry with respect to water treatment. Greater detail is provided in appropriate sections.

Aeration is the process of adding air to water either by passing air through water or by passing water through air resulting in degasification. Volatile compounds exist in lower concentrations in air than in water, so they tend to leave the water and move into the air. Examples of aeration in a water system are the:

- Release taste and odor causing substances such as hydrogen sulfide;
- Removes substances that may add to treatment costs such as carbon dioxide;
- Removes radon gas; and
- Remove volatile organic compounds.

Oxidation is the addition of oxygen and/or the removal of hydrogen or the removal of electrons to create a more stable substance. An example would be the oxidization of soluble minerals such as iron and manganese into solids to ease removal by traditional treatment.

Aeration and oxidation can be accomplished by the use of:

- Blowers which compress air into the water;
- Cascades and Sprays which are waterfall devices that pass water through air; and,
- Stripping is a combination of both by flowing water over packing and blowing air through the packing.

Coagulation is the both a chemical and physical process of the clumping together of very fine particles (colloids) into larger particles by the use of chemicals. Colloids are very small, finely divided solids that remain dispersed in a liquid for a long time due to their small size and electrical charge. When most of the particles have a negative charge they tend to repel each other and remain suspended.

### **Factors affecting coagulation:**

1. Alkalinity - can be defined as the capacity of the water to neutralize acids based on the content of carbonate, bicarbonate and hydroxide ions and scaled the by the measure of acid added to a liquid to lower the pH to 4.5. The coagulants react with the alkalinity to form floc. For every 1 ppm of alum added, 0.45 ppm of bicarbonate alkalinity is needed for a complete reaction to occur. So, changes in the alkalinity content affect the chemical reaction of the coagulation process.

Examples of treatment chemicals that **lower** alkalinity are:

- Aluminum Sulfate (Alum)-acidic and corrosive;
- Carbon dioxide-can cause suffocation;
- Chlorine gas- mixes with water or body sweat to form hydrochloric acid;
- Ferric Chloride-can decompose to form hydrochloric acid;
- Ferric Sulfate-acidic when mixed with water; and
- Sulfuric Acid-highly corrosive, burns skin.

Examples of treatment chemicals that **raise** alkalinity are:

- Calcium hypochlorite (HTH)-gives off chlorine gas, attacks eyes and skin, can cause fire;
- Caustic Soda (Sodium hydroxide)- dissolves skin, reacts with metals, generates heat when mixed with water;
- Hydrated Lime (Calcium hydroxide)- can cause injury to eyes;
- Soda Ash (Sodium carbonate)- mildly alkaline, causes dust; and
- Sodium Aluminate (Soda alum)- noncorrosive, dust problems.

2. As water temperature decreases, the density of the water increases resulting in slowing the settling rate solids or particles.

- Reactions are more complete and quicker in warm water
- Coagulant doses may need to be increased in cold water
- Lower temperatures require higher mixing turbulence
- Temperature changes are usually slow to occur and so do not require drastic changes

3. pH is the expression of the intensity of the basic or acidic condition of a liquid. Natural waters usually have a pH between 6.5 and 8.5. The best pH for coagulation is between 5.0 and 7.0.

Examples of treatment chemicals that **lower** pH are:

- Aluminum sulfate (Alum)
- Carbon dioxide
- Chlorine gas
- Ferric chloride
- Hydrofluosilicic acid
- Sulfuric acid

Examples of treatment chemical that **raise** pH are:

- Calcium hypochlorite
- Caustic soda
- Hydrated lime
- Soda ash
- Sodium aluminate
- Sodium hypochlorite

Coagulants are the chemicals that neutralize the electrical charges of fine particles in the water. When using metallic salts, sufficient quantities must be added to the water to exceed the solubility limit of the metal hydroxide creating floc which then adsorbs in the turbidity in the water. The effectiveness of the chemical coagulant used is dependant on the pH, temperature and alkalinity of the water.

Primary coagulants

- Aluminum Sulfate
- Ferrous Sulfate
- Ferric Sulfate
- Ferric Chloride

### Primary coagulants/Aids

- Cationic Polymer (positive charge)
- Calcium Hydroxide
- Calcium Oxide
- Sodium Aluminate

Coagulant Aids- used to add density to floc particles to improve settling

- Bentonite
- Calcium Carbonate
- Sodium Silicate
- Anionic Polymer (negative charge)
- Nonionic Polymer (negative and positive charge)

Polymers are synthetic organics referred to as polyelectrolytes. Polymers are classified according to the charge.

- Cationic polymers have a positive charge and are normally fed with metallic coagulants to reduce the amount of chemical needed and reduction of the sludge produced.
- Anionic polymers have a negative charge.
- Nonionic polymers have no preferred charge.

Over feeds of polymer can coat particles and lead to carryover and clog filters.

All colloids are electrically charged but the charge varies based on the type of material. Colloidal charge may change with a change in external conditions. So, both Aluminum and Ferric flocs may be positive or negative.

Flocculation, sedimentation and filtration are mechanical, physical or natural processes utilized to remove floc or solids from the water. The turbidity of the process effluent is used to indicate the efficiency of the process.

Disinfection is the process designed to kill or inactivate most microorganisms in water, with chlorination being the most common. The factors that effect disinfection are:

- pH - chlorine disinfects much faster at a pH of 7.0 than at a pH of 8.0 or above, because at a level between 5 and 10 hypochlorous acid (free chlorine) and hypochlorite ions form. At a pH of 7.5 approximately 50 % of the chlorine is hypochlorous acid and 50 % is hypochlorite ion. As the pH increases, the hypochlorous acid disassociates into the hydrogen ion and hypochlorite ion.
- Temperature - as the temperature increases the rate of diffusion of the disinfectant through the cell wall increases. The germicidal efficiency increases with temperature as the rate of diffusion increases. At lower temperatures a longer contact time is required to disinfect water.
- Turbidity - excessive turbidity will reduce the efficiency of the disinfecting process. Suspended matter can create a chlorine demand and decrease the effectiveness of the chemical.
- Organic matter - humic acids and bromides in the water can consume great amounts of chlorine and form harmful disinfection byproducts (THMs and HAA5s)

- Reducing Agents - chlorine combines with inorganic agents such as hydrogen sulfide, ferrous iron, manganous ions and nitrite ions and reduces available disinfection chemical.
- Microorganisms - the number and type of microorganisms greatly affect the concentration disinfecting chemical needed. Non-spore forming bacterial are less resistant than spore forming bacteria. Cysts and viruses can be very resistant to certain types of disinfectants

Corrosion is the process where metals are dissolved into surrounding water.

Chemical factors that effect corrosion are:

- Alkalinity - The carbonate and bicarbonate neutralize an acid or base. High concentration of carbonate and bicarbonate in water has a strong tendency to resist a change in pH.
- pH - at levels below 7.0, water tends to be corrosive and at levels above 7.5 water is protective of pipe materials. Very high pH levels have a tendency to deposit excessive amounts of scale
- Dissolved Oxygen - the most corrosive component of water chemistry. Oxygen reacts at both the anode and cathode to accelerate the rate of corrosion. So the higher the concentration of dissolved oxygen present then the greater the tendency for corrosion to occur.
- Dissolved Solids - the higher the dissolved solids content of the water the greater the potential for corrosion due to increased conductivity. A common method to determine TDS is to measure the conductivity of the water.
- Hardness - since hardness is made up of calcium and magnesium ions the most common corrosion control measure is the creation of a calcium carbonate film on the inside of the pipes
- Chloride and Sulfate - these ions keep the hardness ions in solution and inhibit the creation of a protective film. The alkalinity mg/L should be maintained at 5 times the sum of the chloride and sulfate ions mg/L.

Chemical tests used for detection of corrosion:

- Dissolved Oxygen - oxygen must be present for corrosion to occur. If samples are tested at various points in a distribution system you can calculate how much oxygen is used up. Loss could indicate the presence of organic matter or gross corrosion is occurring.
- Marble Test - used to determine the calcium carbonate saturation level.
- Langlier Index - most common index used to indicate how close a water's calcium carbonate content is in equilibrium to the hydrogen ion concentration or alkalinity.

Chemical compounds used for corrosion control:

- Zinc phosphates are capable of forming an effective cathodic film to control corrosion.
- Sodium Polyphosphates reduce corrosion enhancing products by forming positively charged particles of ferric oxide, calcium compounds and metaphosphates. At high pH and low dose they dissolve iron and calcium by a

sequestering mechanism. **Note:** Polyphosphates should be fed before chlorine to effectively sequester iron and manganese due to chlorine's ability to oxidize.

Softening is the reduction of the hardness of the water. Hardness is caused by the presence of metallic the cations of calcium and magnesium in water. Problems associated with the hardness of the water are: scale formation on fixtures; clogging of pipes; increased use of soap/detergent.

#### Methods of Softening

1. Chemical precipitation (Lime-soda) - converts hardness causing ions from soluble to solid form at high pH levels.

- can only reduce hardness to 80 to 90 mg/L
- requires a high degree of control to be efficient
- creates large quantities of sludge
- lime converts alkalinity from bicarbonate to carbonate which causes calcium to precipitate out
- more lime increases the alkalinity to a level where hydroxide becomes present and allows magnesium to precipitate as magnesium hydroxide
- lime use will remove carbonate hardness
- sodium use will remove noncarbonate hardness
- caustic soda will remove both carbonate and noncarbonate hardness
- increased sodium chemical feed can increase sodium levels above the recommended 20 mg/L level
- caustic soda reacts with carbon dioxide and carbonate hardness to create sodium carbonate (soda ash) which will react with the noncarbonate hardness

2. Ion Exchange - Resin is saturated with sodium ions and as hard water passes through the resin hardness ions are exchanged for sodium ions and are left on the resin

- best applied to waters high in noncarbonate hardness and where total hardness does not exceed 350 mg/L
- can reduce hardness to 0 mg/L
- must be backwashed with a sodium solution to remove the calcium and magnesium and recharge with sodium ions.

**Note:** One result of the addition of treatment chemicals that are sodium based is the increase of sodium released into the water. Sodium content should be monitored for this reason.

## THE PERIODIC CHART OF THE ELEMENTS

The Periodic Chart of the Elements is just a way to arrange the elements to show a large amount of information and organization. As you read across the chart from left to right, a line of elements is a Period.

The Periodic Chart is based on the properties of matter. A property is a quality or trait or characteristic. We can describe, identify, separate, and classify by properties. There are two types of property of matter. Physical properties describe the material as it is. Chemical properties describe how a material reacts, with what it reacts, the amount of heat it produces as it reacts, or any other measurable trait that has to do with the combining power of the material.

Physical properties include such things as: color, brittleness, malleability, ductility, electrical conductivity, density, magnetism, hardness, atomic number, specific heat, heat of vaporization, heat of fusion, crystalline configuration, melting temperature, boiling temperature, heat conductivity, vapor pressure, or tendency to dissolve in various liquids. These are only a few of the possible measurable physical properties.

Chemical properties include: whether a material will react with another material, the rate of reaction with that material, the amount of heat produced by the reaction with the material, at what temperature it will react, in what proportion it reacts, and the valence of elements.

For every element there is one and only one upper case letter. There may or may not be a lower case letter with it. When written in chemical equations, we represent the elements by the symbol alone with no charge attached. The seven exceptions to that are the seven elements that are in gaseous form as a diatomic molecule, that is, two atoms of the same element attached to each other. The list of these elements is best memorized. They are: hydrogen, nitrogen, oxygen, fluorine, chlorine, bromine, and iodine. The chemical symbols for these diatomic gases are: H<sub>2</sub>, N<sub>2</sub>, O<sub>2</sub>, F<sub>2</sub>, Cl<sub>2</sub>, Br<sub>2</sub>, and I<sub>2</sub>. Under some conditions oxygen makes a triatomic molecule, ozone, O<sub>3</sub>. Ozone is not stable, so the oxygen atoms rearrange themselves into the more stable diatomic form.

Groups of two or more element symbols attached to each other without any charge on them indicate a compound. CaCO<sub>3</sub>, calcium carbonate, is a compound with one calcium atom, one carbon atom, three oxygen atoms. CuSO<sub>4</sub>·5H<sub>2</sub>O, copper sulfate pentahydrate, is also a compound. It has one copper atom and one sulfate ion consisting of a sulfur atom and four oxygen atoms attached to five molecules of water.

Charged particles, called ions, when written with symbols will have the charge, either positive (+) or negative (-), written to the right and superscripted to the chemical symbol. For instance, F<sup>-</sup> is the symbol for the fluoride ion. Atoms or polyatomic ions with charges of more than one, either positive or negative, have a number with the charge. For instance (CO<sub>3</sub>)<sup>2-</sup> is the symbol for the carbonate ion. The carbonate ion has one carbon atom in it, three oxygen atoms, and a charge of negative two. Observe that the charge is outside the parentheses, indicating that the charge is from the polyatomic ion as a whole.

The noble gases, or inert gases, have the following properties: For the most part, they do not make chemical combinations with any elements. There have been some compounds made with

the noble gases, but only with difficulty. There are certainly no natural compounds with this group. They are all gases at room temperature. They all have very low boiling and melting points. They all put out a color in the visible wavelengths when a low pressure of the gas is put into a tube and a high voltage current is run through the tube. This type of tube is called a neon light whether the tube has neon in it or not. The inert gases are non-metals because they are not metals, but they are significantly different from the other non-metals. As closely akin as all the noble gases are to each other, they should surely be considered a separate group.

By far the largest category of elements on the Periodic Chart is the metal elements. Metals share a set of properties that are not as universal to them as the inert gases. Metal elements usually have the following properties: They have one, two, or three electrons on the outside electron shell. The outside electrons make it more likely that the metal will lose electrons, making positive ions. The ions of metals are usually plus one, plus two, or plus three in charge. Metals tend to lose electrons to become stable. They will attach to other elements with ionic bonds almost exclusively. When metal atoms are together in a group, there is a swarm of semi-loose electrons around the atoms. These electrons move about freely among the metal atoms making what is called an electron gas. The electron gas accounts for the shininess of metals. When there is a smooth surface on the metal it will reflect electromagnetic waves (to include visible light) in an organized manner. The shininess is also called metallic luster. The same electron gas accounts for the cohesive tendencies of metals. Cohesive means the material clings to itself. This property can be easily seen with mercury. Mercury atoms cling to other mercury atoms or other metal atoms with an incredible tenacity. This same cohesion of metals occurs in the solid state. Silver is very malleable. That means that if you hit it, the material would more likely change shape than shatter. At one time US half dollar coins were made of ninety percent silver. It is illegal to deface money, but school children would take a spoon and beat the sides of the silver half dollars until the edges curled inward. When the center became the right size, it was taken out to make a silver ring beaten to fit your finger. Wire is made by pulling metals through a die. The metal coheres to itself so much that it will reshape itself to the shape of the die as it passes through the hole in the die. This property of being able to be pulled through a die to make wire is called ductility. The presence of the electron gas makes metals good conductors of electricity. Again due to the cohesive property, metals have high melting and boiling points. Almost all metals are solids at room temperature. Metals are usually good conductors of heat. Active metals react with acids. Some very active metals will react with water. Metal elements tend to be denser than non-metals.

Non-metals have the following properties: Non-metals usually have four, five, six, or seven electrons in the outer shell. When they join with other elements non-metals can either share electrons in a covalent bond or gain electrons to become a negative ion and make an ionic bond. When non-metal elements join by covalent bonds, it is usually to other non-metals. Non-metals can attach together with covalent bonds to make a group of (usually non-metal) elements with a common charge called a radical or polyatomic ion. Elemental non-metals often have a dull appearance. They are more likely to be brittle, or shatter when struck. Although not a constant rule, non-metals tend to have lower melting and boiling points than metals and the solids tend to be less dense. Non-metals are not as cohesive as metals and certainly not ductile. Non-metals are not usually good conductors of heat or electricity. Many non-metals form diatomic or polyatomic molecules with other atoms of the same element.

We have pretended that there is a sharp dividing line between the metals and non-metals. This is not the case. The staircase-shaped line between metals and non-metals has several elements on or near it that have properties somewhere between the two categories. By having three electrons in

the outside shell, boron should be a metal element. It is not. Boron is more likely to form covalent bonds like a non-metal than donate electrons like aluminum, the next element down the chart in the same group. Aluminum is definitely a metal in most of its traits, but it has its own idiosyncrasy. Aluminum is amphoteric; it reacts with both acids and bases. Silicon, germanium, arsenic, antimony, and tellurium are on the line between metals and non-metals and exhibit some of the qualities of both. These elements do not really comprise a clear-cut category, but, due to the mix of properties they show, they are often lumped into a classification called semi-metals. Many of the elements on the line are semiconductors of electricity, meaning that they have the ability to conduct electricity somewhere between almost none and full conduction. This property is useful in the electronics industry.

We have failed to include hydrogen in any of the categories, for good reasons. Hydrogen just does not match anything else. The positive hydrogen ion is what is responsible for acids. There really is no such thing as a (positive) hydrogen ion. Having only a proton and an electron, hydrogen becomes only a proton if it loses its electron. Loose protons attach themselves to a water molecule to make  $\text{H}_3\text{O}^+$  ion, a hydronium ion. This hydronium is the real chemical that produces the properties of acids. Elemental hydrogen is a diatomic gas. Except for having a valence of +1, hydrogen has few other similarities with the Group 1 elements. Hydrogen makes covalent bonds between other hydrogen atoms or other non-metals.

This section is not intended as an exhaustive study of the groups of the Periodic Chart, but a quick-and-dirty overview of the groups as a way to see the organization of the chart.

Group I (1) elements are also called the alkali metal elements. They are all very soft metals that are not found free in nature because they react with water. In the element form they must be stored under kerosene to keep them from reacting with the humidity in the air. They all have a valence of plus one because they have one and only one electron in the outside shell. All of the alkali metals show a distinctive color when their compounds are put into a flame.

Group II (2) elements all have two electrons in the outside ring, and so have a valence of two. Also called the alkaline earth metals, Group 2 elements in the free form are slightly soft metals. Magnesium and calcium are common in the earth's crust.

Group III (3) elements are a mixed group. Boron has mostly non-metal properties. The rest of the group are metals. Aluminum is the only one common in the earth's crust. Group 3 elements have three electrons in the outer shell.

Group IV (4) elements are not a coherent group either. Carbon and silicon bond almost exclusively with four covalent bonds. They both are common in the earth's crust. Germanium is a rare semi-metal. Tin and lead are definitely metals, even though they have four electrons in the outside shell.

Group V (5) is also split between metals and non-metals. Nitrogen and phosphorus are very definitely non-metals. Both are common in the earth's crust. All of the Group 5 elements have five electrons in the outer shell. For the smaller elements it is easier to complete the shell to become stable, so they are non-metals. The larger elements in the group, antimony and bismuth, tend to be metals because it is easier for them to donate the five electrons than to attract three more. Arsenic, antimony and bismuth have valences of +3 or +5. Arsenic is very much a semi-

metal, but all three of them show some semi-metal weirdness, such as brittleness as a free element.

Group VI (6 or 16) elements have six electrons in the outside shell. Tellurium is the only element in Group 6 that is a semi-metal. Oxygen, sulfur, and selenium are true non-metals. They have a valence of negative two as an ion, but they also bond covalently. Oxygen gas makes covalent double-bonded diatomic molecules. Oxygen and sulfur are common elements.

On some charts you will see hydrogen above fluorine in Group VII (7 or 17). Hydrogen does not belong there any more than it belongs above Group 1. Fluorine, chlorine, bromine, and iodine make up Group 7, the halogens. Halogens have a valence of negative one when they make ions because they have seven electrons in the outer shell. They are all diatomic gases as free elements near room temperature. They are choking poisonous gases. Fluorine and chlorine are yellow-green, bromine is reddish, and iodine is purple as a gas. All can be found attached to organic molecules. Chlorine is common in the earth's crust. Fluorine is the most active of them, and the activity decreases as the size of the halogen increases.

The inert gases or noble gases all have a complete outside shell of electrons. Helium is the only one that has only an 's' subshell filled, having only two electrons in the outer and only shell. All the others, neon, argon, krypton, xenon, and radon, have eight electrons in the outer shell. Since the electron configuration is most stable in this shape, the inert gases do not form natural compounds with other elements.

Transition elements are all metals. Very few of the transition elements have any non-metal properties. Within the transition elements many charts subdivide the elements into groups, but other than three horizontal groups, it is difficult to make meaningful distinctions among them. The horizontal groups are: iron, cobalt, and nickel; ruthenium, rhodium, and palladium; and osmium, iridium, and platinum.

Lanthanides, elements 57 through 70, are also called the rare earth elements. They are all metal elements very similar to each other, but may be divided into a cerium and a yttrium group. They are often found in the same ores with other elements of the group. None are found in any great quantity in the earth's crust. Of the Actinides, elements 89 through 102, only the first three are naturally occurring, the rest being manufactured elements. Of the three naturally occurring ones, only uranium is likely to be referred to in any way in a basic chemistry course. Elements 103 through 109 have been manufactured, and they have been named by the IUPAC (International Union of Pure and Applied Chemistry), but they are not of much importance to this course.

## COMMON NAMES & SYMBOLS FOR WATER TREATMENT CHEMICALS

<u>Chemical Name</u>	<u>Common Name</u>	<u>Chemical Formula</u>
Aluminum hydroxide	Alum floc	Al(OH) <sub>3</sub>
Aluminum sulfate	Filter alum	Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> •14H <sub>2</sub> O
Ammonia		NH <sub>3</sub>
Calcium bicarbonate		Ca(HCO <sub>3</sub> ) <sub>2</sub>
Calcium carbonate	Limestone	CaCO <sub>3</sub>
Calcium hydroxide	Hydrated lime/slaked lime	Ca(OH) <sub>2</sub>
Calcium hypochlorite	HTH	Ca(OCl) <sub>2</sub>
Calcium oxide	Quick lime/unslaked lime	CaO
Calcium sulfate		CaSO <sub>4</sub>
Carbon Activated	Carbon	C
Carbonic acid		H <sub>2</sub> CO <sub>3</sub>
Chlorine		Cl <sub>2</sub>
Chlorine dioxide		ClO <sub>2</sub>
Copper sulfate	Blue vitriol	CuSO <sub>4</sub> •5H <sub>2</sub> O
Dichloramine		NHCl <sub>2</sub>
Ferric chloride		FeCl <sub>3</sub> •6H <sub>2</sub> O
Ferric hydroxide		Fe(OH) <sub>3</sub>
Ferric sulfate		Fe(SO <sub>4</sub> ) <sub>3</sub> •3H <sub>2</sub> O
Fluosilicic acid	Hydrofluosilicic acid	H <sub>2</sub> SiF <sub>6</sub>
Hydrochloric acid	Muratic acid	HCl
Hypochlorous acid		HOCl
Manganese dioxide		MnO <sub>2</sub>
Monochloramine		NH <sub>2</sub> Cl
Potassium permanganate		KMnO <sub>4</sub>
Sodium bicarbonate	Baking soda	NaHCO <sub>3</sub>
Sodium carbonate	Soda ash	Na <sub>2</sub> CO <sub>3</sub>
Nitrogen trichloride		NCl <sub>3</sub>
Sodium fluoride		NaF
Sodium fluosilicate	Sodium silicofluoride	Na <sub>2</sub> SiF <sub>6</sub>
Sodium hydroxide	Caustic soda/Lye	NaOH
Sodium hypochlorite	Bleach	NaOCl
Sodium phosphate		Na <sub>3</sub> PO <sub>4</sub> •12H <sub>2</sub> O
Sodium silicofluoride	Sodium fluosilicate	Na <sub>2</sub> SiF <sub>6</sub>
Sulfuric acid	Oil of vitriol	H <sub>2</sub> SO <sub>4</sub>
Trichloramine	Nitrogen trichloride	NCl <sub>3</sub>

## **WATER TREATMENT**

The primary purpose of water treatment is to produce water that is safe to drink. Unfortunately, unless the water is also pleasant to drink, it may be rejected by the consumer in favor of an alternate supply that may not be safe. Consequently, water delivered to the consumer from a public water supply should meet certain basic requirements, such as:

- It should contain no disease-causing organisms;
- It should contain no toxic metals or chemicals;
- It should be colorless and clear ;
- It must taste good and be free from offensive odor;
- It should be non-corrosive;
- It must be free from objectionable gases, such as hydrogen sulfide;
- It should be free from objectionable staining minerals, such as iron and manganese; and,
- It should be plentiful and low in cost.

The type of treatment selected depends upon the contaminants that need to be inactivated or removed from the water. Contaminants, and other objectionable characteristics of water, which are of concern include the following categories:

- Turbidity and Particulate Matter;
- Microorganisms;
- Iron and Manganese;
- Color, Taste and Odor, and Other Organics;
- Objectionable Gases;
- Hardness;
- Nitrate;
- Corrosive Properties; and,
- Biological Nuisances (Algae, Iron Bacteria, etc.).

Some treatment methods may be applied to more than one category. There are many books and manuals that discuss the water treatment methods that are common to larger systems.

Operators interested in more detailed information should refer to the reference materials listed at the end of this manual.

## **PRETREATMENT**

The pretreatment processes aim to improve the quality of the raw water prior to the main treatment process. Many of them seek to reduce the natural variations or extremes in water quality. A typical case is turbidity (measured as NTU), used to indicate how much suspended material is present in the water. During heavy rainfall and its run-off, rivers may reach levels of several hundred NTUs during such events, tending to overwhelm the filtration processes by the sheer volume of the solids to be removed.

Pretreatment processes may reduce the level of these solids by factors of ten or more, allowing a treatment plant to continue functioning rather than shutting down or damaging any treatment components.

### **Oxidation Processes**

Aeration is the most common process for removing dissolved gases. Aeration is also used to help in precipitating dissolved iron and manganese. Sometimes the direct addition of an oxidizing chemical may be needed to help precipitate the metals. The following oxidizing chemicals are in common use:

- Chlorine, in any form, will oxidize ferrous iron to ferric iron, making it insoluble so that it precipitates out.
- Potassium permanganate is very effective at destroying some organic substances and oxidizing manganese. Again, the manganese is rendered insoluble and precipitates out.
- Ozone, usually used to oxidize taste and odor compounds because many of these compounds are very resistant to oxidation, but also used to oxidize iron and manganese.

### **Presedimentation**

Presedimentation is used to remove gravel, sand, and other large or gritty or floating material from the raw water, and to dampen particle loading to the rest of the treatment plant. Presedimentation is similar to conventional sedimentation, except that presedimentation may be operated at higher loading rates and may not involve use of chemical coagulants. Also, some water supplies operate the presedimentation process periodically and only in response to periods of high particle loading. Sometimes a presedimentation basin is no more than a pond that has been dug out between the intake and the water treatment plant.

## **IRON AND MANGANESE CONTROL**

Iron and manganese are common in groundwater supplies used by many small water systems. Exceeding the suggested maximum contaminant levels (MCL) usually results in discolored water, laundry, and plumbing fixtures. This, in turn, results in consumer complaints and a general dissatisfaction with the water utility. Surface water generally does not contain large amounts of iron or manganese, but iron and manganese are found frequently in water systems that use groundwater.

There are secondary standards set for iron and manganese, but these are not health related and are not enforceable. The secondary (aesthetic) MCLs for iron and manganese are 0.3 milligrams per liter (mg/l) and 0.05 mg/l, respectively. If water contains more than 0.05 ppm iron, or 0.01 ppm manganese, the operator should implement an effective hydrant-flushing program in order to avoid customer complaints.

Small water plants may choose to either sequestrate or remove iron and manganese. Sequestration only works for combined iron and manganese concentrations up to 1.0 mg/L and only in cases where the treatment is not permanent. Removal is usually achieved through ion exchange or oxidation/filtration. There are a number of chemical oxidants and filtration media available that can be used in various combinations.

### **Problems Associated with Iron and Manganese**

Small amounts of iron are often found in water because of the large amount of iron present in the soil and because corrosive water will pick up iron from pipes. Clothing washed in water containing excessive iron may become stained a brownish color. The taste of beverages, such as tea and coffee, may also be affected by iron. Manganese produces a brownish color in laundered clothing, leaves black particles on fixtures, and—as with iron—affects the taste of beverages, including coffee and tea.

Groundwater from the faucet or tap is usually clear and colorless. However, when water containing colorless, dissolved iron is allowed to stand in a cooking container or comes in contact with a sink or bathtub, the iron combines with oxygen from the air to form reddish-brown particles (commonly called rust). Manganese forms brownish-black particles. These impurities can give a metallic taste to water or to food.

The rusty or brown stains on plumbing fixtures, fabrics, dishes, and utensils cannot be removed by soaps or detergents. Bleaches and alkaline builders (often sodium phosphate) can make the stains worse. Over time, iron deposits can build up in pressure tanks, water heaters, and pipelines, reducing the quantity and pressure of the water supply.

Iron and/or manganese in water creates problems common to many water supply systems. When both are present beyond recommended levels, special attention should be paid to the problem. How iron and manganese are removed depends on the type and concentration and this helps determine the best procedure and (possible) equipment to use.

### **Bacteria and Iron and Manganese**

Iron and manganese in water also promote the growth of bacteria (including iron bacteria). These organisms obtain energy for growth from the chemical reaction that occurs when iron and manganese mix with dissolved oxygen. These bacteria form thick slime growths on the walls of the piping

system and on well screens. These slimes tend to be rust-colored from iron and black-colored from manganese. Variations in flow can cause these slime growths to separate from pipe walls, resulting in dirty water in the system.

The growth of iron bacteria can be controlled by chlorination. However, when water containing iron is chlorinated, the iron is converted from the ferrous state to the ferric state--in other words, rust--and manganese is converted into black manganese dioxide. These materials form a coating on the inside of the water main and, when they break loose, a customer will sometimes complain of "dirty" water.

Iron bacteria will use even small amounts of iron present in the ferrous state, oxidize it, and then use the energy. Manganese is also used by other bacteria to form organics, which contribute to the iron bacteria slime in the well and/or water system. Iron bacteria are found anywhere a food source of iron is available. The presence of one bacterium is all that is needed to start an infestation in a well or a distribution system.

### **Iron and Manganese Removal**

The majority of iron and manganese treatment systems employ the processes of oxidation/filtration. The oxidant chemically oxidizes the iron or manganese (forming a particle), and kills iron bacteria and any other disease-causing bacteria that may be present. The filter then removes the iron or manganese particles.

Oxidation followed by filtration is a relatively simple process. The source water must be monitored to determine proper oxidant dosage, and the treated water should be monitored to determine if the oxidation process was successful.

### **Aeration**

Iron is easily oxidized by atmospheric oxygen. Aeration provides the dissolved oxygen needed to convert the iron and manganese from ferrous and manganous (soluble) forms to insoluble oxidized ferric and manganic forms. It takes 0.14 ppm of dissolved oxygen to oxidize 1 ppm of iron, and 0.27 ppm of dissolved oxygen to oxidize 1 ppm of manganese.

Aeration requires careful control of the water flow through the process. If water flow is too great, not enough air is applied to oxidize the iron and manganese. If water flow is too small, the water can become saturated with dissolved oxygen and, consequently, become corrosive to the distribution system. Corrosive water may lead to increased lead and copper levels at customers' taps.

During aeration, slime growths may develop on the aeration equipment, and if these growths are not controlled, they can produce taste and odor problems in the water. The growth of slime can be controlled by adding chlorine at the head of the treatment plant. The process should be inspected regularly to catch problems early.

A detention basin can be provided after aeration to allow complete oxidation. These basins should be cleaned regularly to avoid sludge accumulation. Detention time can also be provided with head on the filters rather than requiring a separate tank. Detention time before filtration should be at least 20 minutes, more if possible. The pH of the water influences how much time is needed for the reaction to be completed. After oxidation of the iron and manganese, the water must be filtered to remove the precipitated iron and manganese.

Oxidation of iron and manganese with air is by far the most cost-effective method since there is no chemical cost; however, there are disadvantages. The oxidation process can be slowed and the reaction tank has to be quite large (if there are high levels of manganese). In addition, small changes

in water quality may affect the pH of the water and the oxidation rate may slow to a point where the plant capacity for iron and manganese removal is reduced.

### **Oxidation**

Before iron and manganese can be filtered, they need to be oxidized to a state in which they can form insoluble complexes. Oxidation involves the transfer of electrons from the iron, manganese, or other chemicals being treated to the oxidizing agent. Ferrous iron ( $\text{Fe}^{2+}$ ) is oxidized to ferric iron ( $\text{Fe}^{3+}$ ), which readily forms the insoluble iron hydroxide complex  $\text{Fe}(\text{OH})_3$ . Reduced manganese ( $\text{Mn}^{2+}$ ) is oxidized to ( $\text{Mn}^{4+}$ ), which forms insoluble ( $\text{MnO}_2$ ). The most common chemical oxidants in water treatment are chlorine, chlorine dioxide, potassium permanganate, and ozone. Oxidation using chlorine or potassium permanganate is frequently applied in small groundwater systems. The dosing is relatively easy, requires simple equipment, and is fairly inexpensive.

Chlorination is widely used for oxidation of divalent iron and manganese. However, the formation of trihalomethanes (THMs) in highly colored waters may be a problem. Chlorine feed rates and contact time requirements can be determined by simple jar tests. As an oxidant, potassium permanganate ( $\text{KMnO}_4$ ) is normally more expensive than chlorine and ozone, but for iron and manganese removal, it has been reported to be as efficient and it requires considerably less equipment and capital investment. The dose of potassium permanganate, however, must be carefully controlled. Too little permanganate will not oxidize all the iron and manganese, and too much will allow permanganate to enter the distribution system and cause a pink color. In the instance of a potassium permanganate overfeed, PAC may be used to neutralize the problem. Permanganate can also form precipitates that cause mudball formations on filters. These are difficult to remove and compromise filter performance.

Ozone ( $\text{O}_3$ ) may be used for iron and manganese oxidation. Ozone may not be effective for oxidation in the presence of humic or fulvic materials. If not dosed carefully, ozone can oxidize reduced manganese to permanganate and result in pink water formation as well. Manganese dioxide particles, also formed by oxidation of reduced manganese, must be carefully coagulated to ensure their removal.

A low-cost method of providing oxidation is to use the oxygen in air as the oxidizing agent in a tray aerator. Water is simply passed down a series of porous trays to provide contact between air and water. No chemical dosing is required, which allows for unattended operation. This method is not effective for water in which the iron is complexed with humic materials or other large organic molecules. Oxygen is not a strong enough oxidizing agent to break the strong complexes formed between iron and manganese and large organic molecules. Furthermore, the rate of reaction between oxygen and manganese is very slow below pH values of 9.5.

The presence of other oxidizable species in water hinders oxidation of the desired reduced compounds. Volatile organic chemicals, other organic compounds, or taste- and odor-causing compounds may result in an oxidant demand. This additional oxidant demand must be accounted for when dosing the oxidant. The expense of operation derives from the chemical use in most cases, and therefore is directly related to the source water quality.

### **Sequestering**

Soluble iron and manganese can be stabilized, or sequestered, instead of removed. Sequestering keeps the iron and manganese in solution. This effectively eliminates the problem of staining

because it is the insoluble precipitate that causes the staining. The process also delays the precipitation of oxidized iron and manganese, thereby greatly reducing the layer of scale that forms on the pipe. Red water can sometimes be prevented in this way.

Phosphate compounds are a family of chemicals that can surround minerals and keep them in solution. Pyrophosphate, tripolyphosphate, and metaphosphate may all be effective as iron and manganese sequestering agents. The most effective one, however, seems to be sodium phosphate in low concentrations. The proper dose and type of phosphate should be selected only after a qualified technician or consultant performs bench-scale testing.

Phosphate sequestering is effective where the water contains up to 0.3 mg/L of iron and less than 0.1 mg/L of manganese. The phosphate compounds must be added to the water at a point where the iron is still dissolved in order to maintain water clarity and prevent possible iron staining. This should be before your point of chlorination or as close to the well discharge point as possible.

Phosphate compound treatment is a relatively cheap way to treat water for low levels of iron and manganese. Since phosphate compounds do not actually remove iron, water treated with these chemicals will retain a metallic taste. In addition, too great a concentration of phosphate compounds will make water feel slippery.

If the total detention time in the distribution system exceeds 4 days, the phosphates may break down and release the iron and manganese in the outer portions of the system. If the detention is exceeded, the iron or manganese problem may not be resolved with phosphate.

### **Greensand Filtration**

Oxidation/filtration can be used as a special case of pressurized granular-media filtration where the granular media catalyzes the oxidation and precipitation of iron and manganese. Manganese-oxide (MnOx) media, which include manganese greensand and pyrolucite, are commonly used in oxidation/filtration processes because of their unique adsorptive and catalytic capabilities. Greensand is manufactured by coating glauconite with manganese dioxide, while pyrolucite is a naturally mined ore composed of solid manganese dioxide. Greensand media has been shown to be capable of removing up to 80% of arsenic by oxidation/adsorption.

In oxidation/filtration processes, water is passed through a column of MnOx media which adsorbs and catalyzes the oxidation of the iron and manganese. The filtering capacity of the granular MnOx media then retains the precipitated iron, manganese, and arsenic until it is backwashed out of the column. Backwashing creates waste water and sludge, which the water system must properly dispose. Arsenic appears to be removed primarily by the iron precipitates as opposed to those of manganese. Water systems with low levels of influent iron (less than 1.5 mg/L or less than 20:1 ratio with arsenic) may want to consider adding ferric chloride prior to oxidation. It is generally recommended that green sand be preceded by a 12 inch anthracite cap to filter any precipitated iron particulates before the green sand.

In order for greensand to retain its adsorption and catalytic oxidation capabilities for iron and manganese removal, the media must be regenerated with permanganate or chlorine. Typically these oxidants are added ahead of the filter where they provided continuous oxidation of the contaminants as well as regeneration of the MnOx media. Arsenic adsorbs to the iron floc formed in this chemical oxidation step and is physically filtered.

## COAGULATION & FLOCCULATION

All waters, especially surface waters, contain both dissolved and suspended particles. Coagulation and flocculation processes are used to separate the suspended solids portion from the water.

The suspended particles vary considerably in source, composition charge, particle size, shape, and density. Correct application of coagulation and flocculation processes and selection of the coagulants depend upon understanding the interaction between these factors. The small particles are stabilized (kept in suspension) by the action of physical forces on the particles themselves. One of the forces playing a dominant role in stabilization results from the surface charge present on the particles. Most solids suspended in water possess a negative charge and, since they have the same type of surface charge, repel each other when they come close together. Therefore, they will remain in suspension rather than clump together and settle out of the water.

Coagulation and flocculation occur in successive steps intended to overcome the forces stabilizing the suspended particles, allowing particle collision and growth of floc. If step one is incomplete, the following step will be unsuccessful.

### **Coagulation**

The first step destabilizes the particle's charges. Coagulants with charges opposite those of the suspended solids are added to the water to neutralize the negative charges on dispersed non-settleable solids such as clay and color-producing organic substances.

Once the charge is neutralized, the small suspended particles are capable of sticking together. The slightly larger particles, formed through this process and called microflocs, are not visible to the naked eye. The water surrounding the newly formed microflocs should be clear. If it is not, all the particles' charges have not been neutralized, and coagulation has not been carried to completion. More coagulant may need to be added.

A high-energy, rapid-mix to properly disperse the coagulant and promote particle collisions is needed to achieve good coagulation. Over-mixing does not affect coagulation, but insufficient mixing will leave this step incomplete. Coagulants should be added where sufficient mixing will occur. Proper contact time in the rapid-mix chamber is typically 1 to 3 minutes.

### **Flocculation**

Following the first step of coagulation, a second process called flocculation occurs. Flocculation, a gentle mixing stage, increases the particle size from submicroscopic microfloc to visible suspended particles.

The microflocs are brought into contact with each other through the process of slow mixing. Collisions of the microfloc particles cause them to bond to produce larger, visible flocs called pinflocs. The floc size continues to build through additional collisions and interaction with inorganic polymers formed by the coagulant or with organic polymers added. Macroflocs are formed. High molecular weight polymers, called coagulant aids, may be added during this step to help bridge, bind, and strengthen the floc, add weight, and increase settling rate. Once the floc has reached its optimum size and strength, the water is ready for the sedimentation process.

Design contact times for flocculation range from 15 or 20 minutes to an hour or more.

## **Operational Considerations**

Flocculation requires careful attention to the mixing velocity and amount of mix energy. To prevent the floc from tearing apart or shearing, the mixing velocity and energy input are usually tapered off as the size of the floc increases. Once flocs are torn apart, it is difficult to get them to reform to their optimum size and strength. The amount of operator control available in flocculation is highly dependent upon the type and design of the equipment.

## **Conventional Plants**

Conventional plant designs separate the coagulation, or rapid-mix, stage from the flocculation, or slow-mix, stage. Normally this is followed by a sedimentation stage, after which filtration takes place. Plants designed for direct filtration route the water directly from flocculation to filtration. These systems typically have a higher raw-water quality. Conventional designs can incorporate adjustable mixing speeds in both the rapid-mix and slow-mix equipment. Multiple feed points for coagulants, polymers, flocculants, and other chemicals can be provided. There is generally adequate space to separate the feed points for incompatible chemicals.

Conventional plant designs have conservative retention times and rise rates. This usually results in requirements for large process basins and a large amount of land for the plant site. On-site pilot plant evaluation of the proposed process, by a qualified engineer familiar with the source of the water, is advisable prior to selection and construction of the units.

Retention or detention time is the theoretical time in minutes that water spends in a process. It is calculated by dividing the liquid volume, in gallons, of a basin by the plant flow rate in gallons per minute. Actual detention time in a basin will be less than the theoretical detention time because of “dead areas” and short circuiting, which could be due to inadequate baffling.

$$\text{Retention time} = \frac{\text{basin volume (gallons)}}{\text{flow (gpm)}}$$

The rise rate is calculated by dividing the flow in gallons per minute by the net upflow area of the basin in square feet.

$$\text{Rise Rate} = \frac{\text{flow (gpm)}}{\text{area (ft}^2\text{)}}$$

Sedimentation basins are used in conventional plants. Direct-filtration plants skip the sedimentation stage and go directly to filtration. Detention times for sedimentation are in the range of 1 to 4 hours. Inlets are designed to distribute water evenly and at uniform velocities. Overflow rates should not exceed 20,000 gallons per day per foot of weir length. Velocity should not exceed 0.5 feet per minute.

Sedimentation basins are used to settle out the floc before going to the filters. Some type of sludge collection device should be used to remove sludge from the bottom of the basin.

## **Combination Units**

Some designs incorporate coagulation, flocculation, and sedimentation within a single unit. These designs can be separated into upflow solids contact units and sludge blanket units. Most solids contact designs use recirculation of previously formed flocs to enhance floc formation and maximize usage of treatment chemicals. Sludge bed designs force the newly forming flocs to

pass upward through a suspended bed of floc. In both styles of units, the cross-sectional surface of the basin increases from the bottom to top, causing the water flow to slow as it rises, and allowing the floc to settle out. The combination units generally use higher rise rates and shorter detention time than conventional treatment. Numerous manufacturers market proprietary units based on these design concepts. These units are more compact and require less land for plant site location. On-site pilot plant evaluation of the proposed process, by a qualified engineer familiar with the source water, is advisable prior to selection and construction of combined units.

### **Coagulant Selection**

The choice of coagulant chemical depends upon the nature of the suspended solid to be removed, the raw water conditions, the facility design, and the cost of the amount of chemical necessary to produce the desired result.

Final selection of the coagulant (or coagulants) should be made following thorough jar testing and plant scale evaluation. Considerations must be given to required effluent quality, effect upon down stream treatment process performance, cost, method and cost of sludge handling and disposal, and net overall cost at the dose required for effective treatment.

Coagulant chemicals come in two main types - primary coagulants and coagulant aids. Primary coagulants neutralize the electrical charges of particles in the water which causes the particles to clump together. Primary coagulants are always used in the coagulation/flocculation process. Coagulant aids add density to slow-settling flocs and add toughness to the flocs so that they will not break up during the mixing and settling processes. Coagulant aids, in contrast, are not always required and are generally used to reduce flocculation time.

### **Inorganic Coagulants**

Inorganic coagulants such as aluminum and iron salts are the most commonly used. When added to the water, they furnish highly charged ions to neutralize the suspended particles. The inorganic hydroxides formed produce short polymer chains which enhance microfloc formation.

Inorganic coagulants usually offer the lowest price per pound, are widely available, and, when properly applied, are quite effective in removing most suspended solids. They are also capable of removing a portion of the organic precursors which may combine with chlorine to form disinfection by-products. They produce large volumes of floc which can entrap bacteria as they settle. However, they may alter the pH of the water since they consume alkalinity. When applied in a lime soda ash softening process, alum and iron salts generate demand for lime and soda ash. They require corrosion-resistant storage and feed equipment. The large volumes of settled floc must be disposed of in an environmentally acceptable manner.

Common coagulant chemicals used are alum (aluminum sulfate), ferric sulfate, ferric chloride, ferrous sulfate, sodium aluminate, polyaluminum chloride, and polymers. The first four will lower the alkalinity and pH of the solution while the sodium aluminate will add alkalinity and raise the pH.

### **Polymers**

Polymers--long-chained, high-molecular-weight, organic chemicals--are becoming more widely used, especially as coagulant aids together with the regular inorganic coagulants. Anionic (negatively charged) polymers are often used with metal coagulants. Low-to-medium weight, positively charged (cationic) polymers may be used alone or in combination with the aluminum

and iron type coagulants to attract the suspended solids and neutralize their surface charge. The manufacturer can produce a wide range of products that meet a variety of source-water conditions by controlling the amount and type of charge and relative molecular weight of the polymer.

Polymers are effective over a wider pH range than inorganic coagulants. They can be applied at lower doses, and they do not consume alkalinity. They produce smaller volumes of more concentrated, rapidly settling floc. The floc formed from use of a properly selected polymer will be more resistant to shear, resulting in less carryover and a cleaner effluent.

Polymers are generally several times more expensive in their price per pound than inorganic coagulants. Selection of the proper polymer for the application requires considerable jar testing under simulated plant conditions, followed by pilot or plant-scale trials. All polymers must be approved for potable water use by regulatory agencies.

## COAGULANTS, POLYELECTROLYTES & COAGULANT AIDS

Numerous chemicals are used in coagulation and flocculation processes. There are advantages and disadvantages associated with each chemical. The designer should consider the following factors in selecting these chemicals:

- Effectiveness;
- Cost;
- Reliability of supply;
- Sludge consideration;
- Compatibility with other treatment processes;
- Environmental effects; and,
- Labor and equipment requirements for storage, feeding, and handling.

Coagulants and coagulant aids commonly used are generally classified as inorganic coagulants and polyelectrolytes. Polyelectrolytes are further classified as either synthetic-organic polymers or natural-organic polymers.

### **Inorganic Coagulants**

The three main classifications of inorganic coagulants are:

- Aluminum derivatives ;
- Iron derivatives; and,
- Lime.

With exception of sodium aluminate, all common iron and aluminum coagulants are acid salts and, therefore, their addition lowers the pH of the treated water. Depending on the influent's pH and alkalinity (presence of  $\text{HCO}_3^-$ ,  $\text{CO}_3^{2-}$ , and  $\text{OH}^-$ ), an alkali, such as lime or caustic, may be required to counteract the pH depression of the coagulant. This is important because pH affects both particle surface charge and floc precipitation during coagulation. The optimum pH levels for forming aluminum and iron hydroxide flocs are those that minimize the hydroxide solubility. However, the optimum pH for coagulating suspended solids does not always coincide with the optimum pH for minimum hydroxide floc solubility. A list of several common inorganic coagulants along with associated advantages and disadvantages is listed in the table below.

**Advantages and Disadvantages of Alternative Inorganic Coagulants**

<b>Name</b>	<b>Advantages</b>	<b>Disadvantages</b>
Aluminum Sulfate (Alum) $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$	Easy to handle and apply; most commonly used; produces less sludge than lime; most effective between pH 6.5 and 7.5	Adds dissolved solids (salts) to water; effective over a limited pH range
Sodium Aluminate $\text{Na}_2\text{Al}_2\text{O}_4$	Effective in hard waters; small dosages usually needed	Often used with alum; high cost; ineffective in soft waters
Polyaluminum Chloride (PAC) $\text{Al}_{13}(\text{OH})_{20}(\text{SO}_4)_2 \cdot \text{Cl}_{15}$	In some applications, floc formed is more dense and faster settling than alum	Not commonly used; little full scale data compared to other aluminum derivatives
Ferric Sulfate $\text{Fe}_2(\text{SO}_4)_3$	Effective between pH 4–6 and 8.8–9.2	Adds dissolved solids (salts) to water; usually need to add alkalinity

Ferric Chloride FeCl <sub>3</sub> ·6H <sub>2</sub> O	Effective between pH 4 and 11	Adds dissolved solids (salts) to water; consumes twice as much alkalinity as alum
Ferrous Sulfate (Copperas) FeSO <sub>4</sub> ·7H <sub>2</sub> O	Not as pH sensitive as lime	Adds dissolved solids (salts) to water; usually need to add alkalinity
Lime Ca(OH) <sub>2</sub>	Commonly used; very effective; may not add salts to effluent	Very pH dependent; produces large quantities of sludge; overdose can result in poor effluent quality

### Aluminum Derivatives

Common aluminum coagulants include aluminum sulfate (alum), sodium aluminate, and polyaluminum chloride. Dry alum is available in several grades, with a minimum aluminum content (expressed as %Al<sub>2</sub>O<sub>3</sub>) of 17%. Liquid alum is about 49% solution, or approximately 8.3% by weight aluminum as Al<sub>2</sub>O<sub>3</sub>. Alum coagulation works best for a pH range of 5.5 to 8.0; however, actual removal efficiency depends on competing ions and chelating agent concentrations.

Sodium aluminate is an alternative to alum and is available in either dry or liquid forms, containing an excess of base. Sodium aluminate provides a strong alkaline source of water-soluble aluminum, which is useful when adding sulfate ions is undesirable. It is sometimes used in conjunction with alum for controlling pH.

Polyaluminum chloride (PACl), another aluminum derivative, is a partially hydrolyzed aluminum chloride solution. Although still not widely used, it has been reported to provide stronger, faster settling flocs than alum in some applications.

### Iron Derivatives

Iron coagulants include ferric sulfate, ferric chloride, and ferrous sulfate (copperas). Compared to aluminum derivatives, iron coagulants can be used successfully over a much broader pH range of 5.0 to 11.0. However, when ferrous compounds are used, the solution is typically chlorinated before it is sent into the coagulation vessel. As this reaction produces both ferric chloride and ferric sulfate, chlorinated ferrous sulfate has the same field of usefulness as the other iron coagulants. Because ferrous sulfate works better in feeding devices, compared with the ferric coagulants, chlorinated copperas is sometimes preferred. The ferric hydroxide floc is heavier than alum floc and therefore settles more rapidly.

Although lime is primarily used for pH control or chemical precipitation, it is also commonly used as a co-coagulant.

### Polyelectrolytes

Polyelectrolytes are water-soluble organic polymers that are used as both primary coagulants and coagulant aids. Polyelectrolytes are generally classified as follows:

- Anionic—ionize in solution to form negative sites along the polymer molecule;
- Cationic—ionize to form positive sites; and,
- Non-ionic—very slight ionization.

Polyelectrolyte primary coagulants are cationic, containing materials with relatively low-molecular weights (generally less than 500,000). Cationic charge density (available positive-charged sites) is very high.

Coagulant aids, which are polyelectrolytes, may be anionic, cationic, or near-neutrally charged. Their molecular weights are relatively high (range up to 20,000,000). They function primarily through interparticle bridging.

The efficiencies of polyelectrolyte primary coagulants depend greatly on the exact nature of the turbidity particles to be coagulated, the amount of turbidity present, and the turbulence (mixing) available during coagulation.

### **Polyelectrolytes vs. Inorganic Coagulants**

Although they cannot be used exclusively, polyelectrolytes do possess several advantages over inorganic coagulants. These are as follows:

- During clarification, the volume of sludge produced can be reduced by 50 to 90%;
- The resulting sludge is more easily dewatered and contains less water;
- Polymeric coagulants do not affect pH. Therefore, the need for an alkaline chemical such as lime, caustic, or soda ash is reduced or eliminated;
- Polymeric coagulants do not add to the total dissolved solids concentration; and,
- Soluble iron or aluminum carryover in the clarifier effluent can result from inorganic coagulant use. By using polymeric coagulants, this problem can be reduced or eliminated.

### **Coagulant Aids**

The coagulation process is often enhanced through the use of coagulant aids (or flocculants). Sometimes, excess primary coagulant is added to promote large floc sizes and rapid settling rates. However, in some waters, even large doses of primary coagulant will not produce a satisfactory floc. In these cases, a polymeric coagulant aid can be added after the coagulant, to hasten reactions, to produce a denser floc, and thereby reducing the amount of primary coagulant required. Because of polymer “bridging,” small floc particles agglomerate rapidly into larger more cohesive floc, which settles rapidly. Coagulant aids also help to create satisfactory coagulation over a broader pH range. Generally, the most effective types of coagulant aids are slightly anionic polyacrylamides with very high-molecular weights. In some clarification systems, non-ionic or cationic types have proven effective. The two types of coagulant aids discussed below are synthetic-organic and natural-organic.

Synthetic organic polymers are the most commonly used coagulant aids for coagulation and flocculation of heavy metal precipitates. This is because metallic precipitates typically possess a slight electrostatic positive charge resulting from charge density separation. The negatively charged reaction sites on the anionic polyelectrolyte attract and adsorb the slightly positive charged precipitate. Synthetic organic polyelectrolytes are commercially marketed in the form of dry powder, granules, beads, aqueous solutions, aqueous gels, and oil-in-water emulsions. Generally, liquid systems are preferred because they require less floor space, reduce labor requirements, and reduce the potential for side reactions because the concentrate can be diluted in the automatic dispensing systems. Typical dosage requirements for metals-containing waters are in the 0.5 to 2.0 mg/L range. Polyelectrolytes work most effectively at an alkaline and intermediate pH but lose effectiveness at pH levels lower than 4.5.

Natural organic coagulant aids are derived from natural products include starch, starch derivatives, proteins, and tannins. Of these, starch is the most widely used. The price per kilogram for these natural products tends to be low; however, dosage requirements tend to be high. In addition, because of the composition of natural products, they are more susceptible to microbiological attack, which can create storage problems.

## ENHANCED COAGULATION REQUIREMENTS

The Stage 1 DBP regulations, require surface water systems that use conventional treatment or softening to remove a specified minimum percentage of the **total organic carbon (TOC)** from their raw water using a process called enhanced coagulation. TOC removal is required because other DBPs besides THMs and HAAs are formed when disinfectants react with a NOM, measured as TOC. The occurrence and health effects of these unidentified DBPs are unknown at this time. This part of the regulation is to control the formation of unknown, as well as known, DBPs by requiring that a minimum percentage of NOM in the raw water, measured as TOC, is removed by the plant.

The percentage of TOC removal required is based on the TOC and alkalinity levels of the plant's raw water. These TOC removal requirements are broken down into nine different percent TOC removal categories. They are presented in a table for three different alkalinities and raw water TOC levels.

Plants that cannot meet the specified percent TOC removals will follow a "Step 2" procedure to determine what levels of TOC removal are "reasonable and practical" to achieve. The plant uses this information to request an alternative TOC removal requirement from its primacy regulatory agency.

The "Step 2" procedures consist of special jar tests to determine the maximum percent TOC removal that they can achieve by incremental increases in coagulant dose. Coagulant dose is increased in 10 mg/L increments until a specified pH level (depending on the raw water alkalinity) is achieved. Residual TOC levels in each jar are then measured, and an analysis is made of the **point of diminishing return (PODR)**. The PODR is defined as when a 10 mg/L increase in coagulant does not decrease the residual TOC by more than 0.3 mg/L. This percentage TOC removal would then be considered "reasonable and practical" and would be used in discussions with the primacy agency relative to giving the plant an alternate enhanced coagulation requirement.

When a water system meets one of a variety of conditions it may be exempted from the enhanced coagulation part of the regulation. It was recognized that only the humic fraction of the raw water TOC is amenable to removal by enhanced coagulation. Plants, therefore, with high levels of nonhumic TOC may not be able to meet any of the enhanced coagulation removal requirements and could be exempt from this part of the regulations. Plants can assess the amount of humics in their raw water by measuring its specific UV absorbance or SUVA. SUVA is defined as the UV absorbance divided by the dissolved organic carbon (DOC). SUVAs of ~3 L/mg-cm represent largely nonhumic materials, and SUVAs in the 4-5 L/mg-cm range are mainly humic. SUVA values can also be used to request exemption from the regulations and to determine PODR.

Plants may find that achieving desired TOC removal will require some significant changes in plant process control procedures. Enhanced coagulation typically requires that additional coagulant and/or acid is added to depress the pH to a point where the TOC is removed in the coagulation process. As with control of DBPs, potential conflicts exist from the standpoint of plant process control procedures. Chemical feed rates needed to meet the turbidity performance goals may not be compatible with those needed for enhanced coagulation.

## SEDIMENTATION

Sedimentation, or clarification, is the process of letting suspended material settle by gravity. Suspended material may be particles, such as clay or silts, originally present in the source water. More commonly, suspended material or floc is created from material in the water and the chemical used in coagulation or in other treatment processes, such as lime softening.

Sedimentation is accomplished by decreasing the velocity of the water being treated to a point below which the particles will no longer remain in suspension. When the velocity no longer supports the transport of the particles, gravity will remove them from the flow.

### **Factors Affecting Sedimentation**

Several factors affect the separation of settleable solids from water. Some of the more common types of factors to consider are:

#### **Particle Size**

The size and type of particles to be removed have a significant effect on the operation of the sedimentation tank. Because of their density, sand or silt can be removed very easily. The velocity of the water-flow channel can be slowed to less than one foot per second, and most of the gravel and grit will be removed by simple gravitational forces. In contrast, colloidal material, small particles that stay in suspension and make the water seem cloudy, will not settle until the material is coagulated and flocculated by the addition of a chemical, such as an iron salt or aluminum sulfate.

The shape of the particle also affects its settling characteristics. A round particle, for example, will settle much more readily than a particle that has ragged or irregular edges.

All particles tend to have a slight electrical charge. Particles with the same charge tend to repel each other. This repelling action keeps the particles from congregating into flocs and settling.

#### **Water Temperature**

Another factor to consider in the operation of a sedimentation basin is the temperature of the water being treated. When the temperature decreases, the rate of settling becomes slower. The result is that as the water cools, the detention time in the sedimentation tanks must increase. As the temperature decreases, the operator must make changes to the coagulant dosage to compensate for the decreased settling rate. In most cases temperature does not have a significant effect on treatment. A water treatment plant has the highest flow demand in the summer when the temperatures are the highest and the settling rates the best. When the water is colder, the flow in the plant is at its lowest and, in most cases, the detention time in the plant is increased so the floc has time to settle out in the sedimentation basins.

#### **Currents**

Several types of water currents may occur in the sedimentation basin:

- Density currents caused by the weight of the solids in the tank, the concentration of solids and temperature of the water in the tank.
- Eddy currents produced by the flow of the water coming into the tank and leaving the tank.

The currents can be beneficial in that they promote flocculation of the particles. However, water

currents also tend to distribute the floc unevenly throughout the tank; as a result, it does not settle out at an even rate.

Some of the water current problems can be reduced by the proper design of the tank. Installation of baffles helps prevent currents from short circuiting the tank.

### **Sedimentation Basin Zones**

Under ideal conditions, the sedimentation tank would be filled with the water that has been coagulated, and the floc would be allowed to settle before any additional water is added. That is not possible for most types of water treatment plants.

Most sedimentation tanks are divided into these separate zones:

#### Inlet zone

The inlet or influent zone should provide a smooth transition from the flocculation zone and should distribute the flow uniformly across the inlet to the tank. The normal design includes baffles that gently spread the flow across the total inlet of the tank and prevent short circuiting in the tank. (Short circuiting is the term used for a situation in which part of the influent water exits the tank too quickly, sometimes by flowing across the top or along the bottom of the tank.) The baffle could include a wall across the inlet, perforated with holes across the width of the tank.

#### Settling Zone

The settling zone is the largest portion of the sedimentation basin. This zone provides the calm area necessary for the suspended particles to settle. 50% should settle

#### Sludge Zone

The sludge zone, located at the bottom of the tank, provides a storage area for the sludge before it is removed for additional treatment or disposal.

Basin inlets should be designed to minimize high flow velocities near the bottom of the tank. If high flow velocities are allowed to enter the sludge zone, the sludge could be swept up and out of the tank. Sludge is removed for further treatment from the sludge zone by scraper or vacuum devices which move along the bottom.

#### Outlet Zone

The basin outlet zone or launder should provide a smooth transition from the sedimentation zone to the outlet from the tank. This area of the tank also controls the depth of water in the basin. Weirs set at the end of the tank control the overflow rate and prevent the solids from rising to the weirs and leaving the tank before they settle out. The tank needs enough weir length to control the overflow rate, which should not exceed 20,000 gallons per day per foot of weir.

### **Selection of Basin**

There are many sedimentation basin shapes. They can be rectangular, circular, and square.

#### **Rectangular Basins**

Rectangular basins are commonly found in large-scale water treatment plants. Rectangular tanks are popular as they tend to have:

- High tolerance to shock overload;
- Predictable performance;
- Cost effectiveness due to lower construction cost;
- Lower maintenance; and,
- Minimal short circuiting.

### **Circular and Square Basins**

Circular basins are frequently referred to as clarifiers. These basins share some of the performance advantages of the rectangular basins, but are generally more prone to short circuiting and particle removal problems. For square tanks the design engineer must be certain that some type of sludge removal equipment for the corners is installed.

### **High Rate Settlers**

High rate tube settlers are designed to improve the characteristics of the rectangular basin and to increase flow through the tank. The tube settlers consist of a series of tubes that are installed at a 60 degree angle to the surface of the tank. The flow is directed up through the settlers. Particle have a tendency to flow at an angle different than the water and to contact the tube at some point before reaching the top of the tube. After particles have been removed from the flow and collected on the tubes, they tend to slide down the tube and back into the sludge zone.

### **Solids Contact Units**

A solids contact unit combines the coagulation, flocculation, and sedimentation basin in one unit. These units are also called upflow clarifiers or sludge-blanket clarifiers. The solids contact unit is used primarily in the lime-soda ash process to settle out the floc formed during water softening. Flow is usually in an upward direction through a sludge blanket or slurry of flocculated suspended solids. The volume of the sludge blanket is dependent upon the efficiency of the removal of turbidity and must be measured on a regular basis.

## FILTRATION

Removal of suspended solids by filtration plays an important role in the natural treatment of groundwater as it percolates through the soil. It is also a major part of most water treatment. Groundwater that has been softened or treated through iron and manganese removal will require filtration to remove floc created by coagulation or oxidation processes. Since surface water sources are subject to run-off and do not undergo natural filtration, it must be filtered to remove particles and impurities.

### **Filtration Process**

The filter used in the filtration process can be compared to a sieve or microstrainer that traps suspended material between the grains of filter media. However, since most suspended particles can easily pass through the spaces between the grains of the filter media, straining is the least important process in filtration. Filtration primarily depends on a combination of complex physical and chemical mechanisms, the most important being adsorption. Adsorption is the process of particles sticking onto the surface of the individual filter grains or onto the previously deposited materials. The forces that attract and hold the particles to the grains are the same as those that work in coagulation and flocculation. In fact, some coagulation and flocculation may occur in the filter bed, especially if coagulation and flocculation of the water before filtration was not properly controlled. Incomplete coagulation can cause serious problems in filter operation.

### **Types of Filters**

Several types of filters are used for water treatment. The earliest ones developed were the slow sand filters. They typically have filter rates of around 0.05 gpm/ft<sup>2</sup> of surface area. This type of filter requires large filter areas. The top several inches of the sand has to be removed regularly--usually by hand--due to the mass of growing material (schmutzdecke) that collects in the filter. The sand removed is usually washed and returned to the filter. These filters are still in use in some small plants, especially in the western U.S. as well as in many developing countries. They may also be used as a final step in wastewater treatment.

Most filters are classified by filtration rate, type of filter media, or type of operation into:

- A. Gravity Filters
  - a. Rapid Sand Filter
  - b. High Rate Filter
    - Dual media
    - Multi-media
- B. Pressure Filters
  - Sand or Multi-media

### **Rapid Sand Filters**

Rapid sand filters can accommodate filter rates 40 times those of slow sand filters. The major parts of a rapid sand filter are: filter tank or filter box; filter sand or mixed-media; gravel support bed; underdrain system; wash water troughs; and filter bed agitators.

The filter tank is generally constructed of concrete and is most often rectangular. Filters in large plants are usually constructed next to each other in a row, allowing the piping from the sedimentation basins to feed the filters from a central pipe gallery. Some smaller plants are designed with the filters forming a square of four filters with a central pipe gallery feeding the filters from a center well.

## **Filter Sand**

The filter sand used in rapid sand filters is manufactured specifically for the purpose of water filtration. Most rapid sand filters contain 24-30 inches of sand, but some newer filters are deeper. The sand used is generally 0.4 to 0.6 mm in diameter. This is larger than the sand used in slow rate filtration. The coarser sand in the rapid filters has larger voids that do not fill as easily.

## **Graded Gravel**

The gravel installed under the sand layer(s) in the filter prevents the filter sand from being lost during the operation. The under-gravel also distributes the backwash water evenly across the total filter.

This under-gravel supports the filter sand and is usually graded in three to five layers, each generally 6-18 inches in thickness, depending on the type of underdrain used.

## **Underdrain**

The filter underdrain can be one of many types, such as: pipe laterals; false floor; and Leopold system.

### Pipe laterals

A pipe lateral system uses a control manifold with several perforated laterals on each side. Piping materials include cast iron, asbestos cement, and PVC. The perforations are usually placed on the underside of the laterals to prevent them from plugging with sand. This also allows the backwash to be directed against the floor, which helps keep the gravel and sand beds from being directly disturbed by the high velocity water jets.

### False floor

The false floor design of a filter underdrain is used together with a porous plate design or with screens that retain the sand when there is no undergravel layer. This type of underdrain allows the plenum or open space under the floor to act as the collection area for the filtered water and for the distribution of the filter backwash water.

### Leopold system

The Leopold system consists of a series of clay or plastic blocks that form the channels to remove the filtered water from the filter and distribute the backwash water. This type of underdrain is generally used with an undergravel layer, although some new designs allow for sand retention without gravel.

## **Washwater Troughs**

Washwater troughs placed above the filter media collect the backwash water and carry it to the drain system. Proper placement of these troughs is very important to ensure that the filter media is not carried into the troughs during the backwash and removed from the filter. The wash troughs must be installed at the same elevation so that they remove the backwash evenly from the filter and so that an even head is maintained across the entire filter. These backwash troughs are constructed from concrete, plastic, fiberglass, or other corrosion-resistant materials.

## **Surface Wash**

During the operation of a filter, the upper six-to-ten inches of the filter media remove most of the suspended material from the water. It is important that this layer be thoroughly cleaned during the backwash cycle. Normal backwashing does not, in most cases, clean this layer completely;

therefore, some method of agitation is needed to break up the top layers of the filter and to help the backwash water remove any material caught there.

The surface wash system consists of a series of pipes installed in the filter that introduce high velocity water or air jet action into the upper layer of the filter. This jet action will generally be supplied by rotating arms that are activated during the backwashing of the filter.

A newer design of surface wash uses compressed air to mix the upper layer and loosen the particles from the sand so that the backwash water can remove the particles more easily. This air wash generally is turned on before the backwash cycle. If both are used at the same time, some sand may be washed away. The compressed air rate can be two-to-five cubic feet per minute per square foot (cfm/ft<sup>2</sup>) of filter surface, depending on the design of the filter.

### **High Rate Filters**

High rate filters, which operate at a rate three-to-four times that of rapid sand filters, use a combination of different filter media, not just sand. The combinations vary with the application, but generally they are sand and anthracite coal. Multi-media or mixed-media filters use three or four different materials, generally sand, anthracite coal, and garnet.

In rapid sand filters, finer sand grains are at the top of the sand layer with larger grains farther down into the filter. As a result, the filter removes more suspended material in the first few inches of the filter. In the high rate filter, the media size decreases. The top layer consists of a coarse material with the finer material farther down, allowing the suspended material to penetrate deeper into the filter.

The material in a filter bed forms layers in the filter, depending on their weight and specific gravities. In the coarse layer at the top, the larger suspended particles are removed first, followed by the finer materials. This allows for longer filter runs at higher rates than is possible with rapid sand filters.

The type of filter media used in a high rate filter depends on many factors, including the raw-water quality, raw-water variations, and the chemical treatment used. Pilot studies help the operator evaluate which material, or combination of materials, will give the best result.

### **Pressure Filters**

Pressure filters fall into two categories: pressure sand and diatomite filters.

#### **Pressure sand filters**

This type of filter is used extensively in iron and manganese removal plants.

A pressure sand filter is contained under pressure in a steel tank, which may be vertical or horizontal, depending on the space available. As with gravity filters, the media is usually sand or a combination of media. Filtration rates are similar to gravity filters.

These filters are commonly used for iron and manganese removal from groundwater, which is first aerated to oxidize the iron or manganese present, then pumped through the filter to remove the suspended material.

Because the water is under pressure, air binding will not occur in the filter. However, pressure filters have a major disadvantage in that the backwash cannot be observed; in addition, cracking of the filter bed can occur quite easily, allowing the iron and manganese particles to go straight through the filter. When using pressure filters for iron and manganese removal, the operator must regularly measure the iron and manganese concentration of the filter effluent and backwash the filter before breakthrough occurs. Because of these limitations, pressure filters must not be used to treat surface water.

### **Diatomaceous Earth Filters**

This type of filter is commonly used for the treatment of swimming pools. The process was developed by the military during World War II to remove microorganisms that cause amoebic dysentery from water used in the field.

### **Filtration Processes**

Two basic types of filtration processes are currently used in the U.S. Conventional filtration, the traditional design for many years, provides effective treatment for just about any range of raw-water turbidity. Its success is due partially to the sedimentation that precedes filtration and follows the coagulation and flocculation steps. Sedimentation, if operated properly, should remove most of the suspended material. After sedimentation, the water passing through to the filters should not have a turbidity higher than 10-to-15 NTU. Rapid sand filters were once used in the conventional process, but many have been converted to multi-media filters in an attempt to increase plant capacity.

In the other type of filtration process--direct filtration--no sedimentation follows the coagulation phase. Direct filtration is designed to filter water with an average turbidity of less than 25 NTU. Dual and multi-media filters are used with direct filtration. They are able to remove more suspended material per cubic foot of filter media than sand filters. Direct filtration plants have a lower capital cost. However, the process cannot handle large variations in raw water turbidity.

### **Filtration Operation**

Filtration operation is divided into three steps: filtering, backwashing, and filtering to waste.

### **Filter Control**

Control of the filter operation requires the following equipment:

- Rate of flow controller;
- Loss of head indicator; and,
- On-line turbidimeter

### **Rate of flow controllers**

Flow rates through filters are controlled by one of two different methods:

#### Declining rate

This method of control is used where the head loss through the plant is quite large. It allows the filter head to increase until the filter becomes plugged with particles and the head loss is too great to continue operation of the filter. The rate through the filter is much greater in the beginning of a filter run than at the end when the filter is dirty. This method tends to be the most commonly installed in new filter plants.

### Constant rate

This type of control monitors the level of water on the top of the filter and attempts to control this level from the start of the operation to the end. This is accomplished by the controller operating a valve on the effluent of the filter. The valve will be nearly closed at the start of the filter run and fully open at the end. This design is used when the head or pressure on the filter is limited.

Both controllers consist of a venturi tube or some other type of metering device as well as a valve to control the flow from the filter. In most cases, the valve is controlled by an automatic control device, often an air-actuated type valve that is controlled by the flow tube controller.

### **Loss of head indicator**

As filtration proceeds, an increasing amount of pressure, called head loss across the filter, is required to force the water through the filter. The **head loss** should be continuously measured to help determine when the filter should be backwashed. Usually the difference in the head is measured by a piezometer connected to the filter above the media and the effluent line.

### **In-line turbidimeter**

Turbidity in water is caused by small suspended particles that scatter or reflect light so that the water appears to be cloudy. Turbidity of the filtered water may shelter bacteria, preventing chlorine from reaching it during the final disinfection process. The turbidity of the filtered water is one of the factors that determines the length of a filter run. At some point, the suspended material will start to break through the filter media and increase the turbidity of the filter effluent. At this time, the filter should be backwashed. Continuous turbidity monitors provide information about when the filter is approaching this point so that the operators can start the backwash before the turbidity is too great. Turbidity measurements will also indicate whether the coagulation and other treatment processes are operating properly.

### Filtration Process

Water-either from the source or, more commonly, from pre-treatment processes-is applied to the top of the filter; it then flows downward. The water level above the filter bed is usually kept at 2 to 6 feet. When the filtration is started after being backwashed, there will be little head loss. In filters with a control valve installed on the filter effluent pipe, the filter flow is restricted during this time. The control valve also has the important function of preventing filter surges, which could disturb the media and force floc through the filter.

The rate of flow on a filter depends on the type of filter. A rapid sand filter will have a flow of 2 to 3 gpm/square foot of filter area. The high rate filter may have 4 to 6 gpm/square foot applied to the surface. A constant rate flow valve is almost fully closed when a filter is clean so that the desired water level on top of the filter is maintained. As the filter becomes dirty with suspended material, the valve opens gradually until the increase in the water level above the filter indicates that the filter needs backwashing.

In filters with variable declining rate flow control, the filters are allowed to take on as much water as they can handle. As the filters become dirty, both the headloss and the depth of the water on the surface increase until the filters need backwashing. This method is generally preferred because it requires less operator attention. With this method, a filter accepts as much flow as it can handle. As the filter becomes dirty, the flow through the filter becomes less and, if the plant has more than one filter, additional flow redistributes across the other filters. A flow

restrictor is placed in the filter effluent pipe to prevent a filter inflow that is too great for the filter.

In most cases the filter backwash rate will not break up the mass on the top of the filter. The design engineer will recommend the installation of a surface wash of some type, the most common being a set of rotary arms that are suspended above the media during filtration. During filter backwash, the media expands upwards and around the washing arms. A newer method of surface wash involves using air scour before the water wash. This is a very efficient method but requires the installation of a large air blower to produce the air. The normal design for the air wash will be 2 to 5 cubic feet of air per square foot of filter area.

The filter should be backwashed when the following conditions have been met:

- The head loss is so high that the filter no longer produces water at the desired rate; and/or
- Floc starts to break through the filter and the turbidity in the filter effluent increases; and/or
- A filter run reaches a given hour of operation.
- If a filter is taken out of service for some reason, it must always be backwashed prior to be putting on line.

The decision to backwash the filter should not be based on only one of the above conditions. If a filter is not backwashed until the headloss exceeds a certain number of feet, the turbidity may break through and cause the filter to exceed the standard of 0.5 NTU of turbidity. Similarly, depending on filter effluent- turbidity alone can cause high head loss and decreased filter flow rate, which can cause the pressure in the filter to drop below atmospheric pressure and cause the filter to air bind and stop filtering.

If the water applied to a filter is very good quality, the filter runs can be very long. Some filters can operate longer than one week before needing to be backwashed. However, this is not recommended as long filter runs can cause the filter media to pack down so that it is difficult to expand the bed during the backwash.

### **Backwashing Process**

The normal method for backwashing a filter involves draining the water level above the filter to a point 6 inches above the filter media. The surface wash is then turned on and allowed to operate for several minutes to break up the crust on the filter. After that, the backwash valve is opened, allowing backwash water to start flowing into the filter and start carrying suspended material away from the filter. For a filter with an air wash instead of a water-surface wash, the filter backwash water and the air wash should not be used together. This would be possible only if some means of controlling the media carryover is installed.

1. The time elapsed from when the filter wash is started until full flow is applied to the filter should be greater than one minute. After a few minutes, the filter backwash valve should be fully opened to allow full expansion of the filter media. Generally, this expansion will be from 20 to 40% over the normal filter bed volume. The expansion needed will depend on how much agitation is needed to suspend the filter media to remove to suspended material trapped in the filter. With a multi-media filter, the rate must be high enough to scrub the interface between the coal and the sand, where the highest amount of suspended solids will be removed from the media. The filter will be washed for 10 to 15 minutes,

depending on the amount of solids that must be removed. The best way to determine how long the filter should be washed is to measure the turbidity of the backwash water leaving the filter. In most cases, a filter is washed too long. This could be costly. Water used to backwash a filter should not be more than 2% to 4% of the total water produced by that filter since the last backwash. Too much backwash water is used, and it must be treated after use. Backwash valves must be opened slowly. Opening the valves too rapidly can cause serious damage to the filter underdrain, filter gravel, and filter media.

### **Disposal of Filter Backwash Water**

Water from the filter backwash cannot be returned directly to the environment. Normally the water is discharged into a backwash tank and allowed to settle. The supernatant, or cleared liquid, is then pumped back to the head of the treatment plant at a rate not exceeding 10% of the raw water flow entering the plant. The settled material is pumped to a sewer or is treated in the solids-handling process of the plant. This conserves most of the backwash water and eliminates the need to obtain a pollution discharge permit from the **West Virginia Department of Environmental Protection (WVDEP)** for the disposal of the filter backwash water. Add NPDES

Since backwash is a very high flow operation, the surges that are created from the backwash coming from the filter must not be allowed to enter the head of the plant. Therefore, the spent backwash water must be stored in storage tanks and returned slowly to the treatment process.

### **Filtering to Waste**

When filtration is started after backwash, filtered water should be wasted until the turbidity in the effluent meets standards. Depending on the type of filter, this may last from two to 20 minutes. This wasting is needed as some suspended material remains in the filter media following the backwash. The media needs to become somewhat sticky again to start to capture the suspended material. Also, the filtration rate is higher in a clean filter, causing more material to be swept from the filter during the start-up.

Filtration should always be started slowly after a backwash to reduce turbidity spikes and prevent breakthrough of suspended material.

### **Filter Aids**

Sometimes, when water passes through a filter, the floc is torn apart into smaller particles that will penetrate deeply into the filter media, causing premature turbidity breakthrough. This will require more frequent filter backwashing of the filter and use of large volumes of backwash water to be able to remove the floc that has penetrated deeply into the filter bed.

A filter aid is a material that adds strength to the floc and prevents its breakup. Generally, a polymer is used as a filter aid because it creates strong bonds with the floc. Polymers are water-soluble, organic compounds that can be purchased in either wet or dry form.

Polymers have very high molecular weight and cause the floc to coagulate and flocculate quickly. Polymers can have positive or negative charges, depending on the type needed to cause attraction to the specific floc filtered.

When used as a filter aid, the polymer strengthens the bonds and prevents the shearing forces in the filter from breaking the floc apart. For best results, the polymer should be added just ahead of

the filter. A normal dose of polymer for filter aiding will be less than 0.1 ppm, but the exact dose will be decided by the result of a jar test and by experimentation in the treatment plant. Too much polymer will cause the bonds to become too strong, which may then cause the filter to plug, especially the top few inches of the filter media.

### **Filter Operating Problems**

There are three major types of filter problems. They can be caused by chemical treatment before the filter, control of filter flow rate, and backwashing of filters.

#### 1. Chemical treatment before the filter

The coagulation and flocculation stages of the water treatment must be monitored continuously. Adjustments in the amount of coagulant added must be made frequently to prevent the filter from becoming overloaded with suspended material. This overload may cause the filter to prematurely reach its maximum headloss.

If there is early turbidity breakthrough in the filter effluent, more coagulant may have to be added to the coagulation process. There may be a need for better mixing during the coagulation or the addition of more filter aid. If there is a rapid increase in filter head loss, too much coagulant may be clogging the filter. Less coagulant or less filter aid should be used. The operator needs to learn to recognize these problems and choose the proper corrections.

#### 2. Control of filter flow rate

When a filter is subjected to rapid changes in flow rate, the turbidity of the effluent may be affected. The dirtier the filter media, the greater the effect.

When a plant flow changes, the filter flow also has to change to produce the water needed. If an increase is necessary, the flow should, if possible, be increased gradually over a ten-minute period to reduce the impact on the filter. Addition of filter aids may also reduce the impact on the filter effluent.

When backwashing a filter, and therefore temporarily taking it out of service, the remaining filter(s) must pick up the additional flow. This can cause an abrupt change in flow that will cause turbidity breakthrough. This problem can be avoided by keeping one filter in reserve to accept this additional flow. If the plant has a backwash storage basin, this will also prevent surges to the filters.

Many plants are not operated continuously, and the start-up at the beginning of the day will cause a surge to the filter(s). The filters should be backwashed before putting them back into operation or operated to waste until the effluent meets the standards.

#### 3. Backwashing of filters

Backwashing of the filters is the single most important operation in the maintenance of the filters. If the filter is not backwashed effectively, problems may occur that may be impossible to correct without totally replacing the filter media. These problems could be caused by improper backwashing procedures:

- Mud balls are formed by the filter media cementing together with the floc that the filter is supposed to remove. If the filter is backwashed effectively, the mud balls are broken apart and removed. As the balls gain weight, they will settle to the bottom of

the filter and occupy valuable filter volume. This will cause the flow to increase in the areas of the filter that have not been plugged. Additional problems, such as filter cracking and separation of the media from the filter walls may also be the result of mud-ball formation.

- Filter bed shrinkage or compaction can result from ineffective backwashing. Media grains in a clean filter rest directly against each other with very little compaction. Filter media in a dirty filter are surrounded by a soft layer which causes it to compact. This causes filter bed cracking and separation of the filter media from the walls of the filter. When the filter is cracked, it is obvious that the filter will short circuit. The flow will seek the crack and go straight through, resulting in excessive turbidity in the effluent.
- Filter bed shrinkage or compaction can result from ineffective backwashing. Media grains in a clean filter rest directly against each other with very little compaction. Filter media in a dirty filter are surrounded by a soft layer which causes it to compact. This causes filter bed cracking and separation of the filter media from the walls of the filter. When the filter is cracked, it is obvious that the filter will short circuit. The flow will seek the crack and go straight through, resulting in excessive turbidity in the effluent.
- Air binding of the filter is not common as long as the filter is washed regularly. Air binding is the result of pressure in the filter becoming negative during operation. This causes the air dissolved in the water to come out of the solution and become trapped in the filter, resulting in resistance and short filter runs. This negative head generally occurs in a filter that has less than five feet of head above the unexpanded filter bed. If a filter head of five feet is not possible, filter backwash should be started at a lower head loss than normal.
- Air binding can also be caused by the water being cold and super-saturated with air. This air bubbles out as the water warms up. It is not possible for the operator to control this situation. If it happens, the filter must be backwashed more frequently to correct the filter air binding.
- Media loss is normal in any filter. Some are lost each time the filter is backwashed, especially if the filter surface wash is used. If a large amount of media is being lost, the method of washing should be inspected and corrected. The bed should not have to be expanded more than 20% during the backwash cycle. It may help to turn off the surface wash approximately two minutes before the end of the backwash. If this does not correct the problem, the filter troughs may have to be raised to prevent the excessive media loss.

After a well-operated filter backwash, the filter should be level and smooth with no cracks or mud balls at the surface. A good bed will appear to move laterally during the backwash and there will be no boils at the surface. The filter should clear up evenly cleaning. If some areas are not clean, there could be an under-drain problem.

### **Filtration Treatment Technologies Listed in the SWTR**

Filtration is the most commonly used treatment for reducing turbidity and microbial contaminant

levels in domestic water supplies. Common drinking water filtration processes involve passing water through a filter media to remove suspended particulate material, larger colloidal materials, and, for some filter media, to reduce levels of smaller colloidal and dissolved contaminants. Examples of suspended particulates include clay and silt, microorganisms, humic and other aggregated organic materials, and aluminum and iron oxide precipitates. Familiar filter media include silica sand, diatomaceous earth, garnet or ilmenite, and a combination of coarse anthracite coal overlaying finer sand. Filtration may involve single media, dual media (e.g., coal-sand), and tri-media (e.g., an added third layer of sand). Filtration may be rapid or slow, depending upon the application, and may involve different removal processes, cleaning methods, and operation methods.

The filtration technologies discussed are used to remove suspended particulate matter from water. For filtration processes that involve the addition of a chemical coagulant, coagulation refers to the complex over-all process of particle aggregation within a water being treated, including coagulant formation, particle destabilization (surface charge alteration of suspended particles), and inter-particle collisions. Flocculation may be considered a part of the coagulation process and refers to the process of promoting inter-particle collisions and thus the aggregation of larger particles (floc). Larger suspended particles may be removed by simple filtration or by sedimentation (gravity settling) or flotation (floc rises to the surface and is skimmed off). Simple filtration involves the physical trapping of suspended particles that are larger than the pore volumes of the filter media; the bulk water passes through unimpeded and leaves the particles behind. As finer suspended particles pass through the filter medium, they are destabilized, resulting in coagulation and adherence to the filter medium. In the case of slow sand filtration, which does not involve the addition of coagulants, colloidal and dissolved organic materials may be removed by biological processes in the *schmutzdecke* (“black layer” or biologically-active layer) and in the filter medium below. In the case of direct filtration, which requires influent water with much less turbidity, the coagulation and flocculation step is followed immediately by filtration. Since there is less aggregated material to remove, sedimentation or flotation is not required to prolong the filter cycle. Some dissolved chemicals may be removed by chemical sorption at the surface of the filter media, especially in the cases of higher surface area filter media (e.g., fine sand and diatomaceous earth), but these processes account for much less of the bulk contaminant removal compared to physical sorption processes.

For the purposes of meeting the performance criteria under the SWTR and to protect public health, disinfection treatment is commonly applied following filtration.

### **Conventional filtration**

Conventional filtration includes pre-treatment steps of chemical coagulation, rapid mixing, and flocculation, followed by floc removal via sedimentation or flotation. After clarification, the water is then filtered. Common filter media include sand, dual-media, and tri-media. Design criteria for specific sites are influenced by site-specific conditions and thus individual components of the treatment train may vary in design criteria between systems. Conventional treatment has demonstrated removal efficiencies greater than 99% for viruses and 97 to 99.9% (rapid filtration with coagulation and sedimentation) for *Giardia*.

There are a variety of coagulation/filtration package plants applicable to small systems. In package plants that utilize sedimentation, the sedimentation step usually occurs in tube settlers. In “dual-stage filtration”, the sedimentation step is replaced by a passive

flocculation/clarification step that occurs in an initial “depth clarifier” tank. The clarified water is then passed through a depth filter. Other modes of clarification are possible, including the use of the various upflow and downflow flocculation/filtration processes, also known as “roughing filter” processes. Typically, roughing filters are not as versatile as sedimentation or flotation, but some varieties may perform comparably. Coagulation/filtration package units have demonstrated the ability to effectively remove turbidity, color, disinfection by-product precursors, viruses, bacteria, and protozoa (e.g., *Cryptosporidium* and *Giardia* cysts).

Conventional filtration is the most widely used technology for treating surface water supplies for turbidity and microbial contaminants. Although conventional filtration has the advantage that it can treat a wide range of water qualities, it has the disadvantage that it requires advanced operator skill and has high monitoring requirements. It is reiterated that the performance of conventional filtration is extremely sensitive to the proper management of the coagulation chemistry involved; if the coagulation step is disrupted or improperly executed, the removal efficiencies for turbidity and microbiological contaminants decrease dramatically in a matter of minutes.

### **Direct filtration**

Direct filtration has several effective variations, but all include a pre-treatment of chemical coagulation followed by rapid mixing. The water is then filtered through dual- or mixed-media using pressure or gravity filtration units. Pressure units, which are used primarily by small systems, have the advantage of not requiring repumping for delivery of the filtrate to the point of use. Gravity units have the advantage of allowing easy visual inspection of the filter medium during and after backwash. Besides the mode of filtration, variations of direct filtration include filter media and mixing requirements. In-line filtration is the simplest form of direct filtration and consists of filters preceded by direct influent chemical feed and static mixing. In general, direct filtration usually requires low turbidity raw water and is attractive because of its low cost relative to conventional treatment.

The National Research Council has suggested that small systems not use direct filtration for waters with average turbidities above 10 NTU or maximum turbidities above 20 NTU. Two other important considerations are color and algae. Since color removal requires coagulant additions in proportion to the degree of color, an upper limit of color is appropriate for direct filtration. Direct filtration has demonstrated removal efficiencies of 90 to 99% for viruses, 50% for *Giardia* without coagulation, and 95-99% for *Giardia* with coagulation pre-treatment.

Direct filtration has the disadvantage that it requires advanced operator skill and has high monitoring requirements. It is reiterated that the performance of direct filtration is extremely sensitive to the proper management of the coagulation chemistry involved; if the coagulation step is disrupted or improperly executed, the removal efficiencies for turbidity and microbiological contaminants decrease dramatically in a matter of minutes.

### **Slow sand filtration**

Slow sand filters are simple, are easily used by small systems, and have been adapted to package plant construction. Slow sand filters are similar to single media rapid-rate filters in some respects, but there are crucial differences in functional mechanisms (other than the obvious difference in flow rate): the schmutzdecke removes suspended organic materials and microorganisms by biodegradation and other biological processes, instead of relying solely on

simple filtration or physico-chemical sorption. Advantages of slow sand filtration include its low maintenance requirements (since it does not require backwashing and requires less frequent cleaning) and the fact that its efficiency does not depend on actions of the operator. However, slow sand filters do require time for the schmutzdecke to develop after cleaning, during which the filtration performance steadily improves; this interval is called the “ripening period”. The ripening period can last from six hours to two weeks, but typically requires less than two days. A two day filter-to-waste period is recommended for typical sand filter. Since few remedies are available to an operator when the process is ineffective, slow sand filtration should be used with caution and should not be used without pretreatment or process modifications (e.g., GAC layer addition) unless the raw water is low in turbidity, algae, and color. Package plant versions with a granular activated carbon layer located beneath the slow sand filter can adsorb organic materials that are resistant enough to biodegradation to pass through the schmutzdecke. When used with source water of the appropriate quality, slow sand filtration may be the most suitable filtration technology for small systems. Slow sand filtration has demonstrated removal efficiencies in the 90 to 99.9999% range for viruses and greater than 99.99% for *Giardia*.

### **Diatomaceous earth filtration**

**Diatomaceous earth (DE)** filtration, also known as pre-coat or diatomite filtration, can be used to directly treat low turbidity raw water supplies. DE filters consist of a layer of DE (about 1/8-inch thick) supported on a septum or filter element. This pre-coat layer is subject to cracking and must be supplemented by a continuous-body feed of diatomite to maintain porosity of the filter. Problems inherent in maintaining the filter cake have limited the use of DE filtration. DE filtration that does not recycle filtered water may not be appropriate for small systems that filter intermittently, since the filter cake must be changed and the septum must be cleaned after each break in filtration.

DE filtration is very effective for removing *Giardia* cysts, but filtration with plain DE has indicated the inability to remove very small particles, e.g., viruses. Research has shown that modifications can lead to 99% virus removal. Since chemical coagulation is not required, DE filtration is very attractive as a small systems technology and has been used successfully by small systems for many years. Waters that are low in turbidity, color and other organic matter (DBP precursors) are suitable for DE filtration.

### **Membrane Processes**

The four treatments listed below are membrane processes, which make use of pressure-driven semi-permeable membrane filters. Membranes are manufactured in a variety of configurations, materials and pore size distributions. The selection of membrane treatment for a particular drinking water application would be determined by a number of factors, such as: targeted material(s) to be removed, source water quality characteristics, treated water quality requirements, membrane pore size, **molecular weight cutoff (MWC)**, membrane materials and system/treatment configuration.

The membrane technologies listed below have been historically employed for specific drinking water uses:

- **reverse osmosis (RO)** treatment in a high pressure mode, in removal of salts from brackish water and seawater;
- **nanofiltration (NF)**, also referred to as membrane softening or low pressure RO, in removal of calcium and magnesium ions (hardness) and/or natural organics and

disinfection byproducts control;

- **ultrafiltration (UF)**, characterized by a wide band of MWCs and pore sizes, for removal of specific dissolved organics (e.g., humic substances, for control of disinfection byproducts in finished water) and for removing particulates; and,
- **microfiltration (MF)**, as with ultrafiltration utilizing low operating pressures, for removal of particulates including pathogenic cysts.

Pre-filtration and scale-inhibiting chemical addition may be utilized to protect membranes from plugging effects, fouling and/or scaling, and to reduce operational and maintenance costs. For the purposes of meeting the performance criteria under the SWTR and as a safety measure, a disinfectant is commonly applied following membrane treatment to protect distributed water quality.

### **Reverse Osmosis (RO)**

Due to typical RO membrane pore sizes and size exclusion capability (in the metallic ion and aqueous salt range), RO filtration is effective for removal of cysts, bacteria and viruses.

### **Nanofiltration (NF)**

Due to typical NF membrane pore sizes and size exclusion capability (1 nanometer range, e.g., organic compounds), NF is effective for removal of cysts, bacteria and viruses.

### **Ultrafiltration (UF)**

Due to typical UF membrane pore sizes and size exclusion capability (e.g., 0.01 micron, molecular/ macromolecular range), UF is effective for absolute removal of *Giardia* cysts and partial removal of bacteria and viruses, and when used in combination with disinfection appears adequate for removal/inactivation of these microorganisms. Tests have also shown that filtrate turbidity may be kept consistently at or below 0.1 NTU.

### **Microfiltration (MF)**

Due to typical MF membrane pore sizes and size exclusion (e.g., 0.1 to 0.2 micron, macromolecular/microparticle range), MF is effective for absolute removal of *Giardia* cysts and partial removal of bacteria and viruses, and when used in combination with disinfection appears adequate for removal/inactivation of these microorganisms. Tests have also determined that MF filtrate turbidity may be kept below 0.2 NTU and typically at or below 0.1 NTU.

### **Bag filtration**

Bag filtration systems are based on the physical screening process to remove particles. If the pore size of the bag filter is small enough, parasitic removal will occur. In a bag filtration unit system, water to be treated passes through a bag-shaped filtration unit where the particulates are collected on the bag's filter media while allowing the filtered water to pass to the outside of the bag. Bag filters are manufactured and supplied by a variety of companies with different micron ratings (typically from 1 to 40 micron) and material compositions. The sizing of the bag filtration component is conditional on the on raw water quality, including the amount of particulate matter and the turbidity. Unless the quality of the raw water precludes pre-treatment, EPA recommends prefiltration of the raw water using sand or multimedia filters, followed by preliminary bag or cartridge filters of 10 micron or larger pore size, and the use of 15 micron filters as final filters to increase particulate removal efficiencies and to extend the life of the filter. Contingent on the filter manufacturer, bag filters can accommodate turbidity units from 0.1 to 10.0 NTU and flow

between 10 and 50 gpm. However, the bag filters will only last a few hours when turbidity consistently exceeds 1 NTU.

### **Cartridge filtration**

Cartridge Filtration, similar to bag filtration, relies on the physical screening process to remove particles. If the pore size of the filter is small enough, parasites will not pass through the filter. Typical cartridge filters are pressure filters with pleated fabrics, membranes, or strings wrapped around a filter element and housed in a pressure vessel. The pleating allows for higher surface area for filtration. These filters are manufactured and supplied by a variety of companies with different micron ratings (0.3 to 80 micron) and materials. Similar to bag filtration, these units are very compact and do not require much space.

The pore size rating of the cartridge filtration component used is dependent on the on raw water quality, including the amount of particulate matter and the turbidity. Depending on the quality of the raw water, prefiltration of the raw water using sand or multimedia filter, followed by bag or cartridge filters of 10 microns or larger pore size as preliminary filter, and the use of 1-5 micron filters as final filters are recommended to increase particulate removal efficiencies and to extend the life of the filter.

Cartridge filters can be used for removal of *Giardia*. Filtration studies conducted by EPA to determine *Cryptosporidium* using beads as surrogates showed that cartridge filtration with 2 micron rated units exhibited log removals of 3.51 and 3.68.

## MEMBRANE FILTRATION

A membrane is a thin layer of semi-permeable material that separates substances when a driving force is applied across the membrane. Membrane processes are increasingly used for removal of bacteria, microorganisms, particulates, and natural organic material, which can impart color, tastes, and odors to water and react with disinfectants to form disinfection byproducts. As advancements are made in membrane production and module design, capital and operating costs continue to decline. The membrane processes discussed here are microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO).

### **Microfiltration**

Microfiltration is loosely defined as a membrane separation process using membranes with a pore size of approximately 0.03 to 10 microns (1 micron = 0.0001 millimeter), a molecular weight cut-off (MWCO) of greater than 1000,000 daltons and a relatively low feed water operating pressure of approximately 100 to 400 kPa (15 to 60psi). Representative materials removed by MF include sand, silt, clays, *Giardia lamblia* and *Cryptosporidium* cysts, algae, and some bacterial species. MF is not an absolute barrier to viruses. However, when used in combination with disinfection, MF appears to control these microorganisms in water.

There is a growing emphasis on limiting the concentrations and number of chemicals that are applied during water treatment. By physically removing the pathogens, membrane filtration can significantly reduce chemical addition, such as chlorination.

Another application for the technology is for removal of natural synthetic organic matter to reduce fouling potential. In its normal operation, MF removes little or no organic matter; however, when pretreatment is applied, increased removal of organic material can occur. MF can be used as a pretreatment to RO or NF to reduce fouling potential. Both RO and NF have been traditionally employed to desalt or remove hardness from groundwater.

MF membranes provide absolute removal of particulate contaminants from a feed stream by separation based on retention of contaminants on a membrane surface. It is the “loosest” of the membrane processes, and as a consequence of its large pore size, it is used primarily for removing particles and microbes and can be operated under ultralow pressure conditions.

It may be necessary to adjust the feedwater pH by chemical dosing prior to membrane filtration in order to maintain the pH within the recommended operating range for the membrane material employed. It should be noted that pH adjustment is not required for scaling control, since MF membranes do not remove uncomplexed dissolved ions.

MF membranes, under the most conservative conditions, appear to act as an absolute barrier to selected bacteria and protozoan cysts and oocysts. Unlike UF however, MF does not remove appreciable densities of viruses. Therefore, it is necessary to complement MF with a post-membrane disinfection process. Chemical disinfection may be employed by applying chlorine, chlorine dioxide, or chloramines; however, long contact times are required to inactivate viruses.

### **Ultrafiltration**

Ultrafiltration has a pore size of approximately 0.002 to 0.1 microns, an MWCO of approximately 10,000 to 100,000 daltons, and an operating pressure of approximately 200 to 700 kPa (30 to 100 psi). UF will remove all microbiological species removed by MF (partial removal

of bacteria), as well as some viruses (but not an absolute barrier to viruses) and humic materials. Disinfection can provide a second barrier to contamination and is therefore recommended.

The primary advantages of low-pressure UF membrane processes are compared with conventional clarification and disinfection (post-chlorination) processes are:

- No need for chemicals (coagulants, flocculants, disinfectants, pH adjustment);
- Size-exclusion filtration as opposed to media depth filtration;
- Constant quality of the treated water in terms of particle and microbial removal;
- Process and plant compactness; and
- Simple automation .

However, fouling can cause difficulties in membrane technology for water treatment.

### **Nanofiltration**

Nanofiltration membranes have a nominal pore size of approximately 0.001 microns and an MWCO of 1,000 to 100,000 daltons. Pushing water through these smaller membrane pores requires a higher operation pressure than either MF or UF. Operating pressures are usually near 600 kPa (90psi) and can be as high as 1,000 kPa (150psi). These systems can remove virtually all cysts, bacteria, viruses, and humic materials. They provide excellent protection from DBP formation if the disinfectant residual is added after the membrane filtration step. NF also filters nearly all multivalent ions, both cations and anions and a portion of the monovalent species.

Because NF membranes also remove alkalinity, the product water can be corrosive, and measures, such as blending raw water and product water or adding alkalinity, may be needed to reduce corrosivity. Nanofiltration systems are often used as softening systems wherein those minerals contributing to hardness, such as calcium and magnesium (both having a +2 valence) are removed from the feed water along with corresponding anions such as carbonates and sulfates (both having a -2 valence). A municipality would typically use a nanofilter for softening or perhaps for organic removal. In other cases, nanofiltration units can be quite useful in the concentration of dissolved metal solutions.

### **Reverse Osmosis**

Reverse osmosis can effectively remove nearly all organic and inorganic contaminants from water. RO can also effectively remove radium, natural organic substances, pesticides, cysts, bacteria and viruses. RO is particularly effective when used in series with multiple units. Disinfection is also recommended to ensure the safety of water.

Some of the advantages of RO are:

- Removes nearly all contaminant ions and most dissolved non-ions;
- Relatively insensitive to flow and total dissolved solids (TDS level and suitable for small systems with a high degree of seasonal fluctuation in water demand);
- RO operates immediately, without any minimum break-in period;
- Low effluent concentration possible;
- Bacteria and particles are also removed; and
- Operational simplicity and automation allow for less operator attention and make RO suitable for small system applications.

Some of the limitations of RO are:

- High capital and operating costs;
- Managing the wastewater (brine solution) is a potential problem;
- Membranes are prone to fouling; and
- Produces the most wastewater at between 25-50 percent of the feed.

### **Membrane Materials**

Normally, membrane material is manufactured from a synthetic polymer, although other forms, including ceramic and metallic “membranes,” may be available. Almost all membranes manufactured for drinking water are made of polymeric material, since they are significantly less expensive than membranes constructed of other materials.

Membranes constructed of polymers that react with oxidants used in drinking water treatment should not be used with chlorinated feed water. Mechanical strength is another consideration, since a membrane with greater strength can withstand larger trans-membrane pressure (TMP) levels, allowing for greater operational flexibility and the use of higher pressures.

Membranes with bi-directional strength may allow cleaning operations or integrity testing to be performed from either feed or filtrate side of the membrane. Membranes with a particular surface charge may remove particulate or microbial contaminants of the opposite charge due to electrostatic attraction. Membranes can also be hydrophilic (water attracting) or hydrophobic (water repelling). These terms describe how easily membranes can be wetted, as well as its ability to resist fouling to some degree.

MF and UF membranes may be constructed from a wide variety of materials, including cellulose acetate, polyvinylidene fluoride, polyacrylonitrile, polypropylene, polysulfone, polyethersulfone, or other polymers. Each of these materials has different properties with respect to the surface charge, degree of hydrophobicity, pH and oxidant tolerance, strength and flexibility.

NF and RO membranes are generally manufactured from cellulose acetate or polyamide materials, and their various advantages and disadvantages. Cellulose membranes are susceptible to biodegradation and must be operated within a narrow, pH range of 4 to 8 but they do have some resistance to continuous low-level oxidants.

Chlorine doses of 0.5 mg/L or less may control biodegradation and biological fouling without damaging the membrane. Polyamide membranes, by contrast, can be used under a wide range of pH conditions and are not subject to biodegradation. Although these membranes have very limited tolerance for strong oxidants, they are compatible with weaker oxidants such as chloramines. These membranes require significantly less pressure to operate and have become the predominate material used for NF or RO applications.

### **Membrane Modules**

Membrane filters are usually manufactured as flat sheet stock or as hollow fibers and then formed into one of several different types of membrane modules. Module construction typically involves potting or sealing the membrane material into an assembly, such as with hollow-fiber module. These types of modules are designed for long-term use over the course of a number of years. Spiral-wound modules are also manufactured for long-term use, although these modules are encased in a separate pressure vessel that is independent of the module itself.

### Hollow-Fiber Modules

Most hollow-fiber modules used in drinking water treatment applications are manufactured for MF or UF membranes to filter particulate matter. These modules are comprised of hollow-fiber membranes, which are long and very narrow tubes that may be constructed of membrane materials described previously. The fibers may be bundled in one of several different arrangements.

#### Hollow Fiber Cross-Section Photomicrograph

When a hollow-fiber module is operated in an inside-out mode, pressurized feed water may enter the center of the fiber at either end of the module, while filtrate exits through a port located at the center or end of the module. In outside-in mode, feed water typically enters the module through an inlet port located in the center and is filtered into the center of the fiber, where the filtrate exits through a port at one end of the module. Most hollow-fiber systems operate in direct filtration mode and are periodically backwashed to remove the accumulated solids.

#### Spiral-Wound Modules

Spiral-wound modules were developed to remove dissolved solids, and are most often associated with NF/RO processes. The basic unit is a sandwich of flat membrane sheets called a “leaf” wound around a central perforated tube. One leaf consists of two membrane sheets placed back to back and separated by a spacer called permeate carrier. Layers of the leaf are glued along three edges, while the unglued edge is sealed around the perforated central tube.

Feed water enters the spacer channels at the end of the spiral-wound element in a path parallel to the central tube. As feed water flows through the spacers, a portion permeates through either of the two surrounding membrane layers and into the permeate carrier, leaving behind any dissolved and particulate contaminants that are rejected by the membrane.

Filtered water in the permeate carrier travels spirally inward toward the central collector tube, while water in the feed spacer that does not permeate through the membrane continues to flow across the membrane surface, becoming increasingly concentrated with rejected contaminants. This concentrate stream exits the element parallel to the central tube through the opposite end from which the feed water entered.

#### **Deposition Mode**

Membrane filtration systems operating in deposition have one influent (feed) and one effluent (filtrate) stream. These systems are also commonly called “dead-end” or “direct” filtration systems and are similar to conventional granular media filters in terms of hydraulic configuration. In deposition mode, contaminants suspended in the feed stream accumulate on the membrane surface and are held in place by hydraulic forces acting perpendicular to the membrane, forming a cake layer.

Most hollow-fiber MF and UF systems operate in deposition mode. Typically, accumulated solids are removed from MF/UF systems by backwashing. However, some systems operate until accumulated solids reduce the flow and/or TMP to an unacceptable level, at which point the membrane cartridge is replaced.

Some MF/UF systems utilize a periodic “backpulse” or a short interval of reverse flow (which may include air and/or addition of small doses of oxidants) designed to dislodge particles from the membrane surface without removing these solids from the system. This process re-suspends particles, effectively concentrating the suspended solids in the feed near the membrane surface

and increasing the potential for pathogens or other particulate to pass through an integrity breach and contaminate the filtrate.

### **Suspension Mode**

In membrane filtration systems that operate in suspension mode, a scouring force using water and/or air is applied parallel to the membrane during production of the filtrate in a continuous or intermittent manner. The objective of operating in this mode is to minimize the accumulation of contaminants at the membrane surface or boundary layer, thus reducing fouling.

### **Backwashing**

The backwash process is designed to remove contaminants accumulated on the membrane. Each membrane unit is backwashed separately and in a staggered pattern to minimize the number of units in simultaneous backwash at any given time. During backwash, the direction of flow is reverse for 30 seconds to 3 minutes. The force and direction of the flow dislodge the contaminants at the membrane surface and wash accumulated solids out through the discharge line. Membrane filtration systems are 15 to 60 minutes between backwash events. The backwash process reduces system productivity 5 to 10 percent due to the volume of filtrate used during backwash. Backwashing is almost exclusively associated with hollow-fiber MF and UF processes.

Backwashing is conducted according to manufacturer specifications and site-specific considerations. Although more frequent backwashing allows for higher fluxes, this is counterbalanced by the decrease in system productivity. In general, a backwash cycle is triggered when a performance-based benchmark is exceeded, such as operating time, volume, increase in TMP, and/or flux decline. Ideally, the backwash process restores the TMP to its clean level; however, most membranes exhibit a gradual increase in TMP after each backwash, indicating accumulation of foulants that cannot be removed by the backwash process alone. These foulants are addressed through chemical cleaning.

Some systems also utilize pressurized air and/or chlorine in combination with filtered water to remove solids, provide pathogen inactivation and biofouling control, and improve backwash effectiveness. A disinfectant such as chlorine may be added at every backwash to once per day. Some MF/UF membranes use chemicals other than chlorine (such as acids, bases, surfactants, or other proprietary chemicals). These strategies are used to enhance membrane flux and extend intervals between chemical cleanings, thus lowering the cost of operation. State regulators may require enhanced cross-connection control measures for backwash piping and special provisions for rinsing the membranes after backwash be required.

Because spiral-wound membranes generally do not permit reverse flow, NF and RO membrane systems are not backwashed. For these systems, membrane fouling is controlled with chemical cleaning, flux control, and cross flow velocity. The inability of spiral-wound membranes to be backwashed is one reason NF and RO membranes are seldom applied to directly treat water with high turbidity and/or suspended solids.

### **Chemical Cleaning**

Chemical cleaning also controls membrane fouling, particularly inorganic scaling and organic and biofouling that is not removed with backwash. Chemical cleaning is conducted for each membrane unit separately and is typically staggered to minimize the number of units undergoing cleaning at any time.

While chemical cleaning is conducted on both MF/UF and NF/RO systems chemical cleaning is the primary mean of removing foulants in NF/RO systems. Although cleaning intervals may vary on a system-by-system basis, gradual accumulation of foulants makes chemical cleaning necessary. Membrane cartridge filters are an exception, however, in that cartridge filters are usually designed to be disposable and are not subject to chemical cleaning.

The goal of chemical cleaning is to restore the TMP of the system to its clean level. Any foulant that is removed by either the backwash or chemical cleaning process is known as reversible fouling. Over time, membrane processes also experience some degree of irreversible fouling which cannot be removed through chemical cleaning or backwashing. Irreversible fouling occurs in all membrane systems, and eventually requires membrane replacement.

There are a variety of different chemicals that may be used for membrane cleaning, and each is targeted to remove a specific form of fouling. For example, citric acid is used to dissolve inorganic scaling. Strong bases such as caustic are typically used to dissolve organic material. Detergents and surfactants may also be used to remove organic and particulate foulants, particularly those that are difficult to dissolve. Chemical cleaning may also use a strong chlorine solution to control biofouling. Due to the variety of foulants present in source waters, it is often necessary to use a combination of different chemicals in series to address multiple types of fouling.

### **Chemical Cleaning Agents**

Proprietary cleaning chemicals are available, and these specialty cleaning agents may be useful when more conventional chemicals are ineffective. For example, enzymatic cleaners have been effective at dissolving organic contaminants. Chemical cleaning options are limited for membranes that cannot tolerate oxidants and/or extreme pH levels. A chemical cleaning regimen may be specified by the manufacturer based on site-specific source water quality.

Clean-in-place (CIP) is often used to describe chemical cleaning since it is typically conducted while the membrane modules remain within the membrane unit (in-situ). The cleaning process re-circulates a cleaning solution through the membrane system at high velocities (to generate scouring action) and elevated temperature (to enhance the solubility of the foulants).

A soak cycle follows the recirculation phase. After the soak cycle, the membrane system is flushed to remove residual traces of the cleaning solution(s). The processes may be repeated using a different cleaning solution to target different types of foulants until the membranes have been successfully cleaned. Softened or de-mineralized water may be required for the cleaning solution, or as rinse water.

While backwashing may be conducted at more regular intervals, chemical cleaning is done only when necessary. Chemical cleaning is generally necessary for MF and UF systems when periodic backwashing to restore system productivity reaches a point of diminishing returns. For NF and RO systems, a 10 to 15 percent decline in flux or a 50 percent increase in differential pressure may indicate the need for chemical cleaning.

Delaying necessary chemical cleaning can accelerate irreversible fouling, reduce production capacity, and shorten membrane life. A benchmark of 30 days is commonly used as a minimum required interval between chemical cleanings for MF/UF systems, although a well-designed

system may operate for much longer between cleanings. NF/RO systems are normally designed to operate for much longer periods between chemical cleanings, from 3 months to 1 year.

In addition to a CIP when a point of diminishing productivity is reached, some MF/UF membrane system manufacturers recommend a routine, short duration chemical cleaning to minimize the accumulation of foulants. These processes are referred to “chemical washes” or “maintenance cleans,” and are implemented on preset intervals ranging from several times per day to once every several days, depending on the propensity of the water to cause membrane fouling.

Isolating cleaning chemicals from the treated (filtered) water is an important consideration. In addition, it is important to properly flush the membrane unit after the cleaning process and before restarting the filtration cycle. The flushed water should be diverted to waste until filtrate water quality parameters (turbidity for MF/UF systems and pH for NF/RO systems) return to normal levels. The volume of flushed water can be significant when surfactants are used.

For MF/US systems, it is common to recycle as much as 90 percent of the cleaning chemicals for reuse, thus reducing the volume of chemical waste as well as the cost associated with cleaning. Recycling cleaning solutions is less common with NF/RO systems, since used cleaning solutions accumulate dissolved constituents with repeated use, diminishing effectiveness of the cleaning agents.

### **Waste Stream Disposal**

Waste stream disposal is a significant problem in many areas. Unlike conventional treatment processes, in which approximately 5 to 10 percent of the influent water is discharged as waste, membrane processes produce waste streams as much as 15 percent of the total treated water volume. Because little or no chemical treatment is used in a membrane system, the concentrate stream usually contains only the contaminants found in source water (although at much higher concentrations), and concentrate can sometimes be disposed of in the source water. Other alternatives include deep well injection, dilution and spray irrigation, or disposal in municipal sewer. These alternatives are usually necessary for NF wastes, which usually contain concentrated organic and inorganic compounds. Disposal must be carefully considered and applicable discharge regulations must be respected.

### **Membrane Integrity Testing**

One of the most critical aspects of employing membrane technology is ensuring that the membranes are intact and continuing to provide a barrier between the feedwater and the permeate or product water. There are several different methods that can be employed to monitor membrane integrity, including turbidity monitoring, particle counting or monitoring, air pressure testing, bubble point testing, sonic wave sensing, and biological monitoring.

## INDIVIDUAL FILTER SELF ASSESSMENT

Based on individual filter monitoring requirements in the IESWTR, some systems may be required to conduct an individual filter self assessment. Specifically, a system must conduct an individual filter self-assessment for any individual filter that has a measured turbidity level greater than 1.0 NTU in 2 consecutive measurements taken 15 minutes apart in each of 3 consecutive months. The system must report the filter number, the turbidity measurement, and the dates on which the exceedances occurred.

Filters represent the key unit process for the removal of particles in surface water treatment. Although filters represent only one of the “barriers” in a treatment process their role is the most critical as the final physical “barrier” to prevent passage of chlorine resistant pathogenic microorganisms into distribution systems. Properly designed filters used in conjunction with coagulation, flocculation and sedimentation processes (if in use), when in proper physical and operational condition, are capable of treating raw water sources.

For any situation regarding a single poor performing filter, or a bank of poor performing filters:

- Performance limitations observed at the start of a filter run are most often attributed to improper chemical conditioning of the filter;
- Limitations observed during the filter run are most often attributed to changes in hydraulic loading conditions; and,
- Limitations observed at the end of the filter run are most often related to excessive filter runs.

Filter performance issues may only be apparent during excessive hydraulic loading and care should be taken to not attribute all turbidity spikes to hydraulic bumping or overloading. In some circumstances performance “symptoms” for other causes may only be evident during these hydraulic episodes. Oftentimes disrupted filter media may cause filter performance problems. The following section describes the components of an individual filter self assessment.

- **A general description of the filter** including size, configuration, placement of washwater troughs and surface wash type (if applicable) and filter media design(e.g., type, depth and placement) and if filter-to-waste is present and/or used and if any special conditions exist regarding placing a filter back into service (i.e., is the filter rested, polymer or coagulant added prior to placement into service, etc.).
- **The development of a filter run profile** of continuous turbidity measurements or total particle counts versus time for an entire filter run from start up to backwash, including assessment of filter performance while another filter is being washed. The run length during this assessment should be representative of typical plant filter runs. The profile should include explanations of the cause of performance spikes during the run.
- **An assessment of the hydraulic loading conditions of the filter** which includes: the determination of the peak instantaneous operating flow for the individual filter, an assessment of the filter hydraulic loading rate at this peak instantaneous operating flow, and an assessment whether plant flow is distributed evenly among all the filters.
- **An assessment of the actual condition and placement of the media** with a comparison to the original design specifications. The filter bed should be investigated for surface cracking, proper media depth, mudballs and segregation

of media in dual media filters. The media should be examined (using coring and/or gross excavation techniques as appropriate) at several locations to determine the depth of the different media layers in dual and multi-media filters.

- **A description of backwash practices** including length, duration, presence of and type of surface wash or air scour, and method for introducing wash water (i.e., via pump, head tank, distribution system pressure, etc.) and criteria for initiating the wash (i.e., degraded turbidity or particle counts, head loss, run time, etc.), the backwash rate, and bed expansion during the wash.
- **An assessment of the condition of the support media/underdrains** including a filter grid detailing placement of support media, as well as a summary of inspection of the clearwell for the presence of filter media and any observances of boils or vortexing during backwash.
- **An assessment of the filter rate-of-flow controllers and filter valving infrastructure adequacy.** The rate-of-flow controllers and ancillary valving related to the filter can also have an impact on filter performance and should be visually inspected to assure proper operation.

## TURBIDITY MONITORING

Turbidity, or the relative clarity of a liquid, is caused by the presence of microscopic particles such as clay, silt, or other fine undissolved matter. When water is treated for human consumption, its clarity becomes a critical matter. Microscopic particles, even at a very low concentration, can promote microorganism growth, which can inhibit the chlorination process that helps disinfect and purify our water. The measurement of turbidity has become the leading indicator of drinking water quality and can provide key benefits to a drinking water treatment plants operation by:

- Determining incoming or raw water quality to the treatment facility;
- Guiding plant operators in a treatment plan via water quality checks throughout the plant;
- Helping improve plant efficiency and optimizing proper chemical coagulant dosage;
- Providing the assurance of the production of quality safe water for public distribution; and,
- Indicating compliance with current drinking water regulatory standards.

The initial treatment stages in a drinking water plant deal with incoming raw water. Raw water turbidity monitoring, usually in the range of 0-200 NTU, provides a good indication of the solids loading entering the plant. Raw water is typically processed in 3 initial treatment stages:

- **Plant Intake:** Raw water is pumped into the plant from the source. Incoming water is often passed through a screen to remove large debris and, in most cases, pretreatment with chlorine, potassium permanganate or ozone is necessary here to destroy microbiological contaminants and oxidize materials which may cause taste and odor problems.
- **Flash Mixers:** Chemical coagulants like alum, polymers, or ferric chloride are added here to help form floc or aggregate of suspended particles. Carbon may also be added in this stage to control taste and odor.
- **Flocculation Basin:** Treated water is then mixed, ideally for at least 30 minutes, to create enough disturbance to aid the flocculation process. Other chemicals may be added to adjust the pH of the water, making conditions optimum for the formation of floc.

After treatment of the raw water, treated water enters 2 intermediate processing stages:

- **Settling Basin:** The water flows into the settling basin where approximately 90% of the suspended particles, now captured by the floc, settles to the bottom of the basin where it is removed as sludge.
- **Filter Beds:** As suspended solids still remain, the water is next filtered through filter beds. Filter beds usually consist of different grades of stone, sand, and sometimes, activated charcoal. In this stage gravity guides water through the filter bed and any remaining suspended particles are trapped. Low range turbidity monitoring, in the critical 0-1.0 NTU range, is required at this filtration stage - on each individual filter. Periodically, filter beds are cleaned by a backwashing process that reverses the flow of water through the filter bed. This process removes particles that were trapped during gravity filtration and sends this filter bed wastewater off for treatment.

After filtration, the water is treated with some form of chlorine disinfection and sent to a clear well or final processing stage:

- **Clear Well:** Two things take place here. First, the disinfection process is allowed additional contact time to ensure adequate protection from microbial growth as the drinking water moves into distribution. Second, it allows for storage of excess water to ensure the plant has an adequate supply of water available during times of large demand. It is also a combined filter collection point where turbidity is monitored for regulatory reporting purpose, in the critical 0-0.3 NTU range. From here the drinking water is piped to the public through the water distribution system.

## **PARTICLE COUNTERS**

The purpose of a Water Treatment Plant is to remove particulates and pathogens from water that may pose a health threat to consumers. The Surface Water Treatment rule established requirements to include a 3-log removal-inactivation of *Giardia* cysts and a 4-log removal-inactivation of viruses. The upcoming Enhanced Surface Water Treatment Rules include requirements for *Cryptosporidium*. These organisms are very resistant to common disinfection practices; therefore, emphasis is placed on removing these pathogens in the treatment process. The SWTR requires surface water systems to measure turbidity in filtered samples. Turbidity is an indicator of filtration efficiency for removal of pathogens and the treatability of water by disinfection. Most studies show that *Giardia* and *Cryptosporidium* can effectively be removed with an efficient treatment process which includes filtration that reduces turbidity below specific values. *Giardia* sized particles can pass through the treatment process with no substantial increase in filtered water turbidity noted. This happens because low concentrations of micron-sized particles scatter relatively little light. Therefore, turbidity will not always provide a satisfactory measurement of protozoan cyst-sized particles.

### **Turbidimeters**

Turbidity monitoring of filtered water is presently used as a surrogate measurement to indicate that pathogenic organisms such as *Giardia* and *Cryptosporidium* are being removed. In simple terms the interaction between light and suspended particles in water is called turbidity. This interaction is affected by several factors, including size, shape, composition of particles and wavelength of light. An important characteristic of turbidity measurement is that given a mass concentration of particles the turbidity is less for larger sizes. This statement means that larger particles could be in a sample but contribute very little to the turbidity reading. Turbidity is a “relative” measure of water clarity that is not directly related to physical parameters. Most turbidimeters illuminate a relatively large view volume of sample water using a tungsten filament light bulb, then detect the light scattered at right angles from a “cloud” of particles in an electronic photodetector. The brightness of the cloud forms the electronic output of the instrument. If the particles are dark, such as carbon fines or have low light scattering ability like algae or pathogenic microorganisms, the light signal can be deficient. On the other hand if there are high populations of very fine particles, which scatter light more efficiently than larger particles then the light signal will be exaggerated.

### **Particle Counting**

Current advances in light generation technology have afforded a more precise method of particulate monitoring i.e. the particle counter. Particle counting technology has long been established in the medical, manufacturing and electronics fields. This technology has recently been adapted for use in the water treatment field. The number, size, shape and composition of particles in a water sample affects the turbidity. Turbidity is therefore more of an index of water quality. Particle counters on the other hand, size and count particles. Particle counting and its technology extends the sensitivity of measuring particles beyond that achievable from turbidimeters. The sensitivity of the particle counter can be utilized to detect the effects on effluent water quality due to operational procedures, chemical dosage and parametric changes. The particle monitor provides a sensitive indication of low range concentrations of particles in water. The device is extremely sensitive to any particle passing through a sample cell that is greater than 3 microns in size. This sensitivity is especially significant because *Giardia* and *Cryptosporidium* cysts have been shown to be in the 2 to 8 micron size range. In settled or filtered water *Giardia* and *Cryptosporidium* can be entrapped in floc particles.

### **How a Particle Counter Works**

The light blocking type of particle counter is the one most commonly used in potable water applications today. A particle monitor consists of a sampling tube, an infrared light-emitting diode (LED) and photodetector. A narrow light beam from the LED is transmitted through a flowing sample. Fluctuations in the light beam are measured by the photodetector. Particles in the sample stream cross the laser beam blocking a portion of the light, thus creating a moment of diminished light and a corresponding electronic signal pulse. This pulse is proportional to the size of the particles and is measured in height and tabulated according to its respective particle size. At the end of the sample period the counts for each specified particle size range are totaled and the particle counts are calculated and presented on a count per milliliter basis. Thus, optical particle counters furnish a direct measurement of physical parameters, i.e. particle counts per milliliter of sample, categorized by particle size range

### **What Can Particle Counting Tell Us?**

There can be no direct consistent correlation between turbidity as measured in NTU's and particle counts as measured in particles per milliliter. Particle counting provides more information and greater sensitivity since particles are individually sized and counted. What practical use does particle counting have for the water industry? Particle counting provides a precise and vital tool that extends water plant particulate monitoring and analysis to levels far beyond those afforded by turbidity alone. It allows for greater control of particulate removal through more precise monitoring, improved sensitivity, finer resolution and a better understanding of particulate characteristics. Such data has broad applicability for the water treatment process. Particle counting has the potential for:

- analyzing raw water particulates so that treatment could be geared specifically to optimize removal as raw water quality changes;
- optimizing chemical dosage;
- analyses the effectiveness and efficiency of different chemicals alone or in combination in the coagulation process;
- measuring particulates in filter effluent;
- comparing filter effluent water quality from different filters;
- determining filter efficiency in terms of percent removal of particles;
- serving as a surrogate measure for removal of pathogens such as bacteria, viruses, Giardia Lambia, and Cryptosporidium;
- distinguishing performance between different filter media; and
- comparing filter effluent quality between different treatment plants.

## DISINFECTION

Disinfection is used to kill disease-causing (pathogenic) microorganisms in the water system; therefore, it should not be confused with sterilization, which is the destruction of all living microorganisms.

The operator also needs to be aware that changes in the pH may affect the ability of the chlorine to disinfect the water. The operator needs to understand:

1. **Injection point** – whether the injection point and the method of mixing is designed so that the disinfectant can get into contact with all of the water to be disinfected.
2. **Contact time** – expressed as CT value, the residual disinfectant “C”oncentration in mg/L multiplied by the corresponding disinfectant contact “T”ime in minutes. The “C” concentration of the chemical and the “T” length of contact time needed to adequately kill or inactivate pathogens vary with different types of disinfectant.
3. **Effectiveness of upstream treatment processes** – the lower the turbidity (cloudiness) of the water, the more effective the disinfection.
4. **Temperature** – at higher temperatures, the rate of disinfection is more rapid.
5. **Dosage and type of chemical** – usually the higher the dose, the quicker the disinfection rate. The form of disinfectant (chloramines vs. free chlorine) and the type of chemical (gas vs. liquid) used influence the disinfection rate.
6. **pH** – the lower the pH, the better the disinfection action.

When chlorine is initially added to water, the following may occur:

1. If the water contains iron, manganese, organic matter, or ammonia, the chlorine reacts with these materials and no residual is formed, meaning that no disinfection has taken place.
2. If additional chlorine is added at this point, it will react with the ammonia to form chloramines. The chloramines are considered a “combined” chlorine residual. As the chlorine is combined with other substances, it loses some of its disinfection strength. Combined residuals have less disinfection power than free (non-combined) residuals and may be the cause of taste and odor problems.
3. Some systems intentionally add ammonia to extend the life of the chlorine so residuals are carried to end-points in large distribution systems. The resulting combined chlorine is not as strong as free, but lasts longer.
4. With a little more chlorine added, the chloramines and some of the chlororganics are destroyed.
5. With still more chlorine added, free chlorine residual is formed, free in the sense that it can react quickly. Free also dissipates more quickly than combined.

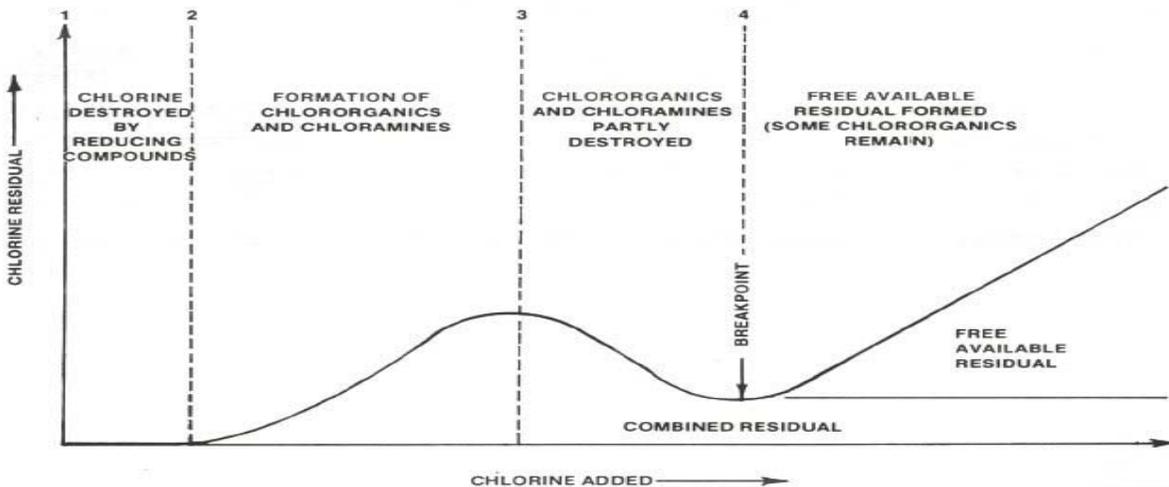
Most chlorine analyses are performed with the DPD method. DPD reagent will change color in the presence of chlorine when added to a water sample. A manual color comparator (color wheel held up to the light) or a colorimeter (digital readout) that automatically measures the intensity of the color is used to determine the concentration of chlorine residual in the water sample.

## Disinfection Requirements

West Virginia requires some form of chlorine to be used during disinfection, in order, to maintain the required 0.2 mg/L of total chlorine residual in the distribution system. West Virginia requires a 4-log removal/inactivation of viruses for groundwater systems.

## Breakpoint Chlorination

When chlorine is added to water that contains no ammonia, the residual that is obtained will be free available chlorine. If ammonia is present, and the demand has been satisfied, some of the free chlorine will react with the ammonia to form chloramines or combined chlorine residual. As more chlorine is added, it will breakdown the chloramines that have been formed and the combined residual will begin to drop. A point will be reached where the residual will begin to rise again after all of the chloramines, that can be, are destroyed. There may be some combined residual left in the water at this point. From this point, any additional chlorine dosage will result in the formation of only free chlorine residual. This is known as the “breakpoint”. All water systems that chlorinate their water will, in fact, practice breakpoint chlorination. They will add enough chlorine to the water to achieve a free chlorine residual of at least 0.2-0.5 mg/L.



## Chlorine Treatment Terms

Several terms are used to identify the various stages and reactions that occur when chlorine is used as a disinfectant. The basic unit of measurement for chlorination, or any other chemical treatment is mg/L or ppm. These are very small units reflecting concentrations that are essentially one part chemical for every million parts of water. To get some idea of how small a concentration this really is it should be pointed out that 1% is equal to 10,000 mg/L or ppm.

## Chlorine Dosage

The chlorine dosage is the amount of chlorine that is added to the water. The dosage can be determined from the number of pounds of chlorine used and the number of millions of pounds of water treated.

## Chlorine Demand

Chlorine is a very reactive oxidizing agent. It will react with a certain substances that may be found in water. This list includes; iron, manganese, hydrogen sulfide, ammonia and other inorganic or organic materials in the water. When chlorine reacts with these substances, it loses its disinfecting properties. This is referred to as the chlorine demand. For chlorine to be effective as

a disinfectant, the dosage must always exceed the demand that is present in the water. The chlorine demand may vary from day to day in a surface water supply. It is usually fairly constant in a groundwater supply.

### **Chlorine Residual**

The chlorine that remains in the water, after it has finished reacting with those substances that represent the demand, is known as the chlorine residual. There are two types of residuals that result from the chlorination of water. They are free chlorine residual and combined chlorine residual.

### **Free Chlorine Residual**

Chlorine in this form has the highest disinfection ability. After the demand has been satisfied, any chlorine that is left will react with water to form hydrochloric acid and hypochlorous acid.

### **Combined Chlorine Residual**

Chlorine reacts with water to form hypochlorous acid. If ammonia is present, the hypochlorous acid will react with it to form compounds known as chloramines. Chloramines are weak disinfectants. They require longer contact times and higher concentrations to achieve disinfection than free chlorine residual. However, they do not breakdown as quickly as free chlorine and remain in the system longer.

### **Total Available Chlorine**

The total available chlorine is the sum of free available chlorine and combined available chlorine.

### **Testing for Chlorine Residuals**

Chlorine residual determinations and reporting are an important responsibility of the operator. Chlorine residual is most commonly measured using a **DPD** (Diethyl-p-Phenylene-Diamine) colorimeter test kit. This kit indicates the chlorine residual level by comparing the color produced with the DPD chemical addition to the water with a standardized color residual indicator. Not all test kits use a “color wheel”. Some kits consist of colorimeters or spectrophotometers for measuring the color intensity.

### **Forms of Chlorine**

Chlorine is applied in one of three forms; chlorine gas, chlorine powder, or an aqueous solution like chlorine bleach.

### **Chlorine Gas**

Chlorine gas is a greenish-yellow material with a penetrating and distinctive odor. It is more than two and a half times as heavy as air so will settle in low areas if it is released into the atmosphere. It is a poisonous gas and must be handled with care. Chlorine gas is not corrosive unless it is in a moist atmosphere or in contact with any moisture. It then becomes highly corrosive and is especially destructive to electrical equipment.

Chlorine gas ( $\text{Cl}_2$ ) is compressed into a liquid for storage. It can be purchased in steel cylinders containing 100, 150 or 2000 pounds of the liquefied gas.

### **Chlorine Powder**

Chlorine in its dry form is calcium hypochlorite,  $\text{Ca}(\text{OCl})_2$ , is a white solid which is available in

powder, granular or tablet form. Only about 65 – 70% of  $\text{Ca}(\text{OCl})_2$  is available as chlorine. The rest is calcium, which is not a disinfectant. It is normally dissolved in water and then injected into the drinking water using a solution feeder. Calcium hypochlorite is a powerful oxidizing agent and must be handled with care, kept dry and away from combustible materials. It may start a fire if the white solid material comes into contact with organic materials, such as an oily rag.

It is also most commonly known by the trade name **HTH (High Test Hypochlorite)**, Perchloron or Pitclor.

### **Chlorine Bleach**

Chlorine bleach is an aqueous solution of sodium hypochlorite,  $\text{NaOCl}$ , containing 5 to 15% available chlorine. The 5.25% solution is sold in grocery stores under trade names such as Clorox, Purex, etc. This form can be used for emergency disinfection and then flushed away, but is not usually used for continuous chlorination. Sodium hypochlorite can be conveniently added to water using a small solution feed pump.

## **Disinfection Treatment Technologies Listed in the SWTR**

### **Ozone**

Ozone is the strongest oxidizing available for water treatment. Ozone is a powerful oxidant able to achieve disinfection with less contact time and concentration than all weaker disinfectants, such as chlorine, chlorine dioxide, and monochloramine. However, ozone can only be used as a primary disinfectant since it cannot maintain a residual in the distribution system. Thus, ozone disinfection should be coupled with a secondary disinfectant, such as chlorine, chloramine, or chlorine dioxide for a complete disinfection system.

Ozone can also be used to oxidize the following types of compounds: taste and odor compounds, certain organics, iron and manganese, and sulfides.

### **Chlorine**

Chlorination in its several forms is the most widely used disinfectant at public water supplies. Hypochlorites are available in solid (e.g., tablet) or liquid (solution pump-fed) forms. The use of gaseous chlorination (while available) at small water supplies may not be among the best disinfection options due to the hazardous nature of the material. Use of gaseous chlorine places greater demand on the need for isolated plant space, on providing trained and attentive operating staff and their protection from any hazards, and, possibly, on liability issues which may boost insurance costs for small PWSs.

### **Chloramines**

Chloramines, while possessing certain advantages over other disinfectants (e.g., long residual effect and low production of disinfection byproducts), have not been widely used in disinfection at small PWSs. Chloramine disinfection requires careful monitoring of the ratio of added chlorine to ammonia. Failure to do so can result in odor and taste problems or biological instability of water in the distribution system. Compared to free chlorine and ozone, chloramines possess less potency as a germicidal agent, and would therefore require longer CTs.

### **Chlorine Dioxide**

Chlorine dioxide, although a powerful oxidant, may be more difficult to handle than other forms of chlorine. Chlorine dioxide requires trained staff to manage its use and is so reactive (and thus,

is consumed very readily) that it may not provide a residual disinfectant in the distribution system.

### **UV Radiation**

**Ultraviolet (UV)** radiation has been found to be an effective disinfectant in relatively clean source waters. Historically, UV has been adapted to disinfect reclaimed water, treated sewage, industrial process water, and small groundwater supplies. Simplicity of installation, ease of operation and maintenance, and low costs relative to chemical disinfection, make UV a useful small systems disinfection technology option.

### **Mixed-oxidants**

Mixed-oxidant disinfection, which involves the on-site electrolytic generation of mixed disinfectants, is an emerging approach to disinfection. The process can also be referred to as “anodic disinfection”. The process involves the generation of ozone, chlorine dioxide, hypochlorite ion, hypochlorous acid, and elemental chlorine from the passage of an electric current through a continuous-flow brine (salt) solution. The solution containing these oxidants is then injected into the raw water for treatment.

Compared to the use of a single oxidant, the use of multiple oxidants can be more effective. This is due to several factors: (1) different oxidants have different ranges of conditions where they are most effective; (2) different oxidants have different residual durability; and (3) combinations of oxidants can act synergistically as disinfectants. Thus, mixed-oxidants are more effective against a broader spectrum of microorganisms when used properly. The increased effectiveness and reaction rate of mixed-oxidants as compared to chlorination is due to the combined action of ozone, chlorine dioxide, and chlorine. Both ozone and chlorine dioxide are considered stronger oxidants than chlorine. Another advantage of mixed-oxidant disinfection is that research indicates that mixed-oxidant disinfection may produce fewer disinfection by-products, such as trihalomethanes (THMs), than other chlorination

## **CHLORINE POINTS OF APPLICATION**

When chlorination of water was first employed for disinfection, terminal treatment of the plant effluent was almost invariably practiced. Now the use of chlorine in various stages of water treatment, and even in the distribution system, is common practice. Multiple or split chlorination schemes are increasingly employed for disinfection and other purposes and frequently enhance the efficiency of many-unit water-treatment processes. Fundamentally, the points at which chlorine is applied depend on the specific objectives of chlorination-technical, practical, safety, economic, and other considerations. In practice, various terms have come into common usage to specify the point and location at which chlorine is applied.

### **Plain or Simple Chlorination**

Simple chlorination involves the application of chlorine to water that receives no other treatment. More than half of all existing water treatment plants in the US fall in this category; thus, this treatment represents their sole public health safeguard. When applied to impounded or naturally elevated surface systems, chlorine usually is injected to the pipeline leading from such a gravity supply. When applied to water pumped into a system, chlorine usually is added at the pump suction, using pressure beyond the pump to operate the chlorine feeders.

### **Prechlorination**

Prechlorination involves the application of chlorine to water prior to any other unit treatment process. Among benefits that can be achieved are improved filter operation by reduction and equalization of the bacterial and algal load and by control of slime and mud ball formation; improved coagulation; reduction of taste-, odor-, and color-producing materials by oxidation and retardation of decomposition (in settling units); and the provision of a safety factor in disinfecting heavily contaminated waters while keeping the chlorine residual in the distribution system at a minimum. When prechlorination is employed it usually is desirable to obtain a contact period that is as long as possible, preferably by applying chlorine to the raw water suction intake to provide contact during the entire purification process. The dosage, of course, depends on the objective. In some cases, free chlorine residuals may suffice. Care must be exercised to maintain the proper residual necessary to accomplish the desired objective.

### **Postchlorination**

Postchlorination involves the application of chlorine to water following any other unit treatment process. The most important form of postchlorination is that following filtration for disinfection, to provide either a free or combined residual chlorine in a part of or the entire distribution system. The contact period provided to effect disinfection is an important consideration; chlorine is usually added to the filter effluent. When postchlorination follows prechlorination and precedes filtration, greater filter residual in the delivered water to a predetermined amount and thus reestablishes the portion of chlorine that had been consumed in the purification process.

### **Rechlorination**

Rechlorination involves the application of chlorine to water, following the previous chlorination treatment, at one or more points in the distribution system. The practice, which may involve free or combined residual chlorination, is especially common where the distribution system is long and complex and where the plant effluent residual is insufficient to control bacterial and algal regrowth, red-water troubles, etc. The chlorine may be applied at the end of a long main in the distribution system, at a point where a main supplies water to an outlying community, or at such places as a reservoir, standpipe, or booster pumping station.

**Dechlorination**

When combined residual chlorination or free residual chlorination is employed, chlorine residuals of a certain type and intensity must be attained to accomplish a particular objective. In some instances the residual might be of such magnitude that the water will be aesthetically or otherwise objectionable, and a portion of the residual will have to be removed. Dechlorination is the partial or complete reduction of residual chlorine in water by any chemical or physical treatment.

## **FULL-TIME CHLORINATION**

PWSs must demonstrate that continuous disinfection is being practiced. The PWS operator must monitor daily the amount of chlorine being added (free chlorine) and the total chlorine residual obtained in the distribution system.

### **Chlorine Gas**

When gas chlorine is used for continuous disinfection it is typically fed by use of a vacuum operated, solution feed chlorinator. For safety reasons, the chlorine is handled under vacuum so any leaks will leak air into the chlorinator instead of allowing chlorine to leak into the air. The vacuum is produced in an ejector in which a small stream of water is pressured through a nozzle orifice. The vacuum produced opens a check valve and an internal valve in the chlorinator allowing chlorine to feed from the tank into the ejector where it is mixed with the water stream from the nozzle. The resulting chlorine solution is mixed with the main stream of water to be disinfected. A variable orifice flow meter (rotometer) mounted on the chlorine gas cylinder indicates the chlorine flow rate with a small black ball suspended in a glass tube. When using a gas chlorinator, the ejector water is usually controlled either by a solenoid valve or by starting and stopping a booster pump so the chlorination system operates while the well pump is pumping and shuts down when the well pump is off.

### **Calcium or Sodium Hypochlorite**

Hypochlorination, using either calcium hypochlorite or sodium hypochlorite, is often the most practical method of disinfection for small water systems.

Calcium hypochlorite is usually the least expensive of the two and is often selected for that reason. Typically, the hypochlorite is dissolved into a water solution and metered into the flowing water stream using a small diaphragm or plunger-type pump.

Calcium hypochlorite tablets will not dissolve readily in water colder than 41°F, so the availability and temperature of the mixing water must be considered. In hard water, calcium hypochlorite may form a calcium carbonate precipitate, which will interfere with the solution feed pump unless the chlorine solution is prepared in a separate tank and allowed to settle. The clear liquid is then siphoned to a storage tank for use.

Sodium hypochlorite may also form some precipitate but may not need to be settled and siphoned. Sodium hypochlorite is often fed at full strength from the container, allowing for fewer problems in handling.

Hypochlorination requires close attention by the operator as the pump and injection point often build scale. The scale will prevent the pump poppet valves from sealing and the pump will not move the solution into the water to be disinfected. Maintenance of the pump, and especially cleaning the pump valves, should be on a regular weekly schedule, or as often as experience indicates.

## CHLORINE MONITORING

Chlorine monitoring assures proper residual at all points in the system, helps pace re-chlorination when needed, and quickly and reliably signals any unexpected increase in disinfectant demand. Monitoring chlorine levels in the system also can serve as a "surrogate" for detecting potentially threatening contamination, because many chemical and biological contaminants are known to combine with chlorine. Therefore, a significant decline or loss of residual chlorine could be an indication of potential threats to the system.

Monitoring for free residual chlorine and total residual chlorine (free available plus combined available chlorine) is a state requirement. The following sections outline the procedures for monitoring the residual chlorine levels in municipal water.

Chlorine concentrations can be measured either in the field using simple field kits or in the laboratory using more sophisticated procedures and equipment. Most field kits work from a similar principal where an indicator is added to a water sample and the color of the solution is compared to a set of colored standards. The colors in the standards have been calibrated in a laboratory to match set concentrations of chlorine. For instance, if a water sample is placed in a glass vial containing an indicator, and the solution turns dark red, this indicates a higher concentration than if the solution turns faint pink.

The limitation to field kits is their detection limits. The detection limit is typically 0.1 ppm. However, even though it cannot be quantified, these kits can identify trace concentrations of chlorine if a faint color is present. Laboratory methods, on the other hand, have lower detection limits, but are generally not applicable because the chlorine dissipates more quickly and will be lost during transport (unless it is in the combined chlorine form).

### **DPD Indicator**

One kit uses **N, N-Diethyl-p-Phenylenediamine (DPD)** as the indicator solution. This method determines chlorine content according to the DPD Method 409F described in the 21th edition of *Standard Methods for Examination of Water and Wastewater*.

The water is collected in a sample tube and the indicator is added to this tube. It uses tablets or powder pillows to dye water samples to a degree proportional to the chlorine content in the sample. When the water in the tube changes color, the color is compared to 9 or 10 colors present in similar smaller tubes located on a color disk. The color disk is rotated until the color closely matches that inside the test tube. The disk color relates to a concentration. The method can differentiate between combined chlorine and free available forms by using different types of indicator. Fresh indicator should always be used as old DPD can give false readings. This type of kit detects from 0.1 to 5.0 ppm chlorine.

### **Spectrophotometers**

There are a number of field spectrophotometers that can be used for measurement of residual chlorine levels. One model is a pocket-sized instrument that tests for free and total residual chlorine over the operating range of 0 to 4.0 ppm. The meter reads in 0.01 ppm increments with an accuracy of 0.05 ppm. The reagent used in these types of instruments is typically DPD, as described above.

## **Laboratory Analysis**

Laboratory analysis for total residual chlorine in water is not recommended due to the very short storage time that a sample can remain stable, and the relatively long turnaround time for results. Chlorine dissipates from a water sample very quickly as a result of exposure to light, increased temperature, and agitation. According to the EPA standard laboratory techniques for residual chlorine analysis Method 4500-Cl, samples to be analyzed for residual chlorine should not be stored at all, but analyzed immediately. The EPA Standard Method 4500-Cl outlines different methods to detect residual chlorine, including:

- Iodometric Method;
- Amperometric Titration Method;
- Low-Level Amperometric Titration Method
- DPD Colorimetric Method;
- Syringaldazine (FACTS) Method; and
- Iodometric Electrode Technique.

The advantage of these methods is that the detection limits are as low as 0.010 mg/L (ppm or 10 µg/L (ppb), depending on the sophistication of the equipment.

*It is recommended that sampling for free and total residual chlorine be completed in the field using a field testing kit to obtain the best results.*

## **Interferences**

The field methods used to measure total residual chlorine can give false readings in some circumstances. For example, the DPD indicator method is subject to interference by oxidized forms of manganese. The test may indicate chlorine is present when it is the interfering compound reacting with the indicator to give a false reading. High sample color and turbidity may also cause interference and give inaccurate readings.

When an interference is suspected, chlorine free samples should be measured to establish background readings. This can be done by taking a water sample and agitating the water for a few minutes to decrease chlorine levels in the sample, and then taking a chlorine reading on that sample. If the reading does not decrease repeat the agitation procedure a few more times. If a positive result is still obtained, it is likely that an interference is present, which must be taken into account during the monitoring program. For example, in the case of the pocket photometer the background reading can be subtracted from the reading obtained with the true sample for low turbidity samples, but not for samples that have a false positive interference.

Another interference may occur when the chlorine residual is a high enough concentration that the reagent (DPD) will bleach out and no color will develop. This will result in a false negative reading.

## **On-line Monitoring**

Effective December 1, 2009, all water treatment plants designed to serve 3,300 people or more shall be equipped with recording chlorine analyzers and continuous recorders monitoring water entering the distribution system. The chlorine residual on-line monitoring requires a continuous flow of water through the flow cell. Every 2.5 minutes a sample is retained in the flow cell to measure blank absorbance (color intensity) before reagents are added. This compensates for turbidity in the sample and provides an automatic zero reference point. Reagents are then added to the flow cell and a magnetic stirring motor mixes the sample. After color development, the

color intensity is measured and compared to the reference. The difference between the two readings is used to calculate the chlorine concentration. Analyzing range is 0-5 mg/L. These units also require about three feet of wall space, 120 VAC, water supply and drain. The analyzer will need to be assembled according to manufacturer's instructions. Once the unit is assembled and installed the buffer and reagent will need to be installed following instructions in the manual. The system will prime itself and be ready for service. High and low chlorine alarms may be set as well. These alarms can be used to take pumps off line, if there is a problem with the chlorination equipment. A 4-20 mA is available for SCADA or chart recorder outputs. Over time, the analyzer can start to drift on the chlorine readings. The analyzer should be checked at least weekly with a grab sample. Depending on water conditions, the flow cell will need to be cleaned weekly. The buffer and reagent must be replaced once a month. The tubing will need to be changed annually.

## CT

This stands for the **contact time (CT)** between disinfectant and microorganism and the concentration of disinfectant. CT is used to calculate how much disinfectant is required to adequately disinfect water. C refers to the final residual concentration of a particular chemical disinfectant in mg/L. T refers to the minimum contact time (minutes) of material that is disinfected with the disinfectant. Therefore, the units of CT are expressed in mg-min/L. For this discussion, chlorine will be used in place of disinfectant.

$$\text{CT} = \text{disinfectant concentration} \times \text{contact time} = \text{C mg/L} \times \text{T minutes}$$

When chlorine is added to water, it does not only react with pathogenic microorganisms, but also with other impurities, such as soluble metals, particles of organic matter and other microorganisms. The chlorine demand is created when the chlorine reacts with these substances. The chlorine demand must first be satisfied, before a chlorine residual concentration can be established. The chlorine concentration (or chlorine dose) that has to be added to water is made up by the sum of the chlorine demand and the chlorine residual. Once there is a chlorine residual, this chlorine residual has to be maintained during the required contact time to kill pathogenic microorganisms. To adequately disinfect the water it is therefore required to supply the water with a higher chlorine dose than the concentration required to kill pathogenic microorganisms. The time required to deactivate a particular microorganism decreases when the applied chlorine dose is increased.

The CT concept was developed specifically for surface water, with the assumption that PWSs would be trying to inactivate both *Giardia* and viruses. Since the CT required to provide 3-log inactivation of *Giardia* is at least enough to provide the required 4-log inactivation of viruses, the EPA just set the standard for *Giardia* and ignored viruses.

The CT is commonly used to determine the effectiveness of a particular disinfectant against a certain microorganism under specified conditions. There is a difference between the relative affectivity of chemical disinfectants against different microorganisms. Often a certain level is added to the CT, for example 99%. This means that 99% of the microorganisms are deactivated by the disinfectant. CT can be used to compare the affectivity of various disinfectants against microorganisms (Table 1). According to Table 1, ozone is the most effective disinfectant; the CT value of ozone is very low. Chloramines are least effective and cannot be used against *Giardia*. Chlorine is effective against *E. coli* bacteria. The CT value of chlorine used against *Giardia* is a lot higher than that of chlorine used against *E. coli* bacteria.

**Table 1: Comparison of CT values for the 99% inactivation of microorganisms at 5 °C**

<b>Organism</b>	<b>Free chlorine (pH 6-7)</b>	<b>Chloramines (pH 8-9)</b>	<b>Chlorine dioxide (pH 6-7)</b>	<b>Ozone (pH 6-7)</b>
<i>E. coli</i> bacteria	0.034 – 0.05	95 – 180	0.4 – 0.75	0.02
<i>Polio virus</i>	1.1 – 2.5	770 - 3740	0.2 – 6.7	0.1 – 0.2
<i>Giardia</i> cysts	47 - 150	-	-	0.5 – 0.6

**The type of microorganism**

Disinfectants can effectively kill pathogenic microorganisms (bacteria, viruses and parasites). Some microorganisms can be resistant. *E. coli* bacteria, for example, are more resistant to disinfectants than other bacteria and are therefore used as indicator organisms. Several viruses are even more resistant than *E. coli*. The absence of *E. coli* bacteria does not mean that the water is safe. Protozoan parasites like *Cryptosporidium* and *Giardia* are very resistant to chlorine.

**The age of the microorganism**

The effectiveness of a particular disinfectant also depends upon the age of the microorganism. Young bacteria are easier to kill than older bacteria. When bacteria grow older, they develop a polysaccharide shell over their cell wall, which makes them more resistant to disinfectants. When 2.0 mg/L chlorine is used, the required contact time to deactivate bacteria that are 10 days old is 30 minutes. For bacteria of the same species and of the age of 1 day 1 minute, contact time is sufficient. Bacterial spores can be very resistant. Most disinfectants are not effective against bacterial spores.

**Water that requires treatment**

The nature of the water that requires treatment has its influence on the disinfection. Materials in the water, for example iron, manganese, hydrogen sulfide and nitrates often react with a disinfectant, which interferes with the disinfection process. Turbidity of the water also reduces the effectiveness of disinfection. Microorganisms are protected against disinfection by turbidity.

**Temperature**

The temperature also influences the effectiveness of disinfection. Increasing temperatures usually increases the speed of reactions and of disinfection. Increasing temperatures can also decrease disinfection, because the disinfectant falls apart or is volatilized.

## LOG INACTIVATION METHODS

The disinfection profile is based on microbial inactivation. As part of the SWTR, EPA developed a method to calculate microbial inactivation for evaluating the effectiveness of disinfection in a water system. Chemical disinfection does not remove microorganisms from water but inactivates them so they can no longer infect consumers. Under the method developed for the SWTR, the actual plant disinfection conditions are converted to a theoretical level of inactivation of specific microorganisms.

The conversion from plant conditions to microbial inactivation is accomplished based on “CT tables” developed for the SWTR, where C is the residual disinfectant concentration (mg/L) and T is the time (in minutes) that water is in contact with the disinfectant. These tables relate CT values to levels of inactivation under various operating conditions. Different tables exist for different disinfectants. As the CT value is increased, a greater percentage of microorganisms are inactivated by chemical disinfection. The CT, and therefore the level of inactivation, can be increased by applying greater doses of the disinfectant or by increasing the time that the water is in contact with the disinfectant.

The level of inactivation is generally referred to in terms of “log inactivation” since inactivation is measured on a logarithmic scale (i.e., orders of magnitude reduction). For example, a 2-log inactivation and/or removal of *Giardia* corresponds to inactivating 99 percent of the *Giardia* cysts through the disinfection process while a 3-log inactivation and/or removal corresponds to a 99.9 percent inactivation.

Log inactivation is a measure of the percent of microorganisms that are inactivated during the disinfection process and is defined as:

$$\text{Log Inactivation} = \text{Log} (N_0/N_T)$$

Where,  $N_0$  = initial (influent) concentration of viable microorganisms

$N_T$  = concentration of surviving microorganisms

Log = logarithm to base 10

Log inactivation is related to the percent inactivation, defined as:

$$\text{Percent Inactivation} = (1 - N_0/N_T) \times 100$$

Therefore, the relationship between log inactivation and percent inactivation is as follows:

$$\text{Percent Inactivation} = (1 - 1/10^{\text{Log inactivation}}) \times 100$$

or

$$\text{Log Inactivation} = \text{Log} (100/100 - \text{Percent Activation})$$

The following two examples illustrate the relationship between influent and effluent concentrations, percent inactivation, and log inactivation.

**Example 1**

A utility has an influent concentration ( $N_0$ ) of active *Giardia* of 10,000 cysts/100 L and a concentration of surviving microorganisms at the first point in the distribution system ( $N_T$ ) of 10 cysts/100 L. What is the log inactivation of this treatment process?

$$\begin{aligned} \text{Log Inactivation} &= \text{Log } (N_0/N_T) \\ &= \text{Log } (10,000/100) \\ &= \text{Log } 1000 \\ &= 3 \end{aligned}$$

**Example 2**

Given that the utility has a 3-Log Inactivation of *Giardia*, what is the percent inactivation of *Giardia*?

$$\begin{aligned} \text{Percent Inactivation} &= (1 - 1/10^{\text{Log inactivation}}) \times 100 \\ &= (1 - 1/10^3) \times 100 \\ &= (1 - 0.001) \times 100 \\ &= 99.9 \end{aligned}$$

As the two examples show, a 3-log inactivation equals 99.9 percent inactivation. Table B-1 presents similar calculations for different log inactivations and corresponding percent inactivations.

**Table B-1: Log Inactivation and Percent Inactivation**

<b>Log Inactivation</b>	<b>Percent Inactivation</b>
0.0	0.00
0.5	68.38
1.0	90.00
2.0	99.00
3.0	99.90
4.0	99.99
5.0	99.999
6.0	99.9999
7.0	99.99999

## **DISINFECTION BYPRODUCTS**

There is no question that the use of chlorine as the primary disinfectant used for water treatment in the U.S. has had an enormous impact on the prevention of waterborne diseases. However, when free chlorine is added to surface waters containing **natural organic material (NOM)** chemical reactions will occur, which produce Disinfection Byproducts (DBP).

If consumed over long periods of time, some DBPs may cause undesirable health effects, including cancer. Consequently, regulatory standards have been established to limit the amount of various DBPs that are acceptable in a PWS.

### **Formation of Disinfection Byproduct**

Natural organic matter is the precursors of disinfection byproduct formation. Natural organic matter in surface waters are generally naturally occurring organic substances, such as humic and fulvic acids. These acids belong to a family of compounds having similar structure and chemical properties and are formed during the decomposition of vegetation. Humic acids are hydrophobic or water repellent and a portion of these can be removed by coagulation and sedimentation. The fulvic portion is not amenable to conventional treatment. It is always more effective to remove precursors prior to disinfection.

Raw waters containing high levels of organic matter, such as lakes and ponds, are at a higher risk of forming DBPs than waters containing low levels of organic matter, such as most groundwater sources. Consequently, small systems utilizing chlorinated surface water sources are more likely to have DBP problems than those using chlorinated groundwater sources. Therefore, DBPs that result from chlorine disinfection have been studied more extensively than DBPs that might result from the use of alternative disinfectants such as ozone.

### **Testing for Precursors**

NOM can be estimated by determining the total and dissolved organic carbon. Since 90% of the organic carbon in a water supply is typically dissolved, the **total organic carbon (TOC)** gives a good approximation of the DBP precursors present.

UV light absorbency at 254-nanometer wavelength can also be used to estimate organic compounds present. This test is particularly effective at assessing the presence of humic substances because these substances absorb light in the UV spectrum. Results are influenced by pH and turbidity and standardization of pH and samples be filtered with a 0.45 um membrane is recommended prior to UV-254 analysis.

The **Specific Ultraviolet Absorbance (SUVA)** test is a further refinement using all these techniques and is the ratio of UV-254 divided by DOC. This value gives a more precise identification of the amount of humic material present. SUVA values of 3 indicate water with nonhumic materials and values above 4 to 5 indicate waters with primarily humic materials present.

### **Predicting Formation of Disinfection Byproducts**

Disinfection Byproducts (DBP) are produced by the reaction of free chlorine with organic material found in natural waters. The **Total Trihalomethane Formation Potential (TTHFP)** of the source water can be measured in a sample incubated for 7 days, using a free chlorine residual of 3 to 5 mg/L, a temperature of 25 °C and pH of 7. Since this test is under severe conditions, the

Uniform Trihalomethane Formation Potential is sometimes used. In this test the incubation period is shortened to 24 hours, the free chlorine residual is at 1 mg/L to 0.40 mg/L and a pH of 8. These conditions are more representative of actual distribution system conditions and correlate better to DBP formation.

### **Trihalomethanes and Haloacetic Acids**

Disinfection byproducts are groups of chemical compounds that are **trihalomethanes (THMs)** and **Haloacetic Acids (HAA5s)** produced by chlorine in the disinfection process when organic compounds are present.

Disinfection byproducts are produced by the reaction of free chlorine with organics in the source water. In this process the chlorine replaces hydrogen atoms with chlorine. THMs are a particular group of compounds where 3 of the 4 hydrogen atoms in a methane compound have been replaced by chlorine or bromine atoms (elements from Group 7 on periodic chart). The bromine replacement in the methane compound is a particular reaction caused by free chlorine. Bromide compounds are typically present in surface water and chlorine oxidizes bromide ions resulting in the formation of free bromine that reacts with the organic material to produce bromoform, bromodichloromethane, dibromochloromethane, monobromoacetic acid and dibromoacetic acid. Three of these compounds are THMs and two of them are Haloacetic Acids. The S1DBPR regulates four specific Trihalomethane compounds and five specific Haloacetic acids or HAA5s. The additive concentrations in mg/L of these compounds are called **Total Trihalomethanes (TTHMs)** and HAA5s. The MCLs for TTHMs and HAA5s are 0.080 mg/L and 0.060 mg/L, respectively.

### **Treatment Methods to Remove Disinfection Byproducts**

DBP are difficult to remove once they are formed. Absorption with activated carbon and ion exchange can be effective but are generally very costly. Coagulation, sedimentation, filtration and softening are very limited in removing DBPs. Aeration can remove THMs since they are volatile.

Source water control strategies involve managing the source water to lower the concentration of naturally occurring precursor or TOC removal is always more effective than DBP treatment. To ensure effective control of DBP precursors, the S1DBPR sets process performance standards for TOC removal for surface and GWUDI water treatment plants.

### **Factors Governing THM and HAA5 Formation**

A number of factors can affect the formation of DBPs. These include the types and concentrations of organic materials present when disinfectant is added, the dosage of disinfectant, the temperature and pH of the water, and the reaction time.

To control the formation of DBPs during chlorination, there are three effective strategies:

1. Remove the byproducts after they are formed, which can be difficult and costly;
2. Use alternative disinfectants or disinfectant combinations that do not produce or reduce the undesirable byproducts; and,
3. Reduce the concentration of organics in the water before oxidation or chlorination to minimize the formation of byproducts. This is the most effective strategy and will provide the highest quality finished water.

## TRIHALOMETHANES

Free chlorine is added to drinking water as a disinfectant. The naturally occurring organics get into the water when the water partially dissolves organic materials from algae, leaves, bark, wood, soil, and other similar materials. While it is possible to form THMs by reactions between chlorine and industrial organic chemicals, the overwhelming bulk of THM precursors in water are from natural organic compounds.

One source of bromide is seawater and another is brine from gas well drilling. Bromide reaction products can be found in most surface waters, even where bromide concentrations are low.

Very little is known about the specific reactions that free chlorine and natural organics (precursors) undergo. In general, the effects of time, temperature, pH, and concentrations of the chemicals of the production of THMs are fairly well understood. For many systems, a large part of the production of THMs will take place after the water leaves the treatment plant.

The higher the temperature, the faster the THMs will be produced. As might be expected, a dependence on temperature will probably show up as a seasonal effect—higher THM levels in the summer than in the winter. Temperature may not be the only controlling factor.

The higher the pH of the water, the faster the production of THMs. Utilities raising the pH of treated water for corrosion control should be aware that free chlorine in contact with natural organics at a pH of 10.5 or higher will produce THMs much faster than if the pH was near 7.0.

The higher the concentrations of free chlorine and natural organics in the water, the more THMs will be produced. In the past, the amount of free chlorine that utilities used was only limited by economics and possible taste and odor complaints from consumers. Careful use of chlorine may help a utility to lower the THMs in its system. However, because of the danger of using too little chlorine (inadequate disinfection) in a system, the THM regulation specifically requires state approval of major treatment changes to meet the regulation.

The concentration of precursors in water is as important as the types of precursors that are found in water. Some naturally occurring organic compounds can produce 10 to 100 times more THMs on an equivalent basis than organics from another source. Also, some types of precursors will produce THMs faster than others. For this reason it is important to evaluate the total trihalomethane formation potential (TTHMFP) of each source of supply for control measures.

The effect higher bromide concentrations on THM production is not as clear as the effects of temperature and pH. The more bromide present, the more bromide-containing THMs will be formed. Free chlorine selectively attacks the bromide ion and changes it to bromine, which reacts quickly with precursors to form bromoform, dibromochloromethane, and bromodichloromethane. The usual result of high bromide levels is higher THM levels because the higher molecular weights of these compounds mean more molecules are available for these chemical reactions.

The three treatment options available to control THMs are as follows:

- Remove THMs after they are formed;
- Remove THM precursors before chlorine is added; and
- Use a disinfectant other than free chlorine.

Removing THMs after they are formed is generally not the strategy of choice unless there is a particular circumstances at the utility that warrants its evaluation. Since precursors are not necessarily removed when THMs are removed, there is the problem of continued THM formation, especially in the distribution system.

Removing precursors before free chlorine is added has some major advantages, particularly if the precursors can be removed by a fairly inexpensive process. Also, removing precursors allows the continued use of free chlorine as a disinfectant. Using a disinfectant other than free chlorine has a number of advantages and disadvantages that must be evaluated case by case.

There are three treatment processes available to remove THMs after they have been formed:

1. Oxidation
  - a. Ozone
  - b. Chlorine dioxide
  - c. Ozone/ultraviolet light
2. Aeration
  - a. Open storage
  - b. Diffused air
  - c. Towers
3. Adsorption
  - a. Powdered activated carbon
  - b. Synthetic resins

Oxidation of the THMs using any one of the three oxidants listed above has not been very successful. The combination of ozone/ultraviolet light showed some promise; however, the cost-effectiveness of the process has yet to be demonstrated.

In contrast, aeration is an effective process for removing THMs from water, although the individual THMs are removed at different efficiencies. More efficient removal of the THMs can be accomplished if energy is put into the aeration process. A convenient way to do this is by bubbling air into the water. Aeration is the most effective on the more volatile chemicals.

THMs can be removed by a wide variety of activated carbons and synthetic resins. The adsorption process involves the individual THM compounds leaving the water and becoming attached to the surface of the carbon or resin.

A variety of treatment processes have been investigated to remove THM precursors before they come in contact with chlorine. These include:

1. Aeration
2. Oxidation
  - a. Ozone
  - b. Chlorine dioxide
  - c. Permanganate
  - d. Ozone/ultraviolet light
  - e. Hydrogen peroxide
3. Clarification
  - a. Coagulation/sedimentation/filtration
  - b. Softening

#### 4. Adsorption

- a. Powdered activated carbon
- b. Granular activated carbon
- c. Synthetic resins

Since THM precursors are not volatile compounds, it is not surprising that aeration is ineffective in removing them from water. All of the oxidants listed above have some effect on removing or modifying THM precursors. The clarification process used in water treatment plants has the potential for removing significant amounts of THM precursors. Moving the addition of free chlorine to a point following the clarification process is the key to success for this approach. The use of PAC and GAC are effective in removing THM precursors; however, the economics of these processes must be carefully evaluated. Synthetic resins show limited removal potential for THM precursors.

## **CHLORINE SAFETY**

Although it is used as a disinfectant, it is a dangerous and potentially fatal chemical if used improperly. Chlorine, in any form, can be a difficult and hazardous chemical to handle in the concentrations used in water treatment.

Chlorine gas can be especially hazardous to handle and all personnel should be thoroughly aware of its hazardous properties. All personnel handling chlorine should know the location and use of the various pieces of personal protective equipment and be instructed in safety procedures. In a moist atmosphere, or in contact with any moisture, chlorine is highly corrosive and is especially destructive to electrical equipment. When combined with the moisture in mucous membranes of the nose and throat, and with the fluids in the eyes and lungs, a very small amount of chlorine gas in the air can be very irritating and can cause severe coughing. Heavy exposure can be fatal.

Chlorine gas leaks may be detected by passing an ammonia-soaked cotton swab near the suspected area. If chlorine gas is leaking and comes in contact with ammonia, a white smoke appears. Do not spray ammonia on the leak, because too much white smoke will be formed to see the leak area and may fill the room so that even the exit is difficult to find. If a chlorine cylinder is leaking, it should only be handled by a person equipped with and trained to use a proper **self-contained breathing apparatus (SCBA)** in good operating condition.

Chlorine gas storage rooms and rooms where chlorine gas is used are required to have mechanical exhaust systems that draw air from the room at a point no higher than 12 inches above the floor. This low height is necessary so the exhaust fan will remove the settling chlorine gas from the room.

Empty tanks, tanks in use and back-up tanks must be restrained using a chain or other means so that they cannot be knocked over.

Sodium and calcium hypochlorite are not as hazardous as gaseous chlorine and therefore are easier and safer to handle. This certainly should be one of the major considerations for a small system when determining which form of chlorine to use. Personal protective equipment (mask, apron, gloves) should be used when handling hypochlorite since it can cause damage to eyes and skin upon contact. If spilled on skin, the affected area should be washed quickly with large amounts of water. Hypochlorite solutions are very corrosive. Large volumes of water should be used to wash-down spills. Hypochlorite compounds are non-flammable; however, they can cause fires when they come in contact with organics (oily rags) or other easily oxidizable substances.

### **General Chlorine Safety**

Chlorine is a greenish-yellow gas. It is 2.5 times heavier than air. Chlorine gas is very corrosive. It turns into hydrochloric acid when it comes in contact with moisture (in the water, in the chlorine lines, or in your eyes or lungs). It does not support combustion but can be harmful if inhaled in small quantities and fatal in larger doses. Chlorine leaks can be located using ammonia vapors.

### **Chlorinator Room**

The chlorinator room should have a window in the door so that the operator in the room can be seen from the outside. The light and vent switches should also be located outside the room. The room should have ventilation located at floor level since chlorine gas is heavier than air and will

settle in the lowest spot in the room. The room should be kept between 60°F and 120°F. Below 60°F, chlorine gas forms chlorine hydrate, also known as “green ice,” when it comes in contact with water. This green ice can clog the injector and gas piping, creating a serious maintenance problem.

When a chlorine cylinder is full and at room temperature, it is about 85% full of liquefied chlorine. As the temperature rises, the liquid expands and takes up more space in the cylinder. At 157 °F the liquid will expand to occupy 100% of the cylinder. If the liquid expands any further the cylinder will rupture, causing a massive chlorine leak.

### **Chlorine Storage**

The room where chlorine cylinders or HTH drums are stored must be kept dry and well ventilated. Chlorine should always be stored in a room separate from other chemicals. Chlorine cylinders that are empty should be separated from those that are full. All cylinders should be chained to the wall.

### **Chlorine Cylinders**

NEVER remove the valve hood from a chlorine cylinder unless it is chained to the scales and ready to be put on the system. All cylinders should be chained to the wall or the scales unless they are being moved. Every system that operates a gas chlorine system should have an emergency kit or be able to get access to one on very short notice. To prevent the cylinder from rupturing when it gets too hot, every gas cylinder will have a “fusible plug” that is designed to melt at 157 °F. There is one in the valve assembly of every 150 lb. cylinder and six (three on each end) in the body of every 1-ton cylinder. As one of these fusible plugs melts, it will allow the release of chlorine gas from the cylinder. This still represents a serious problem, but the release will be more gradual than it would if the tank ruptured.

### **Respiratory Protection**

Anyone involved in handling chlorine should have access to respiratory protection equipment. There are two basic types of respiratory protection. One is the gas mask that uses a filtering device to remove chlorine. These are either a full-face mask or a mouth/nose type respirator. A respirator with its own air source is called a supplied-air respirator or **Self Contained Breathing Apparatus (SCBA)**. It consists of either a self-contained unit that the worker wears or a hose connecting a worker to a remote air source. The SCBA provides continuous positive air pressure into a facemask. Both of these devices may be rendered ineffective if the wearer has facial hair that interferes with the face-to-mask seal.

## **CHLORINE SAFETY PRECAUTIONS**

### **Chlorine Gas**

Chlorine gas is a hazardous substance and should be handled with care. The following list gives some general safety precautions that should be taken when handling 100 or 150-lb chlorine cylinders:

- Chlorine cylinders should be moved on properly balanced hand trucks, preferably with rubber tires. A clamp or chain support two-thirds of the way up the cylinder should be used to secure the container.
- Chlorine cylinders should be transported and stored in an upright position.
- Chlorine cylinders must be secured so that they cannot be tipped over
- Chlorine cylinders should not be dropped, allowed to strike forcefully against anything, or struck forcefully by other objects.
- Chlorine cylinders should be stored so that they can be moved in the event of a leak or fire.
- Chlorine cylinders should not be stored or used in an area below ground level, because chlorine gas is heavier than air and will settle into and remain in such areas.
- When receiving a shipment of chlorine cylinders, inspect the shipment before accepting it.
  - Check each cylinder for serious dents, cuts, or gouges that might decrease the wall thickness of the container.
  - Look for signs of corrosion or pitting that might be serious enough to weaken the cylinder.
  - Check for obvious bulges
  - Put your hand on each cylinder to see if it is hot to the touch. This could indicate internal moisture contamination. If there appears to be internal moisture, return the cylinder to the manufacturer or supplier
  - Visually inspect the valves and fusible plugs.
- If any of the chlorine cylinders appear of questionable status, return the cylinder to the manufacturer or supplier.
- Whenever there is any indication of a leak or other problem with the chlorine cylinders, take safety precautions immediately. Only authorized, trained personnel with suitable self-contained breathing apparatus should investigate; all other persons should be kept away from the affected area. When you suspect problems with a chlorine cylinder, the chlorine supplier should be contacted for emergency assistance.

### **Calcium Hypochlorite**

While calcium hypochlorite is not as dangerous as chlorine gas, it should be handled according to the recommended procedures. The following is a short list of precautions that should be taken when working with this solid form of chlorine.

- Calcium hypochlorite should be stored only in the original container and away from moisture.
- Calcium hypochlorite is relatively stable but will decompose in storage. It can ignite or explode on contact with organic materials (oil, rags, or alcohol), and it should not be exposed to fire or elevated temperatures.
- When handling calcium hypochlorite, the operator should wear a protective apron, rubber gloves, eye protection, and a dust-protection respirator.

## **Sodium Hypochlorite**

The following is a list of precautions to take when working with this liquid form of chlorine:

- Sodium hypochlorite should be stored in a cool, dark place to minimize decomposition.
- Always store sodium hypochlorite in a container made of a proper material, such as plastic, because the chemical is corrosive to many types of materials. The containers should be kept closed. Fumes escaping from the containers are corrosive.
- When working with this product, wear protective gloves, apron, and eye protection.

## **HOW TO HANDLE CHLORINE GAS SAFELY**

Chlorine gas is greenish-yellow and smells like bleach. It is highly corrosive and irritating to the eyes, nose, throat, and mucous membranes. It reacts violently with petroleum products such as gasoline, diesel, oil, solvents and turpentine. Chlorine gas is about 2.5 times heavier than air and will settle in low-lying areas unless there is sufficient wind for dispersal. It can form phosgene (a toxic and corrosive gas) in the presence of carbon monoxide from a fire, and sulfuryl chloride (a toxic corrosive gas) in the presence of sulfur dioxide from auto exhaust.

Despite these hazards, chlorine does not have to be a serious risk to those who handle it if they are properly trained. Although not a substitute for formal training, this segment discusses chlorine handling and safety practices, particularly for small water treatment systems.

### **Emergency Help**

Don't wait until you need a phone number. Make a list of all relevant contact numbers and keep them posted at several locations in the plant and office. The list should include the fire department that will respond to your facility and the police department, and any other facilities in the area that may be of help. Posting these numbers is especially important if you don't have 911-service in your area. Keep the numbers updated.

Inform local police and fire departments of the possible hazards associated with all the chemicals used in your plant, especially chlorine, so they can be prepared in the event of an emergency. Organize escape plans from areas where there might be chlorine emission. Taking short cuts may not only be dangerous, they could be deadly.

### **Protective Equipment**

Systems using gas chlorine should have respiratory protection equipment that meets National Institute for Occupational Safety and Health requirements available where chlorine gas is handled. This equipment should be stored at a convenient location but not inside any room where chlorine is used or stored. The unit(s) should use compressed air, have at least a 30 minute capacity and be compatible with – or exactly the same – as the units used by the fire department that will respond to your water treatment plant. The unit(s) should also be tested and refreshed on a regular basis. Ask your fire department to inspect and test the unit(s).

### **The Buddy System**

Having a second person at the plant when changing or handling chlorine is ideal. If one operator is incapacitated, the other can call for help. If you are working alone, let someone know when you are handling chlorine. Right before going into the chlorine room, call someone familiar with your work and location and then, when finished, call back so they know that you are all right

### **Separate Chlorine Room**

A separate room for chlorine, especially gas chlorine, is important. Check with WV State Design Standards (64CSR77) and the Chlorine Institute for requirements on inside storage and use of chlorine. The chlorine room should be enclosed, sealed and separated from other operating areas. It should have a shatter-resistant inspection window mounted in an interior wall that is built to seal all openings between the chlorine room and the remainder of the plant. The room should have doors equipped with panic hardware that opens outward to the building exterior providing an easy escape.

Locate the chlorine room on the downwind side of the building—away from entrances, windows, louvers, walkways and so on. The room must be equipped with a ventilating fan that provides one complete air exchange per minute when the room is occupied. The fan should move air as far as practical from the door and air inlet, and discharge to the outside atmosphere. In addition, louvers should facilitate airtight closure for air intake near the ceiling and exhaust near the floor.

Locate separate switches for the fan and lights outside the chlorine room and at the inspection window. Protect outside switches from vandalism. Provide a signal light indicating fan operation at each entrance when the fan can be controlled from more than one point.

The floor of the room should be finished in a non-slip surface, and floor drains are discouraged. If a floor drain is used, it should discharge to the outside of the building and should not be connected to other internal or external drainage systems. The end of the drain should discharge to the outside atmosphere, above-grade, so it does not contaminate air inlets or entrance doors to any rooms or structures. The room should be at least 60 °F and protected from excessive heat.

### **Chlorine Leak Detection**

The room should have continuous leak detection equipment with sound and visual warnings that can be heard and seen throughout the treatment plant. This unit should be calibrated and tested at regular intervals and documented. A bottle of ammonium hydroxide, 56% ammonia solution, should be available for chlorine leak detection. A leak repair kit approved by the Chlorine Institute should be provided (Kit A for 150 pound cylinders and Kit B 1 ton for containers).

### **Response to a Chlorine Release**

As soon as there is any indication of a chlorine release, immediate steps must be taken to correct the condition. Chlorine leaks always get worse if they are not promptly corrected. When a chlorine leak occurs, authorized, trained personnel equipped with respiratory and appropriate other PPE should investigate and take proper action. Personnel should not enter into atmospheres containing concentrations of chlorine in excess of the IDLH Concentration of 10 ppm without appropriate personal protective equipment and back-up personnel.

### **Response to a Fire**

If fire is present or imminent, chlorine containers and equipment should be moved away from the fire, if it is possible to do so safely. If a non-leaking container or equipment cannot be moved, it should be kept cool by applying water on it.

Water should not be used directly on a chlorine leak. Chlorine and water react forming acids and the leak will quickly get worse. However, where several containers are involved and some are leaking, it may be prudent to use a water spray to help cool the non-leaking containers. Whenever containers have been exposed to flames, cooling water should be applied until well after the fire is out and the containers are cooled. Containers exposed to fire should be isolated and the supplier should be contacted as soon as possible.

### **CHEMTREC**

During a chlorine emergency, any carrier, customer, or civil authority can obtain basic emergency information and contact information for the closest chlorine emergency group through CHEMTREC (U.S.) or their chlorine supplier. The emergency response call center, i.e. CHEMTREC provides immediate advice for those at the scene of emergencies. CHEMTREC will promptly contact the appropriate responder group as required. In many cases, the responder

will be the shipper. However, in some cases, the designated response group is called and then the shipper is notified.

### **Employee Training**

Safety in handling chlorine depends, to a great extent, upon the effectiveness of employee training, proper safety instructions and the use of suitable equipment. It is the responsibility of the employer to train employees and to document such training as appropriate and as required by regulation. It is the responsibility of employees to carry out correct operating procedures safely and to properly use the safety equipment provided.

Employee training should include but is not limited to:

- Instruction and periodic refresher courses in operation of chlorine equipment and handling of chlorine containers.
- Instruction in the properties and physiological effects of chlorine, including the information on the MSDS.
- A MSDS is provided by the chlorine supplier.
- Instruction to report to the proper authority all equipment failures and chlorine leaks.

Instruction and periodic drills regarding:

- Locations, purpose, and use of chlorine emergency equipment, fire fighting equipment, fire alarms and shut-down equipment such as valves and switches.
- Use and installation of emergency kits, such as the Chlorine Institute Emergency Kits A, B, or C and the recovery vessel if they are part of emergency equipment and planning at the location.
- Locations, purpose, and use of personal protective equipment.
- Locations, purpose, and use of safety showers, eye washes, or the closest source of water for use in emergencies.
- Locations, purpose, and use of any specialized first aid equipment.

### **Safety tips for 150 pound cylinders and one-ton containers:**

- Never lift a cylinder by its hood.
- Always keep the hood in place, except when the cylinder is being used.
- Never expose cylinder to heat or direct sunlight.
- Never drop a cylinder, or knock a cylinder over.
- Never tamper with a fusible plug.
- Always keep empty cylinders separate from full ones.
- Always secure empty and full cylinders with a cable or chain.
- Never store liquid or gas chlorine with ammonia.
- Do not move full one-ton containers with equipment designed to handle less than two tons.
- Do not connect liquid valves of two or more containers to a common manifold.
- Never store combustible or flammable materials near chlorine containers.
- Never attempt to weld an “empty” chlorine pipeline without purging it with air.
- Do not spray water on a leaking container. It will make the leak worse.
- Take shallow breaths in the chlorine room until you are sure there is not a chlorine leak.

## **CHLORINE FIRST AID**

### **Inhalation**

1. Remove victim from contaminated area.
2. Keep victim warm, in a reclining position with head and shoulders elevated.
3. Give artificial respiration, if necessary.
4. Administer oxygen as soon as possible.
5. Call a physician immediately.

### **Skin Contact**

1. Shower victim, removing all contaminated clothing.
2. Wash affected area with soap and water.

### **Eye Contact**

1. Irrigate eyes with water for 15 minutes, holding eyelids wide apart.
2. Call a physician immediately.
3. Irrigate a second 15 minute period if physician is not immediately available.

### **Health Effects**

- Low concentrations: Burning eyes, nose and throat; redness in the face; sneezing and coughing.
- High concentrations: Tightness in the throat and difficulty breathing.
- 1,000 ppm is fatal after a few breaths.
- Even an hour later, 35-51 ppm can be fatal.

### **Chlorine Resources**

**2,500 pounds or more:** The EPA regulates chlorine quantities of 2,500 pounds or more.

**The Chlorine Institute** has a variety of information on safe chlorine handling online at <http://www.chlorineinstitute.org/>

### **Changing 150-Pound Cylinders**

1. Turn valve stem clockwise to close cylinder.
2. Allow float in flow meter to drop to zero. Indicator on front of gas feeder should indicate no gas.
3. Wait about one minute. Float should remain at zero. If float flutters or does not drop to zero, the valve may not be closed tightly. Make sure the valve is closed before proceeding.
4. Turn off ejector, and make certain the gas supply indicator stays in the “No Gas” position by turning the “Reset” knob. If the indicator resets, either gas pressure is still present or there is an air leak in the system. Refer to instruction manual if an air leak is evident.
5. Loosen gas feeder yoke screw. Remove gas feeder from valve.
6. Replace gas cylinder.
7. Remove old lead gasket. Inspect and clean mating surfaces of gas feeder and valve. Install new unused lead gasket.
8. Position gas feeder on new gas cylinder and tighten yoke screw. Do not tighten excessively.

9. Crack open gas cylinder valve and close quickly. Check for leaks. If leaks exist, turn on ejector and repeat steps 2, 3, 4, and correct leaks.
10. Leak test solutions: Ammonia.
11. Open gas cylinder valve, about ¼-turn only, and leave cylinder wrench on valve.
12. Turn ejector.

**NOTES:**

Contact your gas supplier if the cylinder valve or cylinder is considered to be defective.

**Changing Ton Cylinders**

1. Turn the valve stem clockwise to close ton container valve.
2. Allow float in flow meter to drop to zero. Indicator on front of gas feeder should show red indicating no gas. All liquid must be vaporized from the trap.
3. Wait about one minute. Float should remain at zero. If float flutters or does not drop to zero, valve may not be closed tightly. Make certain valve is closed before proceeding.
4. Turn off ejector and make certain the gas supply indicator stays in the “No Gas” position by turning the “Reset” knob. If the indicator resets, either gas pressure is still present or there is an air leak in the system. Refer to instruction manual if an air leak is evident.
5. Loosen gas feeder yoke screw. Remove gas feeder from valve.
6. Replace ton container. Make sure the full container is oriented with the valves in the vertical position, one valve above the other. The top valve will always supply gas chlorine and the bottom valve will give liquid chlorine.
7. Remove old lead gasket. Inspect and clean mating surfaces of gas feeder and valve. Install new unused lead gasket.
8. Position gas feeder on new gas cylinder and tighten yoke screw. Do not tighten excessively.
9. Be sure heater is plugged in and operating. An operating heater provides heat to vaporize any trapped liquid.
10. Crack open gas cylinder valve and reclose quickly. Check for leaks. If leaks exist, turn on ejector and repeat steps 2, 3, 4, and correct leaks.
11. Leak test solutions: Ammonia.
12. Open ton container valve slowly about ¼-turn only and leave cylinder wrench on valve.
13. Turn on ejector.

**NOTES:**

Contact your gas supplier if the cylinder valve or cylinder is considered to be defective.

## **CHLORAMINATION**

Chloramines are formed when free chlorine reacts with ammonia and may be present as monochloramine, dichloramine, and/or trichloramine. The chloramine compounds react more slowly than free chlorine and as a result, they form fewer DBPs and are more persistent in the distribution system. Some studies have shown that chloramine compounds can penetrate biofilms more effectively than free chlorine. Monochloramine is generally considered the preferred species for disinfection purposes because of its biocidal properties, relative stability, and infrequent taste and odor problems. Because monochloramine is a weaker disinfectant than free chlorine, it is more frequently used as a residual disinfectant in the distribution system. If not properly controlled, the use of chloramines can lead to nitrification episodes in the distribution system and may cause taste and odor issues, loss of disinfectant residual, and other problems.

### **Advantages of Chloramines**

The use of chloramination presents numerous benefits in terms of implementation and operation. Advantages include:

- Lower DBP formation;
- More persistent than free chlorine residuals; and
- Biofilm control in the distribution system.

### **Lower DBP Formation**

Compared to free chlorine, chloramines react more slowly with organic matter resulting in lower concentrations of total trihalomethane (TTHM) and haloacetic acid (five) (HAA5). Although detectable concentrations of mono- and dichloroacetic acids can be produced, these are generally significantly lower than corresponding concentrations produced by free chlorine. Replacing chlorine with chloramines as a secondary disinfectant typically reduces TTHM levels 40 to 80 percent.

If chlorine is added to the water before ammonia, the byproducts associated with the use of free chlorine can be formed, although additional formation will be significantly retarded once the ammonia has been added. Because free chlorine is a much more effective disinfectant for viruses, surface water systems generally add chlorine early enough in the treatment train so that CT requirements for viruses are achieved before the ammonia is added.

### **More Persistent than Free Chlorine Residuals**

Chloramines have a lower oxidation-reduction potential and a slower reaction time than free chlorine, so they are less likely to be consumed by reactions with organics and reduced metals. Therefore, they are longer lasting in the distribution system and are generally more persistent than a free chlorine residual. This characteristic helps to protect distribution system water quality, particularly in areas with long detention times. It also helps maintain compliance with the Surface Water Treatment Rule (SWTR)'s requirement to maintain a disinfectant residual.

### **Biofilm Control in the Distribution System**

Chloramine compounds are better able to penetrate the biofilm layer and inactivate attached organisms because they are more limited than chlorine in the types of compounds with which they will react. In iron pipes, 3 to 4 mg/L doses of free chlorine did not control biofilm growth. Chloramines, however, did control biofilm growth at doses starting at 2 mg/L.

### **Disadvantages of Chloramines**

Potential issues associated with the use of chloramines include:

- Nitrification;
- Increased corrosion and metal release;
- Taste and odor issues;
- Weaker disinfectant;
- Issues with ozonation and GAC filtration; and
- Safety concerns;

### Nitrification

Biological nitrification is the oxidation of ammonia to nitrite and then eventually to nitrate by bacteria and other organisms. Nitrification adversely impacts the effectiveness of chloramines by increasing the chloramine demand, depleting chloramine residuals and thus allowing bacterial regrowth. A loss of disinfectant residual in the distribution system can result in a violation of the SWTR, and may lead to increased vulnerability to contamination. Other adverse effects of nitrification on distribution system water quality include:

- Decrease in dissolved oxygen;
- Increase in nitrite and nitrate levels;
- Decrease in pH;
- Decrease in alkalinity; and
- Decrease in ORP.

Systems that chloraminate can experience nitrification episodes under certain system conditions including but not limited to:

- Excess free ammonia;
- Low chloramine residual;
- Long water detention times in the distribution system, such as in storage tanks, areas with low demand, and dead ends;
- Water temperatures of 25°C - 30°C; and
- A pH in the range 7.0 to 8.0 is optimum for nitrifying bacteria.

Nitrification may be controlled by taking certain preventative measures and by implementing corrective actions when monitoring indicates the onset of a nitrification event.

The most important preventive measures include:

- Distribution system flushing;
- Increasing chloramine residual; and
- Modifying chlorine-to-ammonia nitrogen ratio.

Additional preventive methods include maintaining low concentrations of residual ammonia at the treatment plant effluent, using a source water with the lowest temperature whenever possible, and modifying distribution system hydraulics to minimize water age (e.g. improve water circulation, eliminate dead-ends, open valves, increase turnover rate in storage facilities).

Some systems that chloraminate periodically switch to free chlorine disinfection for a few weeks or months to reduce the population of nitrifying bacteria in the distribution system. Given the higher levels of DBPs observed following a switch to free chlorine, utilities may be better served by careful maintenance of their ammonia feed such that nitrification episodes are minimized.

The recommended monitoring parameters for the baseline monitoring program include total chlorine, monochloramine, free ammonia, total ammonia, nitrite, nitrate, HPCs, and water residence time. The investigative monitoring program includes these parameters plus temperature and dissolved oxygen. Monitoring locations may include raw water, point-of-entry to the distribution system, reservoir inlets/outlets, coliform monitoring stations, selected dead-end sites, and low flow sites, depending on the monitoring objective (baseline vs. investigative) and the monitoring parameter.

Corrective actions that may be implemented when a nitrification event is occurring were:

- Pipe flushing (found to be the most effective corrective action);
- Blending low-TOC water which possesses a higher and more stable chloramines residual with nitrifying water (effective in small tanks);
- Combining pipe flushing and monitoring until adequate water quality is reestablished; and
- Modifying distribution system hydraulics (eliminate dead-ends).

#### Increased Corrosion and Metal Release

Nitrification resulting from the use of chloramines can lower the alkalinity and the pH of the water in the distribution system. This can prove detrimental for lead and copper control. Corrosion products and tubercles also interfere with the disinfection of coliform and heterotrophic bacteria, which can lead to increased microbially-induced corrosion.

Changing from free chlorine to chloramines in the distribution system could potentially impact the stability of pipe scales, particularly redox-sensitive minerals such as lead, copper, manganese, and iron. Changes in the solubility and/or permeability of scale materials could possibly result in their desorption and release into the bulk water.

The switch to chloramines following historically high levels of chlorine residual (and relatively high oxidation reduction potential as described above), along with the absence of a reevaluation and modification to corrosion control treatment, is the suspected cause of the LCR action level exceedances experienced by Washington, D.C.'s Water and Sewer Authority (DCWASA) beginning in 2002. DCWASA made the conversion from free chlorine to chloramines in late 2000 with the goal of reducing TTHM and HAA5 levels in the distribution system. After the conversion to chloramines, elevated lead levels were found in compliance samples from homes with lead service lines. To address the lead corrosion problem, the city accelerated its lead service line replacement program and began orthophosphate treatment in August 2004. The treatment program was successful in reducing elevated lead levels. LCR monitoring results for 2005 and 2006 showed that the calculated 90th percentile values were at or below the lead action level.

Therefore, maintaining optimal conditions for monochloramine formation may help prevent materials deterioration as well as help control nitrification. Optimal conditions for monochloramine include pH of 8.3, a temperature of 25°C, and a 4:1 to 5:1 weight ratio of chlorine to ammonia.

Systems can minimize lead corrosion by:

- Optimizing the pH, alkalinity, and DIC of the water; and
- Adding a corrosion inhibitor (i.e., a substance that is phosphate- or silica-based) to the finished water to form a protective coating on the pipes.

### Taste and Odor Issues

Chlorine-based disinfectants have some associated taste and odor impacts. Monochloramine has a higher odor threshold and variations in residual concentrations produce less noticeable odors than free chlorine. Dichloramine and trichloramine, however, have much stronger odors than either monochloramine or free chlorine. Taste and odor problems can also arise from nitrification episodes caused by excess ammonia. Control measures to prevent nitrification are discussed earlier in this section.

To prevent the formation of dichloramine and trichloramine that cause taste and odor problems, the chlorine to ammonia ratio should be carefully controlled and pH should be kept above 7.0. When the chlorine to ammonia ratio exceeds 5:1, dichloramine frequently begins to form. In general, maintaining a ratio between 3:1 and 5:1 should minimize odor problems.

### Weaker Disinfectant

Monochloramine is a weaker disinfectant than free chlorine as illustrated by the required CT values to achieve inactivation of viruses and *Giardia* cysts. Both chlorine and monochloramine are ineffective against *Cryptosporidium* oocysts. Even at relatively high doses of monochloramine, extremely long residence times are required to achieve required levels of inactivation for viruses and *Giardia* cysts. Systems that switch from free chlorine to monochloramine as their primary disinfectant must benchmark for virus and *Giardia* inactivation.

Systems can compensate for the lower disinfecting power of monochloramine by using a different disinfectant as the primary disinfectant and using monochloramine to maintain a disinfectant residual in the distribution system. Frequently this is done by adding the ammonia some time after the chlorine has been added. This allows a period of time for free chlorine disinfection. While this scheme will result in higher DBPs than using chloramines as the primary disinfectant, it will still result in lower DBP concentrations than when free chlorine is used as both a primary and residual disinfectant.

Systems with very high TOC may wish to avoid free chlorine altogether. These systems can switch to a different primary disinfectant such as ozone, UV, or chlorine dioxide.

### Issues with Ozonation and GAC Filtration

Ozone used prior to chloramination increases the assimilable organic carbon (AOC) concentration and could destabilize the chloramine residual, leading to problems with chloramine residual concentrations at the ends of the distribution system.

Adding chloramines before a GAC filter may lead to nitrification in the GAC filter. It has been found that a reaction between chloramines and GAC may free up ammonia and encourage the growth of ammonia oxidizing bacteria in the GAC filters.

Installing a GAC filter after ozone to remove AOC, and then allowing a few minutes of free chlorine contact time to oxidize any remaining organics before ammonia is added can be a more reliable way to allow the formation of a stable chloramine residual. Chloramines should not be added prior to GAC filters.

### Safety Concerns

Various safety issues should be considered when switching to chloramines, depending on the type of ammonia used. High concentrations of ammonia can form an explosive mixture of trichloramine when it reacts with chlorine. Ammonia gas is also toxic if released to the atmosphere in sufficient concentrations. Ammonium sulfate does not have as many safety issues as either anhydrous ammonia or aqueous ammonia, but it is considerably more expensive and should be kept dry to avoid feed problems.

To avoid the possibility of an explosive reaction between bulk chlorine and bulk ammonia, the two chemicals should be stored in separate rooms. Feed points and pipes for chlorine and ammonia should also be placed at least five feet apart. To avoid the release of ammonia into the atmosphere, several precautions should be taken. Anhydrous ammonia should be stored in pressurized containers away from temperature extremes (temperatures greater than 125°F will cause pressure buildups in the tank). Aqueous ammonia tanks should be vented to keep pressure from building up from ammonia volatilization. Keeping the temperature low will also help to prevent volatilization, which can cause vapor lock in pumps. Buildings where ammonia is stored should be well-ventilated and should include storage areas for respirators just outside the ammonia storage area. If large amounts of ammonia are stored, an emergency scrubber should also be installed.

## OZONATION

Ozone is a powerful chemical disinfectant and an alternative to free chlorine. It is an unstable gas that is generated on-site, using either air or liquid oxygen. It is very effective at disinfecting many microbes and as a pre-oxidant. It can, however, convert bromide to bromate, a DBP regulated by the Stage 1 D/DBPR. It also oxidizes organic matter into smaller molecules, which can provide a more easily degradable food source for microorganisms in the distribution system. Because of its instability in water, ozone cannot be used to provide a disinfectant residual in the distribution system. Furthermore, ozone can produce odor compounds such as aldehydes and ketones.

### **Advantages of Ozonation**

The main advantages of ozone are:

- Effective against pathogens;
- Does not form chlorinated DBPs;
- Effective pre-oxidant;
- Can oxidize taste and odor compounds;
- Can raise UV transmittance of water and UV disinfection effectiveness;
- Independent of pH; and
- Can aid coagulation.

### Effective Against Many Microbes

Ozone is a highly effective disinfectant because of its high oxidation potential. It is the strongest of all the commonly used chemical disinfectants. It is most effective against viruses and slightly less effective against *Cryptosporidium* oocysts. As with most chemical disinfectants, the degree of microbial inactivation is temperature dependent. Inactivation is greater at higher temperatures.

In addition to satisfying microbial disinfection requirements, ozone can aid in compliance with the Stage 2 DBPR by eliminating chlorine as a primary disinfectant and lowering the required dose of secondary disinfectant. Systems with DBP concentrations above a certain threshold that switch to ozone from another primary disinfectant are required by the IESWTR, LT1ESWTR, and LT2ESWTR to benchmark for *Giardia*, *Cryptosporidium*, and viruses.

### Does Not Form Chlorinated DBPs

Ozone by itself does not form chlorinated DBPs. Therefore, using ozone instead of chlorine for primary disinfection can lower DBP formation and aid in compliance with the Stage 2 DBPR. Ozone can react with bromide, however, to form bromate, which is a non-chlorinated DBP with an MCL of 10 ppb set under the Stage 1 D/DBPR.

### Effective Pre-oxidant

Ozone's high oxidation potential also means it acts well as a pre-oxidant. It can be used to oxidize iron and manganese so they can be removed through coagulation and sedimentation. Ozone can oxidize arsenic (III) to arsenic (V) which enhances its removal. Many organic compounds are oxidized by ozone as well. If the dose is high enough, ozone can even completely mineralize some organics, lowering the concentration of DBP precursors and aiding in Stage 2 DBPR compliance.

### Can Oxidize Taste and Odor Compounds

Ozone is especially useful in oxidizing taste and odor compounds such as geosmin and 2-methylisoborneol (MIB). The efficiency of ozone at degrading geosmin and MIB is further increased if hydrogen peroxide is added in addition to the ozone, a process referred to as peroxone.

#### Raises UV Transmittance of Water

Low UV transmittance (UVT) of the water will result in less efficient UV disinfection. Ozone treatment before UV can oxidize those compounds that absorb UV, thereby increasing transmittance and UV's disinfection effectiveness. Although it may be cost-prohibitive to install both UV and ozone, a system with one of the two technologies in place may benefit from installation of the other. This arrangement would require either chlorine or chloramines to maintain a distribution system residual.

#### Independent of pH

The disinfection efficiency of ozone, unlike chlorine, does not depend on pH for the range of pH values normally encountered in water treatment. This enables plants to adjust pH to optimize coagulation, prevent corrosion, or alter DBP formation reactions without losing disinfection capability. It also removes some of the seasonal variability that is usually found in disinfection benchmarks. Note, however, that bromate formation is impacted by the pH of the water.

#### Can Aid Coagulation

Some systems have reported improvements in coagulation when they added ozone prior to coagulation. Other systems have found no change or even increases in filtered water turbidity after ozonation. The interaction between ozonation and coagulation is complex and entails the interaction of many parameters. Therefore, results will vary significantly from plant to plant. Systems should conduct bench-scale and preferably pilot-scale tests to determine how ozone will affect the systems water quality. Note that adding ozone after coagulation and sedimentation may have the advantage of lowering ozone demand allowing the same CT with a lower ozone dose.

#### **Disadvantages of Ozonation**

The main operational and simultaneous compliance issues associated with ozone are:

- May form bromate;
- Forms smaller organic compounds;
- Does not provide a residual in the distribution system;
- May increase dissolved oxygen in the water;
- Can form taste and odor compounds;
- Can increase corrosion; and
- Ozone bubbles can hinder filter performance.

#### May Form Bromate

If bromide is present in the source water, it can react with ozone to form bromate. In the presence of organic matter, ozone can also form brominated THMs and HAAs. The Stage 1 D/DBPR requires compliance with a 10 µg/L MCL for bromate. Therefore, systems considering installing ozone should evaluate whether compliance with the bromate MCL may be an issue.

Whether bromate or brominated organic DBPs form depends on the pH and organic content of the water. Lower pH water and high dissolved organic carbon (DOC) concentrations tend to favor the formation of brominated organic compounds. Systems using ozone may be able to reduce their chlorine dose, however, and as a result improve compliance with TTHM and HAA5

MCLs. Higher pH and low dissolved organic concentration generally lead to greater bromate formation.

There are several techniques that public water systems can use to control DBP formation when bromide ion is present. These include:

- Optimizing the pH;
- Keeping the ratio of ozone to DOC low; and
- Adding ammonia.

Lowering the pH favors formation of brominated organic compounds over bromate. Performing ozonation at a pH below 7 will lower the formation of bromate. This is a particularly good option for systems that have low DOC concentrations and do not have problems with high TTHM or HAA5 concentrations in their finished water. If DOC concentrations are high, however, this method of bromate control may result in exceeding HAA5 or TTHM MCLs. Systems also need to consider other effects of lowering pH such as increased corrosion, impacts on the effectiveness of secondary disinfectants, and impacts on coagulation.

If the ratio of ozone to DOC is kept low, the formation of bromate and brominated organic compounds can be reduced. This can be done by either lowering the ozone dose or by lowering DOC concentrations. Lowering the ozone dose would mean increasing the contact time, unless the system currently achieves more than the required CT. The ability to extend the contact time will depend on the ozone demand and decay of the water as well as operational limitations. Determining the ozone demand and decay rate of a given water before ozone is installed will help determine the possibilities of this option. DOC can be lowered by removing it prior to the ozone addition. If a system does not need to use ozone for pre-oxidation, it may want to add the ozone after sedimentation, or even after filtration, to achieve a lower ozone to DOC ratio. It is not typical, however, to ozonate after filtration, because of higher AOC concentrations being introduced into the distribution system and the related problems of total coliform rule (TCR) compliance and nitrification that may occur. If a system needs to pre-oxidize, a small dose of ozone can be added to the raw water and a higher dose can be added after sedimentation or filtration. Using biological filtration in this case can be especially effective for lowering DBPs, since biological filtration tends to remove aldehydes and other small organic compounds that can make up a large fraction of the DOC after ozonation.

Adding ammonia to water containing bromide and ozone will lead to bromamine formation. Bromamines react more slowly with organic matter and form fewer brominated organic compounds and less bromate. Ammonia addition, however, can lead to nitrification problems in the distribution system.

Systems with high bromide concentrations, especially those with high DOC as well, may not be able to use ozone even if they adopt these mitigation methods. Systems that use ozone to inactivate *Cryptosporidium* may have an especially hard time, in this regard, because *Cryptosporidium* requires a much higher ozone dose. Since the LT2ESWTR does not grant disinfection credit for an ozone residual in the first contact chamber, many systems will want to increase their ozone dose to help them gain CT in subsequent chambers. Bromide can be removed by the use of anion exchange, but this is generally not a cost-effective solution.

### Forms Smaller Organic Compounds

Ozone breaks down organic compounds into smaller chain organic molecules, especially aldehydes and ketones. These smaller organic molecules often measured as “assimilable organic carbon” (AOC) are more readily biodegradable and can increase biological growth downstream of the ozone addition point. AOC is a measure of the organic carbon readily available as food for microorganisms. Some systems that have added ozone without biological filtration have experienced increased AOC and microbial growth in the distribution system. Increased biological growth in the distribution system can lead to higher disinfectant demand and potentially TCR violations. Biological growth can also cause increased corrosion, possibly leading to violations of the Lead and Copper Rule (LCR) as well as to taste and odor problems.

An effective way to reduce AOC is biological filtration. Biological filtration can be achieved by not having a disinfectant residual in the water entering the post-ozone filter. The increased dissolved oxygen that results from the ozonation, combined with the high surface area per volume of the filter media, provide conditions for biological growth to occur on the filters. The biological growth on the filters then consumes the AOC, using it as a food source. Biological filtration has been shown to lower AOC effectively, even when very short residence times are used. Longer residence times can lead to the reduction of other organic compounds as well

Any type of filter media can accommodate biological filtration. Slow sand filters, rapid rate dual media filters, and GAC filters have all been successfully used for biological filtration. Rapid rate filters have been shown to remove AOC, though they may not remove all of the biodegradable dissolved organic carbon (BDOC), which is a portion of organic matter that can still be used by microbes as a food source but takes longer for the microbes to metabolize than AOC. Slow sand filters and GAC contactors have been shown to remove both BDOC and AOC. GAC has the added benefit that it will adsorb or concentrate organics, thus extending the time available for the microbes to metabolize the organic matter.

Switching to biofiltration can present its own challenges. Although biofilters remove turbidity as well as other filters, they have shown higher particle counts than traditional filters. They have also shown increased headloss over traditional filters.

#### Does Not Provide a Disinfectant Residual in the Distribution System

Ozone reacts very quickly and therefore is not able to provide a residual for use in the distribution system. A secondary disinfectant is, therefore, required to maintain a disinfectant residual in the distribution system as required by the SWTR.

Chlorine can often be used as an effective residual disinfectant after ozonation. Since ozone is used to achieve primary disinfection, lower doses of chlorine can be used as a secondary disinfectant, resulting in lower DBP levels. Ozone followed by biological filtration reduces DBP precursors, which also leads to lower DBP levels. If biological filtration is not used, the system should be careful that the additional smaller organic molecules do not react with chlorine added as a secondary disinfectant to produce higher DBP concentration than if chlorine alone were added. Chloroform has been found to be higher in some systems which used ozone without biological filtration than it was before ozone was implemented.

Chloramines can also be used to provide a distribution system residual after ozonation. Chloramines will result in lower DBPs than chlorine. As mentioned above, adding ammonia with the ozone will provide benefits regarding the formation of brominated DBPs. If this approach is taken, chlorine can be added after filtration to form the chloramines.

### May Introduce Dissolved Oxygen into the Water

When ozone reacts in water it forms dissolved oxygen. This oxygen may remain dissolved in the water. Dissolved oxygen can increase corrosion of metals. It can also cause increased growth of aerobic bacteria and problems with TCR compliance.

Corrosion-resistant materials should be used in the ozone feed equipment, the contact chamber, and any other plant equipment that comes into contact with the water after ozonation and before the dissolved oxygen is dissipated. The best way to prevent dissolved oxygen from entering the distribution system is to run the filters in biologically active mode. This will lower the dissolved oxygen, as well as remove AOC.

Systems using ozone after filtration and unfiltered systems may need to take steps to control microbial growth in the distribution system. Control measures include ensuring a sufficient residual throughout the system, looping dead ends in the distribution system, and minimizing retention time in reservoirs. Systems may also want to raise the pH of the water or add a corrosion inhibitor to prevent corrosion.

### Can Form Taste and Odor Compounds

Ozone is generally very effective in destroying taste and odors compounds, but in some cases ozonation of organic matter forms aldehydes and other compounds that can impart tastes and odors to water.

Systems should consider using a GAC filter or biologically active filtration to help eliminate aldehydes formed during ozonation, before the water reaches customers.

### Increases Corrosion

Ozone is corrosive and can corrode steel pipes and fittings, concrete, rubber gaskets, and other material with which it comes into contact in the treatment plant.

All material that comes into contact with ozone residual should be resistant to ozone. This includes any equipment which might be exposed to off-gassed ozone. Equipment manufacturers should be contacted to ensure compatibility of their equipment with ozone.

### Ozone Bubbles Can Hinder Filter Performance

Ozone can de-gas in the filter and bind to the filter media. This can adversely affect filter performance and reduce the effectiveness of filter backwashing. If ozone is injected under pressure, it should be de-gassed before the filters.

## CHLORINE DIOXIDE

Chlorine dioxide is an alternative chemical disinfectant that can be used to lower DBP production while maintaining adequate levels of inactivation. Because it is unstable, it is generated onsite using chlorine dioxide generators. Chlorine dioxide has gained popularity because it produces relatively few THMs and HAAs. It is also very effective against bacteria, viruses, and *Giardia* cysts, and can provide some inactivation of *Cryptosporidium* oocysts at higher temperatures. The main drawback of chlorine dioxide is that the chlorine dioxide MRDL of 0.8 mg/L combined with an MCL of 1.0 mg/L for chlorite, the main byproduct of chlorine dioxide, limit the dose that can be applied. In addition, low water temperatures can make it more difficult to use chlorine dioxide.

### **Advantages of Chlorine Dioxide**

Chlorine dioxide's advantages include:

- Effectively inactivates bacteria, virus, and *Giardia* cysts; can achieve some *Cryptosporidium* oocyst inactivation;
- Less TTHM and HAA5 formation than chlorine;
- Effective oxidant for the control of iron, manganese, hydrogen sulfide, and phenolic compounds;
- May treat high-bromide, high-TOC waters better than chlorine or ozone; and
- Not significantly affected by pH values between 6 and 9.

### Effective Disinfectant

Chlorine dioxide is a strong oxidant and can therefore effectively inactivate a wide range of microbes. Chlorine dioxide is slightly less effective than chlorine against viruses and bacteria, but is more effective against *Giardia* and *Cryptosporidium*.

Chlorine dioxide can achieve some inactivation of *Cryptosporidium* oocysts. Required CT levels for *Cryptosporidium* inactivation are relatively high though, so achieving more than a half log inactivation is unlikely given restrictions on dose. Chlorine dioxide can, however, be a relatively low cost alternative for systems that require a 0.5 log *Cryptosporidium* inactivation to comply with the LT2ESWTR.

### Less TTHM and HAA5 Formation

Chlorine dioxide provides a good alternative to chlorine for systems that wish to lower the formation of TTHM or HAA5. Pure chlorine dioxide does not form significant amounts of TTHM or HAA5. Most chlorine dioxide generators do produce some chlorine as a byproduct, however, so some TTHM and HAA5 will still be formed. The DBP of greater concern when chlorine dioxide is used is chlorite, which has a 1.0 mg/L MCL. Systems contemplating changing to chlorine dioxide will be required to perform a disinfection benchmark for viruses, *Giardia*, and *Cryptosporidium* and consult with the state to ensure adequate disinfection levels are maintained.

### Effective Oxidant

Another advantage to chlorine dioxide is that it is a strong oxidant. It can effectively oxidize many compounds including iron and taste and odor compounds. Under the right pH conditions it can oxidize arsenic, which is often the first step in arsenic treatment. Oxidation of arsenic does not alone result in the removal of arsenic from water, but it enhances its removal during additional treatment. Systems that were previously using chlorine to pre-oxidize these chemicals

may be able to achieve the same goals using chlorine dioxide, and simultaneously reduce TTHM and HAA5 to comply with the Stage 2 DBPR.

#### Not Significantly Affected by pH

The efficiency of chlorine dioxide does not vary significantly in the pH range of 6 to 9. This benefits systems trying to meet benchmarks since the CT achieved will not vary with pH. This also gives systems more flexibility with their treatment. They can adjust pH values to improve coagulation, reduce corrosion, or reduce DBP formation without concern for losing disinfection efficiency. It is possible, however, that some plants using enhanced coagulation or enhanced softening may fall outside the pH range of 6 to 9.

#### **Disadvantages of Chlorine Dioxide**

Potential issues with using chlorine dioxide include the following:

- Forms chlorite, a regulated DBP;
- Reduced effectiveness at low temperature;
- Chlorine dioxide MRDL of 0.8 mg/L;
- Can form brominated DBPs;
- Degrades when exposed to UV light;
- Residual dissipates quickly;
- Potential odor problems; and
- Safety concerns.

#### Chlorite Formation

One of the biggest disadvantages of using chlorine dioxide as a disinfectant is that it forms chlorite. The MCL for chlorite was set at 1.0 mg/L by the Stage 1 D/DBPR. Systems using chlorine dioxide must monitor daily at the entrance to the distribution system for chlorite. 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. This especially limits *Cryptosporidium* inactivation, since the required CT values for *Cryptosporidium* are much higher than for other microbes.

High oxidant demand and high pH also lead to higher chlorite production. If there is substantial oxidant demand in a system's water due to natural organic matter (NOM) or reduced metals, the oxidant demand will consume the chlorine dioxide and form chlorite, but the chlorine dioxide consumed in this way will not achieve any disinfection. Systems then have to add higher chlorine dioxide doses to achieve sufficient inactivation, and as a result generate higher chlorite concentrations.

Water pH values above 9 also lead to increased production of chlorite. Systems with high pH as a result of enhanced softening or corrosion control may have trouble complying with the chlorite MCL.

There are several ways to minimize chlorite concentrations. Adding chlorine dioxide after the filters, after the oxidant demand has been reduced, can result in lower chlorite concentrations. In order to comply with the LT1ESWTR or IESWTR, systems must benchmark and check with the state before moving the point of disinfection. Systems using chlorine dioxide as a pre-oxidant may also reduce the water's oxidant demand by using pre-sedimentation before chlorine dioxide is injected.

Systems that increase pH during treatment should try to do so after the chlorine dioxide contact chamber. They may want to reduce the treated water's pH to below 9 before adding the chlorine dioxide.

Even if systems control pH and have no oxidant demand outside of microbial inactivation, 50 to 70 percent of the chlorine dioxide consumed will form chlorite. This puts an effective limit on the dose that can be applied. Most systems will not be able to apply chlorine dioxide doses of greater than 1.2 mg/L without risking exceeding the chlorite MCL. Systems that cannot achieve the desired inactivation with a chlorine dioxide dose of less than 1.2 mg/L may want to consider using another disinfectant in addition to chlorine dioxide to achieve the necessary inactivation. Another possibility is that the chlorite could be reduced using a reductant such as thiosulfate, which would then allow the use of higher chlorine dioxide doses.

#### Reduced Effectiveness at Low Temperatures

The disinfection effectiveness of chlorine dioxide is temperature sensitive. It is much less effective at colder temperatures. As a result of this temperature dependence, systems in cold weather climates may not be able to use chlorine dioxide to meet the *Cryptosporidium* inactivation requirements of the LT2ESWTR.

Systems may be able to achieve some inactivation by increasing the chlorine dioxide dose and then using a reducing agent such as thiosulfate to reduce the chlorite to chloride, or by using a second disinfectant. In general though, systems that regularly experience near freezing temperatures should probably investigate other disinfection techniques.

#### Chlorine Dioxide MRDL

Chlorine dioxide itself can have health effects at elevated levels. Therefore it has an MRDL of 0.8 mg/L. Systems using chlorine dioxide will have to monitor the chlorine dioxide residual daily at the entry point to the distribution system, before the first customer. Systems using chlorine dioxide may have to limit their doses to prevent exceeding the MRDL. If the daily entry point sample exceeds the MRDL, systems are required by the Stage 1 D/DBPR to monitor the chlorine dioxide residual in the distribution system.

Chlorite can react with excess chlorine in the distribution system to reform chlorine dioxide. Some systems may opt to boost with chlorine to maintain a residual in the distribution system. If doses are high enough, systems could exceed either the chlorine dioxide MRDL or the chlorite MCL. Reformed chlorine dioxide can also volatilize at consumer's taps and react with volatile organics to cause odor problems.

Systems that use chloramines for distribution residual may have difficulty measuring chlorine dioxide because chloramines can interfere with its measurement.

If chlorine dioxide doses are kept below 1 mg/L, exceeding the MRDL should not be a problem. If reformation of chlorine dioxide is not desired, chloramines can be used in the distribution system instead of chlorine. If doses much higher than 1.2 mg/L are used, a reducing agent can be added to the water before it enters the distribution system to reduce any chlorine dioxide residual or chlorite to chloride. This will also prevent formation of chlorine dioxide in the system by booster addition of chlorine.

If a system intentionally re-forms chlorine dioxide by boosting with chlorine in the distribution system, the system should conduct bench scale tests to determine the correct chlorine dose to add to achieve an adequate residual without exceeding either the chlorine dioxide MRDL or the chlorite MCL. Systems should take into consideration the expected residence time in the distribution system.

If a system is using chloramines to maintain a distribution system residual, there are amperometric titration techniques which can be used to determine between various chlorine species.

#### Can Form Brominated DBPs

Chlorine dioxide can oxidize bromide ions to bromine. The bromine can then react with organic matter to form brominated DBPs. Systems with high bromide concentrations that are near the Stage 2 DBPR limits for TTHM or HAA5 will need to take this into account.

Systems with high bromide concentrations that are near the Stage 2 DBPR limits for TTHM or HAA5 can lower DBP formation by adding chlorine dioxide after the filters, where organic concentrations are lower. Enhancing coagulation will also lower the amount of organic matter available to react with chlorine dioxide after the filters. Systems that use chlorine dioxide for pre-oxidation may be able to achieve some organic removal by using pre-sedimentation basins. Systems with very high bromide can remove it using ion exchange columns, but this is rarely an economical solution.

#### Degrades When Exposed to UV Light

Chlorine dioxide is sensitive to UV light and will degrade to form chlorate when exposed to UV light. This will reduce chlorine dioxide residuals and therefore lower inactivation.

Systems using chlorine dioxide can prevent degradation by light by covering the contact basin. If a building or hard cover are not cost-effective or require too much space, floating covers can shield the chlorine dioxide from the UV light. The manufacturer should be consulted in selecting the cover material to be sure it is compatible with chlorine dioxide.

Systems using chlorine dioxide and UV disinfection together should add the chlorine dioxide either after the UV reactor or sufficiently ahead of the reactor that there is no residual entering the reactor. Systems should not use the residence time of UV reactors to receive contact time credit for chlorine dioxide added earlier in the treatment process.

#### Residual Dissipates Quickly

Chlorine dioxide is highly reactive and will react with GAC and anthracite in filters. Chloride formed by the reaction of chlorine dioxide and GAC can also adsorb to the GAC and cause weaker binding elements to be released. Chlorine dioxide is also volatile and can be lost in rapid mix basins or other unit processes that have high turbulence and are exposed to the atmosphere.

Filters should not be used to achieve contact time for chlorine dioxide. Rapid mix basins can be used for contact time, but may require higher doses to achieve the same inactivation level. Adding the chlorine dioxide after filtration will avoid any unnecessary residual loss and will maximize the chlorine dioxide dose that is available for disinfection. Systems adding chlorine dioxide as a pre-oxidant can add the chlorine dioxide in the coagulation basins. Systems with low alkalinity may see a slight rise in pH after chlorine dioxide addition.

### Potential Formation of Odor-Causing Compounds

Chlorine dioxide residuals in customers tap water has been found to volatilize at the tap and to react with volatile organic compounds (VOCs) in customer's houses forming compounds with particularly bad kerosene-type odor. It can also sometimes give a strong chlorinous odor.

The appearance of odors in customer's homes is difficult to predict and therefore prevent. Utilities can keep good customer complaint records and provide public education on what to do if such odors occur. Suggestions for dealing with odors in the household include improving ventilation and using carbon filters to remove the chlorine dioxide residual.

### Safety Concerns

The nature of chlorine dioxide and the chemicals used to generate it requires additional training and safety precautions to ensure safe operation of the treatment plant. Sodium chlorite is often used to generate chlorine dioxide. When acidified, it can produce large amounts of gaseous chlorine dioxide. Chlorine dioxide at concentrations greater than 0.1 ppm is toxic and can cause shortness of breath, coughing, respiratory distress, and pulmonary edema. Gaseous chlorine dioxide concentrations greater than 10 percent can be explosive. Sodium chlorite fires burn very hot and produce oxygen as a byproduct.

Systems should contact their chlorine dioxide equipment manufacturer to schedule any necessary training. Sodium chlorite should be stored away from other chemicals, especially acids and reducing agents. It should be stored in an area made of fire resistant materials such as concrete. The area should be equipped with monitoring equipment to detect chlorine dioxide and other chlorine components in the atmosphere. Proper ventilation and scrubbers should be provided in the area. A special plan should be developed to respond to leaks or fires in the area and the necessary equipment to implement the plan, including respirators, should be stored and accessible outside the sodium chlorite storage area. If more than 1,000 pounds are stored on site the plan must be formalized into a Risk Management Plan (RMP) and OSHA's specific requirements for storage of chlorine dioxide must be satisfied.

## ULTRAVIOLET LIGHT

Recent research indicating that UV light can inactivate *Cryptosporidium* at relatively low lamp intensities has spurred interest in its use for drinking water disinfection. UV light works by damaging the genetic material of microorganisms, interfering with the ability of pathogens to replicate and therefore with their ability to be infective. Similar to chemical disinfectants, the extent of UV inactivation depends on the intensity of the light and the time the microorganism is exposed to it. UV is an effective way to disinfect without producing regulated DBPs. UV does not provide a residual, however, so it is not effective in providing a distribution system residual.

If UV is being used as a toolbox option to comply with LT2ESWTR, UV reactors must be validated according to state guidelines and operate within the validated parameters. For purposes of design and operation, EPA recommends that systems strive to deliver the required UV dose at all times during treatment.

### **Advantages of UV**

UV light's advantages include:

- It can inactivate chlorine-resistant pathogens such as *Cryptosporidium* oocysts and *Giardia* cysts at relatively low doses;
- It does not produce regulated DBPs; and
- Its effectiveness is not pH or temperature dependent.

### Inactivates *Cryptosporidium* and *Giardia*

UV disinfection gained attention in the U.S. drinking water market when it was shown that it could inactivate *Cryptosporidium* oocysts and *Giardia* cysts. This gives UV an advantage over chlorine or chloramines, which are ineffective against *Cryptosporidium*. If properly tested and validated, UV is one of the least expensive options for systems that are required to achieve additional *Cryptosporidium* inactivation under the LT2ESWT. UV can also meet SWTR requirements for *Giardia* inactivation.

### Does Not Produce Regulated DBPs

UV disinfection, as a photochemical process, does not produce any of the regulated byproducts that chemical disinfectants such as chlorine, ozone, and chlorine dioxide produce. Surface water systems and systems using GWUDI of surface water may meet Stage 2 DBPR requirements by switching to UV disinfection and lowering their doses of chemical disinfectants. Systems making this change will be required to benchmark their disinfection process under LT2ESWTR requirements before making the change. Systems will also need to continue to meet the residual disinfection requirements of the SWTR.

### Not pH or Temperature Dependent

Research has shown that temperature effects on UV dose-response are minimal. Dose response is also independent of pH in the range of 6 to 9. This gives systems more flexibility to adjust pH to control coagulation, or to lower production of DBPs without also affecting disinfection efficiency. This could also mean simpler operations if the UV dose does not need to be adjusted seasonally (although dose could vary seasonally if the levels of UV absorbing compounds in the water being treated vary seasonally).

### **Disadvantages of UV**

Potential operational and simultaneous compliance issues associated with UV disinfection include:

- Substances in water can interfere with UV disinfection;
- Hydraulic upsets can lower the delivered dose and possibly cause lamp breakage;
- Much higher doses are needed for virus inactivation;
- UV disinfection provides no distribution system residual; and
- Power quality problems can disrupt disinfection.

#### Substances in Water Can Interfere with UV Disinfection

Because UV disinfection relies on UV light interacting with the organism's genetic material to be effective, any substance that either absorbs or refracts the germicidal UV light can interfere with disinfection. A common measure of the fraction of germicidal light (i.e., light specifically with a wavelength of 254 nanometers) transmitted through a material is UV Transmittance (UVT). The higher the UVT, the better UV light can be transmitted through the water and the more effective the treatment. Compounds in source waters that can absorb or refract UV light and reduce UVT include humic and fulvic acids, phenols, metals (e.g., iron and manganese), and anions (e.g., nitrates). LT2ESWTR requires water systems to account for UV absorbance of the water during validation testing.

In addition to absorbing UV light and decreasing UVT, compounds in the water can foul the external surfaces of the lamp sleeves. The rate of fouling depends on water quality characteristics such as hardness, alkalinity, ion concentration, and pH. The presence of disinfectants upstream of UV treatment can impact UV performance. Ozone is a strong absorber of UV light and can interfere with disinfection if not quenched prior to UV treatment. Ozone treatment, however, can be effective in increasing the UVT. Some chlorine residual can be lost if water with a free or total chlorine residual is passed through a UV reactor.

Systems should carefully evaluate their water quality during the planning phase for their new UV facility. UVT is the most important water quality characteristic affecting UV facility design; therefore, care should be taken to characterize UVT during typical operations as well as during storm events, seasonal changes, reservoir turnover, and source water blends. UV absorbance of the water (i.e., UVT) must be accounted for during validation testing.

EPA recommends that systems determine a "fouling factor" during the planning phase to account for lower UVT caused by fouling of the lamp sleeves. This factor is defined as the estimated fraction of UV light passing through a fouled sleeve compared to a new sleeve. UV reactors typically allow for cleaning of lamp sleeves to remove deposited material. Three common approaches are off-line chemical cleaning, on-line mechanical cleaning, and online mechanical-chemical cleaning. More frequent lamp cleaning can increase the fouling factor. Lamp fouling should be accounted for during validation testing.

Systems can modify their treatment to increase UVT and reduce the potential for fouling of lamp sleeves. Pre-oxidation and enhanced coagulation are potential treatments that can be used for this purpose. Their usefulness should be evaluated on a case-by-case basis.

Ozone, if used for taste and odor control, will generally be added before the filters and will not enter the UV reactor. If this is not the case and an ozone residual is present in the water before it enters the UV unit, the ozone should be quenched. Ozone can be quenched by air stripping in the last chamber of the ozone contactor, or by using a reducing agent such as hydrogen peroxide.

Some studies suggest, however, that ozone quenching using hydrogen peroxide can be slow in low-alkalinity water. The ozone residual should not be quenched with thiosulfate, as thiosulfate also absorbs UV.

If chlorine dioxide is being used, it should be added after the UV reactor. If corrosion inhibitors that contain UV-absorbing compounds are used, they should be added after water has passed through the UV reactor.

#### Lamp Breakage

Lamp breaks can be caused by debris in water, temperature variations, water hammer, electrical surges, or improper installation. Lamps in most UV reactors contain mercury or an amalgam of mercury and another compound such as gallium or indium. If lamps break during reactor operations, there is a risk of exposure to mercury.

Very few incidents of on-line lamp breaks have been documented. To isolate the mercury, systems can install spring-return actuated valves with a short closure time on the reactor inlet and outlet piping. Systems should also consider installing a strainer or mercury trap. EPA recommends that systems evaluate the applicability of various isolation techniques on a case-by-case basis.

#### Virus Inactivation

While UV disinfection is highly effective against protozoa such as *Cryptosporidium*, it is less effective against viruses. The LT2ESWTR requires systems considering substituting current chlorination with UV disinfection to benchmark with respect to viruses, *Giardia*, and *Cryptosporidium* and consult with the state to be sure that sufficient inactivation is maintained.

This ratio can be compared to the ratio of UV dose required for inactivation of viruses and the UV dose required for the inactivation of *Cryptosporidium*. This ratio is much lower for chlorine dioxide and ozone compared to UV, meaning that chlorine dioxide and ozone are more effective for inactivation of viruses compared to *Cryptosporidium*, while UV is the opposite.

Systems that adopt UV disinfection will need to take special care to ensure that the virus benchmark is achieved. The state should be consulted throughout the planning process to ensure that inactivation requirements can be met to achieve the necessary credit.

To receive credit for disinfection with UV light, the LT2ESWTR requires water systems to demonstrate through validation testing that the UV reactor can deliver the required UV dose. The testing must determine a range of operating conditions that can be monitored by the system and under which the reactor delivers the required UV dose. At the time of this publication, EPA is not aware of an available challenge microorganism that allows for full-scale testing of UV reactors to demonstrate 4-log inactivation of viruses at a required dose of 186 mJ/cm<sup>2</sup>. Methodologies for challenge testing at doses necessary to inactivate UV resistant viruses may be developed in the future.

Until then, UV technology should be used in a series configuration or in combination with other inactivation or removal technologies to provide a total 4-log treatment of viruses. The second option uses a different treatment to achieve virus inactivation and uses UV only for *Cryptosporidium* and *Giardia* inactivation. If a chemical disinfectant is used, it could be added after the UV reactor to maintain a residual in the distribution system or it could be added prior to

the UV reactor where it could also serve as a preoxidant. Surface water systems will need to add secondary disinfection to comply with the entry point and distribution system residual requirements of the SWTR. If a second disinfectant is used also for additional virus inactivation, it must achieve the required inactivation before the first customer. Chlorine will provide virus inactivation with a relatively low dose, but may produce DBPs and could create problems with Stage 2 DBPR requirements. Chloramines will have less DBP formation but will require significantly longer contact time in the clearwell to ensure appropriate inactivation before the first customer.

If pre-oxidation is practiced, chlorine, ozone, or chlorine dioxide can be used. Chlorine may not be an attractive solution because the production of DBPs. Ozone will likely be cost prohibitive unless it is already installed; in which case it would have numerous advantages.

#### UV Does Not Provide a Residual

UV disinfection, because it is not a chemical disinfectant, does not leave a residual and cannot be used to meet SWTR requirements regarding entry point and distribution system residuals.

Free chlorine or chloramines can be used to maintain a residual disinfectant. Chlorine is effective against viruses and bacteria but can cause significant problems with Stage 2 DBPR compliance, especially in portions of the distribution system with long residence times where organic carbon is present. Chloramines as a residual disinfectant after UV disinfection have the potential to provide adequate distribution system residual and very low DBPs. Problems with chloramines include potential issues with nitrification, potential corrosion problems, and taste and odor issues if the chlorine-to-ammonia ratio is not maintained properly.

#### Power Quality Problems Can Disrupt Disinfection

A UV lamp can lose power in the event of a power interruption, voltage fluctuation, or power quality anomaly. Common causes of power quality problems include faulty wiring and grounding, weather-related damage, and power transfers to emergency generators or alternate feed. Systems are required to monitor lamp status to ensure that reactors are operating within validated limits. Loss of power can result in the reactors operating off-specification.

## **CORROSION CONTROL**

Corrosivity can be defined as the tendency of water to dissolve metal. It can affect metal structures and equipment, such as pipes, valves and pumps parts. Water that has a strong tendency to do this is said to be highly corrosive, water that does not do so readily is said to be weakly corrosive or non-corrosive. Highly corrosive water (water having high corrosivity) poses both a health hazard and an economic burden. Undesirable metals dissolved by corrosive water may be detrimental to health. An example of this is lead and/or copper dissolved in water as a result of the corrosive action on copper pipes and lead-based solder. If corrosion goes unchecked metal pipes and equipment will be severely damaged or destroyed. Replacement of corrosion damaged material and equipment can be very costly.

Corrosion is an extremely complex phenomenon. Corrosion is affected by five water quality parameters; pH, hardness, alkalinity, temperature, and **total dissolved solids (TDS)**. Of these, pH has the greatest influence. Generally, the lower the pH the more corrosive the water will be. The presence of hardness and alkalinity tends to lessen the corrosivity, so water with higher hardness and alkalinity are usually less corrosive than water with lower hardness and alkalinity. TDS and temperature are less important, but an increase of either one tends to increase corrosivity.

As a general rule, surface water sources are more corrosive than groundwater sources. This is due to the fact that most surface water sources have low pH, low hardness, low alkalinity, and low TDS, whereas groundwater tends to be just the opposite; higher pH, higher hardness, higher alkalinity and higher TDS.

Since pH has the greatest impact, corrosivity can be controlled by the addition of chemicals to raise the pH. As it happens, the most common chemicals used to raise pH (lime and soda ash) also increase hardness and alkalinity, which help reduce corrosivity.

Corrosivity is considered a secondary contaminant with a SMCL of noncorrosive. The **Langlier Saturation Index (LSI)**, which takes into consideration pH, total dissolved solids, hardness, alkalinity, and temperature, is commonly used to determine if water is corrosive or not. The analytical lab doing your water tests can determine your LSI.

There are two strategies to reduce or control the corrosivity of water; adjustment of the chemical characteristics of the water (primarily, pH control), known as precipitation, and covering the surface of pipes with a protective coating, known as passivation.

### **pH Control**

Of the five factors that affect corrosivity, pH is the most significant. Low pH contributes to the corrosivity of water. So raising the pH will reduce corrosivity. There are a number of pH increase treatment options available to small systems to increase pH.

### **Aeration**

Some waters may have excess dissolved carbon dioxide (CO<sub>2</sub>). This is most likely to happen in slow moving streams or lakes when metabolic activity releases CO<sub>2</sub> and the lack of turbulence allows the dissolved CO<sub>2</sub> to buildup. A buildup of CO<sub>2</sub> results in a low pH because of the CO<sub>2</sub>/H<sub>2</sub>CO<sub>3</sub> equilibrium. An increase in CO<sub>2</sub> increases the carbonic acid (H<sub>2</sub>CO<sub>3</sub>), thus lowering the pH. If CO<sub>2</sub> is removed the process is reversed, resulting in an increase in pH and a decrease

in corrosivity. CO<sub>2</sub> is most prevalent in groundwater although it can occur in surface water under ice cover.

### **Limestone Contactors**

A limestone contactor, sometimes called a neutralizing filter, can be used to raise the pH of water. Limestone is calcium carbonate (CaCO<sub>3</sub>). As low pH water passes through the contactor it dissolves the CaCO<sub>3</sub>. Through a chemical reaction, similar to the CO<sub>2</sub>/H<sub>2</sub>CO<sub>3</sub> resulting in a higher pH and a decrease in corrosivity. A limestone contactor is an inline canister device that is convenient for small system applications. A possible drawback with the use of a limestone contactor is that calcium ions are also released into the water which increases hardness.

### **Soda Ash**

Soda ash (Na<sub>2</sub>CO<sub>3</sub>) can also be used to raise the pH. The chemistry is similar to the use of and causes a higher pH and a decrease in corrosivity results. Soda ash is normally fed into the water system as a solution using a liquid chemical feed pump. The feed equipment is almost the same as that used to feed sodium or calcium hypochlorite.

### **Sodium Hydroxide**

Sodium hydroxide (NaOH), commonly called caustic soda, is readily soluble in water and a very strong base. It can be used to raise pH in water systems, but it is extremely corrosive and can be very dangerous if mishandled. It is critical that workers who handle NaOH be well trained. Diluted NaOH is normally fed into the water system using a liquid chemical feed pump. The feed equipment is almost the same as that used to feed sodium or calcium hypochlorite.

### **Chemical Coatings**

Corrosion can be inhibited by adding chemicals to the water that adhere directly to the pipe surface or in combination with naturally-occurring constituents in the water form films or coatings on the pipe surface. These coatings prevent contact between the metal pipe surface and the corrosive water, providing a barrier to corrosion reactions.

### **Phosphates and Silicates**

Silicates and orthophosphates are frequently used by small systems to form protective films on pipe surfaces. The protective coating prohibits the corrosive water from contacting the metal pipe. Sodium silicate and phosphate must be continuously added to the systems to be effective.

### **Carbonate Precipitates**

When calcium and magnesium carbonates precipitate they can form a protective coating on the inside of water pipe. Whether or not the carbonates will precipitate depends on the pH and amount of alkalinity and hardness present in the water. If they all are relatively high, precipitation is enhanced. Consequently, when limestone (CaCO<sub>3</sub>) and soda ash (Na<sub>2</sub>CO<sub>3</sub>) are used to raise the pH there is a side benefit of the protective carbonate coating. In fact, some corrosion control strategies increase pH, alkalinity and hardness

## LANGELIER SATURATION INDEX

The LSI is one of several tools used by water operators for stabilizing water to control both internal corrosion and the deposition of scale. The LSI is an equilibrium model derived from the theoretical concept of saturation and provides an indicator of the degree of saturation of water with respect to calcium carbonate. It can be shown that the LSI approximates the base 10 logarithm of the calcium saturation level. The Langelier saturation level approaches the concept of saturation using pH as a main variable. The LSI can be interpreted as the pH change required to bring water to equilibrium.

Water with a Langelier saturation index of 1.0 is one pH unit above saturation. Reducing the pH by 1 unit will bring the water into equilibrium. This occurs because the portion of total alkalinity present as  $\text{CO}_3^{2-}$  decreases as the pH decreases, according to the equilibria describing the dissociation of carbonic acid:

- If LSI is negative, then the water is under saturated with calcium carbonate and will tend to be corrosive in the distribution system. There is no potential to scale and the water will dissolve  $\text{CaCO}_3$ .
- If LSI is positive, then the water is over saturated with calcium carbonate and will tend to deposit calcium carbonate. Scale can form and  $\text{CaCO}_3$  precipitation may occur in the distribution system.
- If LSI is close to zero: then the water is just saturated with calcium carbonate and will neither be strongly corrosive or scale forming. Water quality or changes in temperature, or evaporation could change the index.

The LSI is probably the most widely used indicator of cooling water scale potential. It is purely an equilibrium index and deals only with the thermodynamic driving force for calcium carbonate scale formation and growth. It provides no indication of how much scale or calcium carbonate will actually precipitate to bring water to equilibrium.

The LSI is an approximate indicator of the degree of saturation of calcium carbonate in water. It is calculated using the pH, alkalinity, calcium concentration, total dissolved solids, and water temperature of a water sample collected at the tap.

It simply indicates the driving force for scale formation and growth in terms of pH as a master variable. In order to calculate the LSI, it is necessary to know the alkalinity (mg/L as  $\text{CaCO}_3$ ), the calcium hardness (mg/l  $\text{Ca}^{2+}$  as  $\text{CaCO}_3$ ), the total dissolved solids (mg/L TDS), the actual pH, and the temperature of the water ( $^{\circ}\text{C}$ ). If TDS is unknown, but conductivity is, one can estimate mg/L TDS using a conversion table such as the one presented here. LSI is defined as:

$$\text{LSI} = \text{pH} - \text{pH}_s$$

Where:

**pH** is the measured water pH

**pH<sub>s</sub>** is the pH at saturation in calcite or calcium carbonate and is defined as:

$$\text{pH}_s = (9.3 + \text{A} + \text{B}) - (\text{C} + \text{D})$$

Where:

$$\text{A} = (\text{Log}_{10} [\text{TDS}] - 1) / 10$$

$$\text{B} = -13.12 \times \text{Log}_{10} (^{\circ}\text{C} + 273) + 34.55$$

$$\text{C} = \text{Log}_{10} [\text{Ca}^{2+} \text{ as } \text{CaCO}_3] - 0.4$$

$D = \text{Log}_{10} [\text{alkalinity as CaCO}_3]$

However, there is some controversy concerning the correlation of these indices, and particularly the LSI, with the corrosivity of waters. While some sectors of the water management industry squarely use the indices as a measure of the corrosivity of their waters, more alert specialists are very cautious as to how far one can extrapolate the indices to such usage.

## **FLUORIDATION**

Fluoride is a naturally occurring element found in small but varying amounts in water, air, soil, plants, and animals. Water fluoridation is the deliberate addition of fluoride into drinking water in accordance with scientific and dental guidelines. When used appropriately, fluoride is a safe and effective agent that can be used to prevent dental cavity formation. However, fluoride above 2.0 parts per million (ppm) may result in enamel fluorosis in developing teeth.

### **Regulations**

These levels are based on the annual average of the maximum daily air temperature in the area of the involved school or community. The recommended optimal fluoride concentrations for fluoridated water supply systems are stated in WV 64CSR3. Systems are recommended to maintain a fluoride concentration of 0.8 ppm to 1.3 ppm, with an optimum level of 1.0 ppm. The Safe Drinking Water Act established a fluoride Maximum Contaminant Level (MCL) of 4.0 ppm to protect against crippling skeletal fluorosis and a Secondary MCL (SMCL) of 2.0 ppm to protect against dental fluorosis.

### **Dental Fluorosis**

Dental fluorosis is defined as the whitish to brownish spots seen on teeth. It has been clearly established that high levels of fluoride in the drinking water will cause fluorosis (or “mottled enamel”, as it is sometimes called). Dental fluorosis has been recognized since the turn of the century in people with high exposure to naturally occurring fluoride in drinking water. It has always been more prevalent in fluoridated than non-fluoridated areas. Dental fluorosis occurs only during tooth formation and becomes apparent upon eruption of the teeth. It ranges from very; mild symmetrical whitish areas on teeth (very mild dental fluorosis) to pitting of the enamel, frequently associated with brownish discoloration (severe dental fluorosis). The very mild form is barely detectable even by experienced dental personnel. Moderate and severe forms of dental fluorosis, considered by some investigators as presenting a cosmetic problem, do not appear to produce adverse dental health effects, such as the loss of tooth function, and represents less than 6% of the cases of fluorosis nationally.

### **Fluoride Chemicals**

The most commonly used fluoride compound is hydrofluosilicic acid. Other commonly used fluoride compounds are sodium fluorosilicate and sodium fluoride. Fluoride compounds must conform to ANSI/NSF and AWWA standards. The water supplier should insist that the chemical supplier furnish only compounds that meet these standards. The water supplier should also periodically request Material Safety and Data Sheets and chemical composition test results from the chemical supplier.

Several factors must be considered in selecting a fluoride chemical. For suppliers that use a powder or crystal form, the solubility of the chemical in water is important since the chemical must dissolve readily in water and remain in the solution. Operator safety and ease of handling must also be considered, as well as storage and feeding requirements and, of course, cost.

Hydrofluosilicic acid must be handled cautiously. It is very dangerous, can cause burns, and produces acidic fumes that must be vented to the atmosphere. These acidic fumes can etch glass on gauges, corrode electrical equipment and irritate skin. Sodium fluoride is the easiest chemical to feed because of its uniform solubility in water.

### **Sodium Fluoride**

The first fluoride compound used in water fluoridation was sodium fluoride. Sodium fluoride (NaF) is a white, odorless material available either as a powder or in the form of crystals of various sizes. It is a salt that in the past was manufactured by adding sulfuric acid to fluorspar and then neutralizing the mixture with sodium carbonate. Sodium fluoride has a formula weight of 42.00, a specific gravity of 2.79, and its solubility is practically constant at 4.0 grams per 100 milliliters in water at temperatures generally encountered in water treatment practice.

The relatively constant 4% solubility of sodium fluoride is the basis for the design of the saturator. The pH (hydrogen-ion concentration) of a sodium fluoride solution varies with the type and amount of impurities, but solutions prepared from the usual grades of sodium fluoride exhibit a nearly neutral pH (approximately 7.6). It is available in purities ranging from 97 to over 98%, with the impurities consisting of water, free acid or alkali, sodium fluorosilicate, sulfites and iron, plus traces of other substances. Approximately 19 pounds of sodium fluoride will add 1 ppm of fluoride to 1 million gallons of water.

### **Sodium Fluorosilicate**

Sodium fluorosilicate ( $\text{Na}_2\text{SiF}_6$ ), also known as sodium silicofluoride is widely used as a chemical for water fluoridation. Sodium fluorosilicate is a white, odorless crystalline powder. Its molecular weight is 188.06 and its specific gravity is 2.679. Its solubility varies from 0.44 grams per 100 milliliters of water at 0° C to 2.45 grams per 100 milliliters at 100° C. The pH's of solutions are definitely on the acid side, with saturated solutions usually exhibiting a pH between 3.0 and 4.0 (approximately 3.6). Sodium fluorosilicate is available in purities of 98% or greater, the principal impurities being water, chlorides, and silica. Approximately 14 pounds of sodium fluorosilicate will add 1 ppm of fluoride to 1 million gallons of water.

### **Fluorosilicic Acid**

Fluorosilicic acid ( $\text{H}_2\text{SiF}_6$ ), also known as hydrofluosilicic, hexafluosilicic, or silicofluoric acid is a 20 to 35% aqueous solution with a formula weight of 144.08. It is a straw-colored, transparent, fuming, corrosive liquid having a pungent odor and an irritating action on the skin. Solutions of 20 to 35% fluorosilicic acid exhibit a low pH (1.2), and at a concentration of 1 ppm can slightly depress the pH of poorly buffered potable waters. It must be handled with great care because it will cause a "delayed burn" on skin tissue. The average density of 23% acid is 10.1 lbs/gal. Fluorosilicic acid (23%) will freeze at approximately 4° F or -15.5° C. It takes approximately 46 pounds (4.4 gallons) of 23 % acid to add 1 ppm of fluoride to 1 million gallons of water.

Hydrofluoric acid is an extremely corrosive material. Its presence in fluorosilicic acid, whether from intentional addition, i.e., "fortified" acid or from normal production processes demands careful handling. The hydrofluoric fumes from fluorosilicic acid are lighter than air, unlike chlorine fumes, which are heavier than air. Thus, the acid fumes will rise instead of settling to the floor.

Attempts to dilute the acid are subject to errors in measuring both the acid and the diluting water. It is much better to use the acid undiluted as it comes from the containers in which it is shipped. If the acid is too concentrated for the solution feeder to handle, then weaker solutions of other compounds are generally indicated—for instance, saturated solutions of sodium fluoride. CDC strongly recommends against the dilution of acid. If the acid must be diluted, care should be taken to avoid the formation of a precipitate of silica, which will appear despite the quality (hardness) of the water used for dilution. Dilutions between 10:1 and 20:1 (water: acid) are

where insoluble silica precipitates are most likely to occur. Softening the water will not prevent this precipitation.

### **Fluoridation Systems**

Fluoride can be added to water in liquid or powder form. In liquid form, a chemical pump adds the fluoride in a controlled dosage. In powder form, a dry feeder adds the chemical to a water solution which is then added to the water.

### **Displacement Pump**

A dual head or 2 single headed positive displacement pump designed of a corrosion-resistant material. If the pump discharges to an open tank with an airbreak such as a clearwell or filter, the double-head pump is not required. The airbreak will prevent any chance of backsiphonage.

### **Break Box**

A break box is required to prevent an overfeed of fluoride chemical. This is a single compartment tank with one head of the pump discharging into one side and the second head using that same compartment as the suction for the pump that discharges to the feed point. This box must be made from acid resistant material that can withstand the corrosion of the hydrofluosilicic acid. There is an overflow line back to the day tank. (Corrosion-resistant shelving should be used for mounting feed pumps and the breakbox).

### **Day tank**

The solution or day tank is generally a calibrated polyethylene tank that can withstand the corrosivity of an acid. This tank generally holds at least 50 gallons of fluoride solution. It should be calibrated in one-gallon units. The solution tank should be sealed and vented to the outside.

### **Chemical**

Whenever possible, full-strength chemical should be fed. If it isn't, a method for diluting the acid with water is needed. The dilution can be done manually; otherwise, a transfer pump is required to move the acid needed to make up the solution from the storage tank to the dilution tank. A water source is also needed and must be protected from cross-connection.

### **Safety and Ventilation**

When working on the fluoridation system, the operator needs to use safety equipment consisting of neoprene apron, gloves, and goggles. Ventilation must be provided. An exhaust fan and solution-tank vents help protect against indoor acid fumes which could etch glass and corrode electrical equipment. All tank vents should be terminated outside the building.

### **Chemical Feed Pump**

The size of the feed pump is determined by:

- The required rate of feed from the well or plant (gallons treated);
- The natural fluoride concentration in the raw water; and
- The percentage of purity and availability of fluoride in the chemical.

The pump purchased should be sized so that the required amount of acid per day is in the mid-range of its capacity. This will give a more accurate feed. If the water flow is less than 100 gpm, acid may be diluted; however, in most cases--even with a low flow--a pump small enough to feed accurately can be purchased. Dilution is not recommended. The pump should be sized to

accommodate low flow. The chemical feed equipment must be wired to start and stop with the well pump so that chemical is fed only when water flows.

### **Operation and Maintenance**

Operation of the pumping equipment is simple, but anything mechanical occasionally breaks down. In most cases, diaphragm pumps are operated by either electronic or mechanical controls. Electronic pumps are becoming more popular because of their reliability and versatility. Electronic pumps can accurately deliver very small volumes because both the length of the stroke and its frequency can be finely adjusted. Mechanical pumps are typically immersed in oil and require more maintenance.

When the pump operating the diaphragm moves a given distance for each stroke, it opens the check on the suction side, allowing a given amount of acid to flow into the pump. The amount of acid will depend on the volume of the cavity that the diaphragm movement creates. When the diaphragm reverses the stroke to expel the acid, the suction check closes and the discharge check opens, allowing the acid to flow away from the pump.

Maintenance of the pumping equipment involves the replacement of the check valve balls, diaphragm gaskets, and related parts. Most operators should be able to repair the pump without too much trouble; however, if the power source is the problem, it may require an electrician or the pump supplier's service representative.

### **Installation**

Prior to the start-up of the equipment, the operator should make sure:

- Chemical is injected into the water system at the lower half of a discharge pipe located downstream of the pump. The injection pipe located in the lower half of the pipe will prevent corrosion of the pipe;
- Power supply for the feed pump is activated by the well or water-pumping equipment so the fluoride pump will start and stop the same time as the water pump; and
- All valves on discharge side of feed pump are open to allow chemical flow.

Once these items are checked, and corrected, an operator should:

- Prime the feed pump with potable water, and run the pump at full capacity until all air has been bled from the lines;
- Use a graduated cylinder and stop watch to calibrate the feed rate of the pump and make any necessary adjustment; and
- After the feed has started, check the water samples for the proper fluoride concentration. These samples should be taken at least 100 feet from the point of fluoride application.

### **Troubleshooting**

If low fluoride concentration is detected, and if the problem is determined to be related to low pump output (not an error in the feed calculations), the following possible causes should be investigated:

- Low pump setting - An increased pump setting may solve the output problem;
- Trapped air or loss of prime - If air is found in the chemical feed lines, determine how it entered. It might be due to a faulty seal, a tubing or fitting leak, air suction due to a depleted feed solution supply, or other similar causes;

- Ruptured diaphragm - A ruptured diaphragm should be replaced immediately since an acid leak can cause internal pump damage; and
- Clogged tubing or valves - Make sure liquid flows freely through the system.

If the pump is operating properly and a low concentration is detected, the cause must lie in the feed solution or water pumpage rate and you should check:

- Proper feed dilutions - Prepare a small amount of the proper solution concentration. Feed this into the system and test for the actual fluoride concentration; and
- Pump rate - Check the meter with a stop watch for a given length of time.

If the pump is operating properly and a high concentration is detected, the cause may be high pump output. The pump setting is too high or the fluoride solution is being siphoned into the water piping. Siphoning is less likely to be the problem since most solutions are added at the discharge side of a well pump against higher pressure. However, siphoning might occur if pressure is lost in the water system. A break box is provided in the feed system to safeguard against excessive feed due to siphoning action.

### **Sodium Fluoride Feed**

In a fluoride saturator, the incoming water becomes saturated with sodium fluoride as it percolates up through the granulated sodium fluoride bed. This provides a 4% sodium fluoride solution. This solution is injected into the water supply at a rate calculated to maintain a fluoride concentration of 1.0 ppm.

### **Installation**

To prevent scale formation, a softener should be used to soften the makeup water for the saturator when the hardness exceeds 50 ppm as calcium carbonate or 4.4 grains. This softened incoming water should then go through a water meter, a solenoid valve, or a flow control valve and a backflow preventer. The water is piped into the saturator through a diffuser system. A constant water level is maintained inside the saturator by means of a float connected to a liquid level switch. The upward flow rate should not exceed 2 gpm. The tank should be filled manually each day while recording the amount used so that the level remains constant.

### **Operation and Maintenance**

To operate the saturator, the following steps should be taken:

- Mark the outside of the saturation tank at the five-inch level. This is the minimum depth of sodium fluoride needed in the tank to maintain a four-percent solution. Add additional sodium fluoride when it reaches this line;
- Turn on the power source for the valves to allow the water to fill the tank and begin to dissolve the sodium fluoride. The flow of water should shut off automatically when the proper level is reached in the saturator. There should be a minimum of 1 foot of water above the sodium fluoride bed; and
- Submerge the chemical feed pump suction line just below the water surface and start the pump. Set the pump at the desired feed rate (which will have to be calculated).

The saturator should be cleaned periodically according to the following procedures:

- Allow the system to operate without adding chemical until the fluoride bed is depleted to a point that the diffuser is exposed;

- Disconnect the power to the level control. Allow the chemical pump to run until only about one foot or less of solution remains above the fluoride bed;
- Remove the cover from the saturator;
- Remove the drain plug and allow the tank to drain. Agitation or stirring may be necessary to loosen the hardened material. Be careful not to damage the diffuser. The diffuser assembly can be removed if it is not embedded in the fluoride bed;
- If you are draining to a septic system or gravel pocket from a floor drain you should dilute the solution with running water while draining or, consider draining to a municipal sanitary sewer system; and
- Rinse the inside of the tank to remove any built up deposits.

### **Chemical Handling and Safety**

Operating a fluoridation system, especially one using hydrofluosilicic acid, involves handling corrosive liquids. Hazards may be reduced greatly by following some simple safety precautions and general housekeeping rules:

- Appropriate personal protective equipment must be used when handling chemicals or working with fluoridation equipment. These include such items as face shields, neoprene goggles, gloves, and aprons;
- Splashed acid is dangerous to the body, especially the eyes. An eye-wash station and deluge shower must be present at all fluorosilicic acid installations, and should be located as close as possible to the fluoridation equipment;
- Keep storage containers and tanks clearly labeled and chemicals separated; and
- Keep your chemical area clean and free of obstructions. An accident is less likely in a clean area.

### **Operational Reports**

OEHS requires a monthly operation report from each water supply regarding operation of fluoridation systems. It is recommended that water systems test the natural background fluoride concentration of their water sources regularly, and perform the following daily.

- Analyze distribution system sample fluoride concentrations;
- Calculate finished water pump flows from meter readings;
- Calculate fluoride amount used; and
- Record findings on the Monthly Fluoridation Report, which must be submitted to OEHS the beginning of each month.

Municipal water supplies must test for fluoride concentration daily using an approved analytical method. Records of these results must be kept by the water supplier and reports submitted monthly to OEHS. A monthly fluoride water sample must be submitted to approved for analysis. This sample serves to verify that optimum fluoride levels are being maintained and to check the water supplier's testing equipment accuracy.

### **Fluoride Testing**

The SPADNS method, measures the change of color intensity in the SPADNS reagent when a sample containing fluoride is added. The change can be measured by comparison with color standards provided with a SPADNS test kit or by photometric measurements using a color meter. Some chemicals other than fluoride may interfere with the SPADNS test result and cause faulty readings. This method relies on the fact that when fluoride reacts with certain zirconium dyes, a colorless complex anion and a dye are formed. The complex, which is proportional to the

fluoride concentration, tends to bleach the dye which therefore becomes progressively lighter as the fluoride concentration increases. Polyphosphate is the most common chemical used in drinking water that will give you a false high reading. Alkalinity, aluminum, iron and sulfates have negative effect on the results while chloride. Distillation is necessary for samples containing high concentration of dissolved solids. The dissolved solids interfere with the fluoride analysis.

Fluoride electrode and a meter indicate the fluoride concentration. Other chemicals usually do not interfere with this test method.

Sample containers and other glassware used must be very clean. If possible, use items for fluoride tests only. Wash potentially contaminated containers with 1:1 nitric acid or hydrochloric acid. Then rinse thoroughly with deionized water. To eliminate uncertainty about container effect, repeat the test using the same container. Consistent results indicate no container contamination.

## TASTE AND ODOR

Most customers judge the quality of drinking water by taste and odor. If the customer is satisfied with these qualities, it is assumed the water is safe to drink. Many harmful contaminants in water cannot be detected due to taste or smell and many of the contaminants found in drinking water that have a detectable taste or odor are not harmful. Sources of taste and odor problems can be found in surface water and groundwater.

Source water protection involves the prevention of contaminants from entering the source. Surface water or groundwater may become contaminated by pollutants such as gasoline, industrial solvents or a wide variety of volatile organics. The removal of contaminants from surface water or groundwater is costly and may involve the use of aeration, powdered activated carbon, or both.

If taste and odor must be controlled at the treatment plant, oxidation, aeration and adsorption can be effective in reducing taste and odor, and improved coagulation filtration.

### **Common Odors in Groundwater**

Methane gas from the decomposition of organic matter tastes like garlic and the biggest danger from the presence of methane is its explosiveness. It can be removed by aeration.

Hydrogen sulfide (H<sub>2</sub>S) in water is a common problem that is therefore discussed separately from the other taste and odor problems. The most common method of removing hydrogen sulfide from water is by aeration. Carbon adsorption is also effective, but more expensive.

### **Common Odors in Surface Water**

Most taste and odors in surface water are organic and derived from algae blooms. Algae growths can be influenced by the pollution from domestic waste, run-off from fertilizer, and animal, domestic, and industrial waste.

Algae are simple forms of plant life that exist in relatively clean water, are widely distributed in nature, and usually present in lakes, ponds, and streams. Most are microscopic in size and vary from single cells to filaments, chains or groups of cells. Their presence normally does not constitute a health risk. There are thousands of types of algae species; however, the most common types that cause taste and odors are:

- Cyanophyceae - These types are responsible for most taste and odor complaints. They are blue-green in color and float at or near the surface of a surface source;
- Diatomaceae - These are one-celled plants reproduce by splitting. The cell walls contain green and brown coloring matter. Dead organisms produce a fishy or geranium odor in the spring and fall; and
- Chlorophyceae - These are one-celled green algae that are mostly free floaters which produce a grassy or fishy odor or taste.

Since algae are aquatic plants, they require the same conditions (sunlight and nutrients) as land plants. Algae analysis has shown that as much as ten percent of the weight is nitrogen and that they contain significant amounts of phosphorus. Nitrogen and phosphorus are important components of fertilizers. The amount of run-off from farms and city lots may be the reason that some bodies of water support heavy algae growths while others do not. Other factors, such as a water surface's size, shape, and depth also influence the growth of different types of algae.

- Protozoa - These microorganisms belong to the simplest form of animal life and some forms have characteristics from both the animal and plant kingdoms. Odors and tastes caused by protozoa have been described as fishy, aromatic, cucumber-like, or muskmelon-like.
- Schizomycetes - These microorganisms, known as iron and sulfur bacteria, cause hydrogen sulfide to be found in water supplies. They include crenothrix and beggiatoa. Most often found in groundwater supplies, they produce an offensive odor of decaying matter.
- Actinomycetes - Closely allied with microscopic plants, actinomycetes are one-celled, filamentous microorganisms occupying a separate group between fungi and bacteria, but more closely associated with the latter. They account for a large part of the microbial population of soils and bottoms of lakes and rivers. Odors associated with this group have been described as earthy or musty.

Most compounds that pollute surface water are organic. These materials can, under certain conditions, cause persistent difficulties even when present in only trace amounts. Many compounds used in industrial operations can cause problems for the operator even at very low levels. Even small concentrations of these compounds can cause problems. In most cases, the consumer will not be able to identify the exact chemical that is causing the problem, but will instead report a specific type of taste, such as medicinal or metallic. Phenols and related compounds are often the source of the medicinal taste.

The taste of phenols is intensified by the addition of chlorine. Refinery waste from a paper mill can cause a distinctive odor. Hydrocarbons from this waste form an oily film on the water; the waste of a paper mill using the sulfite process will have that characteristic paper-mill smell.

Zinc, copper, and other metals produce characteristic taste in water. Wastes from a metal industry can cause taste, but not odor, problems.

Domestic wastewater contains a mixture of organic material. In wastewater treatment, some of these compounds may be partially oxidized and produce an odor. When wastewater effluent chlorinated to control bacteria, it may develop a chlorine odor from the formation of chlor-organic compounds. Domestic wastewater may also contain a relatively high concentration of nitrogen compounds. During stabilization of nitrogen, ammonia is produced which will produce chloramines when combined with chlorine. These compounds have a very persistent swimming-pool odor.

**METHODS FOR CONTROLLING TASTE AND ODOR & DISINFECTION  
BYPRODUCTS**

Taste and odor in drinking water are two of the most widespread causes of customer complaints. Although there are no associated health effects, the extensive public relations difficulties resulting from taste and odor make it important to treat these problems.

Treatment involves the implementation of a taste and odor control program, which should be found at every treatment plant. Under some circumstances, this program may be as simple as routinely monitoring for taste and odor problems and performing preventive maintenance on the system. In other cases, treatment is more complex and can involve special equipment to treat the taste and odor problems.

First consider prevention and testing, which are at the core of the taste and odor control program, followed by the various techniques which can be used for active treatment of taste and odor problems. In any case, an understanding of the causes of taste and odors in water will make treatment more effective.

Taste and odor can enter water in a variety of manners. Surface water sources can become contaminated through algal blooms or through industrial wastes or domestic sewage introducing taste- and odor-causing chemicals into the water. Groundwater supplies can be afflicted with dissolved minerals, such as iron and manganese, which enter the water when it passes through rocks underground. Tastes and odors can also enter either type of water in the raw water transmission system and in the treatment plant due to algal growths, accumulated debris and sludge, or disinfection byproducts. The distribution system can have many of the same causes of taste and odor as previously mentioned, with the addition of problems resulting from cross-connections and low flow zones.

The table below lists some of the chemicals which cause the most common taste and odor problems in water.

<b>Chemical cause</b>	<b>Taste/odor</b>	<b>Origin</b>
Geosmin	Earthy or grassy odors	Produced by actinomycetes, blue-green algae, and green algae.
2-Methylisoborneol (MIB)	Musty odor	Produced by actinomycetes and blue-green algae.
2t, 4c, 7c-decatrienal	Fishy odor	Produced by blue-green algae.
Chlorine	Bleach, chlorinous, or medicinal taste and odor	Addition of chlorine as a disinfectant.
Chloramines	Swimming pool, bleach, or geranium odor	Addition of chlorine and ammonia as a disinfectant.
Aldehydes	Fruity odor	Ozonation of water for disinfection.
Phenols and Chlorophenols	Pharmaceutical or medicinal taste	Phenols usually originate in industrial waste. Chlorophenols are formed when phenols react with disinfecting chlorine.

Iron	Rusty or metallic taste	Minerals in the ground.
Manganese	Rusty or metallic taste	Minerals in the ground.
Hydrogen sulfide	Rotten egg odor	Produced by anaerobic microorganisms in surface water or by sulfates in the ground.
Methane gas	Garlic taste	Decomposition of organic matter.

### Prevention

The best way to treat taste and odor problems is prevention. Algal blooms in reservoirs can be prevented by using copper sulfate while algae growing on walls of the treatment plant basins can be removed through shock treatment with chlorine. Since hydrogen sulfide is produced during anaerobic conditions, preventing these conditions in the reservoir, the distribution system, and in sludge in the sedimentation basin will prevent hydrogen sulfide formation. In the distribution system, periodic flushing and maintaining an adequate chlorine residual will keep the pipes clean and odor free.

### Testing

An integral part of any taste and odor control program is testing the water for taste and odor problems. The two methods used for these tests - the Threshold Odor Test and the Flavor Profile Analysis - are far more subjective than the methods used to test other water characteristics since both the Threshold Odor Test and the Flavor Profile Analysis depend on human perception of the taste and odor in the water. However, despite the difficulty of performing the tests objectively, they still provide valuable information which can help the operator determine what is causing the taste or odor problem, how concentrated the problematic chemical is, and how the problem should be treated.

The **Threshold Odor Test** is used to determine the amount of odor found in water. During the procedure, the water being tested is diluted with odor-free water and is smelled. The dilutions continue until no odor can be discerned. The last dilution at which odor is detected determines the **Threshold Odor Number (TON)**, which is a measure of the amount of odor in the water. If several people independently perform the Threshold Odor Test, the averaged TON can be relatively accurate.

While the Threshold Odor Test is used to determine the *concentration* of odor-causing problems in water, the **Flavor Profile Analysis** can be used to determine *which* tastes and odors are present in water. This test uses a panel of trained judges who taste the water and list which tastes they can detect. Since the tastes present are described carefully, the Flavor Profile Analysis can be helpful in determining which chemicals are at the root of the problem.

These tests can be performed to find the source of a particular problem or as part of routine monitoring. To find the source of a problem, the water should be tested at various locations, from the source water to the customer's tap. In contrast, routine monitoring can be less intensive but requires good record-keeping. Past records can help the operator predict seasonal variations in taste and odor problems so that he can prevent problems before they reach the customer. Records of past treatment methods can make it much easier to determine which treatment methods will be effective during current outbreaks.

## **Disinfection Byproducts**

While not a taste and odor problem, disinfection byproducts can sometimes be treated with the same methods used for taste and odor control. As you will remember, disinfection byproducts are by-products of chlorination and include several chemical groups such as trihalomethanes and haloacetic acids. Since these substances are suspected to cause cancer in humans, their concentrations in drinking water are carefully controlled.

Disinfection byproducts are formed when organic compounds in the water come in contact with chlorine. The organic matter is primarily **humic substances**, the organic part of the soil which results from the decay of plant matter. Humic substances are more likely to be found in surface water than in groundwater since they can enter water from algae, leaves, bark, wood, or soil.

Treatment methods include prevention of disinfection byproduct formation, removal of disinfection byproducts from treated water, or removal of disinfection byproduct precursors (humic substances) before chlorine is added to the water. The first treatment method - prevention - involves using a disinfectant other than chlorine to treat water. If the equipment for other types of treatment are not already available at the treatment plant, then using an alternative disinfectant is usually the most economical option for disinfection byproduct control.

The methods used to remove disinfection byproducts or disinfection byproducts precursors will be included since the same methods can be used for taste and odor control. If treatment involves removing only disinfection byproducts themselves, it should be realized that more disinfection byproducts can form when the chlorine residual reacts with organics in the distribution system. Therefore, it is most effective to remove the precursors before the disinfection byproducts have a chance to form.

## **Active Treatment Method**

The choice of an active treatment method for taste and odor problems depends on the cause of the problem. In addition, some methods can be used to solve other problems, such as disinfection byproduct formation, which should be factored into the choice of a treatment method. Active treatment may involve optimizing plant processes, using ion exchange units, air stripping, performing chemical or mechanical oxidation, or performing adsorption.

## **Optimizing Plant Processes**

Chlorine smells are one of the most common problems reported by water customers and are also one of the simplest odor problems to treat. Chlorine smells can be dealt with by simply optimizing the chlorine dosage.

If the tastes and odors are associated with color and turbidity or with floating algae, then optimizing the coagulation/flocculation, sedimentation, and filtration processes may take care of the problem. This is often the simplest and most economical treatment method for taste and odor problems since the equipment is already in place. In addition, these typical plant processes can remove disinfection byproduct precursors in many cases if pre-chlorination is not used at the treatment plant.

## **Ion Exchange**

Ion exchange units are not usually used for taste and odor removal but can be used to remove disinfection byproduct precursors if anion exchange resins are used. However, this process can be expensive and creates the problem of waste disposal.

## **Air Stripping**

Volatile compounds can sometimes be removed from water using aerators which strip the compounds from the water. This technique is usually more helpful at controlling odors than tastes, and is very effective at removing hydrogen sulfide. Disinfection byproducts can be removed from water using aeration if the aeration follows chlorination. However, in that type of setup, the operator must be aware that passing air through treated water can add contamination back into the water.

## **Oxidation**

Oxidation is another frequently used method to remove tastes, odors, and disinfection byproduct precursors. Oxidation can be either mechanical (using an aerator) or chemical (by adding chlorine, potassium permanganate, ozone, or chlorine dioxide.) Use of aerators is usually only effective at removing tastes associated with iron and manganese. In other cases, chemicals must be used.

Chlorine is the most widespread chemical used for oxidation of tastes and odors since chlorine is already in use in many treatment plants as a disinfectant. When using chlorine to oxidize taste and odor problems, the dosage of chlorine must be greater than that used for disinfection, a method called **superchlorination**. After superchlorination has removed the taste and odor problems, the excess chlorine must be removed from the water, which can be achieved using granular activated carbon (which will be discussed later.) Chlorination can deal with fishy, grassy, or flowery odors and with iron and hydrogen sulfide. However, chlorination can make some problems worse, especially those caused by phenols. And, of course, chlorination will increase the disinfection byproduct concentration.

Other chemicals used for oxidation include potassium permanganate, chlorine dioxide, and ozone. Potassium permanganate is used to treat organic contaminants while chlorine dioxide does well against phenolic and algal tastes. Ozone is a very strong oxidant which will treat more problems than chlorine and lacks the objectionable by-products. All of these methods can also be used to remove or modify disinfection byproduct precursors, but with variable efficiency.

## **Adsorption**

The final treatment method is adsorption. Adsorption occurs when Van der Waal's forces pull contaminants out of the water to stick them onto the surface of some other material. This material, known as the **adsorbent**, has a very large surface area to allow the removal of large amounts of contaminants. Adsorbents use large pores to increase their surface area.

Several different materials can be used as adsorbents in water treatment. The most widespread of these materials is **activated carbon** which is formed when carbon from wood, coal, peat, or nut shells is exposed to heat in the absence of oxygen. The popularity of activated carbon stems from its lack of specificity which allows it to treat many different taste and odor problems. The other two types of adsorbents are activated alumina and synthetic resins, both of which are typically used as filter media. Activated alumina is used to remove excess fluoride from water as well as to remove arsenic and selenium. Synthetic resins are more relevant to this lesson since they can remove disinfection byproducts from water. However, synthetic resins are very costly and their use is still in the developmental stages.

## Types of Activated Carbon

Powdered activated carbon, or PAC, is a form of activated carbon with a very small particle size. Treatment involves adding PAC to water, allowing the PAC to interact with contaminants in the water, then removing the PAC by sedimentation or filtration. The feed location of PAC can be at any point prior to filtration. The most common locations are in the flash mixer or flocculator since these pieces of equipment will mix the PAC into the water very well. However, some plants feed PAC just before filtration so that the PAC will form a layer on top of the filter and ensure that all water comes in contact with the activated carbon. Adding PAC just before filtration can cause problems, though, since the small PAC particles can pass through the filters and cause dirty water complaints from customers or can cake filters and result in reduced filter runs.

Regardless of the feed location, PAC can be added to water using either a dry feeder or as a slurry. Dry feeders are most often used in small plants when PAC is fed at intervals in response to periodic taste and odor problems. In contrast, **slurrries** (mixtures of PAC with water) are used in larger plants or when PAC is fed continuously. Since it is difficult to make the PAC mix with water, the mixer should have an overhead spray system.

The effectiveness of PAC in adsorbing tastes and odors depends on adequate mixing, contact time, dosage, and on the cause and concentration of the taste/odor problem. Mixing and contact time are determined by the location at which the PAC is added in the treatment process, so adjustments made by the operator will usually involve only dosage adjustments. The dosage usually ranges from 1 to 15 mg/L but must be much higher, in the range of 100 mg/L or more, when the PAC is being used to remove disinfection byproducts or disinfection byproduct precursors. The operator chooses an appropriate dosage using jar tests and the results from odor and taste tests.

Granular activated carbon, also known as GAC, has a larger particle size than PAC with an associated greater surface area. Like PAC, GAC can remove disinfection byproduct precursors as well as taste and odor compounds. GAC is used as a filter medium, either as a layer in a rapid-sand filter or in a separate filter known as a contactor. When contactors are used, the contactor is placed downstream of the filter so that turbidity won't clog the contactor.

Like filters, contactors must be designed to provide adequate contact time of water with the filter medium. This is done by calculating the **empty bed contact time**, or **EBCT**, which is calculated similarly to detention time, as the volume of the filter divided by the flow rate. The calculation is called "empty bed contact time" because the volume taken up by the GAC in the contactor is not taken into account. Empty bed contact time should be about five minutes.

During operation of a GAC filter or contactor, a variety of factors must be monitored. If the GAC is part of a filter designed to remove particulate matter as well as to adsorb tastes and odors, then the effluent turbidity should be monitored. Similarly, the taste and odor contaminants in the effluent should be monitored to determine whether the GAC is operating properly. The operator should make regular checks for bacteria since microorganisms often grow on GAC filters and result in clogging problems. Finally, head loss must be monitored as it would be for any other filter to determine when the unit needs to be backwashed. Washing a GAC filter involves backwashing with a 50% bed expansion and surface washing.

Although GAC filters can be operated like a rapid sand filter in most ways, backwashing and surface washing are not the only cleaning required for the units. The entire surface of the GAC will eventually become covered with contaminants, just as a softener's resin will become covered with magnesium and calcium ions. A GAC filter can typically operate for months or years before reaching this state, depending on the contaminant levels in the influent water. Once the GAC has reached its adsorption capacity, it must be regenerated using the same heating process used to activate the carbon. In many plants, GAC is simply replaced rather than investing in the equipment required for regeneration.

### **Choosing a Type of Activated Carbon**

GAC and PAC each have advantages and disadvantages. In general, PAC is used more often due to the low initial cost and to the flexibility of dosage which allows the PAC concentration to be adjusted to deal with changing contaminant levels. However, PAC has a high operating cost if used continuously, cannot be regenerated, produces large quantities of sludge, and can break through filters to cause dirty water complaints by the customers. In addition, the dust resulting from the small particles of PAC make handling difficult, as does the flammability of the particles.

GAC becomes a more economical choice in larger systems or where taste and odor must be controlled continuously. Disadvantages of GAC include a high initial cost to buy the filter or contactor, and the tendency of GAC filters to grow bacteria.

## AREA WIDE OPTIMIZATION PROGRAM (AWOP)

Is your water treatment plant optimized? West Virginia is one of states in the nation who are involved in an **Area Wide Optimization Program (AWOP)**. The purpose of this program is to achieve, among systems in a selected pilot area, optimized surface water treatment facilities in order to reduce the threat of microbiological contamination of drinking water provided to the consumer. It has been demonstrated that reducing the filtered water turbidity from 0.3 NTU to 0.1 NTU, or less, provides an additional approximate 1 log reduction in particles, or a reduction of 10 particles per 100 particles. This becomes extremely important when you consider that some of these particles could be *Cryptosporidium* oocysts. This indicates one can substantially reduce the risk of drinking water containing *Cryptosporidia* by making only a slight improvement in filtered water turbidity, possible without major physical improvements/additions!

Optimization, which is a continuing process, can be considered achieved when the following goals are being met at a water treatment facility:

### Sedimentation

- Settled water turbidity is less than 1.0 NTU 95 percent of the time when daily average raw water turbidity is less than or equal to 10.0 NTU during the same period
- Settled water turbidity is less than 2.0 NTU 95 percent of the time when daily average raw water turbidity is greater than 10.0 NTU during the same period

### Filtration

- Filtered water turbidity is less than 0.1 NTU 95 percent of the time based on the maximum values recorded during 2-hour time increments
- Maximum turbidity of any filtered water measurement is never greater than 0.2 NTU.

### Monitoring Requirements

- Daily raw water turbidity is determined at 2 hour increments
- Settled water turbidity is determined at 2 hour increments from each sedimentation basin
- Filtered water turbidity is determined at 2 hour increments from each filter
- One filter backwash turbidity profile is performed each month for each filter

### Recommended Instrumentation

- Each filter effluent is equipped such that turbidity is continuously monitored and recorded
- The pH of raw and filtered water is continuously monitored and recorded
- Plant is equipped with an adequately sized PC for recording and electronically transmitting raw, settled and filtered water data, and for generating turbidity vs. time graphs

## **DISTRIBUTION SYSTEM**

### **STORAGE**

The distribution system is a network of storage tanks, pipes, valves, hydrants, service connections, and meters that are needed to get water from the point of production to the customer. The distribution system begins at the point where water enters the system at usable pressure. It ends at the customer's side of the meter installation.

Each water system has its own unique requirements for water storage. These depend on such factors as the system's pressure, normal water usage, low and peak demand, and fire protection requirements. Ground elevations in the area should be surveyed and the storage tanks located at the highest possible elevation to the area served. Ample storage capacity in a water distribution system will mean lower operating costs and fewer pressure problems for the operator.

#### **Storage Tanks**

The two primary purposes for the use of storage tanks within a water distribution system are to provide volume and pressure. Sufficient storage should be based on a typical operating day in any PWS involves varying demands for the water. The most common method of creating system pressure is through the use of an elevated water storage tank to develop the necessary feet of head to force water through the system. The operation of storage tanks is also critical to maintaining a continued flow of water to a distribution system for domestic, commercial, or industrial use and for fire protection.

#### **Types of Storage Tanks**

Water storage facilities come in a variety of tank types or configurations including:

- Gravity storage: ground storage, elevated tanks, standpipes, and
- Pressure storage: hydropneumatic or diaphragm (bladder) tanks.

Depending on their type, they are usually constructed of either steel or concrete. Their primary purpose is to store water during periods of low demand for distribution during periods of high demand.

#### **Gravity Storage Tanks**

Adequate ground and elevated storage tanks are essential for the proper operation of a water system. These tanks are necessary in order to provide an ample supply of water during peak demands, dependable fire protection, adequate water pressure to outlying areas, and lower pumping costs.

A gravity storage system offers several advantages over other (e.g., hydropneumatic) systems and should be considered where topographic conditions are favorable. The larger water systems have greater advantages. However, even smaller systems will have these advantages:

- Less variation in pressure
- Storage for fire fighting use
- One to two days storage to meet water requirements
- Greater flexibility to meet peak demands
- Use of lower capacity wells (pumping not necessary to meet peak system)

- demand)
- Sizing of pumps to take better advantage of electric load factors
  - Reduced on and off cycling of pumps
  - Tie-in of several wells, each pumping at its optimal rate

### **Ground Storage Tanks**

The purpose of ground storage is to hold enough water in reserve to compensate for fluctuation of the water demand in the system. Ground storage tanks are constructed of reinforced concrete, pre-stressed concrete, and steel and are circular or rectangular. Reinforced or pre-stressed concrete is the preferred material since it is more resistant to deterioration when in contact with water. Some ground storage tanks are built above ground while others may be partial or completely underground. Underground storage should be located above the local groundwater table. All tanks should be located so that surface and underground drainage is away from the structure. Tanks should never be located within the 100-year flood plain. Sewers, drains, standing water, and similar sources of possible contamination must be kept at least 50 feet from the tank.

The most common location of ground storage tanks is near the treatment plant. These storage tanks are usually referred to as clear wells. Ground storage tanks are also used to store additional water, which can be pumped into the system for fire fighting purposes. A ground storage tank should provide storage equivalent to 2 times average daily demand or 150 gallons per customer per day. This amount will usually permit a uniform pumping rate throughout the day. Ground storage tanks should contain additional storage for filter backwash water.

Ground storage tanks can provide system pressure if they are located on hills within or near the distribution system area. Such situations are ideal since ground storage tanks are usually less expensive to construct than elevated storage tanks.

### **Standpipe Tanks**

Standpipes are essentially ground storage tanks constructed to a height that is greater than their diameter. Their diameter is constant from the ground to the top, and they are completely filled with water. In most installations, only the water in the upper portion of the tank will furnish usable system pressure. When the water level falls to less than 70 feet from the ground surface, there will be less than 30 psi of pressure. For this reason most standpipes are constructed with an adjacent pumping station that can be used to boost the pressure of water from the lower section of the standpipe when needed.

### **Elevated Storage Tanks**

Elevated storage tanks are generally located where the land is flat. These water tanks are supported by towers (or legs) and are said to "float" on the system. This means that they are directly connected to a system main and hold large volumes of water high enough in the air to supply the system with an adequate and fairly uniform pressure during peak demands. In this type of storage tank the system pressure is provided by the height of the water above the ground. The overflow point of the tank is the maximum system pressure. One limitation of elevated storage tanks is that the pressure in the distribution system may vary with the water level in the tank. In order to maintain a static pressure of 50 psi, water must be stored 115 feet above the customer.

## **General Operation of Ground and Elevated Storage Tanks**

Water contained in a vessel or pipe 100 feet high will exert a pressure of 43.33 pounds per square inch at the bottom of the pipe. The pressure is constant no matter the diameter of the pipe. It could be one inch or ten feet in diameter, but the pressure at the bottom of this vessel will still be 43.33 pounds per square inch.

### **Pressure Storage**

Pneumatic storage tanks are pressurized by a surcharge of air that forms a bubble in the tank. Pneumatic systems are very common for use in storing and distributing small quantities of water. They combine the energy from a pump with the principle of air pressure to force water into the distribution system. The compressed air maintains water pressure when use exceeds the pump capacity and keeps the pump from cycling off and on every time a faucet opens. Pneumatic tanks are also used in large systems as surge protection systems. As the pressure from water hammer surge enters the tank, the force is exerted against the air pocket. The air pocket is compressed and absorbs the energy to dampen the shock wave.

Understanding how a pneumatic system works requires understanding basic system operation and the role of system components.

- The pump starts up when the pressure inside the tank falls to a certain pressure (cut-in pressure), and it pumps water into the tank. The pocket of air in the tank gets smaller and the pressure inside the tank increases as more water is pumped into the tank.
- When the pressure builds to a certain point (cut-out pressure), the pump stops and the air forces the water into the distribution system, as it is needed.
- When the pressure becomes too low, the pump starts up again, and the cycle is repeated. The cycle rate is the number of times the pump starts and stops in 1 hour.

Pneumatic systems are a good, reliable source for providing water to a small number of customers. In West Virginia, they cannot serve more than 75 living units. The gross volume of the pneumatic tank (in gallons) shall be at least 10 times the capacity of the largest pump (rated in gallons per minute). For example, a 250 gallon per minute pump must have a 2,500 gallon pressure tank. They are not a good storage vessel for fire protection purposes due to the small volume of water within the vessel.

### **Disinfection of Water Storage Facilities**

New storage facilities and ones that have been repaired or cleaned must be disinfected before being placed in service. The storage facilities must be disinfected in accordance with current AWWA Standard C652. The following forms of chlorine may be used: gaseous chlorine, sodium hypochlorite or calcium hypochlorite.

There are several methods used for disinfection. Below is a brief description, the complete procedure can be found in Section 4: Alternative Methods of Chlorination of the AWWA Standard for Disinfection of Water-Storage Facilities (C652).

The three methods are:

1. Chlorination of the full storage facility such that, at the end of the appropriate retention period, the water will have a free chlorine residual of not less than 10 mg/L
2. Spraying or painting of all storage facility water-contact surfaces with a solution of 200 mg/L available chlorine

3. Chlorination of the full storage facility with water having a free chlorine residual of 2 mg/L after 24 hours.

The disinfection procedure (AWWA C652 chlorination method 3, section 4.3) that allows use of the chlorinated water held in the storage tank for disinfection purposes is not recommended. When this procedure is used, it is recommended that the initial heavily chlorinated water be properly disposed in order to prevent the release of water that may contain various chlorinated organic compounds into the distribution system.

After the chlorination procedure is completed and before the tank is placed in service, water from the full tank must be tested for bacteriological safety. Three or more successive sets of samples, taken at twenty-four (24) hour intervals, must be microbiologically satisfactory before the facility is placed into operation. If the test results are unsatisfactory, the process must be repeated.

The chlorine level must be reduced to acceptable levels before the water is used or discharged. Disposal of heavily chlorinated water from the tank disinfection process must be in accordance with the requirements of the WVDEP.

## **WATER MAINS**

Water mains are the pipes that carry water from the source to the storage facilities and throughout the distribution system. The size of the main is an important factor. It will determine how well the main transmits water through the system. This is due to the fact that smaller pipes allow less water flow due to the size restriction and the friction loss. This is the friction created between the water and the inside of the pipe.

There are three general types of piping systems used by water utilities in the distribution system.

### **Transmission Mains**

Transmission mains are designed to carry large quantities of water from the source of supply to the distribution mains. They usually run in a nearly straight line and have only a few side connections.

### **Distribution Mains**

Distribution mains are the pipelines that carry water from the transmission mains and distribute it throughout the system. They have many side connections and are frequently tapped for customer connections and fire hydrants.

### **Service Lines**

Service lines or “services” are small diameter pipe that run from the distribution mains to the customers homes.

## **WATER MAIN DESIGN**

### **Pressure**

All water mains, including those not designed to provide fire protection, must be sized after a hydraulic analysis based on peak flow demands and pressure requirements. The system must be designed to maintain a minimum pressure of 20 pounds per square inch (psi) at ground level at all points in the distribution system under all conditions of flow and 30 psi under static conditions. The normal working pressure in the distribution system must be designed based

upon the pipe manufacturer's recommendations and the applicable AWWA standards for the type of pipe.

### **Fire Protection**

The minimum size of a water main for providing fire protection and serving fire hydrants must be of 6-inch diameter. Larger size mains will be required if necessary to allow the withdrawal of the required fire flow while maintaining the minimum residual pressures. Any departure from minimum 6 inch diameter requirements must be justified by hydraulic analysis and future water use, and can be considered only in special circumstances; however, no mains less than 2 inches are permitted.

When fire protection is to be provided, system design must be such that fire flows and facilities are in accordance with the requirements of the ISO. Under no circumstances must fire flows be less than 250 gallons per minute.

### **Dead Ends**

In order to provide increased reliability of service and reduce head loss, dead ends must be minimized by making appropriate tie-ins whenever practical. Where dead-end mains occur, they must be provided with a fire hydrant if flow and pressure are sufficient, or with a flushing hydrant or blow-off, approved by the Environmental Engineering Division, for flushing purposes in order to prevent taste and odor problems. Flushing devices must be sized to provide flows that will give a velocity of at least 2.5 feet per second in the water main being flushed.

## **INSTALLATION OF WATER MAINS**

Specifications must incorporate the provisions of the AWWA standards and manufacturers recommended installation procedures.

### **Bedding**

A continuous and uniform bedding must be provided in the trench for all buried pipe. Backfill material must be tamped in layers around the pipe and to a sufficient height above the pipe to adequately support and protect the pipe. Stones found in the trench must be removed for a depth of at least 6 inches below the bottom of the pipe.

### **Depth**

All water mains must be covered with sufficient earth or other insulation to prevent freezing. All distribution mains must be provided with a minimum of 36 inches of earth covering; 42 inches are recommended. All mains of less than 8 inches in diameter within 5 feet of a heavily traveled highway must be provided with at least 42 inches of cover.

### **Blocking**

Water in motion can exert a tremendous pressure if it is suddenly stopped or there is a change in direction of flow. Wherever tees, bends, plugs and hydrants exists in a pipeline having flexible joints, the force (thrust) created by the water motion is likely to open the joints nearest the fittings, unless there is a backing block to resist the thrust. The purpose of the backing (thrust) block is to spread the thrust over an area large enough to absorb or restrain it. It is important for the block to be centered on the thrust force and to cradle the fitting to distribute the force. The magnitude of the thrust varies with the amount of bend, diameter of pipe, and the pressure inside the pipe. Pipelines should not be pressure tested until the thrust block has been set.

### **Pressure and Leakage Testing**

All types of installed pipe must be pressure tested and leakage tested in accordance with AWWA Standard C600. This testing will determine if the pipe has been installed correctly and if it is ready for service. Hydrostatic testing is by far the most common and logical. Pressures for testing are normally at least 50 psi above normal operating pressure for operating pressures that do not exceed 200 psi. Where the operating pressure is greater than 200 psi, the test pressure should be 1.5 times the operating pressure, but no more than the design rating of the pipe and valves. This will disclose faulty pipes, bad joints, breaks, and other major defects. The duration of the test should be no less than 2 hours and no more than 24 hours.

When pressure tests reveal an excessive water loss, the source of the leakage must be found and corrected and additional tests made.

### **Disinfection**

Disinfection will ensure that the water delivered to the customer is safe. The problems encountered with main disinfection will be lessened, if proper precautions are taken during pipe installation to prevent dirt, trench water, and other foreign material from entering the pipe.

All new, cleaned or repaired water mains must be disinfected in accordance with AWWA Standard C651. The following forms of chlorine may be used: gaseous chlorine, sodium hypochlorite or calcium hypochlorite. The disinfection procedure consists of three operations.

Below is a brief description:

- 1) Preliminary flushing. Mains must be flushed, prior to disinfection, by running a sufficient amount of water through them.
- 2) Disinfection. The chlorine dosage should be 50 mg/L for 24 hours.
- 3) Final flushing and testing. Mains should be flushed until there is a normal, operating chlorine residual (usually 1 mg/L). Bacteriological samples should be collected from newly installed mains every 1,200 feet, at the end of the line, and from each branch. Bacteriological samples must be collected, 24 hours apart. Results must be negative for 2 consecutive days.

Disposal of heavily chlorinated water from the tank disinfection process must be in accordance with the requirements of the West Virginia Department of Environmental Protection (WVDEP).

### **Separation of Water and Sewer Lines**

Adequate separation should always be maintained between water mains and sewer lines. The theory is that sewers are likely to leak and contaminate the soil with wastes. If at the same time the adjoining water main depressurizes, the wastes can be drawn into the water main. Water mains must be laid at least 10 feet horizontally from any existing or proposed sewer. The distance must be measured edge to edge. Water mains must cross above sewers and must be laid to provide a minimum vertical distance of 18 inches between the bottom of the water main and the top of the sewer.

### **Flushing**

West Virginia recommends flushing of water mains twice a year from the source out to the dead ends with a minimum velocity of 2.5 feet per second (fps).

## **PIPING**

Of the many types of pipe in use today, no one type fits all conditions of service. Knowledge of the different types of pipe will allow the operator to select the one that best fits the installation. Pipe is classified based on its composition: Cast Iron Pipe; Ductile Iron Pipe; Steel Pipe; Asbestos Cement Pipe; and Plastic Pipe.

### **Pipe Size and Location**

Water mains should be placed in the public right of way or easements must be obtained if it becomes necessary to cross private property. The overall pattern of the system should provide for as many closed loops as possible. Long isolated lines terminating in dead ends without interconnections should be avoided.

The separation required to avoid contamination of the water main must be laid 10 feet from a sanitary sewer when they are running parallel. The distance must be measured edge to edge. Water mains must cross above sewers and must be laid to provide a minimum vertical distance of 18 inches between the bottom of the water main and the top of the sewer. At crossings, one full length (20 feet) of water pipe must be located so both joints will be as far from the sewer as possible. Special structural support for the water and sewer pipes may be required.

The size of the water main will depend on what services it will supply and the flow expected. When determining the water demand, pressure losses have to be taken into consideration. If fire protection is required, the minimum size of a water main must be six inches in diameter. Some utilities have adopted an eight-inch minimum size for the main network.

### **Service Line Design**

The condition of the service lines is often an overlooked part of the water system. In most systems, the total length of service lines may nearly equal and sometimes even exceed the total length of the mains.

Service lines consist of two parts: the service connection that extends from the main in the street to the property line or curb stop; and the portion of the pipe that runs from the curb stop to the building. In most cities, the water operator needs to be concerned only with size, selection of pipe materials, and installation of the service connection.

Materials and installation practices apply equally to that portion of the service line located on the customer's property. Every water utility should have regulations consistent with the WV CSR Series 64 Title 77 requirements. These regulations shall cover such items as approved materials, depth of lines, installation procedures, inspections, responsibility for the work, responsibility for payment of costs, and other information necessary to provide an understanding of the requirements.

### **Service Line Parts**

Each service connection consists of:

1. The connection at the main, which is made with the use of a corporation stop or valve to control the pressure during installation. This valve will generally be installed by a tapping machine and with the main pressurized, called a wet or hot tap.
2. A length of pipe long enough to reach from the water main to the property line, where another valve is installed to control the water service.

3. A shutoff valve at the property line to allow the water to be shutoff without having to dig in the street. In most cases, this valve remains the property of the utility. The shutoff valve can be operated only with a special wrench, preventing the property owner from operating the valve.
4. Meters installed to measure the amount of water supplied to the customer. In some cases, the meter is installed at the curb line, but in Minnesota the normal location of the meter is inside the customer's premises.

## VALVES

Valves are mechanical devices used to stop flow, regulate water flows, reduce pressure, provide air and vacuum relief, blow off or drain water from the system, to prevent backflow and to isolate sections of the piping system for repair and maintenance.

Valve placement depends on the layout of the system, location of the customers, location of points susceptible to damage, and cost factors. The OEHS requires valve spacing of every 500 feet in commercial districts and at not more than 800 foot intervals in other districts. Where systems serve widely scattered customers and where future development is not expected, the valve spacing must not exceed 2,500 feet.

Valves are installed at enough points on a water system to minimize loss of water service during repairs. It is common to place valves at street intersections or at the extension of property lines. Valves are supplied with valve boxes or pits for maintenance.

Valves come in a variety of styles, shapes and sizes, but their main purpose is to regulate or stop the flow of water. Most of the valves in a distribution system are installed for isolation of sections of piping for maintenance and repair. Control valves are designed to control pressures and throttle flows to prevent damage to the system.

## ISOLATION VALVES

Isolation valves are used throughout the system to stop the flow of water. They are usually gate valves or butterfly valves. Each branch line should have an isolation valve at the point of connection to the main line. The proper location of these valves is important in order to isolate small sections of line for repair in an effort to minimize the number of customers that are out of water.

### Gate Valves

The most common type of valve used in a water distribution system is the gate valve. It receives its name because of its gate-like operation. When fully open, gate valves provide almost unrestricted flow. A gate valve is not well adapted for throttling flow or for frequent operation. Either will cause excessive wear on the seating edges of the discs and guides.

The number of turns needed to open or close a gate valve that is not gear reduced is equal to 3 times the diameter plus 1-3 turns to seat properly. So a 6" valve will take  $3 \times 6 = 18 + 1-2$  or about 19-20 turns to close. Larger valves will take 2-3 extra turns.

### Butterfly Valves

The butterfly valve consists of a shaft-mounted disc that rotates in a 90° arc from fully open to fully closed. Although butterfly valves are frequently used in place of gate valves to shut off services, the butterfly is also used in throttling or in automatic control of the flow of water. The valve will open, close, or throttle on command from a controller.

### **Ball Valves**

Ball valves are similar to butterfly valves. They are the second most common type of valve used in most systems. Ball valves offer little or no resistance to the flow of liquids. One of its features is that a 90° turn quickly opens or closes the valve completely. The handle position also indicates whether or not the valve is in the opened or closed position. Its simple design allows the valve to operate easily and offers ease of repair. They are used as corporation stops on service lines and curb stops on meter setters.

### **Globe Valves**

Globe valves are installed where there is to be a frequent change of operation and can be used as an isolation or control valve. It receives its name because the main body is globelike in shape. Because of its design, this type of valve offers a significant resistance to the flow of liquids but does provide a more positive shutoff. Except for some special service applications, the globe valves used in water systems are generally three inches or smaller. The high-pressure loss in this valve limits it to smaller sizes. Globe valves are commonly used for water faucets and other household plumbing.

## **CONTROL VALVES**

Control valves are designed to control flows or pressures in the system. Control valves are usually one of the least understood components of a water system. They are designed to control the flow of water by reacting to changes in the system and automatically opening or closing the valve to compensate. They are globe valves. There are a number of different applications for the control valves that may be used in the system.

### **Check Valves**

A check valve is designed to allow flow in only one direction. These types of valves are most commonly used on the discharge side of the pumps to prevent backflow when the power is turned off. Foot valves are a special type of check valve installed on the bottom of pump suction to prevent loss of prime when the pump is turned off.

### **Air Release Valves**

Air release valves are used to allow air that may be trapped in the line to escape. The trapped air can create pressure and pumping problems, milky-water complaints, and pressure spikes that resemble water hammer. They are very useful in systems that are in hilly country. They should be located at the top of hills where the trapped air will collect.

### **Altitude Valves**

An altitude valve is a control valve that is designed to close when an elevated storage tank is full. They are needed when there are several storage tanks at different elevations in a system. Altitude valves will be used on the lower tanks to prevent them from overflowing. Each valve will isolate its tank so that the top tank can be filled and not drain out through the lower tanks. This is one of the most common uses of control valves in water systems.

### **Pressure Reducing Valves**

Another common use of a control valve is found in areas where the differences in elevation in the system create unacceptably high water pressures in the lower elevations. A control valve can reduce and maintain a steady pressure on the downstream side of the valve. There is a maximum and minimum flow that a PRV can handle. When the low drops too low the valve will chatter or start slamming open and closed. This will create severe water hammer problems. To avoid this problem, PRV's are sometimes installed in pairs with a small valve in parallel with the larger valve. The small valve is set at a higher pressure. This will allow it to handle the low flows and keep the large valve shut so it doesn't chatter.

### **Pressure Relief Valves**

Pressure relief valves are similar to globe valves, but their disks are normally maintained by a spring. Pressure relief valves are used to provide protection against high pressures that may develop in the system. They should be located in any part of the system where pressure is controlled by a pressure-reducing valve. They are also used at booster pump stations. When the valve senses a high pressure upstream, it will open to pass enough water to drop the pressure back down to set point. The water is discharged to a storm sewer or ditch. If the pressure upstream drops, it will close automatically. The set point should be about 10-15 psi higher than the normal system pressure at that location.

### **Valve Operation and Maintenance**

Valves normally suffer from a lack of operation, not wear. Valves four inches and larger should be exercised annually. Exercising valves means completely opening and closing the valve manually to assure they operate properly and easily. If not, they may become frozen and inoperative when isolation is necessary. Where the water carries small amounts of sand or silt, the valve seats may fill with deposited material unless operated at regular intervals to keep the valve seat clear.

When operating valves, they must be opened and closed slowly. If they are opened or closed rapidly a quick rise and fall of water pressure throughout the distribution piping system takes place. Also called a water hammer because it sounds like someone hammering on the pipe. Water hammer can cause serious damage to the distribution pipes and components. Water hammer results when a moving column of water is suddenly stopped by the closing of a valve.

## **FIRE HYDRANTS**

Fire hydrants have a number of uses in the distribution system. Although fire protection is the most important, there are several other uses that are equally important in operating and maintaining the distribution system.

### **Types of Fire Hydrants**

There are 2 types of fire hydrants used in water systems; wet barrel and dry barrel. A wet barrel hydrant is always pressurized and the main valve is at the top of the hydrant barrel. A dry barrel hydrant has the valve at the bottom of the barrel and a drain hole that drains the barrel when the hydrant is closed. These hydrants are used in areas where freezing occurs in the winter. An additional advantage to the dry barrel hydrant: it comes with special breakaway unions on the stem and flanges on the upper barrel that allow it to break cleanly if hit by vehicle and that there is no flow of water from a broken hydrant because the main valve is underground.

### **Fire Hydrant Requirements**

The size of the hydrant refers to the size of the opening in the valve. For example, a 4 inch hydrant has a 4 inch valve. Hydrants can be furnished with 1 to 4, 2.5-inch nozzles and 1 to 2, 4 inch steamer nozzles. The length of the hydrant is referred to as the depth of buries and is the distance from the surface of the ground to the bottom of the inlet pipe. It is also recommended that fire hydrants be installed with the nozzles at least 18 inches above grade. This is the clearance needed to operate a hydrant wrench when removing the nozzle. In West Virginia, fire hydrants must have a bottom valve size of at least 5 inches, on 4.5 inch pumper nozzle and 2, 2.5 inch nozzles.

### **Hydrant Operation and Maintenance**

Regular flushing, recommended twice a year, of hydrants is important to ensure that they work and are in operational condition at all times. In addition, flushing can reveal information about the condition of the water system. When the system is flushed, the velocity has to be high enough (at least 2.5 ft/sec) to clear out any material that has accumulated in the system.

Hydrants should not be used to regularly fill tanks and should never be operated with the valve partially opened for throttling. A fire hydrant should be opened slowly and fully and then closed fully, in order to prevent water hammer.

## **METERS**

### **Displacement Meters**

The common small diameter service meter is of the displacement type. Displacement meters are capable of measuring small flows with relatively high accuracy. Water flowing through the meter is measured by counting the number of times the chamber is filled and emptied.

### **Velocity or Current Meters**

A velocity meter, or current meter as it is more commonly called, registers the volume of water passing through it by measuring the velocity of the flow within a known cross-section area. The two basic current-meter types in use are the turbine and the propeller meters.

### **Compound Meters**

In situations in which a customer's water use fluctuates regularly over a wide range, compound meters are used to accurately measure the water consumption. A compound meter is a combination meter with a turbine section for high flows and a displacement section for low flows. In normal operation, the low flows pass through the displacement section until the friction loss is so great that the valve opens, allowing the water to flow through the turbine section of the meter. A compound meter in good repair is capable of measuring flow with 98 percent accuracy over a wide range of flow conditions.

### **Meter Maintenance**

Having meters installed at the customers' locations provides the only fair and equitable method of charging for water. This is one of the most economical means of reducing water waste. Meters are the "cash registers" of the water system and should be maintained in proper working order.

The maintenance of positive displacement meters consists of temporarily removing them from the customer's service, taking them apart, and thoroughly cleaning and inspecting all parts. Meters should be inspected and tested every 10 years.

### **Meter Records**

A suitable meter record provides full and complete information about the installation repair and testing of each meter. Any record system should provide such basic data as the date of purchase, size, make, type, location of meter, and the data on all tests and repairs.

## **PUMPS**

Many different types of pumps can be used with the selection depending on the work that needs to be done. Pump selection depends on the maximum flow needed in gallons per minute (gpm) and the head it needs to pump against.

### **System Pressure and Head**

Head is a measurement of the pressure or force exerted by the water. Head is expressed in feet to represent the height of the water above some reference point such as a gauge.

**Pressure Head** is the amount of energy in water due to pressure. The reading of a pressure gauge can be converted to feet of water by multiplying it by 2.31. For example, the gauge reads 52 psi x 2.31 = 120 feet of head (water above the gauge).

**Lift**, or suction lift, is the vertical distance in feet from the water surface to the pump, plus friction losses in the pipe and fittings between the pump and the foot valve (this will be zero for a submersible pump).

**Friction Head** loss is the energy that water loses from friction while it is moving in the system through pipelines and valves. When water moves through a pipe, it must overcome resistance caused by friction from contact with the pipe walls and its own turbulence. The amount of friction loss depends on the flow rate, pipe characteristics such as length, size and type of pipe, and on the number and type of pipe fittings.

Head loss can be significant if the pipe surface is roughened by corrosion (pitting), tubercles (crusty corrosion build-up), slime growth, or sediment. The amount of pipe roughness is referred to as the C factor. The higher the C factor, the smoother the pipe. Head loss can also be caused by water suddenly changing direction or velocity as a result of valves, bends, and reducers.

**Elevation Head** is the vertical distance in feet from the pump to the highest point of the water system, plus friction losses in pipe and fittings between pump and point of discharge.

**Total Dynamic Head (TDH)** is the total amount of energy that a pump has to deliver to move water from one point to another. Dynamic means the water is in motion rather than static. For example: the well pump has to lift water from a 150 ft pumping level and push it 120 ft up to the storage tank. Not factoring friction head loss, the total dynamic head would be 150 ft suction lift + 120 ft discharge head = 270 ft TDH.

**Diaphragm pumps** – the amount of chemical fed is determined by either adjusting the length of the stroke or the number of strokes per minute.

It is recommended that your diaphragm pump be equipped with a four function valve. The functions of this valve are:

1. Anti-siphon (automatic): prevents siphoning when pumping downhill or into a vacuum.
2. Backpressure (automatic): supplies approximately 25 psi backpressure to prevent over pumping when little or no system backpressure is present.
3. Pressure relief (automatic): if the discharge line is overpressurized, the valve opens sending the chlorine solution back to your supply tank.
4. Line depressurization (manual): by pulling both knobs, the discharge line will drain back to your supply tank.

The pump should be placed so that it is lower than the chlorine level in the tank so that the pump does not lose its prime. It is recommended to have a back-up pump.

**Centrifugal pumps** – are widely used in the water industry and consist of a pump casing and an impeller mounted on a rotating shaft. A motor turns the shaft, spinning the impeller. The impeller creates centrifugal force, which throws water into the outer casing or volute. Water is directed into the discharge.

- Vertical turbine pumps – commonly used for well installations and booster pumps. They are capable of producing high capacities at high head.
- Submersible pumps – common for well installations. The entire pump and motor assembly is submersed in water. The motor is mounted below the bowls (impeller housing) so the pump does not have as long a pump shaft as the turbine.

Centrifugal pumps major parts include:

- Casing – the housing that surrounds the impeller, often called a bowl, for turbine pumps.
- Shaft – the rod the impeller is mounted on and is turned by the motor.
- Impeller – rotating bladed disc that gives force to the water being pumped. Design can vary (enclosed, open, semi-enclosed). Design used depends on pumping requirements.
- Wear rings – brass or bronze rings placed on the impeller or casing to control leakage from discharge to suction side.
- Bearings – support and guide the shaft.
- Shaft seals – packing or mechanical seals are used to prevent air from being sucked into the pump along the shaft and to control water leakage along the shaft from the impeller.
- Motor – provides power to turn the impeller.

### **Pump Cavitation**

Pump cavitation is the formation and collapse of gas pockets or bubbles on the blade of an impeller or the gate of a valve, causes the pump or valve to vibrate and sounds like chattering marbles. Commonly occurs in pumps when the pressure at the pump inlet drops below the pressure of the water being pumped. Cavitation may cause the formation of pits on the impeller and the eventual wearing away of the impeller and can be caused by allowing intakes to become clogged or by using a pump that discharges more water than it is designed to pump. To prevent cavitation:

- The intake of the pump must remain clear.
- If pump discharge is excessive, throttle with discharge valve.
- Coat the impeller and volute with epoxy-metallic materials.

**Water Hammer** occurs when moving water suddenly stops, such as by closing a valve too fast. Water oscillates in the pipe, causing a loud banging or hammering sound. Fluctuating pressures can damage piping and connections.

### **Pump Maintenance**

Major areas of maintenance concern:

- Couplings must be properly aligned.
- Inspect and lubricate motor/pump bearings on a regular basis.
  - Reduce friction and wear to moving parts.
  - Prevent corrosion by sealing out dirt and contaminants.
  - Lubricating water should be of a quality equal to or greater than the pumped water.
  - Too much lubrication – high heat can result; too little lubrication – excessive wear can result.
  - Wrong kind of lubricant – may contaminate potable supply or may not provide adequate wear protection.
  - Contamination of lubricant – may result in excessive wear and high heat.
- Seals – mechanical or packing type.
  - Packing type must be allowed to leak a small amount (20 drops/min) for lubrication.
  - Mechanical type does not normally leak water.

### **Motor Maintenance:**

- The motor should be properly lubricated.
- Motor should be kept clean, dry, and cool.
- Motor guards/ventilation screens must be in place.

## **PUMP & MOTOR MAINTENANCE**

Maintenance is one of the most important and most often neglected tasks in water system operations. When money gets tight maintenance is often one of the first things to go. More and more water systems are finding that cutting maintenance to save money is false economy. Almost without fail, the cost to repair damage caused by lack of maintenance is much higher than the cost to maintain the equipment.

All systems should develop a preventive maintenance program. A preventive maintenance program allows virtually all maintenance to be performed during normal operating hours. Emergency maintenance is reduced to a minimum.

In maintaining a pump and motor there are three major areas of maintenance concern: the couplings, the bearings, and the pump stuffing box.

### **Couplings**

Close-coupled pumps have no coupling with which to be concerned. All other pumps, in which the pump and motor are separate units, must have some device to attach the motor to the pump. Couplings are used for this purpose. Couplings perform some or all of these functions:

- Connect the motor to the pump to allow the motor to turn the pump.
- Flexible couplings allow for some pump to motor misalignment.
- Because of slack (called internal clearance) in bearings, the pump and motor shafts can move away from and toward each other. Couplings allow for this to happen without damage.
- Vibration can damage equipment. Couplings can reduce the amount of vibration transmitted from one piece of equipment to another.
- Electricity can flow from the motor to the pump causing pitting in bearings and their premature corrosion and failure. Couplings can be used that will insulate the pump shaft against stray current.
- Couplings absorb the torque created when the motor starts.

Energy transfer and compensation for misalignment are the two most important functions performed by a coupling. There are two types of couplings, rigid and flexible couplings. Rigid couplings do not compensate for any misalignment. Flexible couplings allow for small amounts of pump to motor misalignment.

### **Coupling Alignment**

The key to maintaining a flexible coupling or rigid coupling is to monitor the alignment between the drive unit and the pump. Neglect or completely overlooking alignment will certainly result in early failure of the coupling, and result in damage to the motor and pump. The types of misalignment that may be encountered are: angular and parallel.

### **Angular Misalignment**

Angular misalignment is the type most likely to cause severe damage to the pump and motor. A characteristic of this type of misalignment is that the motor is set at an angle to the pump. This angle can either be to the left or right, up or down. If the center lines of the motor and pump were extended, they would cross each other, rather than run parallel. When aligning a pump and motor, angular alignment should be checked first.

### **Parallel Misalignment**

Parallel misalignment occurs when the two center lines are parallel, but they are not in the same plane vertically or horizontally. Generally, parallel misalignment results in less vibration than angular misalignment. Parallel misalignment is also the easiest to detect. If parallel misalignment is beyond the tolerance limits, it is difficult, if not impossible, to join the coupling halves.

### **Combination Misalignment**

The third type of misalignment encountered is combination misalignment. As the name implies, the motor is misaligned angularly, and at the same time is either displaced to the right or left, or on a different level than the pump.

In order to align the pump and motor, it is necessary to let either the pump or motor remain still, while moving the other to bring it into line. It is best to align the motor with the pump. Moving the pump will put stress on the piping system. As the pipe tries to pull back to relieve the stress, the pump will be shifted. If the pump is left in place while the motor is shifted, this problem will not occur.

### **How to Use a Dial Indicator\* to Determine Pump & Motor Shaft Runout**

(Determine if shaft is straight or bent).

1. Give the pump and motor shafts a rough, “eyeball,” alignment.
2. Check the pump and motor shaft for run out by placing the dial indicator clamp on the pump shaft.
3. Place the dial indicator in contact near the end of the motor shaft, insuring that the scale is reading off zero.
4. Rotate the dial indicator scale until it reads zero.
5. Rotate the pump shaft until the dial indicator gives its highest reading.
6. Put a mark on the pump shaft to insure this point on the pump shaft remains at the top.
7. Repeat this procedure on the motor shaft.

\*(Dial Indicators are available from many machine shop supply houses and auto parts stores).

### **How to Use a Caliper to Determine Angular Misalignment Between a Motor & Pump**

1. Measure the distance between the coupling halves at the top of the couplings.
2. Mark the coupling halves where the measurement was taken.
3. Rotate the coupling 90 degrees and measure again.
4. Rotate the coupling 90 degrees so that the marks are now at the bottom, and measure again.
5. Rotate the coupling 90 degrees and measure again.
6. If the motor is out of alignment horizontally, simply shift the motor toward the side on which the greatest gap is found. If the greatest gap was found at the top of the coupling, add shims to raise the rear of the motor.
7. If the greatest gap was found at the bottom of the coupling, add shims to raise the front of the motor. The shim thickness should be one half as thick as the gap is wide.

### **How to Check a Pump and Motor for Angular Misalignment Using a Dial Indicator**

1. Give the pump and motor shafts a rough, “eyeball,” alignment.

2. Attach the dial indicator to the pump half of the coupling. Attach a block to the motor coupling half, contacting the dial indicator in such a way that the scale reads off zero.
3. Rotate the coupling halves so that the dial indicator is in the three o'clock position, reading the dial indicator.
4. Rotate the coupling halves so that the dial indicator is on the six o'clock position, read the dial indicator.
5. Rotate the coupling halves until the dial indicator is at the nine o'clock position; read the indicator.
6. Shift the motor or add shims to correct the alignment.
7. Re-check the alignment.

### **How to Use a Straight edge to Check for Parallel Misalignment**

1. Lay a straight edge across the top of the coupling halves, insuring it is parallel to the shafts. Check for clearance using a thickness gage.
2. Mark the point at the top, where this measurement was made.
3. Rotate the coupling until the mark is in the 3 o'clock position. Place the straight edge at the marks, insuring the straight edge is parallel to the pump and motor shafts. Using the thickness gauges, measure any gap between the straight edge and either coupling.
4. Check the coupling in the 6 and 9 o'clock positions.
5. Make any corrections necessary in the motor's position; re-check.

### **How to Use a Dial Indicator to Check for Parallel Misalignment**

1. Attach the dial indicator to the pump half of the coupling.
2. Adjust the dial indicator to read off zero.
3. Rotate the dial indicator to read zero.
4. Check the dial indicator readings in the 12, 3, 6, and 9 o'clock positions.
5. Make any adjustments in the motor position and re-check the alignment.

### **Motor Maintenance**

Maintenance of electric motors requires that extreme care be exercised to avoid harm to the person performing the maintenance and to avoid damage to the motor. When performing maintenance on motors be certain to always turn off the power supply. Also lock out the power supply to prevent someone from accidentally turning the power back on while you are working on the equipment.

Exterior maintenance of electric motors is fairly simple. It is a matter of keeping the exterior clean and painted. Do not allow the paint finish to deteriorate to the point that the motor's exterior begins to corrode. Do not allow grease, dust, and dirt to build up on the motor body.

Do not allow paint to build up on the motor body. All of these things prevent the motor from radiating heat. Heat will build up and shorten the life of the motor. Blocking ventilation will also cause heat to build up. When painting a motor, be certain that the data plate is not damaged or covered with paint. The data plate should be readable.

A routine lubrication schedule should be set up and followed. For more information, consult the manufacturer's literature. The manufacturer's literature will have information on what type of lubricant, how much lubricant to use, and how often the equipment should be relubricated. Maintenance of the insulation in the inside of a motor is an important and difficult task. In order

to maintain the motor insulation, keep it clean, dry and cool. The insulation should be free of contaminants such as dust, salt, chemicals, lint, and oil. To keep the inside of a motor clean and in working order, you need to:

- Select the motor enclosure type that is best suited to environmental conditions under which the motor must operate;
- Remove the source of contamination, if possible;
- Clean contamination from the windings; and,
- Clean the exterior and keeping the ventilation openings clear.

Insure that the insulation is kept dry. Some insulations are porous and can absorb water, causing failure to the motor. Dirt and other contaminants attract moisture. Proper enclosures can reduce or eliminate most moisture problems. In very cold or humid areas, it may be necessary to provide heaters to keep motors dry.

Contamination problems are generally attributable to the shoddy greasing practices or to water contamination from excessive packing leakage or flooding. Lubricants and all equipment associated with relubrication should be cleaned immediately after use, and inspected before use to insure it is clean. All grease fittings should be wiped off thoroughly with a clean cloth towel before attaching the grease gun.

An oil lubrication system is the simplest system to monitor. It requires the person performing maintenance to monitor and oil level frequently, and add oil to the machinery as needed.

### **Motor Lubrication**

Lubrication is one of the simplest maintenance procedures to perform. It is also the maintenance procedure which is most often neglected or done incorrectly. It is estimated that about 70-80% of all bearing failures in water and wastewater systems are caused by improper lubrication.

Lubrication failures will normally fall into one of four categories:

- Too much lubricant;
- Too little lubricant;
- Wrong kind of lubricant; and
- Contamination of lubricant.

Too much, too little, and the wrong kind of lubricants are problems which are easily solved. Before relubricating the pump and motor, consult the manufacturer's literature. It will tell how much lubricant to use, how often to lubricate the equipment, and give recommendations as to which brands are compatible with the equipment and service.

Lubrication oil should be changed at the recommended interval. If for some reason the oil should become overly hot in operation, more frequent changing will be required. When choosing an oil the most important characteristic to look for is the viscosity. Viscosity, in simple terms, is a fluid's resistance to flow. Consult the manufacturer's handbook to determine the correct viscosity for the pump or motor. If the viscosity is too high the machinery will have to work harder to turn, especially in cool weather. If the viscosity is too low, the bearing will break through the oil film and wear prematurely, and also build up heat.

To relubricate a pump or motor, using oil, follow this procedure. As in all maintenance procedures, consult the manufacturer's literature before doing the work.

### **How to Change the Oil in Pumps & Motors**

The manufacturer's literature will indicate the proper type of oil, the correct amount, and any special information you may need. The oil should be brought up to operating temperature just prior to changing.

1. Turn off the equipment and lock out the power supply;
2. Remove the drain plug and allow all the old oil to drain out;
3. Replace the drain plug and refill with new oil until the oil level indicator shows the proper levels; and,
4. Return the equipment to service.

Because of adverse reactions due to different additives, DIFFERENT BRANDS of oils should never be mixed. If you must change brands of oil, follow this procedure:

1. Turn off and lock out the power supply;
2. Remove the drain plug, and allow all the old oil to drain out;
3. Replace the drain plug and fill to the proper level with the new brand of oil; and,
4. Operate the equipment until it reaches operating temperature; then repeat drain and fill procedure.

### **How to Change the Oil in Pumps & Motors**

Relubrication procedures using greases depend on the type of fittings furnished. Most grease lubricated equipment is equipped with an alemite grease fitting, to which a grease gun can be attached. Remove the grease relief plug from the pump or motor housing during the relubrication process. This will allow the old grease to be flushed from the bearing housing. If the equipment does not have a grease relief plug, it is very important that the manufacturer's instructions be followed exactly. If the equipment is equipped with a grease relief port, relubrication can be accomplished with little fear of accidental overlubrication. Before relubricating with grease, the manufacturer's literature should be consulted to determine the correct brand, hardness, and amount of grease to be used. Some of the pieces of equipment equipped with grease fittings are also equipped with grease relief plugs.

### **Mechanical Seals**

Water leakage must be controlled at the point where the shaft exits the pump body/volute. In addition to controlling the water that is trying to leak out, we can, at the same time, control air that is trying to get in. There are two ways to control this leakage: through the use of mechanical seals or pump packings.

There are a great variety of brands and styles of mechanical seals from which to choose. Mechanical seals offer several advantages over mechanical packings. Properly installed, mechanical seals control leakage so well that they appear not to leak at all. This eliminates the mess and hazard usually associated with packings—that of having water leaking all over the floor.

Mechanical seals require no maintenance, as packing does. Probably the greatest advantage of mechanical seals is that they put very little demand for extra electricity to drive the pump. They are built with a high degree of precision and require extreme care and skill in installation. The pump must be at least partially disassembled to install or replace a mechanical seal. When they fail, they tend to fail completely and require immediate attention.

There are three key points to remember when deciding whether or not to use a mechanical seal. The first is that a mechanical seal should be installed only on a new pump, or a pump and motor which has been completely rebuilt. Never install a mechanical seal on a pump that has been in service for a time, without first reworking the pump.

The second point is to choose a seal with a multiple spring arrangement. Mechanical seals rely on springs to close the sealing faces. Seals are available with a single, large spring to close the faces. This type of arrangement results in unequal pressure on the sealing faces, resulting in premature failure. The multiple spring arrangement allows for more even pressure on the sealing faces, resulting in longer seal life.

The last consideration is to choose a mechanical seal that is hydraulically balanced. Seals that are hydraulically balanced tend to have a longer operational life.

### **Pump Packing**

The second way to control the leakage around pump shafts is by the use of pump packings. Many types of pump packings are available. Most types of pump packings have been developed to meet specific needs and are not of interest to the water industry. Even so, there is still a large variety of packings from which to choose. Packing selection is simplified if packings are selected following these guidelines:

- Determine the pH of the water being pumped;
- Determine the pressure inside the stuffing box; and,
- Estimate the shaft speed in feet per minute.

Federal regulations require that drinking water pH be within a range of 6.5 to 8.0. Because of this narrow range for pH, pH is the least significant of the three factors under consideration for water system packing selection.

The stuffing box pressure is a factor which is difficult to measure so most people use a general rule of thumb that the stuffing box pressure is usually two-thirds of the pump discharge pressure. Therefore, to determine the stuffing box pressure, put a gauge on the discharge pipe to determine the discharge pressure. Then multiply the pump discharge pressure by 0.67. For example, a pump with a discharge pressure of 150 psi would have a stuffing box pressure of 150 psi X 0.67, or approximately 100 psi. The stuffing box on a pump must be allowed to leak, but the leakage should be controlled. The higher the stuffing box pressure, the more leakage there will be.

### **Example:**

What is the stuffing box pressure on a pump with a discharge pressure of 200 psi?

Stuffing Box Pressure, psi = discharge pressure, psi x 0.67

Stuffing Box Pressure, psi = 200 psi x 0.67 = **134 psi.**

Packing comes in several weaves, from a very loose twisted packing to a moderately tight weave. In some instances it may be necessary to abandon woven packing material all together and use solid packing materials. Solid packing materials control leakage well in pumps with very high stuffing box pressures. Because of the abrasiveness associated with all packing materials, shaft speed is a very important factor to consider. The faster the shaft speed, the better and less abrasive the packing must be. To determine the shaft speed of a pump is a fairly simple matter:

First, multiply the shaft diameter in inches by 3.14. This will determine the shaft circumference in inches. Divide the shaft circumference in inches by 12 to determine the shaft circumference in feet. Next, multiply the shaft circumference in feet by the shaft speed in rpm or revolutions per minute. This will give us the shaft speed in feet per minute.

**Example:**

What would the shaft speed in feet per minute be for a pump with a 2 inch shaft, turning at 1,750 rpm?

$$\text{Shaft circumference, in} = \text{Shaft diameter, in} \times 3.14$$

$$\text{Shaft circumference, in} = 2 \text{ in} \times 3.14 = 6.28 \text{ in}$$

$$\text{Shaft circumference, ft} = \text{Shaft circumference, in} \div 12 \text{ (ft/in)}$$

$$\text{Shaft circumference, ft} = 6.28 \text{ in} \div 12 \text{ (ft/in)} = 0.523 \text{ ft}$$

$$\text{Shaft speed, ft/min} = \text{Shaft circumference, ft} \times \text{rpm}$$

$$\text{Shaft speed, ft/min} = 0.523 \text{ ft} \times 1750 \text{ rpm} = \mathbf{912 \text{ ft/min}}$$

To determine which packing material to use, determine the pH, stuffing box pressure, and shaft speed. Once these are determined, ask your supplier which packing is the best material to meet the indicated operating conditions. The available selection is too diverse to list all of them here.

**Pump Packing Procedure**

As in all maintenance procedures, the manufacturer's literature for the pump should be consulted. You should be able to find out how many packing rings are needed, what size packing is needed, and where the lantern ring should be placed in the stuffing box. Before going further it would be wise to stop and examine in more detail some of the pump parts we are going to be dealing with when we pack a pump. The four parts of the stuffing box are: the gland, the sleeve, the packing and the lantern ring (or seal cage).

There must be some way to control the leakage around where the shaft protrudes into the pump volute. In order to control leakage, a pump is provided with a stuffing box and related parts. The stuffing box and its parts allow us to use packing to control the leakage.

**Controlling Water Leakage**

Since any material used in the stuffing box to control leakage is going to be abrasive to some extent, and this abrasiveness will result in wear and damage to the pump shaft, most pump shafts are equipped with sleeves. The sleeve is a device, slipped over the portion of the pump shaft that passes through the stuffing box, designed to take the wear from the packing and prevent damage to the shaft. Sleeves are cheaper and more easily replaced than shafts.

In order to reduce wear and extend the life of the sleeve, the sleeve and packing must be lubricated. This is accomplished using water. Most centrifugal pumps have an inlet for clean water into the stuffing box. This is called a water seal. Water is injected into the stuffing box under pressure and this water flows out of the stuffing box between the packing material and

sleeve. In so doing, friction between the packing and sleeve is reduced, the sleeve is cooled, and debris is flushed from the stuffing box.

In order for water to flow into the stuffing box unobstructed, a device called a lantern ring or seal cage is sometimes placed in the stuffing box under the water seal inlet port.

The lantern ring is designed to allow the water used for cooling and lubrication to flow into the stuffing box unimpeded. Seal cages also help keep air from entering the pump. In order to function properly the lantern ring must be placed in the correct location within the stuffing box. Consult the manufacturer's handbook.

The gland serves several functions in the stuffing box. The most obvious function is to hold the packing in. The pressure from the water leaking into the stuffing box from the impeller casing (volute) and the water being injected through the inlet port would push the packing out, if the gland were not there to hold the packing in place. The gland also allows for control of leakage from the stuffing box.

In no case should the gland be tightened to the point that water flow from the stuffing box is cut off completely. The gland should only be tightened enough to stop excessive leakage. A general rule to follow in determining the proper amount of leakage from the stuffing box, is to allow at least 20 drops per minute per inch of shaft diameter. For example, a two inch shaft would need 40 drops per minute to leak from the stuffing box.

The gland also serves as an indicator of packing wear. When the gland has been adjusted until it is flush with the stuffing box, it is an indication that the packing is worn out and it is time to change it.

### **How to Pack a Centrifugal Pump**

In replacing the pump packing, first consult the manufacturer's literature. A general guideline to packing replacement is given below:

1. Turn off the pump and lock out the power supply.
2. Close the discharge and suction valves.
3. If there is a separate pump supplying the stuffing box with lubricating water, turn off this sealing water.
4. Remove the gland, and using the packing puller, remove the old packing material. Use proper packing tools, not ice picks, screwdrivers, or coat hangers. These can damage the sleeve or stuffing box housing, causing other problems.
5. Examine the old rings of packing material for damage or unusual wear.
6. Using a wash bottle, clean out all of the debris left in the stuffing box.
7. With a flashlight and mirror, check the sleeve for rust, burrs and wear. Make any necessary repairs to the sleeve or stuffing box before proceeding.
8. Using a straight edge and thickness gages or a dial indicator, check the pump and motor for proper alignment. These procedures are listed elsewhere in the text.
9. Cut the packing material. Packing that is not cut correctly will not function properly and will eventually cause damage to the pump. There are two methods you can use to cut packing correctly. Using a shaft, sleeve, or mandrill of the same size as the shaft as the pump to be packed, wrap either one wrap at a time, or the required number of rings around the sleeve or shaft. Using a sharp knife, make the cut. If no other device is available, wrap the packing around the shaft of

the pump to be packed, and make the cut. The cut is critical. If it is not done correctly, the packing should not be used. An improperly cut piece of packing material will have a joint that will not seal tightly. This loose joint will allow water to flow through the joint, rather than forcing the water to flow between the ring of packing and the shaft.

10. Replace the packing rings individually, seating each ring completely. This will require a tamping tool, or a mandrill like the one shown in the photo.
11. As you replace the rings, do not line up the packing joints. Stagger them at about 90° to each other. It is a good idea to alternate the joints by placing them at 9, 12, 3 o'clock.
12. After placing the last ring of packing, install the gland, making certain that it is square with the stuffing box housing. Run the gland nuts up finger tight.
13. Using a wrench, snug up the gland. **DO NOT OVERTIGHTEN.**
14. Back off on the gland nuts and tighten again finger tight. Insure that each nut is tightened equally and the gland remains square with the housing.
15. Turn on the sealing water.
16. Turn on the pump.
17. Open the discharge and suction valves.
18. Check the leakage from the stuffing box to insure that it is neither excessive nor insufficient. If it is insufficient, loosen the gland nuts.
19. Allow the pump to operate for about 16 to 24 hours. If the pump is still leaking too much water, carefully tighten each gland nut about one-quarter turn. Wait about 1 to 2 hours. If the pump is still leaking excessively, give the gland nuts about one quarter turn each, insuring the gland remains square with the housing. Recheck in one to two hours and make adjustments as necessary until the proper leakage rate is reached.
20. Recheck daily to insure the leak rate remains acceptable, and make one-quarter turn adjustments as necessary.

## **BASIC ELECTRICITY**

Electricity is the flow of invisible particles called electrons, through a conductor. That flow is controlled in an electric circuit. The knowledge that electricity is created by the flow of electrons, and the knowledge of how to capture electrons, makes electricity a convenient and convertible form of energy.

Electrons flow better in some things than in others. Conductors are substances in which electrons flow freely. Metals are excellent conductors. Water is a fair conductor. Since the human body is mostly water, it can conduct electricity fairly well, too. This is why it is important to be very careful when working around electricity.

Insulators are substances in which electrons cannot flow freely. Glass, plastic, and rubber are good insulators. Electrical wiring is always enclosed in a protective covering of plastic or rubber that serve as insulators.

In order to make electrons do useful work, the electrons must have a source of pressure to push on them and cause them to move. Also, the electrons must have a complete path or **circuit** to follow. The basic components of an electric circuit include the following:

- **Source**-The part that provides the electric force or pressure to move the electrons; such as a battery or generator
- **Load**-The part that does the work or uses the electricity; such as a light bulb, heater or motor
- **Conductor**-The part that carries the electricity around the circuit such as wire, cable, or power line.

### **Current Flow: Amperes**

Current is the flow of electrons. To understand current, imagine an electric circuit as a chain. When all three components (source, load, conductor) exist in the circuit, the electrical force causes the electrons to move down the chain. This forced movement of electrons is called current and is measured in amperes. Current is measured with a test instrument called an ammeter. Two types of current flow are: **Direct Current (DC)** - The electrons flow in one direction; and **Alternating Current (AC)** - The electrons flow back-and-forth.

The AC you use at home changes direction 60 times per second. This means the electrons move back-and-forth 60 times per second. This flow in one direction, reversing, and flowing in the other direction is called a cycle. The term 60 cycles AC or 60 Hertz means 60 of these cycles occur each second.

### **Electrical Pressure: Volts**

Electrical pressure is the force that causes electrons to move in a closed electric circuit. It is also referred to as voltage. The pressure or force is measured in volts by a test instrument called a voltmeter. In a DC circuit, a battery produces voltage and in AC circuit a generator produces voltage. A car battery is typically 12 volts DC. That means that the difference in electron pressure between the two terminals is 12 volts. The electric outlets in your well house are 120 volts or 240 volts AC. The voltage difference between the two prongs of the outlet is 120 V or 240 V.

**Resistance: Ohms**

Electrons do not flow freely in a conductor. There is a certain amount of resistance or friction to oppose the electron flow. This resistance is called ohms and is measured by a test instrument called an ohmmeter.

**Water Flow Analogy of Electrical Circuit**

The flow of electrons in an electric circuit can be compared to the flow of water through a closed loop piping system. Volts, amps, and watts measure electricity. Volts measure the pressure under which electricity flows. Amps measure the amount of electric current. Watts measure the amount of work done by a certain amount of current at a certain pressure or voltage.

To simplify the relationship, think of water in a hose. Turning on the faucet supplies the force, which is like the voltage. The amount of water flowing (gallons per minute) through the hose is like the amperage. You would use a lot of water that comes out fast (more watts) to wash off a muddy car. You would use less water that comes out more slowly (less watts) to fill a glass.

**Water circuit vs. Electric circuit Source**

- Water circuit - water pump produces water pressures (psi) to cause water to flow (gpm)
- Electric circuit - generator produces electrical force (volts) to cause electrons to flow (amps)

**Flow measurement**

- Water circuit - flow meter measures water flow in gpm
- Electric circuit - ammeter measures current in amperes (amps)

**Load**

- Water circuit - water wheel does work by rotating
- Electric circuit - light bulb does work by producing light and heat

**Pressure loss**

- To determine the loss of energy, pressure gauges installed before and after the water wheel can measure the loss of water pressure.
- A voltmeter measures voltage drop as the current goes through the light bulb (conversion of electrical energy to light and heat energy).

**Conductor**

- Water circuit - pipe that carries the flow of water
- Electric circuit - wire that carries the electrons

## ELECTRICAL CURRENT

Electricity is a term used to describe the energy produced (usually to perform work) when electrons are caused to directional (not randomly) flow from atom to atom. In fact, the day-to-day products that we all benefit from, rely on the movement of electrons. This movement of electrons between atoms is called electrical current. how electrical current is produced and measured will be discussed on the following pages.

It is very important to have a way to measure and quantify the flow of electrical current. When current flow is controlled it can be used to do useful work. Electricity can be very dangerous and it is important to know something about it in order to work with it safely. The flow of electrons is measured in units called amperes. The term amps is often used for short. An amp is the amount of electrical current that exists when a number of electrons, having one coulomb of charge, move past a given point in one second. A coulomb is the charge carried by  $6.25 \times 10^{18}$  electrons.  $6.25 \times 10^{18}$  is scientific notation for 6,250,000,000,000,000,000. That is a lot of electrons moving past a given point in one second! Since we cannot count this fast and we cannot even see the electrons, we need an instrument to measure the flow of electrons. An ammeter is this instrument and it is used to indicate how many amps of current are flowing in an electrical circuit.

We also need to know something about the force that causes the electrons to move in an electrical circuit. This force is called **electromotive force (EMF)**. Sometimes it is convenient to think of EMF as electrical pressure. In other words, it is the force that makes electrons move in a certain direction within a conductor. But how do we create this “electrical pressure” to generate electron flow? There are many sources of EMF. Some of the more common ones are: batteries, generators, and photovoltaic cells, just to name a few.

Batteries are constructed so there are too many electrons in one material and not enough in another material. The electrons want to balance the electrostatic charge by moving from the material with the excess electrons to the material with the shortage of electrons. However, they cannot because there is no conductive path for them to travel. However, if these two unbalanced materials within the battery are connected together with a conductor, electrical current will flow as the electron moves from the negatively charged area to the positively charged area. When you use a battery, you are allowing electrons to flow from one end of the battery through a conductor and something like a light bulb to the other end of the battery. The battery will work until there is a balance of electrons at both ends of the battery. Caution: you should never connect a conductor to the two ends of a battery without making the electrons pass through something like a light bulb which slows the flow of currents. If the electrons are allowed to flow too fast the conductor will become very hot, and it and the battery may be damaged.

To understand how voltage and amperage are related, it is sometimes useful to make an analogy with water. Look at the picture here of water flowing in a garden hose. Think of electricity flowing in a wire in the same way as the water flowing in the hose. The voltage causing the electrical current to flow in the wire can be considered the water pressure at the faucet, which causes the water to flow. If we were to increase the pressure at the hydrant, more water would flow in the hose. Similarly, if we increase electrical pressure or voltage, more electrons would flow in the wire. Does it also make sense that if we were to remove the pressure from the hydrant by turning it off, the water would stop flowing? The same is true with an electrical circuit. If we remove the voltage source, or EMF, no current will flow in the wires.

Another way of saying this is: without EMF, there will be no current. Also, we could say that the free electrons of the atoms move in random directions unless they are pushed or pulled in one direction by an outside force, which we call EMF.

There is another important property that can be measured in electrical systems. This is resistance, which is measured in units called ohms ( $\Omega$ ). Resistance is a term that describes the forces that oppose the flow of electron current in a conductor. All materials naturally contain some resistance to the flow of electron current. We have not found a way to make conductors that do not have some resistance.

If we use our water analogy to help picture resistance, think of a hose that is partially plugged with sand. The sand will slow the flow of water in the hose. We can say that the plugged hose has more resistance to water flow than does an unplugged hose. If we want to get more water out of the hose, we would need to turn up the water pressure at the hydrant. The same is true with electricity. Materials with low resistance let electricity flow easily. Materials with higher resistance require more voltage (EMF) to make the electricity flow.

The scientific definition of one ohm is the amount of electrical resistance that exists in an electrical circuit when one amp of current is flowing with one volt being applied to the circuit.

Resistance can be both good and bad. If we are trying to transmit electricity from one place to another through a conductor, resistance is undesirable in the conductor. Resistance causes some of the electrical energy to turn into heat so some electrical energy is lost along the way. However, it is resistance that allows us to use electricity for heat and light. The heat that is generated from electric heaters or the light that we get from light bulbs is due to resistance. In a light bulb, the electricity flowing through the filament, or the tiny wires inside the bulb, cause them to glow white hot. If all the oxygen were not removed from inside the bulb, the wires would burn up.

An important point to mention here is that the resistance is higher in smaller wires. Therefore, if the voltage or EMF is high, too much current will follow through small wires and make them hot. In some cases hot enough to cause a fire or even explode. Therefore, it is sometimes useful to add components called resistors into an electrical circuit to slow the flow of electricity and protect of the components in the circuit. Resistance is also good because it gives us a way to shield ourselves from the harmful energy of electricity.

Copper is considered to be a conductor because it “conducts” the electron current or flow of electrons fairly easily. Most metals are considered to be good conductors of electrical current. Copper is just one of the more popular materials that is used for conductors. Other materials that are sometimes used as conductors are silver, gold, and aluminum. Copper is still the most popular material used for wires because it is a very good conductor of electrical current and it is fairly inexpensive when compared to gold and silver. Aluminum and most other metals do not conduct electricity quite as good as copper.

Insulators are materials that have just the opposite effect on the flow of electrons. They do not let electrons flow very easily from one atom to another. Insulators are materials whose atoms have tightly bound electrons. These electrons are not free to roam around and be shared by neighboring atoms. Some common insulator materials are glass, plastic, rubber, air, and wood.

Insulators are used to protect us from the dangerous effects of electricity flowing through conductors. Sometimes the voltage in an electrical circuit can be quite high and dangerous. If the voltage is high enough, electric current can be made to flow through even materials that are generally not considered to be good conductors. Our bodies will conduct electricity and you may have experienced this when you received an electrical shock. Generally, electricity flowing through the body is not pleasant and can cause injuries. The function of our heart can be disrupted by a strong electrical shock and the current can cause burns. Therefore, we need to shield our bodies from the conductors that carry electricity. The rubbery coating on wires is an insulating material that shields us from the conductor inside. Look at any lamp cord and you will see the insulator. If you see the conductor, it is probably time to replace the cord.

Conductors have a very low resistance to electrical current while insulators have a very high resistance to electrical current. These two factors become very important when we start to deal with actual electrical circuits.

Probably the most important mathematical relationship between voltage, current and resistance in electricity is something called “Ohm’s Law”. This formula is used to calculate electrical values so that we can design circuits and use electricity in a useful manner. Ohm's Law is  $I = V/R$ , where  $I$  = current,  $V$  = voltage, and  $R$  = resistance. Ohm’s Law can also be written as  $V = I \times R$  or  $R = V/I$ . All of these variations of Ohm’s Law are mathematically equal to one another.

Let’s look at what Ohm’s Law tells us. In the first version of the formula,  $I = V/R$ , Ohm's Law tells us that the electrical current flowing in a circuit is directly proportional to the voltage and inversely proportional to the resistance. In other words, an increase in the voltage will tend to increase the current while an increase in resistance will tend to decrease the current.

The second version of the formula tells us that if either the current or the resistance is increased in the circuit, the voltage will also have to increase. The third version of the formula tells us that an increase in voltage will result in an increase in resistance but that an increase in current will result in a decrease in resistance.

As you can see, voltage, current, and resistance are mathematically, as well as, physically related to each other. We cannot deal with electricity without all three of these properties being considered.

When we connect various components together with wires, we create an electric circuit. The electrons must have a voltage source to create their movement and, of course, they need a path in which to travel. This path must be complete from the EMF source, through the other components and then back to the EMF source.

The voltage for any electric circuit can come from many different sources. Some common examples are: batteries, power plants, fuel cells. When we plug an appliance into a wall outlet, voltage and current are available to us. That voltage is actually created in a power plant somewhere else and then delivered to your house by the power wires that are on poles or buried underground.

As a matter of fact, since no current can flow unless there is a voltage source, we also refer to these sources as current sources. In other words, without the voltage source, there will be no current flowing. This makes it a current source instead of a voltage source.

Batteries create voltage through a chemical process. Power plants generate electricity from numerous mechanical methods, some burn coal or gas to create steam while others use water flowing through a dam on a lake. There are also nuclear-powered generating power plants. All of these power-generating systems turn large turbines that turn the shaft on a generator. All of these sources of electricity convert something called potential energy to kinetic energy. The potential energy is stored in the fuel, whether it is coal, gas, uranium, water in a dam, etc. When we utilize these fuels to generate electricity, they become kinetic energy. We might say that potential energy is waiting to be used while kinetic energy is being used.

In addition to the voltage source, we need to have wires and other components to build an electric circuit. Remember that copper wires are conductors since they can easily conduct the flow of electrons. We may also use resistors or other forms of loads to form a complete circuit. If we did not include resistors in our circuit, there may be too much current flowing to and from our voltage source and we could damage the voltage source.

Circuit diagrams are a pictorial way of showing circuits. Electricians and engineers draw circuit diagrams to help them design the actual circuits. A capacitor is used to store electrical charge. An example would be a timer.

Now that we have a fairly good understanding of basic electricity terms and concepts, let's take a closer look at some more details of the electrical current itself. The battery we have been using for a current/voltage source generates direct current, which simply means the current flows in only one direction.

As long as electrons are flowing through the atoms of the circuit, work is being done. We can see that work is being done in this circuit because it lights the light bulb. The actual amount of electrons that are flowing is determined by the type and size of the battery as well as by the size and type of the light bulb. We could reverse the polarity of the battery by switching the contacts (wires), and the current would flow in the opposite direction and the bulb would still light. Either way the battery is connected to the circuit, current can only flow in one direction. **Direct current (DC)** can also be generated by means other than batteries. Solar cells, fuel cells, and even some types of generators can provide DC current.

**AC** is short for **alternating current**. This means that the direction of current flowing in a circuit is constantly being reversed back and forth. This is done with any type of AC current/voltage source. The electrical current in your house is alternating current. This comes from power plants that are operated by the electric company. Those big wires you see stretching across the countryside are carrying AC current from the power plants to the loads, which are in our homes and businesses. The direction of current is switching back and forth 60 times each second.

## **PREPARATION OF AN OPERATION & MAINTENANCE PLAN**

This plan should be developed by every public water supplier to provide a written source of material that can be easily referred to for guidance in operating a water system. This plan will be a valuable reference tool for the operating personnel because standard operating procedures for the system and guidelines for start-up and emergency situations will be at their fingertips.

The Operation & Maintenance (O&M) Plan will also provide a ready reference for all equipment data which is necessary for performing normal maintenance and for ordering replacement parts and supplies. It will be an organized system for keeping records of the operation of the system. These records are useful for monthly and annual reports, as supporting documentation of proper operation, and to support the need for replacement or upgrading of treatment facilities. It will have detailed instructions for water sampling and testing which are required for compliance with the SDWA and for routine monitoring of the treatment process for compliance with generally accepted good waterworks procedures.

The plan will contain information regarding start-up and normal operating procedures and emergency operating procedures; descriptions of equipment and facilities; organization responsibilities; names, addresses, and phone numbers of all key personnel; all contractors and suppliers; and state and local officials.

The O&M Plan will become a training manual to provide personnel with a handy source reference while they learn to operate the facilities. The O&M Plan will be used by experienced operating personnel to monitor normal procedures for changes or emergency conditions; as a source for names and phone numbers when emergency notification is required; and as a check of proper maintenance procedures.

### **How to Develop an Effective O& M Plan**

O&M Plans are often prepared by engineers and managers; however, they must be certain that they obtain information from persons actually experienced in plant operation and maintenance. The procedures must be described in terms and language which are readily accepted and understood by the operators. Because of the technical nature of the water treatment process, a basic level of knowledge and understanding by the operators must be assumed. The experienced operator will usually refer to the O&M Plan for confirmation of normal operation and maintenance procedures and as a reference guide for unusual operating conditions. The entry level operator should frequently refer to the O&M Plan for guidance and instruction.

Some water suppliers may have O&M Plans or certain parts of O&M Plans established for their system. These may include Emergency Response Plans, Safety Programs, Water Conservation Programs, Cross-Connection Control Programs, or other formalized procedures. This guidance manual is not intended as a required format which must be followed, but as a presentation of procedures which can be considered for your use in the preparation of your O& M Plan. Plans and programs which have been accepted as good, operating procedures can be directly included in your O&M Plan without rewriting; however, it would be a good idea to review and update your procedures.

Your O&M Plan will be a collection of plans and programs which will probably be stored in loose-leaf notebooks. The appearance of your plan is not as important as the availability of the information to the operating personnel and the ability to revise and update it.

## **O&M PLAN FOR WATER TREATMENT**

Treatment of raw water is necessary in all PWSs to prevent the transmission of contaminants to the consumer. The contaminants could be toxic, cause disease, or have other long-term health effects for the consumer. Water also must be treated for aesthetic contaminants (i.e., color, turbidity, taste, odor, and corrosivity) so the consumer continues to have trust in the quality, taste, and odor of the drinking water. Because of this trust, the water supplier and operators have a continuing challenge to provide water of the highest possible quality at a time when there is an ever increasing possibility of contamination. Outlined in this section are typical examples of operations and maintenance procedures for water treatment processes. The water system may use these as guidelines for preparing similar descriptions for inclusion in an **Operation and Maintenance (O&M) Plan** or may want to develop customized information applicable to a particular process or system.

### **Chemical Addition and Handling**

Chemical addition in the treatment process occurs at several different locations such as "pretreatment" at the head end of the plant; "in process" such as filter aids applied to the filter influent; and "post-treatment" applied to the clearwell. The large variety of chemicals available for water treatment is used for the following purposes: coagulants; pH adjustment; taste and odor control; disinfectants; corrosion control; polymers or filter aids; algae control; softening; and fluoridation. Chemicals also come in a variety of states, such as solid (granular, powder, or flakes), liquid (solutions), and gas. Because of their natures, each must be handled in their own special way. There is a large amount of written material available on this subject so only the more common chemicals and applications will be described. The most important consideration in the addition of a chemical to the treatment process is the determination of the dosage or rate of feed and how the chemical will react with other chemicals used in the process. In addition, it is required that any treatment chemical that come into contact with drinking water must be certified and listed for conformance with the ANSI/NSF Standard 60.

### **Coagulation Chemicals and pH Adjustment**

Coagulation and pH adjustment chemicals - For the purpose of these procedures, these coagulation and pH adjustment processes will be described jointly since they are the foundation of the coagulation/flocculation and sedimentation process. The relationship of pH to floc formation is very important. The most commonly used chemicals for these purposes are aluminum sulfate (alum), either liquid or granular for a coagulant, and calcium hydroxide (hydrated lime) for pH adjustment. The test used to determine the dosage rate for each chemical is the jar test. A jar test is an attempt to duplicate the water treatment processes in glass beakers with varying doses of chemicals so the floc formation and settling can be observed in a laboratory setting.

Many manuals describe the jar test and provide sample forms for recording the test data. From the tests performed, the operator can select what appears to be the most effective combination of chemicals and then can set the chemical feed dosages accordingly. The jar test cannot duplicate exactly the actual plant conditions so the results of those chemical settings must be observed at the effluent of the sedimentation basin and adjustment made accordingly. Jar testing is highly recommended because correct chemical dosage can produce a high-quality water and be a cost-saving factor.

### **Evaluating Jar Test Results**

Visible floc formation should begin shortly after the rapid mix portion of the jar test. During the flocculation mixing, a number of small particles will gradually clump together to form larger particles. Floc particles which are separate and fairly dense in appearance are usually better than floc particles that have a light, fluffy appearance. Large floc is impressive but it is neither necessary nor always desirable. Large, light floc does not settle as well as smaller, denser floc, and it is more subject to shearing (breaking up).

The water between the floc particles should be clear and not hazy or milky in appearance. The best chemical dosage is one which produces a finished water that meets the SDWA standards at the lowest cost. The floc should settle quickly after the mixing has stopped. Floc that remains suspended longer than 15 to 20 minutes would be carried over onto the filter media. The jar tests can be repeated using other combinations of chemicals to produce the best results for turbidity, pH, and alkalinity.

Jar tests are an effective tool for predicting the results of the treatment process and evaluating various combinations of chemical feed and different chemicals. These test results are used to adjust or verify the feed rates in your treatment plant.

A jar test should be run at the beginning of each shift and more frequently when the raw water turbidity is high or changing. There is no substitute for experience in evaluating jar test data. Frequent tests will provide a basis for comparing results of the quality of finished water under different conditions and aid in fine tuning of the chemical feed dose rates. Always verify the effectiveness of a change in treatment based on a jar test result. To verify the jar test results with treatment plant performance, after the changes have been in effect for sufficient time to show results at the rapid mix chamber, collect a sample just down stream from the rapid mix chamber. Mix the sample on the jar test equipment under the same conditions as the original sample (not including the rapid mix simulation). This sample should show similar results to the original test sample and a comparison of these results could be the basis for further fine tuning of the chemical dosage. In addition to jar tests, Zeta potential tests and the use of streaming current detectors also are used to help control the coagulation/flocculation process.

### **Application of Coagulant Chemicals**

The application of the coagulation chemical should be at the rapid mix chamber. Dry chemicals are fed by a dry volumetric feeder which applies the chemical at a constant volume per unit time to a tank or container of water. If necessary, the tank has a small mixer to dissolve the chemical into solution. If the chemical is already in solution (liquid alum), it is pumped into the treatment process by a volumetric pump which pumps a set volume of the liquid per unit of time. Each type of feeder is adjustable for varying rates of feed. The operator should verify the quantity being fed by collecting the output of the feeder for a specific period of time (one minute is normal) and, through weighing or measuring, verify the actual chemical dosage rate.

### **Taste and Odor Control**

The causes of taste and odor problems are many and can show up at any point in the water supply system. Sometimes the effort to treat the water to make it potable destroys microorganisms which release taste and odor compounds. The causes of tastes and odors can range from biological growths (i.e., algae and plankton); environmental conditions (i.e., the depletion of oxygen in certain layers of the lake or reservoir water); the release of organic chemicals by decaying vegetable matter; man's activities (i.e., domestic and industrial wastes);

chemical spills; and agricultural activities (i.e., fertilizers, chemicals, and soil erosion). Within the water system there can be taste and odors due to dead end mains, open reservoirs in which algae grow, septic sludge in settling basins, and the reaction of chlorine to organic materials in the water.

### **Taste and Odor Control Chemicals**

The causes and locations of taste and odor problems are varied, so the chemicals used and the points of application are many and varied. The following list of chemicals includes some commonly used taste and odor controls.

- Powdered activated carbon (PAC) is a dusty, messy material to handle and should be converted to a slurry (mixed with water) as early in the process as possible. The dry material is fed by a dry chemical feeder (volumetric) into a tank of water having a mixer, and the slurry then is pumped into the treatment process. Because the carbon is highly combustible, it should be stored away from other chemicals, particularly potassium permanganate (KMnO<sub>4</sub>) and HTH (high test hypochlorite). The amounts of activated carbon required have been described as up to 15 mg/L, but there is no specific test to determine the necessary amount. The trial and error method will best determine the quantity. Records of what was done in previous incidents could be used as a guideline. The activated carbon can be applied at the intake or at the rapid mix area of the plant, so there is time to react (adsorb) with the taste and odor causing constituents before it reaches the filters which should remove any remaining carbon from the water.

**CAUTION** - Do not add chlorine at the same point or upstream from the activated carbon application since the activated carbon will adsorb the chlorine and neutralize the effectiveness of both chemicals.

Activated carbon can be added to the filter influent to establish a layer of the activated carbon on the top of the filter media. The activated carbon, which is very light in weight, is washed away to waste when the filter is backwashed.

- Granular activated carbon (GAC) can be used as a filter media in a rapid rate sand filter where it can produce a low turbidity water. It also absorbs organic materials that cause taste and odor problems and is effective in the removal of potentially toxic or carcinogenic trace organics. When used for these purposes, the GAC must be regenerated or replaced periodically. GAC is also used as the media in carbon contactors for the adsorption of volatile organic materials.
- Potassium permanganate (KMnO<sub>4</sub>) is supplied as dry, purple crystals which are readily dissolved in water. Potassium permanganate, a highly effective oxidizing agent, destroys tastes and odors, and readily oxidizes soluble iron and manganese into insoluble oxides. This chemical always should be applied upstream from filtration preferably at the intake or at the rapid mix basin. Potassium permanganate usually is applied in dosages up to 5 mg/L. Visual control is possible since it turns the water a pink-purple color. The dosage must be low enough so this color does not extend beyond the filters. This chemical comes in dry crystals and can be mixed with water and fed by dripping or by a solution pump.

- The use of prechlorination (the addition of chlorine at a point at or near the raw water intake or in the rapid mix basin) can be an effective taste and odor treatment since it also is a powerful oxidant; however, sometimes this treatment can aggravate and prolong the problem through the formation of other organic compounds. Only experience will teach the operator the correct action to take in each case. Also, the post-chlorination process can intensify the taste and odor producing compounds in the distribution system resulting in complaints from the customer when the taste and odor cannot be detected at the treatment plant. When this happens, chlorine dioxide or a chloramine compound could be used as a post-disinfectant.
- Copper sulfate ( $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ ) is provided in crystal, lump, and powder form and is an algicide used in raw water supplies to eliminate the growth of algae. There also are liquid solutions available as an algicide which contains copper sulfate. The liquid chemical can be applied by spraying the surfaces of bodies of water. In reservoirs and impoundments, the dry chemical is placed in bags and pulled through the water so the entire surface of the lake, reservoir, or impoundment is covered.

### **Corrosion Control**

Water sometimes is unstable due to low pH, high level of dissolved oxygen, and low alkalinity. This results in chemical reactions causing tuberculation which is the build-up of corroded materials on the inside of the pipes. Buildup reduces the cross sectional area of the pipe and available flow. The roughness of the buildup requires more energy, increasing pumping costs.

The corrosivity in water usually is evidenced by the visual observation of the effects of corrosion on metal pipes when they are excavated for repairs or replacement. Customer complaints of dirty water is also an indication that a corrosive condition exists in the system. Records of customer complaints plotted on a system map can help locate the problems.

Corrosion can cause metals in pipe materials, such as iron, copper and lead, to deteriorate and go into solution. These metals are carried by the water and then consumed by the customer. The iron in the water usually is noticeable in rust stains on clothing. Lead and copper in drinking water is not noticeable to the consumer, but is a serious health hazard when present in elevated levels.

Corrosion in pipes is caused by reactions between the water and the metal in the pipe. This appears as rust and tuberculation (buildup of rust). Some of the factors which affect the rate of corrosion are:

- Temperature - Higher temperatures cause more rapid chemical reactions (i.e., reactions which occur inside hot water tanks);
- Low pH;
- Low alkalinity;
- Velocity - Corrosive water at high velocity causes rapid pipe deterioration but shows little metal pick up. Low velocity with more contact time will have more metal pick up resulting in red water;
- Galvanic corrosion - When two different metals come into contact, there is a chemical reaction which produces a flow of electrons from one metal to the other causing corrosion; and

- Dissolved gases - Oxygen increases the rate of corrosion. Carbon dioxide reduces pH and increases corrosion. Nitrogen tends to lower corrosion rates.

### **Disinfection**

The disinfection of water is the selective destruction of pathogenic organisms. The destruction of all organisms is called sterilization. This is too expensive and not practical in water treatment. The destruction of pathogenic organisms is the destruction of all disease-causing organisms. The Safe Drinking Water Act requirement is to destroy almost all coliform bacteria. The total coliform group merits consideration as an indicator of pollution because these bacteria always are present in the normal intestinal tract of humans and other warm-blooded animals and are eliminated in large numbers in fecal wastes. Thus, the absence of total coliform bacteria is evidence of bacteriologically-safe water.

### **Disinfection Chemicals**

The chemicals commonly used for disinfection are chlorine, calcium hypochlorite, sodium hypochlorite, and sodium chlorite. There are other chemicals (i.e., iodine, bromine, and ozone) which will disinfect water, but are not as commonly used in water treatment.

### **Chlorine**

Chlorine is a greenish-yellow gas which has a very penetrating, acrid odor that burns the eyes and the throat. Chlorine gas is 2 ½ times heavier than air and, therefore, tends to collect in low areas such as pits, basements, and sumps. Chlorine gas is supplied under pressure in 100 or 150 lb. cylinders or in 2,000 lb containers. Chlorine also can be delivered by railroad car, but this is not common for water suppliers. The chlorine cylinders must be protected from exposure to heat because a rise in temperature can cause an increase in pressure which could rupture the steel cylinders. The cylinders are equipped with a fusible plug which softens and melts at 158°F to 165°F to prevent the buildup of pressure. Chlorine cylinders must be secured in an upright position to prevent falling over and damaging the valve. Also, the valve should be protected with a protective cap when not in use.

### **Method of Feeding**

The chlorinators used to feed the chlorine are vacuum controlled so the chlorine gas only can be released when a vacuum is present. The chlorine gas then is injected into a stream of water at the injector. The flow of water, through a small orifice in the injector, creates the vacuum which draws the chlorine gas into the stream of water. The solution of chlorine and water then is conveyed to the point of application. A typical chlorinator has a pressure-reducing valve to lessen the pressure, a rate valve and rate meter to control the rate of flow, and a valve which shuts off the supply of chlorine gas when a vacuum is not present.

### **Determination and Control of Feed Rate**

The amount of chlorine applied depends on the point of application and the expected result. For example, the amount of chlorine applied to raw water to control algae growth and prevent tastes and odors can be at relatively high rates because the organic materials in the water react with the chlorine. In this situation, the goal should be to carry a measurable chlorine residual to the filter influent water. This may require the application of chlorine at rates of 3 to 4 mg/L. The amount of chlorine applied to the clearwell should be adequate to maintain a detectable residual of free chlorine in all parts of the distribution system in the recommended amount of 0.2 mg/L.

The rate of feed in a gas chlorinator is controlled by a flow rate adjusting valve and a rate meter which indicates the rate of flow. In some installations there may be chlorine residual monitoring equipment which automatically paces the rate of feed to maintain a specific chlorine residual at a specified location downstream from the point of application.

### **Precautions and Abnormal Situations**

- Chlorine gas is extremely toxic and can cause death when inhaled. All safety precautions must be observed.
- Exhaust fans must be used to ventilate the chlorine room in the event of a leak. Ideally, fans should push air into the room from the ceiling or a high point on a wall and the exhaust must be from close to floor level. This prevents the chlorine gas from passing over the fan and motor. Chlorine gas is very corrosive and can damage the fan and the motor.
- Self-contained breathing apparatus must be used if there is any suspicion of a leak.
- Chlorine leaks can be checked by using a rag on a stick dipped in ammonia. When passed near the chlorine leak, a white vapor will form.
- When a leak is suspected, always work with a backup person to help you out if you are overcome.
- When a leak cannot be repaired and could become a threat to the area, contact the fire department for help.
- If a chlorine cylinder or container is leaking, call the supplier for help.
- Avoid drawing more than 40 lbs of chlorine per day from any one cylinder. If more chlorine is required, the withdrawal should be from multiple cylinders manifolded together.

### **Calcium Hypochlorite and Sodium Hypochlorite**

Calcium hypochlorite is a dry, white chemical in granular or tablet form. When used for disinfection, it should be mixed in a solution of water and fed by solution pump into the water to be treated.

Sodium hypochlorite is a light yellow liquid which is commonly used as bleach; however, the concentration of sodium hypochlorite used in water treatment is much higher (up to 15 percent). The liquid usually is supplied in five-gallon carboys; however, some smaller systems purchase one-gallon containers.

### **Method of Feeding**

Both calcium hypochlorite and sodium hypochlorite solutions are fed by means of a metered solution pump. The powder or the liquid is diluted with water in a solution crock to a predetermined strength, usually about a one-percent solution.

### **Determination of Feed Rate**

The amount of calcium hypochlorite or sodium hypochlorite applied to the water is determined by the free chlorine residual which is necessary to provide adequate disinfection of the water and maintain a residual in the recommended amount of at least 0.2 mg/L in all parts of the distribution system. Each system should develop criteria to determine the necessary chlorine residual at the point of application. However, the temperature, pH, and any organic substances in the water must be considered when setting application rates.

### **Precautions and Abnormal Situations**

- Calcium hypochlorite is a dry powder which does not fully dissolve in water; therefore, a sediment of undissolved chemicals is present in the bottom of the solution tank. Therefore, the pump suction line should be kept off the bottom of the tank to prevent this sediment from being drawn into the pump.
- The hypochlorite solutions are very corrosive and should not be in contact with metals.
- The hypochlorite solutions are very strong alkali bleaches which can be a skin irritant. Eyes should be protected from solution splashes or airborne powder (dust).

### **Fluoridation Chemicals**

Fluoride is added to water supplies for the purpose of preventing tooth decay. There are three common fluoridation chemicals -- sodium fluoride, sodium silicofluoride, and hydrofluosilicic acid.

Sodium fluoride and sodium silicofluoride are supplied as a dry, white powder usually in paper bags. The dust from these chemicals can irritate the nose and throat. These chemicals are fed either by dry chemical feeders where they are added to water to form a solution or, in the case of sodium fluoride, it is commonly fed through a saturator where water is passed through a layer of sodium fluoride and the chemical is dissolved into solution. These dry chemicals must be handled carefully when loading the feeders. If emptied too quickly, the airborne fluoride dust levels may become too high.

Hydrofluosilicic acid is a liquid supplied in carboys. Normally the chemical is fed at full strength directly from the carboy; however, if the liquid must be transferred, care must be taken to avoid splashes or spills. The liquid is very corrosive and irritates the skin and eyes. The fumes are pungent and irritating. The carboys should be vented to the outside so the fumes and odors do not accumulate. All storage areas should be well ventilated.

### **Conventional Filtration Treatment Plant**

A conventional filtration treatment plant is used for the treatment of surface water to remove turbidity (particulate matter) and microbiological contamination (bacteria, *Giardia* and *Cryptosporidium*). These treatment plants typically have chemical addition, rapid mix, flocculation, sedimentation, and filters as the flow of the treatment processes. A variation of the conventional filtration treatment plant would be a plant which has a solids contact unit which includes the rapid mix, flocculation, and sedimentation processes in one compact unit. Another variation is the direct filtration treatment plant which may omit sedimentation, add the coagulant chemicals to the raw water, and direct the raw water onto the filters. The operation of this type of plant requires very careful monitoring of the process. The following is a brief description of the operation and maintenance of each of these components.

#### **Rapid Mixing**

Rapid mixing is the initial high speed agitation of the water to ensure a quick dispersion of the chemicals in the processed water. This action causes the chemical to be distributed uniformly throughout the water. This process usually is located immediately preceding the flocculation or coagulation basin and immediately following the addition of chemicals. There usually are two parallel mixing units, each mounted over a relatively small square chamber having a maximum detention time of 30 seconds. It is desirable for the water to rapidly come into complete contact with the chemicals so the chemical reactions begin; however, it is not desirable that any settling of chemicals or materials occur in these chambers. Although there are static rapid mixers, the

most common are electric driven motors having a long vertical shaft with a propeller extending into the water flowing through the chamber.

#### *Start-up*

Start-up of the rapid mixers coincides with the start of flow through the plant and the start of chemical additions. A pre-start check should determine:

- Does the shaft turn freely?
- Is any lubrication required?
- Are there any unsafe conditions (e.g., exposed wires)?

#### *Normal Operating Conditions*

Rapid mixing is a continuous process which requires no controls or monitoring.

#### *Monitoring*

Visual monitoring of the rapid mixing units will provide an indication that they are operating and are effective. If they are operating correctly, there will be an obvious turbulence to the water.

#### *Records*

There are no specific records of operation for the rapid mixing units except the records of maintenance and repairs performed.

#### *Maintenance*

Maintenance of the rapid mixing units consists of lubrication in accordance with the manufacturer's recommendations and a periodic check of the mixing chambers for a buildup of chemicals on the walls and bottom. The removal of any buildup should be made before it hinders the operation of the mixers or changes the characteristics of the flow.

### **Coagulation / Flocculation**

Coagulation is the effect of chemicals added to the raw water reacting with the particulate impurities, especially lightweight particles, to form a floc. A floc is the accumulation of the chemicals and the particulate matter to form small jelly-like particles which look like snowflakes in the water. As these pieces of floc clump together and combine with more particulate matter, they grow into larger and heavier floc which will settle out. The coagulation process is a very complex chemical and physical reaction which depends on many factors, such as pH, alkalinity, turbidity, temperature, and hardness. It also depends on the chemicals and dosages of chemicals used for coagulation and the physical treatment of the water, such as rapid mixing, flocculation, and baffles used for rapid and slow agitation of the water to cause collisions between the chemicals (floc) and the particulate matter.

Flocculation units may be of many configurations (i. e. horizontal paddle wheels, vertical paddle wheels, vertical turbines, vertical propellers, etc.). Each configuration should be carefully designed to provide satisfactory performance. The vertical configuration usually requires less maintenance since it eliminates submerged bearings and drive mechanisms. Some flocculation can be caused by the turbulence resulting from baffle and orifices. There usually are two parallel systems of coagulation/flocculation units in a treatment plant to facilitate removing one half of the basins from service for maintenance. The best flocculation usually is achieved by more than one unit in a series. Each unit is separated by baffles to prevent short circuiting. Also, all inlets and outlets are baffled to prevent short circuiting. The flocculators usually are driven by variable speed drive units. With multiple units, it is desirable to reduce the speed of the flocculators in

each succeeding unit to prevent breaking up the large floc particles which have formed. The flocculators should have a detention time of 30 minutes.

#### *Start-up*

The flocculation units should be started approximately at the same time as the start-up of chemical addition and rapid mixing. Prior to start-up, the drive units should be visually checked for any damage such as loose wires or anything which would prevent the normal operation of the unit. During the winter, ice can prevent the rotation of the paddles, or ice cakes can damage the paddles or blades. The operation of the flocculators is not directly interdependent on the operation of the upstream or downstream processes. Under unusual conditions, for a short period of time the treatment plant may continue to be operated with the flocculation units out of service, however, probably at a reduced flow rate. Under these conditions, careful attention to the chemical addition and the quality of water at the end of the sedimentation basins is necessary.

#### *Normal Operating Procedures*

Under normal operating procedures, the flocculation units operate at speeds which have been established by either the manufacturer or the engineer. The speed should not be varied without careful consultation with the engineer. In the event the flocculation units appear to be ineffective, a careful analysis of the process should be done using jar tests, varying both the doses of chemicals and the speed of the flocculators to determine if an improved process could be developed. Any analysis such as this should be carefully documented.

#### *Monitoring*

The flocculation units are monitored through visual observation of the formation of the floc as it passes through the units. The floc formation should be easily detectable with the naked eye. At the inlet to the flocculation units, the floc will be very fine and have a light sparkling appearance. As the heavier floc is formed, the particles will be larger and look like snowflakes. At times, a gradual change to a darker color can be noticed. It is good practice to periodically dip a small sample of water from different points in the treatment process into a glass jar or beaker to observe the formation of the floc. Experience in observing the appearance of the floc at various stages of treatment will be beneficial in evaluating the effectiveness of the treatment process.

#### *Records*

There normally are no separate records kept for the flocculator units except for routine and major maintenance which is recorded in the maintenance records.

#### *Maintenance*

The maintenance of the flocculation drive units usually is lubrication of the motor and drive units according to the manufacturer's recommendations. Horizontal paddles usually have submerged bearings, drive chains, or packing which requires additional checking and maintenance. Care should be taken during the winter to prevent damage from ice and slush. The flocculation basins should be drained approximately every six months to check the condition of the paddles or blades, to remove any accumulation of settled material, and to check on the condition of the basin's structure.

## **Sedimentation**

Sedimentation is the slow, quiet settling of the floc and suspended matter from the water by gravity. The sedimentation basins can be rectangular or circular in shape. There should be at least duplicate units to facilitate cleaning. The basins should have a detention time of 4 hours. The inlet devices should be designed to distribute the water for uniform velocities and care should be taken to prevent short circuiting of flows. The outlet devices also must be designed for uniform flow and to prevent short circuiting. The outlet devices should be submerged orifices. There should be surface skimming to collect floating debris, such as leaves, scum, etc.

There are many variations and accessories which may be designed into a sedimentation unit, such as sludge collection and removal, tube settlers, submerged baffles, and launders which provide both skimming and effluent troughs. Circular units may be called clarifiers and usually have some type of rotating sludge rakes which convey the sludge to a sump where it can be drawn off.

Tube settlers are a variation developed to increase the settling efficiency by producing straight laminar flow in rectangular basins and have been used in circular basins. The water enters the slanted tubes and is forced to flow upward. The suspended solids strike the walls of the tubes, lose their forward velocity, and tend to settle downward along the tube walls. Tube settlers can be added to existing sedimentation basins and solids contact tanks to increase the capacity of these units, or tube settlers can be installed in new facilities to provide a higher capacity in a smaller area at less cost.

### *Start-up*

The start-up procedures for the sedimentation basins usually occur simultaneously and automatically with the start-up of the upstream units. The drive motors for sludge collection equipment also should be turned on at that time. There is no critical requirement that the sludge collection equipment be started immediately since the sedimentation process is very slow.

### *Normal Operating Procedures*

There are no normal operating control procedures for the sedimentation basin except the speed of the sludge collection equipment which should be set according to the manufacturer's recommendations.

### *Monitoring*

The monitoring of the operation of the sedimentation basin is by visual observation of the water entering and leaving the basin. By dipping some of the effluent water into a clear glass container, such as a beaker, and holding it up to the light, the operator should be able to observe a very light suspended floc. The water between the floc should be reasonably clear. It is normal for some of the very light floc to be carried onto the filter beds since this aids the filtration process.

### *Records*

The only records of sedimentation basin operation are either the amount of time since the last basin cleaning or where mechanical sludge removal equipment is used, a record of the withdrawals of sludge, estimated quantities and percent of settled solid. The operator should check periodically for the accumulation of sludge.

### *Maintenance*

Routine maintenance applies only to the sludge collection equipment which should be lubricated according to the manufacturer's recommendations. When the basins are drained for cleaning, the condition of the basins and the sludge collection equipment should be checked carefully. It is recommended that basins be drained and cleaned at least twice a year.

### **Solids Contact Units**

Solids contact units combine the coagulation, flocculation, and sedimentation functions together with recycling of solids for more efficient clarification of the water. The operation of solids contact units requires a good understanding of the operating processes which continuously are interacting within the unit. The mixing zone usually is very small in size and is similar to rapid mixing. The reaction zone is similar to flocculation and the separation zone is similar to sedimentation, except the water is forced down through the reaction zone and flows up through the separation zone. This requires the water to flow through an area which has a heavy accumulation of sludge. Thus, the incoming water comes in contact with the sludge.

The solids contact units have several advantages, such as the all-in-one unit which takes up less space and costs less to construct. The disadvantages are the solids contact units require the operator to have greater technical ability; require closer monitoring; are not suited to operations where the turbidities and solids are subject to large and rapid changes; and are not suited to non continuous operations and temperature changes.

Solids contact units usually are circular in shape. There should be two or more parallel units. The units should be equipped with sampling taps to permit sampling from each zone and at various levels in the separation zone. The flocculation equipment shall have an adjustable drive unit. Detention time should be 2 to 4 hours. Solids contact units should be equipped with sludge collecting equipment and have the piping for periodic sludge withdrawal. The operator should be able to sample the sludge being withdrawn. The effluent shall flow over overflow weirs or through orifices to prevent short circuiting and nonuniform flows.

#### *Start-up*

Solids contact units work best when they are operated continuously and have a buildup of sludge available to aid the process. Therefore, all start-up operations shall be at a reduced flow rate until an adequate volume of sludge is present. Prior to starting the operation of the flocculation and sludge collecting, equipment should be checked. The start-up of the solids contact units should coincide with the start-up of the chemical feed equipment.

#### *Normal Operating Procedure*

The operation of the solids contact units is sensitive to rapid changes in the pH, alkalinity, turbidity, solids, temperature in the raw water, and flow rates. Changes in the above factors can affect the formation of floc, the settleability of the solids, and the maintenance of a sludge zone. The negative effects can be the carry-over of turbid water to the filters or the breakup of the sludge zone carrying large pieces and quantities of sludge on to the filters.

The operation can be controlled by applying the proper chemical dosage for each condition. The operation also is controlled over a longer period of time by controlling the amount of sludge and the recirculation of sludge. These conditions can be observed by checking the volume of sludge present in a sample from the sludge withdrawal piping and a sample from the flocculation zone. After these samples set for 5 to 10 minutes, the sludge volume can be visually observed and

should be from five to twenty percent in the flocculation zone, and over 90% in the sludge withdrawal piping.

#### *Monitoring*

Visual monitoring of the solids contact units effluent water will provide a good indication of its effectiveness. By placing a sample of the effluent into a clear glass container and holding it up to the light, the operator should be able to observe a very light floc and the water should be reasonably clear. The appearance of heavy floc, turbid, cloudy, or large clumps of solids indicates the process is not in proper balance. The operator should perform a jar test to determine the proper chemical dosage.

#### *Records*

By checking the volumes of sludge present in the samples drawn from the sample taps, the operator can determine the level of sludge in the unit and the concentration present. Through experience the operator will learn the proper amount, level, and concentration of sludge for the best operation. The manufacturer's recommendations should be used as guidelines; however, the operator can, by keeping records and through experience, determine the best levels and concentrations of sludge for a particular raw water condition.

#### *Maintenance*

Maintenance of a solids contact unit consists of routine lubrication of the drive units for the sludge collection and recirculation units. The solids contact units usually are drained once a year to check the condition of the sludge collection equipment and the structure. When the units are drained, they should be cleaned of all sludge so that all parts of the sludge collecting equipment and the structure can be observed. Long-term maintenance can consist of repainting steel components, and patching and sealing the concrete structures. The repair of baffles, launders, sludge piping, valves, and sludge pumps can be done at this time.

### **Filtration**

Filtration is the final barrier preventing particulate matter from entering the system. Filtration is the removal of floc and fine suspended particles from the water after it has passed through the sedimentation basins or solids contact units. The filtration process is the passing of the water through a bed of fine material, such as sand, coal, or other fine granular material. The filter media can be uniform in sizing, but higher and more effective filter rates are attained by use of mixed media. The filter process sometimes is described as straining, but the light floc carried on to the filter material from the sedimentation basins adheres to the grains of the filter media and this coating penetrates into the filter bed. This coating on the filter media attracts the suspended particulate matter which enhances the filtered water quality. This coating continues to build on the filter media and attracts more of the floc and suspended particulate matter.

As this coating builds and penetrates into the filter bed, the head loss across the filter becomes greater until the flow rate is greatly reduced. At this time the filter must be backwashed to cleanse the media of the floc and particulate matter. There are several types of filters, such as direct, slow sand, pressure, diatomaceous earth and rapid rate gravity. Rapid rate gravity filters are the most commonly used and will be used for these procedures.

#### *Start-up*

If the filter has been drained, it should be filled slowly so the media are not disrupted. The filter should be filled through the backwash valve so it is filled from the bottom up, thus forcing most of the air out of the media. Fill the filter until the water level is above the washwater troughs.

Any filter which has been out of service for more than a few hours always should be backwashed before being put into service again, because there is a good possibility that many bacteria will have grown in the filter media.

Backwash filter as follows (general outline):

- Check all filter valves to be sure they are closed;
- Close the influent valve;
- Filter until the water is lowered to 6 inches above the surface of the media;
- Close the effluent valve;
- Open drain to waste valve;
- Start backwash pump or turn on source of water for backwash, slowly open the backwash valve until it comes up to the specified rate of flow;
- Start surface wash pump or turn on source of water for surface wash, slowly open surface wash valve;
- The backwash should be run until the desired clarity (desired turbidity and/or particle count) is obtained in the backwash water;
- Use a high pressure hose to wash down the walls of the filters and all other exposed surfaces since the silt particles will adhere to these surfaces. The high pressure hose should be equipped with a backflow preventer to prevent any possibility of a cross-connection;
- The surface wash should be operated for the necessary period of time, but the backwash water should be run at least two or more minutes after the surface wash is shut off;
- Close the backwash valve slowly to prevent water hammer;
- Close drain valve; Open influent valve slowly and allow water to come up to proper level;
- Open filter to waste valve. This flushes any loose sediment left from the backwashing of media, the underdrains and the effluent piping. At the end of the backwash, the filter media are left unconsolidated and the floc coating has been washed off the media. The filter must be filtered to waste until the bed settles in and the effluent water meets the requirements of the Safe Drinking Water Act. If there is no filter-to-waste capability, the bed should be left out of service for 30 to 60 minutes to let the media settle and consolidate. When filtering is first started, it should be at a very reduced rate of flow for the first 30 minutes to an hour and the turbidity should be carefully monitored. In this first hour of filter operation, there is great potential for a turbidity breakthrough which means particulate matter and bacteria can pass through to the clearwell;
- Close filter to waste valve and then open effluent valve.
- Record date, time, and headloss before and after backwash; record number of hours of operation since last backwash, quantity of backwash water used, and quantity of surface wash water used;
- Check rate-of-flow controller for proper operation and adjust flow rate of water onto filter. The filter should be eased into service at a reduced rate of filtration. When the filter is very clean, there can be a turbidity breakthrough until the media again become coated with the light floc. A careful observation of the turbidity monitor will indicate the proper rate of filtration;
- Monitoring of the filter effluent must comply with the requirements of the Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR).

*Normal Operating Procedures*

The three controlling factors for normal filter operation are: (1) flow rate, (2) head loss, and (3) turbidity of the effluent. A recording or indicating gauge should be provided for each of these factors and the operator should make frequent observations.

- **Flow Rate** - A flow rate controller limits the maximum rate of filtration by restricting the flow to a predetermined rate through the effluent pipe when the filter is very clean immediately after backwashing. As the filter media become progressively clogged, the loss of head across the filter increases and the rate of filtration gradually declines, and the low rate controller gradually opens to maintain the predetermined rate. Careful observation of the flow rate will predict the need for backwashing the filter.
- **Head Loss** - The loss of head gauges measures the loss of head (resistance to flow) across the filter. This is the difference in pressure (water level) on top of the filter and the pressure on the filter effluent piping between the filter and the rate of flow controller. This pressure can be best illustrated by the height of water in a clear glass or plastic tube tapped into the effluent piping. The loss of head across a filter is an indication of the filter's condition, for example:
  - Immediately after backwash, the headloss should be nearly zero;
  - When the head loss is approximately seven to ten feet, the filter may develop a negative pressure in the filter media, causing turbidity breakthrough. When this occurs, the filter must be taken out of service; and
  - A sudden increase in headloss can indicate filter clogging caused by a change in raw water conditions.
- **Turbidity** - At the end of a backwash, the filter is left unconsolidated and the floc coating has been washed off the media. The filter must be filtered to waste or left out of service for 30 to 60 minutes until the filter media consolidate and the turbidity level is below the allowable level. When there is no filter to waste capability, the filter when first started should gradually be eased back on line to prevent turbidity break through. Otherwise, water with higher turbidities will be passed to the clear well. Filtration is the final barrier preventing particulate matter from entering the system.

From a water quality standpoint, the turbidity of the filter effluent will provide the operator with one of the best indications of the effectiveness of the overall treatment process. When the turbidity approaches the maximum allowable level, the filter must be removed from service and backwashed.

### *Monitoring*

The visual monitoring of the filter operation includes the observation of the flow rate, headloss, and turbidity of the effluent for each filter. These factors can provide the operator with an accurate evaluation of the filter's condition and will indicate the corrective action to be initiated. For example, the filter should be backwashed when the flow rate decreases, the turbidity increases, and the head loss increases. If these changes happen in a relatively short period of time, the operator should check the filter influent since it may contain large amounts of floc. This would indicate the raw water conditions have changed and the chemical feed rates should be adjusted. If the turbidity increases but the headloss and flowrate do not increase, the operator should check the filter influent which may be cloudy and turbid. This also would require a change in the chemical feed rates. Any changes in chemical feed rates should be determined and verified by use of the jar test.

During the backwash procedure, the operator has a chance to observe a number of factors which will indicate the condition of the filter media. By allowing the water to drain down to the level of the media before starting the backwash, the operator can observe if the media are relatively level and does not have cracking or shrinkage away from walls. If the media are not relatively level, turbulent inflow of water may be the reason. These are all indications of mudballs or deep clogging of the bed. Proper backwashing at slightly higher rates and the use of the surface wash will help alleviate this problem. If the filter is not equipped with a surface wash, manual raking during the backwash will help dislodge the mudballs. There should be no spots boiling up when the backwash begins; however, if there are, this indicates the filter media are not uniformly distributed. If this cannot be corrected by intensive backwash, the media may have to be removed and regraded.

Air binding or entrapment can occur if the head loss limits are exceeded or when dissolved air in cold water is released due to a decrease in pressure. The entrapped air will cause increased head loss and will shorten filter runs. If air entrapment is suspected, the filter should be backwashed slowly at first, since the air can disrupt the uniformity of the filter media and cause media to be carried out of the filter.

If excessive head losses are indicated immediately after backwashing, the underdrain system may be clogged or fouled due to corrosion or chemical deposits. This condition would require the removal of the media to expose the underdrains. If the underdrains are clogged, they must be removed and cleaned or replaced.

Excessive head loss, flow rate, and turbidity readings always should be verified by calibration before any extensive corrective action is taken.

### *Records*

Record keeping of the operation of the treatment plant and the filters is very important because it establishes a history of what was done and how various components reacted. This history is necessary for compiling data for reports to OEHS, for engineers to design replacement or expansion of the treatment units, and for determining actions to take during unusual or emergency situations.

Listed below are types of records to be maintained.

- Water produced;
- Amount of wash water used;
- Volume of surface wash used;
- Number of filter units in service;
- The length of filter runs between washing;
- Turbidity and head loss - Continuous recording as required by the regulations; and
- Process equipment performances; notes on equipment out of service; maintenance performed; equipment calibration; and accidents or unusual occurrences.

### *Maintenance*

- The filter control valves should be checked routinely for proper operation and any leakage.
- The instruments used to check the filter operation, headloss gauge, flowrate controller, particle counter and turbidimeter would be calibrated on a frequent and regular basis.

- The filter media should be examined annually to evaluate its overall condition. Is the media uniformly graded and distributed? Is there the proper depth of each gradation of media? Expose the underdrain system to check if the holes or nozzles are clogged.
- The backwash and surface wash pumps should be checked and lubricated according to the manufacturer's recommendations.
- The surface wash equipment, including nozzles, should be checked periodically for free operation and proper position over the media.

### *Other Types of Filters*

**Pressure Filtration** - Pressure filters can have sand, dual media, and mixed media. These filters are similar to rapid rate gravity filters, except they are completely enclosed in a pressure rated vessel. These filters usually are used only on small installations; however, several may be installed in parallel. These filters have the same operation and problems as gravity filters except the filter media cannot be readily observed.

**Diatomaceous Earth Filtration** - Diatomaceous earth is a very fine silica earth used as the filter media. A slurry of the filter medium is added to the water which then collects on the filter surfaces which are porous pipes or screens. After the coating is applied, water is filtered through the precoated surfaces. The coating may be supplemented during the filtration process by feeding small amounts of the filter medium with the water. These filters most often are used in industrial applications and swimming pools.

**Slow Sand Filtration** - The water is applied to the surface of the filter and is drawn through the sand medium by gravity. The sand medium shall be at least 30 inches deep and supported by a gravel bed. The rate of filtration shall be 45 to 150 gallons per day per square foot of sand area. In a rapid sand filter, the particulate matter and the bacteria are formed into floc by the addition of chemicals. Then the floc is strained from the water by the filter media. In the slow sand filter the particles are removed by straining, adsorption, and biological action which occurs in the top two inches of the sand. This layer is called a Schmutzdecke and is necessary for the filtering action to be effective. When the Schmutzdecke becomes too thick, it must be removed by scraping the top 6 inches off the filter. The sand is washed and replaced when the sand depth is reduced to 2 feet. These filters require rather large areas and must be filtered to waste until the Schmutzdecke is developed. These are effective only on very low turbidity waters and have filter runs up to several months.

**Direct Filtration** - Direct filtration normally is used only on very low turbidity water (preferably not more than 10 NTU). The raw water is treated with coagulant chemicals and a coagulant aid (polymer) passes through a rapid mix chamber or in-line mixing to quickly form a floc. The water then flows directly onto the filters, which are usually multimedia designed specifically for this type of treatment. This treatment process requires careful monitoring to assure that the turbidity standard is not exceeded.

### **Disinfection**

The water supplier must deliver a product which is free of disease-causing organisms. Disinfection destroys disease-causing organisms, also called pathogenic organisms. Through the use of good water treatment practices and, more particularly, the disinfection of water with chlorine, outbreaks of serious diseases such as typhoid and cholera are very infrequent in the United States. The application of a disinfectant as a final treatment process is the typical practice; however, the disinfectant can be applied at other points in the treatment process. It is not unusual

to apply additional disinfection at points in the distribution system or at distribution storage facilities, when necessary.

Water can be disinfected by heat, radiation, or chemical treatment; however, the only widely accepted method is chemical treatment. The reason chemical treatment is so widely accepted is that the chemical is applied in amounts which, after completion of the disinfection, leave a chemical residual which would be available for further disinfection of the water if necessary. The ability to detect this chemical residual, by means of a simple test at any point in the distribution system, is an assurance that the water is free of pathogenic organisms. Only the more commonly used chemicals will be described here. Other methods of disinfection in approved use, now or in the future, may be described by the water system and used in their O&M Plan.

### **Chlorination**

Chlorination is the process of applying chlorine ( $\text{Cl}_2$ ) to water ( $\text{H}_2\text{O}$ ) to form hypochlorous acid ( $\text{HOCl}$ ) which is a free chlorine residual. This chlorine residual reacts with impurities in the water including the pathogenic organisms. As the chlorine reacts with the impurities, it is changed to chloramines and chloroorganic compounds which have a lower potency than the free chlorine residual. The free chlorine will continue to react with the impurities in the water, such as organic materials and organisms, until all the impurities and organisms are destroyed and there is an excess of free chlorine. It is important to recognize that the combination of sufficient free chlorine residual and adequate contact time are essential for effective killing of the pathogenic organisms.

Other critical factors which can affect the disinfection process are:

- Injection point and method of mixing to achieve total contact with water being disinfected;
- Contact time - The longer the contact time, the more effective the disinfection;
- Effectiveness of other upstream treatment processes; (e.g., the lower the turbidity, the better the disinfection because there is less interference from other substances);
- Temperature - The higher the temperature, the more rapid the rate of disinfection and also the more rapid the depletion of the free chlorine residual;
- The dosage and type of chemical - Usually the higher the dosage, the quicker the disinfection. The form of the chemical such as chloramines or free chlorine residual also affects the disinfection rate;
- The pH - The lower the pH, the more effective the disinfection;
- The free chlorine residual - There must be a detectable residual of total chlorine residual (in the recommended amount of at least 0.2 mg/L) in all parts of the distribution system. The regrowth of organisms can occur in the distribution system depleting the free chlorine residual; and
- Higher free chlorine residuals - Systems may increase residual disinfectant levels in the distribution system of chlorine or chloramines (but not chlorine dioxide) to a level to exceed MRDL for a period of time necessary to protect public health, to address specific microbiological contamination problems caused by circumstances such as, but not limited to, distribution line breaks, storm run-off events, source water contamination events, or cross-connection events.

Organics found in the water can consume great amounts of disinfectants while forming unwanted compounds. The reaction of chlorine with certain organic precursors can form trihalomethanes such as chloroform. These trihalomethanes are known to cause cancer.

Prechlorination of raw water containing organic precursors is more likely to form trihalomethanes than post-chlorination because the coagulation/filtration process will remove most of the organic precursors. As the maximum contaminant level (MCL) for the trihalomethane compounds is lowered by regulations, the water system will have to consider alternate methods of disinfecting the water. The points of application of chlorine, for example, can be moved from prechlorination to post-chlorination and alternate chemicals can be used for pretreatment of the raw water such as chlorine dioxide or potassium permanganate.

#### *Start-up*

The application of chlorine should be started as soon as the flow of water through the plant begins. It is important that the chlorine have as much contact time with the water as possible. If a plant has been shut down for a period of time, the chlorine residual in the plant effluent water should be checked and, if necessary, additional chlorine should be added and plant start-up should be delayed at least 20 minutes to allow for adequate contact time before the water is available to the consumer.

#### *Normal Operations*

Normal operations of the chlorination equipment is continuous when water is being produced. Chlorine normally is applied to the water at the inlet to the clearwell or at a point which is farthest from the outlet of the clearwell. The clearwell should have baffles to prevent short circuiting of the treatment. The operator should have sufficient chlorine available so containers can be changed or, in the case of liquid solutions, be refilled before there is any interruption in the treatment. Normal operations should include all safety precautions to prevent injury to the operator or the public.

#### *Monitoring*

The testing for chlorine residual should be performed, as a minimum, on a daily basis at very simple unmanned facilities such as wells. The chlorine residual in the remote sections of the distribution system should be tested on a daily basis. In more complex treatment systems where the water quality is subject to frequent changes, the testing should be performed more frequently; in some cases, chlorine residual monitoring and recording equipment and paced feed rates are necessary.

The chlorine residual at the effluent of the treatment facility should be compared with the chlorine residual in the distribution system. The chlorine feed rate should be adjusted to maintain a detectable residual of total chlorine residual (in the recommended amount of at least 0.2 mg/L) in all parts of the distribution system. Many distribution systems which are large and spread out may have installed additional chlorination facilities to maintain a detectable residual of total chlorine residual, in the recommended amount of at least 0.2 mg/L, throughout the system. These chlorination facilities must be monitored daily for proper operation and rate of feed.

#### *Records*

It is important to maintain records of the operation of the treatment facilities to provide assurance that the water is meeting the requirements of the Safe Drinking Water Act at all times. The results of tests for chlorine residual, both at the treatment facilities and in the distribution system, are the best evidence of meeting this requirement. The water supplier should develop a form for recording these results.

### *Maintenance*

Chlorination usually is accomplished by either gas chlorinators, hypochlorinators or chlorine dioxide generators.

#### **Gas Chlorinators**

On a daily basis chlorinators should be inspected for proper operation and leaks. The items to be checked should include injector water supply pressure, injector vacuum, chlorine supply pressure (after the pressure regulating valve), feed rate on rotometer tube. The chlorine residual should be checked and recorded. The weight of the chlorine cylinders should be recorded (check to see that the change in weight corresponds with the feed rate on the rotometer). Determine when the cylinder is approaching empty, when full cylinders are available, and when cylinders must be changed.

If an automatic chlorine residual analyzer (which adjusts the feed rate as the flow rate changes) is in use, check the actual chlorine residual, sample water flow, and add reagents if required. Change recording chart if necessary.

On a weekly basis check chlorinator feed rates through the full range of its capacity, clean any filters, and check operation of all valves. If automatic equipment is in use, check the operation through the full range of its capabilities, clean filters, clean water sample line, clean all dilution wells and baffles, fill buffer reservoirs, check sample and buffer feed pumps for proper operation, and generally clean all equipment hoses and reservoirs.

On a monthly basis, exercise all chlorine valves, inspect ventilation, heating, and lighting equipment for proper operation. Check the chlorinator vent line for obstructions such as insect nests, inspect the vacuum system for leaks, and perform other maintenance according to the manufacturer's recommendations. The automatic chlorine analyzer should be maintained according to the manufacturer's recommendations regarding lubrication, cleaning, and calibration.

Inspect all safety equipment for proper operation including chlorine alarm system and the self-contained breathing apparatus or gas masks. Some abnormal operating conditions which could occur are:

- Chlorine leak - A chlorine leak is usually detectable by your sense of smell as soon as you arrive at the chlorination location. If a chlorine leak is suspected, do not enter the building or chlorine room without having a backup person with you and without the use of a gas mask or respiratory equipment. Use the ventilator fan to air out the chlorinator room as much as possible. Upon entering the room, turn off the valve at the chlorine cylinder or container first. Allow the chlorinator ejector to continue to operate to clear the chlorine out of the lines.

If the leak is in the piping, equipment, or valves, repair the leak and return the system to service. If the leakage cannot be stopped by shutting off the chlorine cylinder or container valve, it will be necessary to install an emergency kit on the cylinder or container. The supplier of the cylinder or container should be notified in order to provide help in installing these kits.

- Low gas pressure - If the chlorine gas pressure drops, it usually is the result of the chlorine container being empty, clogged filters, or closed valves. To correct, replace the container, clean the filters, and check the valves.

- Injector vacuum too low - If the injector vacuum drops too low, the chlorinator should automatically shut off. The cause of the vacuum being low is a leak in the vacuum hoses, low water pressure, or clogged ejector.

If there is a vacuum leak, repair the leak. If there is low water pressure, check the source, pump operation, or line strainers. If the ejector is clogged, remove and clean it.

If the above does not correct the problem, check the solution line downstream from the ejector for any restriction such as a collapsed line, partially-closed valve, or a clogged diffuser.

### **Hypochlorinators**

Hypochlorinator systems usually consist of a solution tank for the hypochlorite solution and a diaphragm-type metered solution pump. The items to be checked include the level of solution in the tank, the strainer on the solution suction line, the diaphragm pump, and the discharge line. The diaphragm pump has an adjustable feed rate that is used to adjust the chlorine solution feed rate.

On a daily basis the solution tank should be filled, the suction line screen should be checked and cleaned, and the operation of the solution pump should be checked. The volume of solution and volume of water added each day should be recorded. A test for the chlorine residual at the effluent of the facility will indicate if the pump feed rate is at the proper amount. The chlorine residual at the effluent of the facility should be high enough to maintain a detectable residual in the recommended amount of at least 0.2 mg/L throughout the distribution system. If the chlorine residual is too low, the solution pump rate should be increased. If the solution pump rate cannot be increased, then the strength of the solution in the solution tank should be increased by changing the ratio of solution to water.

On a weekly basis, the solution tank should be thoroughly cleaned. Maintenance of the solution pump should be in accordance with the manufacturer's recommendations. On a monthly basis all valves should be checked for proper operation or leaks. All plastic feed lines should be checked for damage, kinking, or clogging. The abnormal situation would be the failure of the solution pump. A spare solution pump should be available to immediately replace the failed pump. If the pump motor is operational, the pump can be rebuilt by replacing the diaphragm and the suction and discharge valves. Unless the pump body is damaged, these parts usually restore the pump to proper operation.

### **Chlorine Dioxide**

Chlorine dioxide is generated by the reaction of a chlorine solution with a sodium chlorite solution in a chlorine dioxide generating tower. The benefits of a chlorine dioxide disinfectant over chlorination are the trihalomethanes compounds are not formed, chlorine dioxide is more effective than chlorine in killing bacteria and viruses at a pH range from 8 to 10, chlorine dioxide does not combine with ammonia, and chlorine dioxide maintains a more stable residual in the distribution system. The equipment required for the generation of chlorine dioxide is the same chlorinator unit used to feed chlorine, a metered solution pump for sodium chlorite, a solution tank for the sodium chlorite solution, and a chlorine dioxide generator.

#### *Start-up*

The start of the chlorine dioxide generator coincides with the start-up of the treatment facilities. The operator should determine that the chlorine feed rate is adequate and that the sodium chlorite

solution tank is filled. The generation of chlorine dioxide is evidenced by the yellow-green color of the water as it rises in the generator. Chlorine residual tests are taken by the same procedures used for chlorination.

#### *Normal Operations*

Normal operations are the continuous feed of chlorine dioxide to the system. The rate of feed can be increased by increasing both the chlorine and the sodium chlorite feed rates.

#### *Records*

Records for the application of chlorine dioxide are the same as chlorine except the quantity of sodium chlorite used is also recorded.

#### *Monitoring*

Monitoring of the chlorine dioxide application consists of the chlorine residual tests. The rate of feed for both the chlorine and sodium chlorite solution can be increased or decreased as necessary to maintain a detectable chlorine residual in the recommended amount of at least 0.2 mg/L in all parts of the distribution system.

#### *Maintenance*

There is no additional maintenance of the chlorine dioxide system over the maintenance of a chlorinator and a metered solution feed pump.

#### *Safety Precautions*

Sodium chlorite is supplied as a dry powder and is very combustible around organic compounds. Whenever spills occur, the sodium chlorite should be neutralized with water. When fires occur, they should be smothered with soda ash. Do not spray water into a burning drum because it may cause an explosion.

### **Other Disinfection Systems**

There are other disinfection systems available for the treatment of water supplies, such as ozone and ultraviolet. At the present time, these systems are not widely used, usually because of the relatively high cost of operation and the lack of any simple test to measure the effectiveness of the system. In addition, water is subject to recontamination in the distribution system and these two methods do not provide any residual disinfecting capability to destroy bacteria after it leaves the treatment facility. If systems such as these are in use, the operation and maintenance procedures should be developed based on the manufacturer's recommendations.

### **Fluoridation**

The effect of fluoride in public water supplies is to reduce dental cavities. There have been many studies to support this theory and it is generally accepted by water suppliers and by the public. These studies have established that water with a fluoride content of about 1.0 mg/L causes a decrease in the number of cavities in children's teeth. Excessive fluorides in drinking water may produce mottling of teeth. The maximum contaminant level (MCL) for fluoride is based on the annual average of maximum daily air temperatures. The reason air temperature is used is because in warmer climates people drink much larger quantities of water than in the colder climates. This results in a larger daily intake of fluoride. Fluoride is available for use in water systems in three common chemical compounds: sodium fluoride, hydrofluosilicic acid, and sodium silicofluoride.

Sodium fluoride (NaF), a white, odorless material available in powder or crystal form, has the unique quality of solubility of 4.0 grams per 100 ml in water temperatures normally encountered in water treatment practice. The relative constant four percent solubility of sodium fluoride makes it ideally suited as the basis of design for the saturator type feeder where water slowly is passed through a bed containing a large amount of sodium fluoride.

Hydrofluosilicic acid ( $\text{H}_2\text{SiF}_6$ ), a 20 to 35 percent aqueous solution, is a clear, straw colored, fuming, corrosive liquid with a pungent odor and the ability to irritate skin. Because hydrofluosilicic acid contains a relatively high proportion of water, the shipping costs can be quite high for large quantities. Attempts to dilute the acid are subject to errors in measuring so it is better to use the acid undiluted from the container. If the acid is too concentrated for the solution feeder to handle, then weaker solutions of other chemical compounds are generally indicated. If the acid must be diluted, care should be taken to avoid formation of precipitate of silica.

Sodium silicofluoride ( $\text{Na}_2\text{SiF}_6$ ) is converted from hydrofluosilicic acid to a dry material containing a high percentage of available fluoride. This material has eliminated the water content of the hydrofluosilicic acid, thus reducing the shipping costs. Sodium silicofluoride is a white, odorless, crystalline powder. Its solubility varies from 0.44 grams per mL at  $0^\circ\text{C}$  to 2.45 grams per 100 mL at  $100^\circ\text{C}$  so it is not suited for use in saturators. Sodium silicofluoride can be fed with a dry chemical feeder into a solution tank with a mixer and the solution is applied to the water supply.

#### *Start-up*

The start-up of chemical feeders, either dry feeders or solution pumps, should be simultaneous with the start-up of the water supply pumps, because the feeding of fluoride to water in the piping system when the water supply pumps are not running could result in harmful overfeed to the consumers. Most chemical feeders are normally wired into the control wiring of the water supply pump.

#### *Normal Operations*

The normal operation is to provide feeding of the fluoride compound to the finished water output of the treatment facility or well. Application should be at a point where all of the water produced passes. If there is multiple output and there is no common point, then a separate feeding arrangement will be necessary for each location. The point of application should be after the filtration process and as far away as possible from any other chemical applications which contain calcium since this could cause the loss of fluoride by precipitation.

#### Chemical Feed Equipment

1. Where saturator chemical feed equipment is used, the operation is similar for either upflow or downflow saturators. In downflow saturators, the water passes through a layer of sodium fluoride which is supported by layers of sand and gravel. There is an inverted cone on the bottom of the container which houses the solution pump suction line. The water dissolves the sodium fluoride to a four percent concentration. As the water passes through, the sand, gravel, and cone prevent particles of undissolved sodium fluoride from passing into the water system.

In the upflow saturator, the water is distributed to the bottom of the solution tank where it passes up through a layer of sodium fluoride. As it passes through the sodium fluoride, the

water attains a four percent concentration of fluoride. The flow rate of water is slow enough so the undissolved sodium fluoride remains on the bottom of the solution tank. The solution pump suction is in a floating strainer and foot valve on the surface of the liquid.

2. Where a dry chemical feeder is used, the chemical is usually sodium silicofluoride and the feeders are either volumetric (by volume) or gravimetric (by weight) to deliver a uniform amount of fluoride chemical per unit of time. The dry chemical drops into a solution tank where it is mixed with water, assisted by either a water jet or a mechanical mixer. A mechanical mixer is more dependable and provides better dissolution of the fluoride in the water. The water in the solution tank then flows, either by metering pump or by gravity, to the point of application.
3. When hydrofluosilicic acid is used, it is fed by a metering pump. Metering pumps are available in several types. The most common are: a diaphragm pump with a flexible diaphragm that moves to force a specific amount of liquid out of the pump chamber and alternately moves in the opposite direction and draws the liquid into the pump chamber from a reservoir; a piston metering pump with a piston that alternately moves forward and back, the forward stroke forcing the liquid out of the chamber and the back stroke drawing in liquid from a reservoir; and peristaltic pumps which force uniform amounts of liquid to flow through a flexible plastic tube by passing movable rollers along the tube. The diaphragm metering pump is the most common because it is economical to purchase and maintain. The piston metering pump is usually more rugged for larger installations. The peristaltic pump has the advantage of providing more uniform flow, eliminating the pulses caused by the diaphragm and piston type metering pumps. The suction line of the metering pump should be run into the acid carboy, which should be vented to the outside since the fumes from the hydrofluosilicic acid are pungent and corrosive.

#### *Fluoride Feed Rates*

The fluoride level in a water supply is accomplished by adding the proper concentration of a fluoride chemical at a consistent rate.

#### *Records*

Records of the operation of the fluoride chemical feed equipment should be kept on a daily basis. The records should show the quantity of the chemical applied each day and in the case of a saturator, the gallons of water fed through the saturator. In all cases, the records should contain enough information so the total amount of fluoride applied can be determined. The results of analysis for fluoride in the system should be recorded daily.

#### *Monitoring*

A sample should be taken from the system and an analysis of fluoride should be made in accordance with an accepted and approved method. The tap at the sample point should be run long enough so the sample is representative of the water in the main. Water samples should be taken and analyzed at least daily.

#### *Maintenance*

The proper maintenance of the fluoride feed equipment will insure the continued normal operation. The maintenance of the equipment always should be in accordance with the manufacturer's recommendations. The basic equipment used for feeding fluoride is the solution

metering pump, the dry chemical feeder, and the mechanical mixer. The maintenance of these units generally consists of keeping the equipment clean and lubricated.

Electric motors usually come with a prescribed schedule for lubrication and many small motors do not require any lubrication. The right type and amount of lubrication is important. Gear boxes used for speed reduction usually require filling with a proper gear oil or lubricant.

Keeping the equipment clean and operative is of prime importance since the fluoride chemicals are very corrosive and tend to build up precipitates which interfere with the flow of water. Spare parts for solution pumps should be kept on hand and a spare pump should be available for use when a pump is being repaired.

### *Safety Precautions*

Fluoride compounds are very corrosive and the fumes from hydrofluosilicic acid are pungent and irritating to the skin. The operators always should wear protective safety gear when handling fluoride chemicals. In the dry state, fluoride is dusty and respirators should be worn. Care should be taken that the dust does not get into any food consumed by the operators. When handling hydrofluosilicic acid, rubber gloves and a face shield should be used to protect against splashes on the face, hands, or arms. Any spills should be washed away with large amounts of water.

### *Abnormal Conditions*

Overfeed incidents - There is always the potential for overfeeding; however, most overfeeds are not of serious consequence but must be recognized and corrected. In the case of serious overfeeds which produce concentrations greater than 2.0 mg/L, OEHS must be notified.

### **Aeration**

Aeration is the introduction of air into water, naturally or by the treatment process. A good example of natural aeration is the tumbling of water over rocks in a stream bed. The turbulence brings the air into contact with the water and the air dissolves into the water.

The induction of air into water can help oxidize iron, manganese, and certain types of tastes and odors; raise the oxygen level in the water; reduce the carbon dioxide, hydrogen sulfide, and methane; and remove volatile organic compounds. Excess carbon dioxide in water can cause corrosion, can make iron removal more difficult, and can inhibit the lime softening process.

- Hydrogen sulfide is a poisonous gas which can be dangerous in water treatment. It has a rotten egg odor and affects the taste of coffee, tea, ice cubes, and other foods. The gas is corrosive to metals and will tarnish silverware.
- Methane, commonly called swamp gas, is flammable and explosive and will impart garlic-like taste into water.
- Iron and manganese in water can cause a metallic taste in addition to staining clothes and plumbing fixtures.
- Some tastes and odors in water can be removed or reduced by aeration if they are caused by volatile substances which are readily oxidized. Many taste and odor causing substances will only be partly reduced by aeration and must be removed by other processes.
- An increase in dissolved oxygen in water is beneficial because it improves the taste of otherwise flat tasting water from the lower portion of lakes or reservoirs. A large amount of dissolved oxygen in water is called saturation and this can cause problems in the treatment process such as corrosion, floating floc, and air binding of filters. The turbulence of a cascade

type aerator can remove excess dissolved oxygen to the atmosphere. There are numerous volatile organic chemical compounds in water as a result of industrial pollution which are known or suspected carcinogens. Also, chlorine tends to react with certain natural organic materials to form trihalomethanes.

### *General Description*

Each type of aerator has its own characteristics and may be more effective for one constituent than another. There are many different types of aerators but they basically fall into the following categories:

**Water into Air Aerators** - In this type of aerator, the water flow is broken into small drops and falls through the air, creating intimate contact with the air. Different types are:

- **Cascade Aerator** - In a cascade aerator the water flows down a series of steps or circular rings stacked together with a central vertical feed pipe;
- **Cone Aerators** - A cone aerator is similar to stacked pans except the water flows from one pan to the next by means of specially-designed cone-shaped nozzles;
- **Slat and Coke Tray Aerator** - The slat and coke tray aerator usually has three to five trays which have spaced wooden slats. The trays are filled with pieces of coke rock, ceramic balls, or limestone. This creates a larger contact area between the air and the water;
- **Draft Aerator** - A draft aerator is similar to the slat and coke tray aerator with a positive upward air flow from a blower introduced at the bottom of the aerator. An induced draft aerator has a top-mounted blower which pulls an upward flow of air from the bottom of the aerator;
- **Spray Aerator** - A spray aerator disperses water out into a fine spray that falls through the air in a fountain effect. These are sometimes located within a structure to prevent windblown losses and reduce freezing problems. A spray aerator also may incorporate the effects of a cascade and a draft aerator for maximum effect.

**Air into Water Aerators** - This type of aerator mixes air into the water by either diffusers or draft tubes. They are:

- **Diffuser Aerator** - A diffuser aerator releases tiny bubbles of compressed air into the water, usually near the bottom of an aeration tank. These diffusers are usually mounted on a manifold pipe at a regular spacing to provide a rolling type mixing pattern to the water;
- **Draft Tube Aerator** - A draft tube aerator is a submersible pump with an air intake pipe. A partial vacuum is created by the eye of the impeller. The air and water are mixed by the turbine impeller and then discharged to the aeration tank.

**Combination Aerators** - This type of aerator produces air mixed in water by mechanical means or by applying water to compressed air or diffusing air into a pressure pipeline. They are:

- **Mechanical Aerators** - Mechanical aerators have a propeller mixing blade which is driven by a motor. The rapidly turning blade causes a violent mixing of the air and water. These have several different configurations: surface, submerged, combination (two blade), and draft tube;

- Pressure Aerators - Pressure aerators are of two basic types: water is sprayed into high pressure air within a pressure tank and air is diffused into water directly in a pressure pipeline.

Air strippers - This type of aerator forces air to flow upward through water which is flowing downward through a packed bed of small pieces of material. Packed tower air strippers which are a vertical column partially filled with small pieces of material use this process. As the flow of water trickles down through the material there is a countercurrent flow of air from a blower upward through the material.

#### *Start-up/Shut-down*

The start-up of aeration units should coincide with the start-up of the flow of water through the treatment process. With forced or induced draft the countercurrent flow of air should be established before the flow of water starts through the aerator. When the aerator is shut down the blower should continue to operate until all water has passed through the aerator facilities. On shut-down, all water pipes and bottom collection chambers should be effectively drained to prevent freezing.

#### *Normal Operations*

Normal operations should include visual inspection of the equipment for any damage due to corrosion.

#### *Monitoring*

During operation of the aeration facilities the following tests should be made:

- DO (dissolved oxygen);
- pH;
- Temperature;
- CO<sub>2</sub> (carbon dioxide);
- Manganese; and
- Taste and odor.

The DO test and the temperature will indicate possible over or under aeration of the water. The pH can be used as an indication of CO<sub>2</sub> removal or of the best pH range for removal of H<sub>2</sub>S or iron and manganese.

Frequency of testing would depend on the normal variations in the source water. In water with very little variation, daily testing may not be necessary.

Where aeration is used to remove volatile organic compounds, the analysis should be made by a laboratory certified for volatile organic compounds and, if necessary, for vinyl chloride. Analyses should be done a minimum of once each calendar quarter.

#### *Records*

Records should be kept for the number of hours of operation, the results of all water quality tests, and any major maintenance or operational problems.

#### *Maintenance*

The operator should maintain the pumps and blowers according to the manufacturer's recommendations. The operator should visually inspect the aerator for damage due to the

corrosive atmosphere such as eroded paint, rust, and rotting of wooden parts. All damaged parts should be replaced as soon as possible and painted surfaces should be restored.

Caution: All paint used must be approved by OEHS and be certified as meeting the NSF Standard 61. The paint shall not transfer any substance to the water which will be toxic or cause foul tastes or odors.

### *Operation Problems*

1. Too much dissolved oxygen (DO) can be added resulting in super-saturation which can cause corrosion of tanks and pipes, floating floc in clarifiers or sedimentation basins, and false clogging of filters. Monitoring of DO and temperature will alert the operator to this problem. As the temperature increases, the saturation concentration for oxygen in water decreases.
2. The growth of algae and slime on the aerators may occur during the summer months. These can be controlled by the addition of copper sulfate, chlorine, or other suitable chemicals.
3. Where diffusers are used, they can become partly clogged from dust, oil, debris, or chemical deposits. This can be prevented by cleaning air filters, not over-lubricating the blowers, and preventing the backflow of water into the diffusers. Diffusers should be cleaned according to the manufacturer's recommendations.

### **Adsorption**

Water contains various organic compounds which can cause color, tastes, and odors. The threat to public health also is a concern in regard to organic compounds, particularly those compounds created by the reaction of chlorine with certain organic compounds (mostly humic materials) and to certain man-made organic compounds such as insecticides, herbicides, and cleaning solvents.

The naturally occurring compounds enter the water supplies due to the decay of animal and vegetable matter on the watersheds of surface supplies. The insecticides and herbicides present in the runoff from agricultural land and the man-made compounds, frequently found in ground-water sources, are the result of accidental spills, discharges, and uncontrolled disposal. Organic chemicals can be partially removed by using chlorine or potassium permanganate to oxidize the compounds or by aeration, by coagulation/flocculation, by sedimentation, and by filtration; however, these processes cannot remove some organic compounds as efficiently as adsorption.

Adsorption is the use of activated carbon for organics removal. Activated carbon is created by heating carbon (usually bituminous or lignite coal) to very high temperatures in the presence of steam. This creates a very porous surface on the particles whose surfaces attract and hold organics. Once the surface of the particles is covered with organics, it loses its ability to adsorb and must be replaced with fresh carbon.

Activated carbon is available as powdered activated carbon (PAC) and granular activated carbon (GAC). PAC typically is added to the treatment process, usually as near the beginning as possible to provide the greatest contact time, and is removed by the filters to prevent carryover to the system. It usually is added only to the water for control of tastes and odors when necessary. GAC typically is used permanently in the treatment process as a filter material or as the media in GAC contactors for the removal of specific compounds such as trihalomethanes.

### **Powdered Activated Carbon (PAC)**

PAC is a very fine dusty material which must be stored and handled with care. This material normally is purchased in 50-lb. bags or, at very large installations, it may be purchased in bulk. The hopper of the dry chemical feeder should be equipped so a bag of carbon can be hung on the open door of the hopper. The top of the bag is slit and the door is closed causing the bag to empty inside the hopper controlling the dust. The dry chemical feeder drops the dry material, at an adjustable rate, into a mixing tank where it is mixed into a slurry with large amounts of water. This slurry should be conveyed to the point of application as quickly as possible to prevent the carbon material from settling out and clogging pipes or troughs.

The PAC should be applied to the raw water or the rapid mix basin if possible and always should be fed ahead of any chlorination, because the chlorine will diminish the effectiveness of the PAC and the PAC will diminish the effectiveness of the chlorine. If possible, prechlorination should be discontinued when feeding PAC.

#### *Start-up*

Before starting the feeding of PAC, the jar test should be done to determine the beginning dose rate, and the prechlorination should be discontinued. Starting would consist of filling the feeder hopper, starting the flow of water in the mixing chamber, starting the solution feed pump and/or opening valves, and setting the indicated dose rate.

#### *Normal Operations*

Normal operations would be to refill the feeder hopper as necessary, adjust the dose rate as indicated by subsequent threshold odor tests on the filter effluent, checking mixing chamber and pipes or troughs for clogging, and cleaning up any carbon dust.

#### *Monitoring*

Monitoring consists of the threshold odor test on the filter effluent, making visual observations of the presence of carbon in the water at various locations in the treatment process. For example, it is desirable for most carbon to be settled out before the filters. Changes in the coagulant dose rate usually can correct this problem. The filters should be watched for shorter than normal filter runs since the PAC will cake on the surface of the filter or can penetrate through the filters. An effluent sample should be filtered through a membrane filter paper. If PAC is present, it will darken the filter paper surface. The free available chlorine residual in the plant effluent water must be monitored carefully since the PAC will reduce the effectiveness of the chlorine.

#### *Records*

Record keeping can provide a guideline for treatment of similar occurrences in the future, particularly for taste and odor problems. A record should include the dates of the occurrence, a description (i.e., "fishy", "septic", "musty", etc.), the treatment changes made, the jar test results, and the amount of PAC fed.

#### *Maintenance*

Maintenance of PAC feeding equipment is routine clean-up of carbon dust, and clearing of any caking or clogging in hoppers, mixing tanks, lines, or troughs. Routine maintenance of the chemical feeder, the mixer, and the solution pump should be in accordance with the manufacturer's recommendations. All electric motors and switches should be frequently cleaned on the outside. All electric equipment should be explosion-proof, so there should be no unnecessary opening of switch and terminal boxes.

### *Operating Problems*

The dust from the fine powder is a fire hazard. The black carbon is hard to remove from clothes and skin. Also, PAC can pass through the filters and enter the distribution system causing "black water" complaints from customers.

### **Granular Activated Carbon (GAC)**

Granular activated carbon has larger particles and typically is used when carbon is required continually to remove organic compounds. GAC is used like a filter material either in conventional filters or in GAC contactors when a greater depth of carbon is required to provide additional contact time necessary to remove certain organic compounds. GAC normally is purchased in bulk and is placed in the filters or contactors in a slurry form using an eductor system to move the slurry and reduce the dust.

The length of time the carbon is effective in the removal of organics depends on the amount of organic compounds in the water and the depth or quantity of carbon. When the carbon loses its ability to adsorb, it must be removed and replaced with fresh carbon.

### *Start-up*

When conventional filters are converted to GAC media, the distance from the top of the media to backwash troughs should be recorded so the bed depth can be checked for loss of media. The backwash rates should be carefully established to prevent the loss of media. All other start-up procedures would be the same as a conventional filter. Carbon contactors are similar in operation to pressure filters and would have no special start-up procedures.

### *Normal Operations*

The normal operations of a GAC filter or a GAC contactor would be the same as a conventional filter.

### *Monitoring*

The operator would monitor the head loss and the turbidity of the effluent water and initiate the backwash procedures when required. The presence of specific organic compounds in the influent and effluent water should be tested a minimum of once per week to determine the remaining bed life of the media. The distance between the top of the wash water trough or some other predetermined reference point and the top of the carbon media should be measured and recorded at least every three months to determine the rate of carbon loss. A check of the backwash water also can indicate the loss of carbon.

GAC manufacturers also can recommend testing procedures to determine the condition of the media. Threshold odor tests should be conducted routinely on raw and finished water as a check on the effectiveness of the filter. Since bacteria are known to thrive in GAC filters, bacteriological examination of filter effluent and final chlorinated water should be taken daily.

### *Records*

In addition to the record keeping recommended for the filtration process, records of the results of the above recommended tests should be compiled so the operator is aware of the amount of carbon lost, the estimated remaining bed life of the carbon media, and the effectiveness of the treatment.

### *Operating Problems*

The same operating problems as filtration exist for the adsorption by GAC such as bed fouling by mud balls, heavy floc carryover, backwash rates, and filter breakthrough. With GAC filters the coagulation, flocculation, and the sedimentation processes must be operated for the highest reduction of suspended materials. Also, the filter flow rates must be kept uniform since fluctuations can cause filter breakthrough which will reduce the contact time with the carbon. Lastly, the backwash rates are critical since too low a rate will under-expand the bed and mud balls will form, and too high a rate will wash the carbon media out causing unnecessary loss of media. The water temperature also should be taken into account when setting the backwash rate since this can affect the percent of bed expansion.

## O&M PLAN FOR DISTRIBUTION

The distribution system includes the conveyance of water from the source to the customer including pumping, transmission mains, distribution mains, valves, fire hydrants, customer service lines, and distribution system storage. The operation and maintenance of a water distribution system is a separate function in the operation and maintenance of a water system.

The water must be delivered in the same potable, ready-to-drink condition that it left the treatment facility. To protect the water quality, the water distribution workers must at all times protect the water from any type of pollution or degradation.

### **Plans and Records**

#### *Distribution System Maps*

When water mains are installed, a plan of the pipe and fittings must be drawn to establish a record of the facilities installed. This information should be either added to the existing plans or a new plan should be started which would be referenced to the overall system plans. A system should be established for all distribution system plans so that they are of the same scale and fit together to cover the entire system.

The distribution plans become the records of the system showing the date installed, the work order or extension number, the material of the mains, the type of valve, the locations of the mains within the streets or rights-of-way, the location of services, fire hydrants, and valves.

#### *Locations of Pressure Zones*

On the system plans the normal operating pressures should be indicated at typical locations such as fire hydrants and customer services. These pressures are useful in comparing operating conditions when there is a suspected leak in the system.

Sometimes a water system must be divided into different pressure zones so that customers at higher locations have adequate pressures for the service they desire. Also, customers and the water system mains must be protected from excessively high pressures which could cause damage and break mains and customers' pipes. To establish these pressure zones, the water system may have booster pump stations which pump the water to a higher elevation or the water system may have pressure-reducing stations which reduce the high pressure to a lower, acceptable level. The pressure zones must be clearly marked on the system maps so that inadvertent flow between the zones does not occur. Also, all valves which should normally be closed to separate the zones should be clearly marked on the plans as normally closed.

A description of the operating procedures for each area of the distribution system including pumps, chlorinators, storage tanks and reservoirs, valves and pressure regulating valves should be included in the O&M Plan. This would describe how each part operates with the other parts of the system (i.e., what are the controlling conditions, how is the system monitored, and what records are maintained).

#### *Updating and Correcting Plans*

When additions or changes are made to the system, the plans should be updated and corrected. Initially, the field personnel such as the maintenance crew or the construction inspector make the changes in pencil on a working set of prints.

### *Production and Pumping Records*

A record of the amount of water produced, the chemicals used in treatment, and the water pumped should be kept for the system. These records provide a history of the operation and indicate the demands of the system and the costs of operation. A comparison of records can be used to identify suspected system problems such as increased pumping or treatment costs, or possible loss of water.

These reports should reflect the water taken from all sources of supply such as wells, streams, rivers, and lakes, or purchased from another supplier. The records should indicate the water in the system storage facilities so a daily system use can be developed. A system of keeping records on a month-to-date basis and a daily average use basis can be compared to previous years performance.

### **Distribution System Components**

#### *Transmission and Distribution Mains*

There are many materials used in transmission and distribution mains. Some of the more common are as follows:

1. Cast Iron - Cast iron pipe has been used for water systems for over a century. The older pipe usually had bell and spigot joints which used jute and lead to make a watertight joint. Because of the labor and skills needed to pour a lead joint, this type of pipe is no longer commonly used; however, sometimes repairs are made using poured lead joints. Another factor to consider is the potential for lead contamination in the water. The more modern joints for cast iron pipe and ductile iron pipe are rubber gasketed joints which provide a simple seal which can be easily installed.
2. Concrete - Concrete pipe has been used for transmission mains because of its long life. It normally is available only in larger diameters and is difficult to make connections. The joints are usually sealed with an O-ring rubber gasket.
3. Asbestos Cement - Asbestos cement pipe was used extensively from 1940 to 1980 as a less expensive material. This pipe can release asbestos fibers to the water if the water is aggressive.
4. PVC (Polyvinyl chloride) - PVC pipe is the less expensive substitute for the ductile iron pipe. This pipe is light in weight and easy to handle and join. It is subject to damage by exposure to sunlight and petroleum products will penetrate the pipe.

#### *Valves*

Several types of valves normally are used in transmission and distribution systems. Some are used for normal control and others have special purposes.

1. Gate Valves - Gate valves are the most commonly used valve in waterworks systems. In a gate valve, there are double discs which by turning the stem are moved downward into the stream of water. When the gates are at the bottom of their movement, a wedge is engaged which spreads the gates apart and forces them against the seats. By turning the stem in the opposite direction, the wedge pressure is released, allowing the gates to move away from the seats. Further turning of the stem raises the gates out of the stream of water to a fully opened position. These valves have proven to be reliable and

maintenance free. Maintenance should consist of periodically exercising the valve to keep the threads clear of buildup and checking the valve stem seals.

2. Butterfly Valves - Butterfly valves frequently are used for the regulation of flow. They have a wafer which rotates in the water stream from fully open to fully closed. The wafer usually has a rubber gasket on its sealing edge. Maintenance consists of replacement of the gasket when it becomes worn.

3. Check Valves - Check valves are used to control the flow in only one direction. This is normally done by having a hinged flapper which the flow of water will move out of the water flow area. When the flow of water attempts to reverse, the flapper is returned across the flow on to the valve seat stopping the flow. The movement of the flapper is caused by the reverse flow of water, exterior springs, or gravity. There are other configurations of check valves which are designed for special purposes.

4. Pressure Relief Valves - Pressure relief valves are used to bleed off a flow of water and relieve a high pressure surge condition. Surges of water, such as from the start-up of a pump, can cause high pressures which could damage pipe and facilities. The pressure relief valve usually is kept closed by a spring pushing against the valve disc. The surge of high pressure overcomes the spring, releasing water. As the pressure is lowered to normal, the spring forces the disc closed.

5. Pressure Reducing or Pressure Regulating Valves - These valves normally are used to maintain a specific pressure on the downstream side of the valve. This action is accomplished by a diaphragm which controls the position of the valve disc. As the pressure on the downstream side drops, the diaphragm opens the disc to allow an increase in the flow of water. As the pressure increases on the downstream side, the diaphragm closes the disc, reducing the flow of water. These valves, because of their constant movement, require frequent maintenance to keep them working and in adjustment. The items needing attention are the strainers, needle valves, pilot valves, and the main diaphragm. These valves frequently are used to control the pressures in various sections of the distribution system.

6. Air Relief Valves - Air can cause serious pipeline problems by restricting the flow. Air can get into the water system through pumps, packing glands, and leaking joints. These valves are installed at the high points on the system and are simple float valves which release air until the water enters the valve body and raises the float.

7. Plug or Ball Valves - This type of valve normally is used on customer service lines and consists of a tapered plug or ball which has an orifice the full size of the water stream. When fully open, the orifice is in line with the water stream and, when fully closed, the orifice is at right angles to the water stream and the sides of the plug or ball completely stop the water flow. These valves are maintenance free and cause little flow resistance when fully open.

8. Globe Valves - Globe valves cause the water to flow up through an orifice. These valves rarely are used in waterworks systems due to their resistance to flow and high maintenance requirements.

9. Altitude Valves - Altitude valves are used to control the height of water in distribution storage tanks. These valves open when the system pressure drops and water flows out of the tank. When the system pressure increases, the water flows into the tank until the tank is nearly full. The altitude valve then closes. This valve is very similar in operation and maintenance to a pressure reducing valve. Maintenance consists of checking the strainers, diaphragms, small piping, and needle valves.

### *Fire Hydrants*

Fire hydrants are used to provide access to the water system by fire fighting personnel. Fire hydrants have an underground valve and a barrel to deliver the water to hose nozzles above the ground. In cold climates, fire hydrants of the dry barrel type are used because of the danger of freezing. Dry barrel hydrants are designed to automatically drain the water from the barrel when the hydrant is shut off. The hydrant nozzles are usually 2 ½-inch diameter "steamers" and 4 ½-inch diameter "pumpers". Fire hydrants usually are manufactured so maintenance of the valve can be accomplished without excavation. All fire hydrants should be equipped with a gate valve on the lateral pipe leading from the water main. This valve will permit the water distribution crews to shut off the hydrant which is damaged or is malfunctioning. Fire hydrants should be flushed and checked at least semiannually for proper operation, particularly that they shut off completely and that the barrel drains.

Fire hydrants should be flushed and checked at least semi-annually for proper operation and for the following items:

- Complete shut off;
- Smooth and ease of operation;
- External parts (i.e., paint, caps, chains); and,
- Hydrant drain (does barrel drain completely).

Flushing the hydrant also helps to clear any sediment from the distribution system. Fire hydrants require frequent maintenance because they are frequently operated, often by untrained personnel. The parts which often need attention are the valve seats, which are resilient rubber; the valve stem packing, which will leak; and the stems, which become twisted due to turning too hard to shut off.

A cooperative effort between the fire fighting personnel and the water system will help reduce hydrant damage and effect prompt repairs when needed. If a hydrant is taken out of service for repairs, the local fire company or municipality should be given notification. A record book should be kept specifically for hydrants taken out of service. It should contain information on the date the hydrant was taken out of service, the time, the hydrant number and location, the municipality, the employee's name who took it out of service, the name of the person from the municipality who was notified, the date returned to service, the time, and the person notified.

### *Blow-offs*

Blow-offs area tee and valve arrangement at locations where fire hydrants do not adequately flush the system. These are usually dead ends or at locations which, due to topography, require frequent flushing such as at low points. These blow-offs must have their flow directed so that no damage occurs. The blow-offs must be located deep enough to prevent freezing and the discharge pipe should be drilled to permit draining.

### *Records*

Records of the locations of all valves, fire hydrants, and blow-offs must be indicated on the system plans. Records of the operation and any maintenance performed must be kept. This information is useful in planning replacement of facilities due to age.

A schedule and scheme for flushing the distribution system should be developed and included in the O&M Plan. The schedule should be at least semi-annual and the scheme should provide for flushing the system from the source towards the extremities of the system.

Schedules should be developed for the following:

- Valve exercising, maintenance, and replacement;
- Fire hydrant flushing, inspection, maintenance, and replacement;
- Meter testing and replacement (includes master meters);
- Main replacements; and,
- Cleaning and inspection of distribution storage facilities including cathodic protection equipment;

### **Pumps**

Pumps are used in water systems to move water or other solutions from one location to another and to add pressure to the water by pumping it to a higher elevation. The common uses of pumps in water systems are well pumps, raw water pumps, chemical feed pumps, backwash pumps, high service pumps, booster pumps, and fire service pumps.

#### *Types of Pumps*

Centrifugal pumps are the most common type of pump used in water systems. These pumps have the ability to adjust to varying head and flow conditions and are available in a wide variety of configurations manufactured to meet specific conditions. The other type of pump used is the positive displacement pump which is used for feeding chemicals. These are either diaphragm type or piston type which delivers a measured volume with each revolution or cycle.

#### *Capacities and Purposes*

The capacities (flow and head) of each type of pump should be matched to its purpose. The capacity of each pump should have been specifically selected when the design of the system or the component was done by the engineer. However, as system components and uses change, so do the capacities and operating conditions for pumps.

Therefore, the water system operator should know the flow and head (pressure) the pump was selected for and should periodically test the pumping unit for the present operating conditions. The operator should plot the results of the pump tests on the pump operating curve to determine if the operating point has changed from the design conditions and what the expected efficiency should be.

#### 1. Well Pumps

Well pumps are usually of a vertical turbine configuration and have multiple stages. However, the small water systems that use low capacity wells are usually equipped with submersible pumps. The well pumps can be driven by a shaft extending down the column from a motor located on the surface or by a submersible motor attached directly on the pump and suspended in the well on the end of the column pipe. Well pumps should have their capacity matched to the capacity of the well so that the well is not overpumped,

causing excessive drawdown of the aquifer which can cause a deterioration of the water quality. If the water is lowered to a level near the pump impellers, the pump also can be damaged. The capacity of the pump (flow and head) would have been selected at the time the well initially was pump tested and put in service. As the pumping level would lower due to depletion of the aquifer, the head would increase and the flow would decrease. The operator should be aware of the original conditions and should monitor the pumping water level in the well through the use of an air line or level sensing equipment.

## 2. Raw Water Pumps

Raw water pumps are used to transfer water from the stream or lake to the treatment facilities. These are usually vertical pumps with an open impeller so they will pump some small pieces of debris. These usually are low head and high capacity. Because these pumps are pumping raw water which contains grit and debris, they are subject to wear which will reduce their capacity. These pumps should be tested periodically for capacity and their efficiencies checked on the pump curve.

## 3. Chemical Feed Pumps

Chemical feed pumps usually are positive displacement type; however, they can be centrifugal. Since these pumps are comparatively small compared to other pumps and motors, operating efficiency is not usually a consideration for these pumps. Chemical feed pumps must reliably deliver specific volumes of solutions at required pressures; any failures could affect the treatment process. For this reason, the water supplier should have spare pumps and parts for repairs available.

## 4. Backwash Pumps

Backwash pumps are used to pump finished (potable) water back through the filter bottoms to clean the filter media. These pumps are centrifugal pumps of high capacity and low head. Backwash pumps have only a limited amount of use and pump clean water; therefore, maintenance problems should be very few.

## 5. High Service Pumps

High service pumps deliver the finished (potable) water from the clearwell to the transmission distribution system. These pumps are usually high capacity and high head. There should be at least duplicate units for reliability. The capacity of these pumps should be equal to the total capacity of the treatment facilities; however, at larger facilities the pumps may be of various capacities so combinations of pumps may be used for operational flexibility. The water pumped is clean and clear and should not produce any excessive wear on the pump parts. These pumps run for long periods of time; therefore, maintenance of bearings and shaft seals is important. The alignment between the pump and the motor also should be checked since misalignment can cause excessive wear on the pump and motor bearings.

## 6. Booster Pumps

Booster pumps are the same type of service as high service pumps except they usually are located at various points in the distribution system to pump water to higher pressure zones. The operation and maintenance of these pumps would be the same as high service pumps.

## 7. Fire Service Pumps

Fire service pumps are the same as high service pumps or booster pumps except these pumps are set with automatic controls to turn on to meet the specific requirements of a large fire flow. These pumps are of high capacity and have only occasional use. The maintenance of these pumps must include checking the controls and actually operating the pumps to verify their reliability of service. All other maintenance is the same as a high service pump.

#### *Reports of Operations and Maintenance*

A record of the hours of operation for each pumping unit should be maintained. This record can be used for planning preventive maintenance of the units. A record of the maintenance and the cost of repairs will help to evaluate the units when they are being considered for repair/rebuilding or replacement.

#### *Monitoring of Pumping Operations*

There are many monitoring and control systems for pumping systems. These vary from very simple manual operation to complete automation.

The following are examples of typical monitoring and control systems:

1. The simplest system would be a manual on/off switch with an indicating pressure gauge and a water meter. This is typical of many small systems with a well, distribution system, and a tank. The operator usually knows the system very well and can adjust the pumping according to the system pressure.
2. A system with a tank level recorder, a pressure recorder, and a flow recorder with automatic pump operation turning the pump on at low tank level and off at nearly full would provide the operator with records and reliability of operation.
3. Where there are various pressure zones on a distribution system, the operation of booster pumps is used to transfer water from one part of the system to another. This type of system requires careful monitoring and usually automatic controls. The information on the operating conditions (tank levels, system pressures, pump flows) must be transmitted to an operations control center so the operator can make decisions which will be best for the entire system. There are electronic systems that review all system parameters on a frequent basis and report the data in a usable form at a central point. These systems also collect data for records and reports and, through the use of a computer, can make operating decisions on the system.
4. In the treatment process there should be monitoring systems in place to control the operation of the pumps. These can be simple visual observance of levels in the tanks or float level controls which indicate levels or can control the raw water pumps. There also are interlocking controls which will stop the pump operation if the water pressure on the suction side of the pump drops below a predetermined value. Another type of interlock is to shut off the pump if the discharge pressure exceeds a predetermined value. There are continuous monitors for turbidity and chlorine residuals which have the capability of interrupting the pumping operation when certain values are exceeded or not met.

## **Distribution Storage Facilities**

Distribution storage facilities can be in-ground earthen, concrete, brick, or steel reservoirs, above ground steel or concrete tanks; or standpipe or elevated tanks. All these storage facilities are used to store treated water for use in the distribution system.

Distribution storage has several purposes such as to provide sufficient water for peak demands which may exceed the pumping capacity, to supply large volumes of fire protection water, and to provide reliability when pumps must be removed from service for maintenance.

### *Types of Reservoirs and Tanks*

- Ground Reservoirs can be concrete, brick, or steel construction at ground level or below ground. Some typical installations are of concrete, masonry, or brick construction. These reservoirs must be properly constructed to prevent potential entry of any contaminants.
- Ground Level Storage Tanks have a diameter greater than the height and are constructed of steel or concrete.
- Standpipes are steel cylinders where the height exceeds the diameter. This tank can hold large amounts of water; however, the pressure does vary depending on the amount of water in the tank.
- Elevated Storage Tanks are steel construction elevated on legs or a pedestal. The elevation of the storage capacity makes all of the capacity available at a usable pressure.

### *Maintenance*

Maintenance of distribution storage reservoirs will depend on the type of material used for construction. All distribution storage facilities should be drained, cleaned, and inspected annually.

The paint system should be inspected for damage, possibly due to ice, and the vent screens should be inspected and repaired to prevent birds and rodents from entering. After cleaning, the interior of the tank or reservoir must be disinfected as required by the Rules for Safe Drinking Water, Chapter 391-3-5. The disinfection should be accomplished in accordance with the procedures outlined in the EPD's Minimum Standards for PWSs.

Steel reservoirs should be painted inside and out with an acceptable paint system. The paint system used on the interior surface of the tank must be certified as meeting the NSF Standard 61 and must be acceptable to EPD. Some types of paint can transfer substances to the water which may be toxic or can cause foul tastes and odors in the water.

The paint system will protect the steel structure from deterioration and, thus, extend its useful life. A good paint system should last from eight to 15 years. The atmospheric conditions in the area can have an effect on the life of the paint system. For example, the paint will have a shorter life in industrial areas, and a longer life in rural areas.

Metal tanks are subject to corrosion from unstable water which can shorten the effective life of the paint system and attack the metal. The corrosion is caused by stray electrical currents, which are created by electrochemical reactions and the grounding of electrical systems. A cathodic

protection system introduces a direct current into the corrosion cycle to offset and cancel out the corrosion-producing action.

Cathodic protection systems use an auxiliary anode of expendable metal which is immersed in the water. Electrical current flowing from the anode to the structure can counteract corrosion losses. Cathodic protection systems require at least annual scheduled maintenance by qualified technical personnel to check the condition of the sacrificial anodes and the wiring connections.

Sacrificial anodes are pieces of metal (transition metals, like magnesium and zinc) more electrically active than the steel piping system. Because these anodes are more active, the corrosive current will exit from them rather than the piping system. Thus, the system is protected while the attached anode is “sacrificed.”

Concrete tanks can be treated with a waterproofing system which will seal the surface cracks and stop any leakage and extend the life of the structure. Any coating system that is used must be approved by EPD. It is required that all products that come into contact with the drinking water must be certified as meeting the NSF Standard 61.

Ground reservoirs should be lined and covered to prevent leakage and contamination. The most common material for this purpose is a rubberized fabric. The structure should be checked for any deterioration, growth of weeds in cracks, etc., and the fabric cover should be checked for damage. These should be checked in the spring of the year since the winter ice can damage the fabric. The rain water, leaves, and debris should be removed periodically from the surface.

#### *Safety Protection*

Access to water system storage facilities can be a safety hazard. Proper precautions must be taken to protect the public and the employees from injury.

- Where open storage reservoirs exist, there is the danger of someone falling into the water and drowning. All facilities such as this should be securely fenced to prevent unauthorized entrance. All employees working around these facilities should use life vests or other flotation devices.
- All ladders on steel storage tanks should terminate at a safe distance above ground, be caged, and have a locked gate to prevent access by unauthorized personnel. All ladders should be caged for their full height or a safety harness should be provided.
- No entrance to a tank should be made by any personnel without first checking for dangerous vapors, fumes, or gases. Also, do not enter a tank without a safety harness and rope tended by a fellow employee from the outside of the tank.
- Fences around all storage facilities are recommended to prevent unauthorized access and possible vandalism.

#### *Records*

A record should be kept of the following:

1. The location, year built and by whom, elevation at the base of the tank and the top of the overflow pipe, the size of the diameter and the height, and the capacity in gallons;
2. Painting records of the interior and exterior showing the year painted, type of paint, and the square area for painting. This information will be useful when setting painting budgets;
3. Altitude Valve Records - The type and size of the altitude valve should be noted, along with the type and number of the leathers needed to make repairs, the date repairs were made, and any parts that were used.

### **Unaccounted-for Water**

Unaccounted-for water is water which is produced but is not used or sold to the consumers. There are many factors which are considered in the determination of the percentage of unaccounted-for water. This percentage is a measure of the efficiency of the system operation.

Factors to consider in the determination of the unaccounted-for water are:

- The water produced - Is this quantity accurately determined, has the meter been calibrated, does the meter measure all of the water?
- The water used for water system purposes such as chemical feed water, filter backwash water, fire hydrant and blow-off flushing - How is each of these uses measured? Careful accounting in the treatment plant is necessary because, in some plants, plant use water is used before the master meter and, in other plants or for other uses, it is used after the master meter.
- The water sold or used by the consumer must be accurately accounted for. A meter testing program should be in place to periodically test the accuracy of the meters. All consumer use must be accounted for. For example, free water may be provided for parks, cemeteries, or municipal purposes at sewage treatment plants, borough buildings, and fire companies. All of this water must be measured and accounted for.
- Water used for fire fighting purposes – This water only can be estimated, but some careful calculations by the fire company and the water system can develop a reasonable value.

The basic calculation is:

The water available for sale is the water produced adjusted for the company uses of water as follows:

- Subtract any plant use water that is taken off the system after the master meter;
- Subtract any water used on the distribution system for flushing fire hydrants and blowoffs, and for fire protection.

The water sold or used is the total quantity of water sold to customers through meters plus an estimate of all unmetered uses either to flat rate customers or for public purposes.

When making the calculation, the time interval must be considered since the amount of water sold only may be determined monthly, quarterly, or annually, and usually all

meters are not read on the same day or at the same time. It is recommended that a one year (four quarters or 12 months) period be considered since this will level off the variables for meter reading, and seasonal variations. This calculation can be made on a monthly basis by using the totals for the previous 12 months,

The normal operating range should not exceed 10 percent for a well maintained system. However, keep in mind that there are many factors that influence the percent of unaccounted-for water in a particular system. A number of these factors are:

- The age and condition of the system. A very old water system which has deteriorated pipe will have many undetected leaks at joints and pinholes. Although the goal may be the 10 percent, it can only be accomplished by replacing large segments of the system. A range of 35 to 40 percent may not be unusual until funds for replacement of mains is available;
- The pressure in the system can affect the rate of leakage. Thus, high pressure systems may have a higher percentage of unaccounted-for water;
- The number of customers per mile of main can affect the unaccounted-for water. Therefore, if a system has a high ratio of miles of pipeline to the number of customers, the percentage of unaccounted-for water will increase;
- Under-registration of customer meters or unauthorized use can increase the percentage of unaccounted-for water.

### **Control of Unaccounted-for Water**

To reduce the percentage of unaccounted-for water, the following are suggested actions:

1. Calculate the cost of producing a thousand gallons or one hundred cubic feet of water and then calculate the amount of money which is being "lost" as unaccounted-for water each month. By identifying this cost, you can justify the cost of the programs to correct the problem;
2. A meter testing program should be installed to test the master meter and other system meters at least annually and to test all customer meters (on a continuing basis) at least every 20 years;
3. An adequate leakage control program:
  - A program of listening to all fire hydrant valves and services to detect leaks,
  - The use of detector type meters on fire lines,
  - Training of meter readers and service personnel to listen for leaks and to detect unauthorized use of water,
  - Review of meter readings to detect stopped meters or obvious under-registering meters;
4. A record of leaks repaired and the estimated amount of water lost at each leak can help to justify replacement of sections of mains which have a high incidence of leakage.

### **Maintenance of Water Mains and Services**

The maintenance of water mains and services, in addition to the routine preventive maintenance of valves and fire hydrants, involves the repair of leaks and the thawing of frozen water mains

and services. A description of the normal procedures should be included in the O&M Plan. The description should include a list of the staff, equipment, and materials normally available for this work, and where you can obtain help such as contractors and suppliers. You also should detail the notifications which are required such as utility locations and sensitive customers (i.e., hospitals, nursing homes, industries, fire companies, and police). You also should consider public notification through the news media for shutdowns of large areas or door-to-door notification for smaller areas.

### *Customer Complaints*

Customer complaints are the normal indication that there is a problem in the distribution system. A record of customer complaints can help the water system identify and locate the problem. As an example, there may be a water system leak which will not surface. A number of low pressure and dirty water complaints in an area can indicate the area where a leak survey should begin. Another use for records of customer complaints is the justification for replacement of facilities. For example, a large number of complaints of dirty water on a dead end main may be justification to loop the main into another part of the system.

### *Water Main Repairs*

The repair of water mains and services can be a very complex operation depending upon the conditions found in the field.

1. The location of water main and service leaks can be a major task since many times the water is flowing into underground passages or into sewers and does not surface. Locating the leaks involves a leak survey using sensitive listening equipment. Sometimes the drilling of holes in the pavement over the line of the water main will reveal the location. In some cases, exploratory excavation is necessary to find the exact location of the leak.
2. Once the leak is exposed, the water should be shut down so a detailed examination of the pipe, fittings, or services can be made to determine the extent of the damage. Frequently, the force of the leaking water causes additional damage to adjacent facilities. Because of the water leak, the earth in the trench frequently is saturated with water and unstable. The workmen should exercise extreme caution and install shoring and bracing as necessary since frequent cave-ins occur.
3. Once the extent of the damage is determined, a method of repair must be selected. This may involve a simple repair clamp or may involve the replacement of lengths of pipe, fittings, and valves.
4. The system operator must consider the area to be affected by the shutdown; the personnel, equipment, and materials required; and the amount of time necessary to complete the repair. Sometimes a temporary repair will permit proper planning and gathering of equipment and materials to effect a proper permanent repair with the minimum amount of customer inconvenience.
5. During the repair of the water main, the existing main and the repair materials can become contaminated. Before returning the facilities to service, the facilities must be disinfected, as required by the Rules for Safe Drinking Water, Chapter 391-3-5, and in accordance with the procedures established by the EPD's Minimum Standards for PWSs.

6. After the repair of the water main, proper support and thrust blocking of the facilities must be provided. Any bends, tees, or end caps must have a thrust block to prevent movement due to water pressure. Because the surrounding earth usually is saturated with water and unstable, it should be removed and replaced with crushed stone or other suitable material. Care should be taken to tamp the crushed stone under the pipe to provide a good solid support. Heavy fittings and valves should be supported on concrete blocks to prevent settlement. The proper backfill of the trench including tamping will minimize the future maintenance of the excavated area.

7. The backfill material and the surface restoration may be specified by the municipality or the West Virginia DOT. A street or highway excavation permit may be required prior to any construction.

8. Upon completion of all repairs and restoration, a record should be made to document what was done. This record can establish the cost of repairs and provide justification for replacement of old and deteriorated facilities. This record can establish the prompt repair and proper notifications of the shutdown.

#### *Thawing of Frozen Mains and Services*

When water mains and services freeze because they are installed at too shallow a depth or because some of the original cover was removed after initial installation, they must be thawed to restore service. Frequently the freezing exerts sufficient internal pressure to break the pipe and after thawing, the main or service must be repaired.

The electrical thawing of frozen mains and services can be performed by special generators or welders; however, there is a danger of damage to customers' homes and electrical appliances and the possibility of causing a fire. For these reasons, the procedures for connecting the wires and disconnecting the customer's meter and any electrical connections must be detailed to limit the possibility of damage and liability for the water system.

Water mains and services can also be thawed by use of steam generating equipment; however, this requires excavation or access to the facilities. These procedures also should be detailed to prevent injury.

## **BIOFILMS**

While water treatment and disinfection systems can remove most of the bacteria found in raw water, the water produced is not sterile, and low levels of bacteria do persist even in properly treated supplies. Bacterial growth in the drinking water distribution system makes monitoring for bacterial quality in the distribution system difficult, hiding significant bacterial contamination introduced after treatment via cross connections, pipe breaks, or backsiphonage. Growths of bacteria on pipe walls, called biofilms, also can provide a haven for potentially pathogenic (disease-causing) bacteria.

Biofilms are formed in distribution system pipelines when microbial cells attach to pipe surfaces and multiply to form a film or slime layer on the pipe. Probably within seconds of entering the piping system, large particles, including microorganisms, adsorb to the clean pipe surface. Some microorganisms can adhere directly to the pipe surface via appendages that extend from the cell membrane; other bacteria form a capsular material of extracellular polysaccharides (EPS), sometimes called a glycocalyx, that anchors the bacteria to the pipe surface. The organisms take advantage of the macromolecules attached to the pipe surface for protection and nourishment. The water flowing past carries nutrients (carbon-containing molecules, as well as other elements) that are essential for the organisms' survival and growth.

Biofilms are dynamic microenvironments, encompassing processes such as metabolism, growth, and product formation, and finally detachment, erosion, or "sloughing" of the biofilm from the surface. The rate of biofilm formation depends on the physicochemical (chemical, thermodynamic) properties of the interface, the physical roughness of the surface, and physiological factors of the attached microorganisms. Sheer forces generated by fluid velocity and possible effects of disinfectants on EPS may be important in the release of biofilms from surfaces. The biofilm may grow until the surface layers begin to slough off into the water. The pieces of biofilm released into the water may continue to provide protection for the organisms until they can colonize a new section of the distribution system.

The factors that lead to biofilm growth:

- Organic materials and sediment accumulate in distribution pipes;
- Disinfectant residuals dissipate;
- Water temperatures increase;
- Environmental factors (e.g., pH, temperature, and rainfall);
- Nutrient availability;
- Presence and effectiveness of disinfectant residuals;
- Internal corrosion and sediment accumulation; and
- Hydraulic effects.

A maintenance program for the distribution system is central to controlling and preventing biofilm growth. However, routine systematic flushing, a primary component of distribution system maintenance, is frequently neglected due to a need to cut costs or lack of personnel. Regular flushing helps to distribute the disinfectant residual to all portions of the system and scour existing biofilms. More aggressive cleaning, using cabledrawn or water-propelled devices (pigging), may be necessary when corrosion tuberculation is severe.

One of the first steps that utilities usually take to control bacterial problems is to increase disinfectant residuals. The disinfectant chosen to control bacteria originating from distribution

system pipe surfaces must be evaluated carefully, however. The problem requires a disinfectant capable of penetrating the biofilm and inactivating attached microorganisms. The disinfectant also must be relatively stable to be able to persist in the distribution system. In addition, it must be potable and not produce hazardous by-products. Removal of compounds that use up the disinfectant through selection of appropriate treatment practices, pipe relining, or main replacement-or all three-can help maintain a disinfectant residual. In the end, a more stable alternative to free chlorine residual (e.g., chloramines) may be needed to help control bacterial growths. Note, however, that for first-stage disinfection of pathogenic organisms in the treatment system, chloramines are not recommended unless the utility can demonstrate adequate inactivation of *Giardia* and viruses.

Resolving bacterial problems in situations where disinfection residuals are low is straightforward: The system is flushed and disinfectant applied so that a residual is maintained in all parts of the distribution system. In some cases, rechlorination facilities may help boost disinfectant residuals. In many cases, this can resolve the problem.

## **O&M OF LABORATORY EQUIPMENT**

In a water treatment plant laboratory, fragile laboratory equipment and delicate instruments are used to detect and precisely measure very small concentrations of contaminants. Therefore, the proper maintenance and operation of the laboratory equipment and instruments is critical. The proper maintenance techniques vary between pieces of equipment which perform the same analyses but are supplied by different manufacturers. As a result, it is important to keep copies of the manufacturers' routine maintenance recommendations and operating manuals for the laboratory equipment in the O&M Plan and to follow these guidelines closely.

This section will outline some general maintenance and calibration procedures for the more widely-used pieces of laboratory equipment and instruments; however, the manufacturers' recommendations should always be referred to first. Recommended laboratory safety equipment will also be discussed. The routine maintenance plan for the water system should include a routine maintenance schedule for the laboratory equipment. The following information may be incorporated into the maintenance schedule.

### **Glassware**

The following procedures should be used in the care and maintenance of lab glassware:

- Glassware should be examined with each use. Items with chipped edges or etched inner surfaces should be discarded. Chipped edges can cut hands, while scratches in the glass decrease visibility through it, possibly resulting in inaccurate analyses.
- Glassware should be cleaned as soon as possible after use to avoid the formation of stains. Do not allow dissolved matter to dry on glassware because future tests may be contaminated if glassware is not cleaned promptly after use.
- Good cleaning procedure involves a thorough washing and two rinses.

### **Laboratory Support Equipment**

#### **Hot Plate**

- The heating surface should be cleaned after each use to avoid a buildup of stains and residue;
- Perform routine maintenance as recommended by the manufacturer.

#### **Magnetic Stirrer**

- After every use, the surface of the stirrer should be wiped clean. The stirring bar also should be thoroughly cleaned before and after use;
- Routine maintenance should be performed according to the manufacturer's instructions.

### **Analytical Balance**

Some of the precautions to be observed in maintaining and prolonging the dependable life of an analytical balance are as follows:

- The balance should be mounted on a heavy, shockproof table, preferably one with an adequate working surface and a suitable drawer for storage of balance accessories. Balance level should be checked frequently and adjusted when necessary;

- Balances should be located away from laboratory traffic and protected from sudden drafts and humidity changes;
- Balance temperatures should be equilibrated with room temperature, especially if building heat is shut off or reduced during nonworking hours;
- When not in use, the beam should be raised from the knife edge, the weights returned to the beam, objects such as weighing dish removed from the pan, and the slide door closed;
- Special precautions should be taken to avoid spillage of corrosive chemicals on the pan or inside the balance case and the interior of the balance housing should be kept scrupulously clean;
- Balances should be checked and adjusted periodically by a service man or balance consultant. If service is not available locally, follow the manufacturer's instructions as closely as possible;
- Operate the balance according to the manufacturer's instructions at all times;
- The balance should be wiped with a soft brush before and after each use. Balance pans should be cleaned after each use and spills should be wiped up immediately;
- Weights should be checked against certified weights monthly to assure balance accuracy.

### **Jar Test Apparatus**

Because even the smallest detail can influence the result of a jar test and all samples in a series of tests should be handled as nearly alike as possible, proper maintenance of equipment is necessary to assure good operation.

### **Stirring Machine**

The stirring machine has three to six paddles, each capable of operating at variable speeds from 0 to 100 rpm. Maintenance of the stirring equipment should be performed on a regular basis as recommended by the manufacturer. The stirring machine should be kept clean and lubricated (according to manufacturer's instructions) so that smooth revolution of the paddles at the specified speed may be assured. Also, the rotation speeds should be checked periodically to ensure that all paddles are rotating at uniform speeds.

### **Floc Illuminator**

Located at the base of the stirrer, the floc illuminator enables observation of small floc particles. Care should be taken to keep the glass clean. The lamp should be checked routinely and replaced when needed. A replacement lamp should be kept on hand for this purpose.

### **Beakers**

The six 1,500 ml beakers should be washed and rinsed after each test. Prior to starting a test, the beakers should be rinsed with tap water and turned upside-down for a few minutes to drain.

### **pH Meter**

The pH meter consists of a sensitive voltmeter, a glass electrode, a reference electrode (made of either calomel or a silver/silver-chloride (Ag/AgCl) compound), and a temperature compensating device. In some units, the two electrodes are mounted in a single unit called a combined electrode. When the electrodes are immersed in the test solution, a circuit is completed through the voltmeter. The meter then converts the voltage change caused by the change in pH to a meter reading expressed in pH units. The temperature compensating device is needed because the pH of a sample is affected by temperature.

Some precautions to be taken in the care and maintenance of the pH meter are:

- Glass electrodes should not be allowed to become dry during periods of inactivity. Follow the manufacturer's instructions for the storage of electrodes, since recommended solutions for short-term storage of electrodes vary with the type of electrode and the manufacturer. Generally, tap water is a better substitute than distilled water, but pH 7 buffer is best for the single glass electrode. Saturated KCl (potassium chloride) solution is preferred for calomel and Ag/AgCl reference electrodes;
- Keep the pH electrodes free of oil, grease, or precipitates. These materials coat the pH electrode and may interfere with pH readings by causing a sluggish response;
- Electrode troubles generally can be traced to a clogged junction which can be cleared by applying suction to the tip or by boiling the tip in distilled water until the electrolyte flows freely when suction is applied to the tip or pressure is applied to the fill hole.
- The electrode may have a crystal buildup and should be flushed with distilled water and refilled with proper solution.
- Routine maintenance should be performed in accordance with the manufacturer's instructions.

Proper calibration (standardization) is essential for accurate pH measurements. The purpose of standardization is to adjust the response of the glass electrode to the instrument. When only occasional pH measurements are made, the instrument should be standardized before each measurement. When frequent measurements are made and the instrument is stable, standardize daily. If sample pH values vary widely standardize for each sample with a buffer having a pH within 1 to 2 pH units of the sample. Calibrate the electrode system against standard buffer solutions of known pH.

Because buffer solutions may deteriorate as a result of mold growth or contamination, prepare fresh solutions daily or when only occasional pH measurements are made, the instrument should be standardized before each measurement. When calibrating the pH meter, the following method should be used:

- Before use, remove electrodes from the storage solution, rinse with distilled water, and blot dry;
- Place the electrodes in the initial buffer solution with a known pH, set the meter scale or needle to the pH of the buffer, and adjust for temperature;
- Select a second buffer and bring sample and buffer to the same temperature;
- Remove the electrodes from the first buffer, rinse thoroughly with distilled water, blot dry, and immerse in the second buffer;
- Record the temperature of measurement and adjust the temperature dial on the meter so that the meter indicates the pH value of the buffer at the test temperature;
- Remove the electrodes from the second buffer, rinse thoroughly with distilled water, blot dry and immerse in a third buffer;
- The reading should be within 0.1 pH unit for the pH of the third buffer. If it is not, then look for trouble with the electrodes or potentiometer. Failure to obtain a correct value for the pH of the third reference buffer solution could indicate a cracked glass electrode, failure to maintain the KCl in the calomel electrode, or oily substances or precipitate coating the surface.

### **Specific Ion Meter**

The unit consists of a millivolt meter and interchangeable electrodes. Each electrode is selectively sensitive to one particular constituent of the water and each specific ion test requires a different electrode. A pH meter with an expanded millivolt scale also can be used with the specific ion electrode.

#### Maintenance

- Routine maintenance should be performed according to the manufacturer's recommendations;
- When a selective ion probe appears to be malfunctioning, the trouble generally can be traced to a clogged junction which can be cleared by applying suction to the tip or by boiling the tip in distilled water until the electrolyte flows freely when suction is applied to the tip or pressure is applied to the fill hole;
- The electrodes should not be allowed to become dry during periods of nonuse and should be stored according to the manufacturer's instructions.
- The manufacturer's instructions should be followed for refilling the probe assembly with the appropriate solution.

#### Calibration

- When using the selective ion meter (or expanded scale pH meter), frequently recalibrate the electrode by checking the potential reading of the standard and adjust the calibration control.
- Always use manufacturer's instructions to calibrate the instrument.
- Commercial standards, often already diluted with buffer, are frequently supplied with the meter. The shelf-life of each standard which should be provided by the manufacturer should be checked and the solution discarded when the shelf-life has been exceeded. The stated concentrations of these standards should be verified by comparing them with standards prepared by the analyst for each ion to be analyzed.
- Recalibrate the meter after reading each unknown and also after reading each standard when preparing the standard curve.

### **Turbidimeter**

The turbidimeter measures the clarity of water by measuring the amount of light scattered by the suspended particles in the sample of water. It consists of a light source, focusing device, sample compartment, detector (phototube), and meter. The light passes through the focusing device, enters the sample compartment, and passes through the sample. The individual particles in the sample that cause turbidity reflect the light on to the detector (phototube) which measures the amount of light reaching it. The meter then indicates the corresponding turbidity.

#### Maintenance

- For production of data with maximum accuracy and precision, the following procedures should be observed:
- It is important to locate the turbidimeter on a sturdy bench which is on solid footing, since vibration can cause high turbidity readings;

- Keep sample tubes clean, both inside and out, and discard them when they become scratched or etched. Special wiping tissues which will not scratch glass should be used to clean the sample tubes;
- Sample tubes should not be handled where light strikes them. Use tubes with a protective case so that they may be handled properly;
- Fill tubes with samples that have been mixed well and allow sufficient time before testing for bubbles to escape;
- Have a supply of replacement lamps on hand.

Follow the manufacturer's operating instructions for calibration.

- The meter can be calibrated using a prepared standard turbidity suspension. The standard turbidity suspension and dilute standards should be prepared fresh by dilution of the stock turbidity suspension.

### **Spectrophotometer**

The spectrophotometer is an electronic device which measures the concentration of a constituent by measuring the intensity of a color. The unit's main components are a white light source, wavelength control unit, sample compartment, detector, and meter. The white light passes through a diffraction grating or prism to produce single-color light (light of a specific wavelength) which, in turn, passes through the sample contained in a glass tube (cuvette) located in the sample compartment. The ratio of the light emerging from the liquid divided by the light entering the liquid is the percent transmittance (% +). This is sensed by the detector and indicated on the meter. The concentration of a measured constituent is found using a previously prepared calibration curve which must be prepared for each constituent to be measured.

### **Maintenance**

Some precautions to be taken in the care and maintenance of the spectrophotometer are:

- Routine maintenance should be done according to the manufacturer's recommendations and, as a minimum, should consist of keeping the unit clean and replacing the lamp when needed. A supply of replacement lamps should be kept on hand;
- The instrument must be protected from high humidities and water vapor to avoid deterioration of the optical system;
- The matched sample cells should be kept very clean, free of scratches' fingerprints, smudges, and evaporated film residues. Clean sample cells after each use.
- Repair of the instrument requires special skills and, therefore, should be performed by a specially-trained service person.

### **Calibration**

Check sensitivity and accuracy frequently by testing standard solutions to detect electrical, mechanical, or optical problems in the instrument and its accessories. Some recommendations are as follows:

- The preparation of a complete set of standards for each set of samples to be analyzed is unnecessary; however, with every group of samples a reagent blank (made by adding reagent to distilled water) and at least one standard near the sample concentration should be prepared or used to verify the constancy of the

calibration curve. This precaution will reveal any unsuspected changes in the instrument, the reagents, or the technique;

- Permanent standards may be subject to fading or color alterations and their validity may depend on certain arbitrary lighting conditions. Therefore, frequently verify the accuracy of these curves or permanent standards by comparing them with standards prepared in the lab using the same set of reagents, the same instrument, and the same procedures as those used for analyzing samples.

### **Safety Equipment for the Laboratory**

**Fire Extinguishers** - May prevent a large laboratory fire if used quickly on a small fire. All laboratories should have at least one all-purpose fire extinguisher that is capable of putting out small fires. All extinguishers should be checked routinely. There are four general types of fire extinguishers. Depending on potential hazards, a laboratory may have more than one type:

- Water-type Extinguisher - Useful for fires with ordinary combustibles like wood, paper, and rags;
- Dry Chemical-Type - Effective against most fires, but particularly those involving flammable liquids and metals, as well as electrical fires;
- Carbon Dioxide-Type - Useful for small fires involving flammable liquids and for limited use around electronic instrumentation and equipment;
- Halon Extinguisher - Good for fires involving electronic equipment because it leaves no residue and does not affect delicate instruments.

**Fire Blanket** - Its major purpose is to extinguish burning clothing, but it can be used to smother liquid fires in small, open containers. The blanket should be stored in a container mounted on a wall in the lab and arranged in the container so that it can be pulled out easily.

**Safety Showers** - Are an integral part of laboratory safety to be used in accidents involving acids, caustic or other harmful liquids, clothing fires, and other emergencies. The shower should be located in a convenient, easy-to-reach location in the lab, and the floor space under it should be kept uncluttered. It should be provided with a floor drain and a large, easy-to-grab pull chain ring. The shower, which should be designed so that once it is turned on it stays on until turned off by a separate valve, should be tested regularly.

**Eye Wash** - Can be bottles with an eye cup or spray nozzle and one liter reservoir used to flood the eye, or they can be permanent plumbing fixtures similar to a drinking fountain. Eye washes should be located at sinks for ease of location in the event of an emergency.

**Personal Protective Equipment and Materials** - The selection and use of this equipment is governed by the particular tasks to be performed. If it is determined that such are needed, it is the responsibility of the manager and the supervisor to ensure that they are used.

- Clothing - Personal clothing creates a barrier between the worker and the hazard. Employees using radioactive materials, suspected carcinogens, and pathogenic materials should change from street to laboratory clothing when entering the work area and should change again when leaving. This not only prevents the transportation of hazardous materials outside the area, but it also permits necessary handling and cleaning of the clothing. A laboratory coat and rubber apron should be available to the employees.
- Gloves - Appropriate gloves should be worn. The type of glove depends on the materials to be handled (i.e., rubber gloves should be worn when handling

hazardous liquids, surgical gloves for pathogenic material, insulated gloves for handling hot or extremely cold objects, and white cotton gloves to protect instruments).

- Safety Shoes - Often safety shoes are required in labs where heavy objects or equipment are to be moved. No open-toed shoes or sandals should be worn in the laboratory.
- Safety Glasses - Safety glasses are worn to protect eyes from splashes, flying objects, powders, or ultraviolet exposure. For certain activities, such as working with acid or caustic materials, a face shield should be worn to protect the face as well as the eyes.

## **CROSS-CONNECTIONS AND BACKFLOW**

Cross-connections are points in a piping system where it is possible for a nonpotable substance to come into contact with the potable drinking water supply. They can provide a pathway for backflow of nonpotable water into potable water. Backflow occurs from negative pressure in the distribution system (termed backsiphonage) or from increased pressure from a nonpotable source (termed backpressure). Backflow from a cross-connection can affect water quality and create health problems. Cross-connections can result in serious illness and even death.

### **Backflow**

Backflow is defined as unwanted, reversed flow of liquid in a piping system. Backflow can be caused by back-siphonage, backpressure, or a combination of the two.

### **Backsiphonage**

Backsiphonage is backflow caused by negative (sub-atmospheric pressure) in the distribution system or supply piping. When the system pressure becomes negative, atmospheric pressure on the distribution system, water columns (from buildings or other elevated piping), or other pressure sources will cause the direction of flow within portions of the system to reverse. If a cross-connection exists in the area where flow reverses direction, contaminants can be siphoned into the distribution system. The effect is similar to sipping a soda by inhaling through a straw.

### **Backpressure**

Backpressure is backflow caused when the distribution system is connected to a nonpotable supply operating under a pressure higher than the distribution system, the direction of flow will reverse if there is no mechanism to stop the flow. A pump, boiler, elevation difference, or other means can create the higher pressure.

## **METHODS USED TO PROTECT AGAINST CROSS-CONNECTIONS**

There are 5 basic assemblies/devices which are used to prevent or reduce the possibility of backflow in cross-connections: air gaps, atmospheric vacuum breakers, pressure-type vacuum breakers, double check valve assemblies, and reduced pressure backflow preventers.

### **Air Gap**

Of the 5 assemblies/devices listed, the air gap (physical separation of the potable and nonpotable systems by an air space) is most reliable backflow prevention measure to use when there is potential for a cross connection to an extreme hazard. The vertical distance between the supply pipe and the flood-level rim should be two times the diameter of the supply pipe, but never less than one inch. This type of backflow prevention can be used in situations in which potable water runs into a tank or a source, which is under atmospheric pressure. Obviously, this type of backflow prevention method cannot be used for a direct connection to a pressurized system.

### **Atmospheric Vacuum Breakers**

Atmospheric Vacuum Breakers (AVB) do not prevent backflow due to backpressure. They must be installed on the discharge side of the last control valve. They must be installed 6 inches above the rim of the fixture they serve. In addition, they cannot be used under continuous pressure for a period of 8 hours or more. Atmospheric vacuum breakers are usually used with hose bibs or sillcocks in situations in which a hose is attached to a sprinkler system or is draining into a tank. Atmospheric vacuum breakers cannot be tested at any time.

### **Pressure Vacuum Breakers**

Pressure vacuum breakers (PVB) are similar to atmospheric vacuum breakers except that these devices can be used under continuous pressure. They cannot prevent backflow due to backpressure and must be installed above the usage point to prevent backsiphonage. They must be installed at least 12 inches above the rim of the device that they are protecting.

### **Double Check Valve Assemblies**

Double check valve assemblies (DCVA) are used for a direct connection between 2 potable water systems. These assemblies may be used to protect against both backsiphonage and backpressure. They can be used under continuous pressure but cannot be used to connect to a contaminated or high-hazard system. The assembly consists of 2 ordinary spring-loaded or balance-weight-assisted swing check valves mounted in series. They offer only a partial degree of protection because particles can prevent proper seating of the valves causing them to leak. Double check valves protect against backpressure and back-siphonage conditions. Once installed, they can be tested.

### **Reduced Pressure Principal Backflow Preventers**

The reduced pressure principal (reduced pressure zone) backflow preventer (RPZ) provides the greatest protection against backflow-caused by backpressure and backsiphonage. The RPZ can be used under continuous pressure and in high-hazard conditions. The RPZ is designed so it will operate even if both the check valves become fouled. A reduced pressure backflow preventer consists of 2 check valves with a zone of reduced pressure between the check valves. The reduced pressure chamber also has a spring-differential pressure relief valve.

Such a backflow preventer can be put on each water line that is used to fill tank trucks. Many private facilities in communities allow farmers or others needing water to fill their tanks. These

facilities should be inspected for approved backflow prevention assemblies/devices. In addition, the city must not allow tanks to fill from hydrants, which are not protected by backflow prevention equipment.

### **Thermal Expansion**

When water is heated it expands in volume. Water in a residential water heater may expand about one-half gallon during each recovery period. In an open system this water will be easily absorbed. However, if a backflow preventer is placed in the service line to a residence it will create a closed system with no room for expansion. Since water is not compressible, it has to go someplace and that is generally out the water heater pressure relief valve. This is a dangerous situation since these relief valves are not designed for frequent operation. In addition, the pressures generated may cause an explosion.

Operators need to recognize the implication of placing a backflow preventer or a check valve upstream of a water heater. If this must be done, installation of a small thermal expansion tank between the water heater and backflow preventer is the simple solution.

### **Inspection and Testing**

All backflow prevention assemblies must be tested by a Certified Backflow Assembly Tester at the time of installation, repair, or relocation, and at least on an annual schedule thereafter.

For more information, please refer to the:

- [Cross-Connection Fact Sheet](#) included.
- Cross-Connection and Backflow Prevention Manual (EW-114) – online at [http://www.wvdhhr.org/oehs/eed/swap/training&certification/cross-connection&backflow/documents/Cross\\_Connection\\_Backflow\\_Prevention.pdf](http://www.wvdhhr.org/oehs/eed/swap/training&certification/cross-connection&backflow/documents/Cross_Connection_Backflow_Prevention.pdf)
- Cross-Connection and Backflow Control Manual – EPA online at <http://www.epa.gov/safewater/pdfs/crossconnection/crossconnection.pdf>
- Website <http://www.wvdhhr.org/oehs/backflow/default.aspx> to [Search for Certified Backflow Prevention & Assembly Inspector Testers in West Virginia](#)
- Website <http://www.wvdhhr.org/oehs/eed/swap/training&certification/cross-connection&backflow/>

## **PRINCIPLES OF HYDRAULICS**

### **Centrifugal pump**

A pump that exploits the rotary motion of a bladed wheel (impeller) inserted in the pump casing itself. The impeller, moving at high speed, projects the water previously sucked outwards in virtue of the centrifugal force developed, channeling the liquid in the fixed casing and then into the discharge pipe.

### **Submerged pump**

A submerged pump is a vertical axis pump, designed to reach great depths thanks to the length of its suction pipe. This should not be confused with a submersible pump which is characterized by its perfectly sealed motor immersed in the very liquid to be pumped.

### **Flow rate**

Quantity of liquid (in volume or in weight) which must be pumped, transferred or raised in a certain time interval by a pump: normally expressed in liters per second (L/s), liters per minute (L/m) or cubic meters per hour (m<sup>3</sup>/h). Symbol: Q.

### **Head**

Height by which a liquid is raised: pumping implies the raising of a liquid from a lower level to a higher level. It can be expressed in meters of a liquid column or in bars (pressure). In this latter case the liquid pumped does not change height but is delivered exclusively at ground level at a given pressure. Symbol: H.

### **Performance curve**

A special graph that indicates a pumps performance: in fact the diagram shows curve formed by flow rate and head values, indicated in reference to a specific type of impeller, a diameter and a particular pump model.

### **Flooded suction**

A particular pump installation, located below the vein from which the water is drawn: in this way the water spontaneously enters the pump without any difficulty.

### **Priming**

Filling of a pump or piping to displace the air within. In some cases self-priming pumps can be used, i.e. pumps equipped with an automatic mechanism which facilitates priming and therefore the starting of the pump that would otherwise be impossible or in any case very slow.

### **Cavitation**

A phenomenon that derives from unstable current flow, cavitation manifests itself with the formation of cavities in the pumped liquid and is accompanied by noisy vibrations, a reduction in flow rate and, to a lesser degree, in pump efficiency. It is caused by the rapid passage of small vapor bubbles through the pump: their implosion generates micro-jets that can also result in severe damage.

### **Friction head losses**

Energy losses due to liquid friction along the pipe walls, proportional to pipe length. These are also proportional to the square of the flow velocity and vary as a function of the liquid pumped.

Any occasion to slow the normal flow of the fluid pumped in any case is a source of friction head loss such as sudden changes in direction or in cross-sections of pipes. In order to properly size a pump, the sum of these losses are added to the differential head already anticipated.

### **Mechanical seal**

Mechanical seal for rotating shafts. Used whenever external dripping of the liquid cannot be tolerated. It is composed of two flat-surfaced rings, one stationary and the other rotating: the two faces press against each other leaving only a very thin hydrodynamic film composed of the liquid to be retained having the function of lubricating the sliding parts.

### **Viscosity**

This is a characteristic of the fluid pumped: it represents the capacity of a fluid to oppose motion. Viscosity varies as a function of temperature.

### **Specific gravity**

Every fluid has a characteristic density. Water, used as a basis for comparison, has by convention a specific gravity (or density) equal to 1 (at 4°C and at sea level). The specific gravity is the value used to compare the weight of a certain volume of liquid with the weight of the same amount of water.

## INTRODUCTION TO PUMP CURVES

A Pump Performance Curve is produced by a pump manufacturer from actual tests performed and shows the relationship between Flow and Total Dynamic Head, the Efficiency, the NPSH Required, and the BHP Required.

- Higher Head = Lower Flow
- Lower Head = Higher Flow
- Lower Flow = Lower Horsepower
- Higher Flow = Higher Horsepower

Pump characteristic curves show the interrelation of pump head, capacity, power, and efficiency for a specific impeller diameter and casing size. It is usual to plot head, power, and efficiency against capacity.

A performance curve is normally a curved line drawn on a grid or graph of vertical and horizontal lines. This curved line represents the performance of a specific pump. The vertical and horizontal lines represent units of measure that illustrate that performance. In our application there is a tank or well full of water. We want to use the water for a specific process or in a home. Often the water is at a lower level and gravity will not allow it to flow uphill, so a pump is used. A pump is a machine used to transfer or move a volume of water (or fluid) a given distance. This volume is measured over a period of time expressed in gallons per minute (gpm) or gallons per hour (gph). This volume is also referred to as capacity or flow. The pump develops energy called discharge pressure or total dynamic head (tdh). This pressure is expressed in units of measure called pounds per square inch (psi) or feet of head (ft.). NOTE: 1 psi will push a column of water up a pipe a distance of 2.31 feet. A performance curve is used to determine which pump best meets the system requirements.

The key thing to remember when reading a pump curve is all curves are based upon the principle of plotting data using the x and y axis. With this in mind, the curves typically plotted are head vs. capacity, power input vs. capacity, and pump efficiency vs. capacity. Therefore the constant between each curve is the capacity or x-axis. To determine the performance data at a particular point, first locate the operating point of the pump. This is the point where the system head curve crosses the pump's head vs. capacity curve. From this point move horizontally to the left until you intersect the y-axis. This will give you the head at which the pump will operate. Next go back to the operating point. By moving vertically down to the x-axis, you can find the capacity that the pump will operate. Now, at the determined flow rate, moving vertically to the input power curve intersection, then move horizontally to the kW input y-axis the appropriate value for motor input can be read. In like manner the pump efficiency can be read by keeping the flow constant once again.

Each of the above items is calculated from the performance data obtained when testing a pump. The pump test can either be done at the factory or in the field with the appropriate equipment. Head, capacity, current, power input, and voltage are all items that are read by the test equipment. Power factor, motor efficiency, motor input horsepower (EHp), brake horsepower (BHP), hydraulic horsepower (WHP), total efficiency, and pump efficiency must be calculated or looked up in tables.

- **Head** - a measure of the pressure or force exerted by the fluid.
- **Capacity** - the rate of liquid flow that can be carried.
- **Current** - the amount of electricity measured in amps which is flowing in a circuit.
- **Power input** - the electrical input to the motor expressed in kilowatts (kW). A measure of the rate at which work is done.
- **Voltage** - the potential or electrical magnetic force (EMF) in an electrical circuit.
- **Power factor** - the ratio of the true power to the volt-amperes in an alternation current (ac) circuit.
- **Motor efficiency** - a measure of how effectively the motor turns electrical energy into mechanical energy. It is the ratio of power input to power output.
- **Motor input horsepower (EHP)** - the power input to the motor expressed in horsepower.
- **Brake horsepower (BHP)** - the power delivered to the pump shaft expressed in horsepower.
- **Hydraulic horsepower (WHP)** - the pump output or the liquid horsepower delivered by the pump.
- **Total efficiency** - the ratio of the energy delivered by the pump to the energy supplied to the input side of the motor. Sometimes referred to as the 'wire to water efficiency'.
- **Pump efficiency** - the ratio of the energy delivered by the pump to the energy supplied to the pump shaft.

## **INSTRUMENTATION**

Like any other business, a water system spends a great deal of money on infrastructure and capital improvements. These expenses include piping, storage and all of the mechanical equipment required to produce, treat, and deliver water. A maintenance program is essential to insuring that the mechanical components of the system stay in good working order and provide the longest possible service life. A preventive maintenance schedule should be utilized to make sure that each piece of equipment gets the proper attention. Most preventive maintenance consists of inspecting, cleaning, and lubricating the equipment. The equipment operators can usually complete these tasks. Specially trained personnel that possess the necessary mechanical skills should handle major maintenance, including component replacement and overhaul.

Instrumentation in water systems allows the operator to maintain and monitor water levels, flows, pressures, and chemical feed rates at a distance. This use of telemetry gives constant readings of changes in the system and allows operational changes to be made from remote locations. This allows the operator to maintain better control and respond more quickly to changes in the process. The best instruments are those that provide stability, accuracy, and repeatability when monitoring these parameters. Instrumentation equipment can range from simple devices like float switches and pressure gauges to complex systems like on-line chemical analyzers.

Instrumentation is usually set up as either a “feed forward” or a “feedback” loop. An example of a feed forward loop would be a venturi flow meter sending a signal to change a chlorine dosage based on a change in well field flow. The meter would be located forward of the chlorine feed point and change the stroke when the flow changed. An example of a feedback loop would be a chlorine analyzer changing the chlorine dosage based on a change in residual downstream of the chlorinator. It would be located downstream and feed the information back to the chlorinator.

Three things determine the rate at which an instrument makes a change in the process. One is the amount of change for each reading. This is referred to as the span. Another is how often readings are taken. This is called the rate. The third is the deadband. Deadband means that there is a range around the setpoint where no action is taken. For instance, a chemical feed instrument may be set to maintain a pH of 7.0. But the deadband may be set so that no action is taken until the pH rises to 7.2 or falls below 6.8. If the rate is too fast or the span too large, the control conditions may fluctuate as the instrumentation “hunts” for the setpoint.

## **SUPERVISORY CONTROL AND DATA ACQUISITION (SCADA)**

**Supervisory Control and Data Acquisition (SCADA)** refers to a system that collects data from various sensors at a plant or in other remote locations and then sends this data to a central computer which then manages and controls the data. As the name indicates, it is not a full control system, but rather focuses on the supervisory level. As such, it is a purely software package that is positioned on top of hardware to which it is interfaced, in general via **Programmable Logic Controllers (PLCs)**, or other commercial hardware.

### **Data Acquisition**

Data acquisition refers to the method used to access and control information or data from the equipment being controlled and monitored. The data accessed are then forwarded onto a telemetry system ready for transfer to the different sites. They can be analog and digital information gathered by sensors, such as flowmeter, ammeter, etc. It can also be data to control equipment such as actuators, relays, valves, motors, etc.

### **Operational Considerations**

SCADA can be used to monitor and control plant or equipment. The control may be automatic, or initiated by operator commands. The data acquisition is accomplished firstly by the **remote terminal units (RTUs)** scanning the field inputs connected to the RTU (RTU may also be called a PLC - programmable logic controller). This is usually at a fast rate. The central host will scan the RTU's (usually at a slower rate.)

The data is processed to detect alarm conditions, and if an alarm is present, it will be displayed on special alarm lists. Data can be of three main types. Analogue data (i.e. real numbers) will be trended (i.e. placed in graphs). Digital data (on/off) may have alarms attached to one state or the other. Pulse data (e.g. counting revolutions of a meter) is normally accumulated or counted.

The primary interface to the operator is a graphical display (mimic) usually via a personal computer screen which shows a representation of the plant or equipment in graphical form. Live data is shown as graphical shapes (foreground) over a static background. As the data changes in the field, the foreground is updated. A valve may be shown as open or closed. Analog data can be shown either as a number, or graphically. The system may have many such displays, and the operator can select from the relevant.

One of key processes of SCADA is the ability to monitor an entire system in real time. This is facilitated by data acquisitions including meter reading, checking statuses of sensors, etc that are communicated at regular intervals depending on the system. Besides the data being used by the RTU, it is also displayed to a human that is able to interface with the system to override settings or make changes when necessary.

In West Virginia, Environmental Health Procedures DW-36 outlines Operator Variance Permits for qualifying and approved PWSs who automate their systems (automatic dialers and automatic equipment shut down). In general, an OVP requires: a minimum one (1) year continuous operation before OEHS would consider issuing and a PWS classification level of Class II or higher. These types of PWS variances are handled by OEHS EED. Again, be sure to obtain a copy of the new DW-36 when it becomes final.

## **BASIC LABORATORY EQUIPMENT**

Using proper laboratory methods is essential for effective water treatment plant operation. In this module we will be exploring sample collection, laboratory procedures and measurements used in water treatment plant operation.

The objective in collection of any sample is to collect a small volume of material that can be conveniently transported to the laboratory while still accurately representing the material being sampled. *Standard Methods for the Examination of Water and Wastewater* is used universally by operators to ensure that sampling techniques are representative, provide accurate measurement of the substances being analyzed and can be compared to samples taken under like conditions at other facilities. *Standard Methods for the Examination of Water and Wastewater* was first published in 1905. Since that time, and through 20 editions, *Standard Methods* has included hundreds of analytical techniques for the determination of water quality. EPA approves by water sampling and testing according to the method that is used. The Federal Register of October 23, 2002 contains the most recent list of those *Standard Methods* test procedures approved for regulatory compliance.

All test methods require that the equipment used is calibrated on a regular basis. This regular calibration ensures that the results obtained are reasonable and accurate. Laboratory test equipment manufacturers will provide the calibration procedures as well as calibration standards that should be followed for each piece of equipment. As part of checking the methods and procedures used for in-house monitoring, the inspector should check the procedure for and the frequency of calibration. In addition, the calibration standards should be checked to determine whether or not the standard is usable based on the date of preparation. In some cases, calibration procedures and frequencies may be dictated by the state primary agency.

### **Types of Glassware**

Laboratory vessels serve three functions: storage of reagents, measurement of solution volumes, and confinement of reactions. The mainstay of the modern analytical laboratory is a highly resistant borosilicate glass, such as that manufactured by Corning Glass Works under the name "Pyrex" or by Kimble Glass Co. as "Kimax." This glassware is satisfactory for all analyses.

### **Volumetric Analysis**

By common usage, accurately calibrated glassware for precise measurements of volume has become known as volumetric glassware. This group includes volumetric flasks, volumetric pipets, and accurately calibrated burets. Less accurate types of glassware including graduated cylinders and serological and measuring pipets also have specific uses in the analytical laboratory when exact volumes are unnecessary.

The precision of volumetric work depends in part upon the accuracy with which volumes of solutions can be measured. There are certain sources of error that must be carefully considered. The volumetric apparatus must be read correctly; that is, the bottom of the meniscus should be tangent to the calibration mark. There are other sources of error, however, such as changes in temperature, which result in changes in the actual capacity of glass apparatus and in the volume of the solutions. Thus solutions must be measured at the temperature at which the apparatus was calibrated. This temperature (usually 20°C) will be indicated on all volumetric ware.

Equipment listed below is applicable for both surface water and groundwater plants:

(1) Copy of the latest edition of “Standard Methods for the Examination of Water and Wastewater”, American Public Health Association, Inc., 1015 Eighteenth Street, N.W., Washington, D.C. 20036

(1) Colorimeter or Spectrophotometer capable of performing various tests to determine the chemistry of both raw and finished water. Tests could include; chlorine (free and total); iron, manganese (high and low range); aluminum; nitrates; phosphorus; fluoride; zinc; and pH. A good colorimeter or spectrophotometer should be capable of performing all of the tests listed in addition to several other parameters which could be applicable to the plant. Contact the WV Department of Health to determine the parameters required. Most manufacturers’ and suppliers offer technical assistance.

(As required) Reagents for tests to be performed with the colorimeter or spectrophotometer, EPA approved if possible.

(1) Bench type pH Meter, preferably with temperature compensation. The pH meter should include a stand for the probe and an electric stirrer. Also, a supply of pH 4, pH 7, and pH 10 buffer solutions should be on hand for calibrating the meter.

(1) Thermometer, -10 to 110 °C.

(As required) Alkalinity, Hardness, and Carbon Dioxide tests usually performed using one of two titration methods. The digital titrator method requires a digital titrator and the appropriate reagent set. The buret method may be purchased as complete outfit, or separately. When purchased separately the following items are required: buret support with large white porcelain base and a buret holder for assembling and steadying automatic burets. Each separate test will require one automatic buret, with stopcock, 50 mL or 100 mL, complete with rubber bulb and reservoir and, the appropriate reagents for each test.

(1) Balance, general laboratory, triple beam, in grams.

(1) Set, technical weights, metric, class C, 1 gram to 1,000 gram for balance calibration.

(1) Stopwatch.

(6) Measuring pipettes 10.0 mL capacity, 0.1 mL subdivisions.

(6) Measuring pipettes 1.0 mL capacity, 0.01 mL subdivisions.

(2) Pipette fillers.

(2) Graduated cylinders, 100 mL capacity, 1.00 mL subdivisions.

(1) Graduated cylinders, 500 mL capacity, 5.00 mL subdivisions.

(1) Graduated cylinders, 1,000 mL capacity, 10.00 mL subdivisions.

(4) Erlenmeyer flasks, 250 mL, wide mouth.

(4) Casserole, porcelain, 210 mL.

(6) Glass stirring rods, 3 mm diameter.

The following items are required in plants treating surface water, or in plants using groundwater under the influence of surface water. These items are in addition to the equipment already listed.

(1) Turbidimeter.

(As required) Primary turbidity standards. Turbidimeters must be standardized using standards approved by the WVDHHR. At this time only Formazin, which you prepare as needed, and AEPA-1, already prepared but expensive, have been approved. The sealed Gelex standards which are furnished with most turbidimeters are to be used as secondary standards only, and must be checked against either Formazin or EPA-1.

(1) Six position stirring apparatus for “jar tests” with variable speed control and light base.

(6) Griffin beakers, 1,000 mL for “jar tests”.

### **Laboratory Facilities**

Adequate laboratory space must be made available. As a guideline there should be approximately 150 to 200 square feet per person, regardless of tests. There should be approximately 15 linear feet of usable bench space including a sink with hot and cold water taps. Raw and post-settling water taps should be provided in the lab area for quality control monitoring. Sufficient electrical outlets must be provided for operating the lab equipment.

### **Glassware**

The glassware purchased for lab use should be composed of Pyrex or Kimax type glass. This type of glass is more resistant to damage by heat, chemicals and abuse than regular soft glass. All volumetric glassware should be marked “Class A”, denoting that it meets federal specifications for volumetric glassware and need not be calibrated before use.

This list includes only the MINIMUM equipment needed to properly operate a water treatment plant. Every water plant is different and may need additional items. However, before purchasing large quantities of unknown lab equipment (as in a new plant) contact the WVDHHR.

Because of the difference in suppliers specific reagents are not listed. The manufacturer of lab equipment will provide a list of reagents that is compatible with their products.

### **Equipment & Techniques**

Accurate measurement is necessary to make standard solutions and reagents. The volumetric flask should be used when the final volume of a solution is specified such as 1,000 mL rather than 1 L or when the used of the flask is specified.

Volumetric flasks are squat bottles with long necks. The neck is marked with a line to indicate the volume it contains.

Volumetric pipettes are used to accurately measure quantities of solutions for diluting to desired strengths. These pipettes are also used to add known volumes of solutions to other solutions. These pipettes are made to deliver specific volumes such as 1, 2, 5, 10 or 25 mL. The pipette is filled to above the zero mark by suction (rubber bulb). The upper end is closed by the index finger and the liquid is gradually lowered to the line by releasing finger pressure on the top. The liquid is allowed to flow into the receiving vessel by removing the finger completely from the top of the pipette. The tip of the pipette must touch the inside of the receiving vessel. The pipette is allowed to drain completely. If a pipette is marked **TD (to deliver)**, do not blow out the last drop of liquid remaining after the pipette drains. If a pipette is marked **TC (to contain)**, blow out the last drop into the receiving vessel.

Mohr pipettes are glass tubes graduated to deliver various quantities of solution up to the volume of the pipette. These pipettes are usually graduated to read 0.1 mL amounts. The pipette is filled in the same way as the volumetric pipette. The liquid level is lowered to the zero line. The desired amount of liquid is allowed to flow from the pipette to the desired volume slowly by releasing partial finger pressure on the top of the pipette and applying again when the desired volume is reached.

Graduated cylinders, commonly called graduates, are calibrated to measure up to 10, 25, 50, 100 and even 1,000 mL. Graduated cylinders are not as accurate as volumetric flasks and must not be used as a substitute for them. Graduated cylinders are used to measure “approximately accurate” volumes.

Burets are glass tubes graduated over their length from 1 to 10, 25, or 50 mL, usually in 0.1 mL increments. The tube has a valve at the lower end and a small tip like a pipette below the valve. The buret is used by clamping it onto a support stand, pouring the standard solution from a beaker into the top of the buret to well above the zero line and carefully draining the surplus solution out until the meniscus reaches zero. All air must be expelled from the valve and tip. Standard solution is added to the sample by opening the valve at the bottom. Solution may be added drop wise, full flow or just a fraction of a drop by manipulating the valve.

Safety bulbs and pipette fillers are used to fill pipettes. Never fill a pipette with any liquid by mouth suction. Some pipette fillers may be left attached to the pipette during the zeroing and draining (measuring) procedures.

Because liquid adheres to the glass walls of burets, pipettes, graduated cylinders, and volumetric flasks, the surface of the liquid forms a curve, known as the meniscus. Therefore, when reading all volumetric glassware, always read from the bottom of the curve, at eye level.

There are many types of balances and scales that may be used in a water laboratory. Rough balances and scales are used to weigh masses up to about one **kilogram (kg)** or **2 pounds (lbs)** with accuracy of only about 0.1 **grams (g)** or more. Analytical balances usually weigh up to 200 g with an accuracy of 0.1 mg. The analytical balance, essential for preparing standard solutions, determining suspended matter, and conducting any test that requires accurate weighing of 0.1 mg to 200 g, is a delicate and expensive instrument and should be treated with care. No chemical is ever weighed directly on the balance pan; instead, it is put into a weighing bottle, crucible, watch glass, plastic or foil weighing pan; or weighing paper. Any article to be weighed must be at room temperature. This may require cooling or warming in a desiccator prior to weighing.

The above items cover the common glassware and laboratory equipment in common use in the average water treatment plant. Other equipment such as spectrophotometers and specialized glassware are used in some laboratories, but are beyond the scope of this class. The operator must refer to the manufacturer's instructions for the proper use of this equipment.

One thing that must be understood is how to properly clean glassware. No matter how the glassware is cleaned, it must be rinsed thoroughly. All glassware may be washed with laboratory detergents provided that they are rinsed with large volumes of distilled or deionized water. All glassware must be cleaned after each use and be kept clean in order to be used effectively. A sure sign that volumetric glassware needs to be cleaned is the absence of a meniscus when a solution is poured into the glassware. If, when the glassware is rinsed and drained, there are any drops of water adhering on the sidewalls of the glassware, it is not clean and the cleaning process must be repeated.

### **Techniques**

The following are some techniques for using various pieces of lab equipment that will demonstrate the efficiency and the maximum benefit of the equipment.

Pouring a solution from one vessel to another without spatter is sometime difficult. One method that can be used to pour from a beaker, flask or other container, is to place a glass stirring rod held against the lip of the pouring vessel. The liquid will flow down this rod without spatter or dribble.

In reading a buret, an index card with the bottom half painted black (a felt tipped marker works well) will aid in reading the bottom of the meniscus. The method of reading is thus: Hold the index card behind the buret with the division line about one eighth inch below the bottom of the meniscus. Center your eye on the bottom of the meniscus. The dark portion of the card will cause the meniscus to appear black and distinct. Reader the upper encircling division for the full mL reading. Count these short division lines from the top down to the bottom of the meniscus. Each such division represents 0.1 mL.

## SAMPLING

### **Importance of Good Sampling Procedures**

The importance of obtaining samples by proper methodology cannot be emphasized enough. Proper sampling is a vital part of protecting the water supply. Without proper sampling techniques the laboratory data obtained from tests conducted on those samples are meaningless, and more importantly, any maintenance of the water supply based on that data could result in a situation which would endanger human health.

### **Representative Sampling**

Remember; with sampling a small quantity of water is being used to evaluate a great quantity of water. Every precaution must be taken to ensure that the small quantity is a good representative sample of the greater quantity. A representative sample is a sample portion of material or water that is as nearly identical in content and consistency as possible to that in the larger body of material or water being sampled.

### **Grab Sampling**

A grab sample is a single water sample collected at no specific time. A grab sample only represents the characteristics of that particular sample at that particular time. There may be times when a grab sample is preferred over a composite sample. These situations may include the following:

- The water to be sampled does not flow continuously;
- The characteristics of the water are relatively constant; and
- The water needs to be tested for water quality indicators that may change with time, such as dissolved gases, coliform bacteria, residual chlorine, temperature and pH.

### **Composite Sampling**

A composite sample is a collection of individual samples obtained at regular intervals over a 24-hour period. The combined sample (the composite sample) forms a single larger representative sample and is analyzed to determine the average conditions during the sampling period. If the individual samples are combined in proportion to the rate of flow when the sample was collected, then it is called a flow proportional composite sample.

### **Sampling Locations**

Sampling location usually depends on the type of system and the analyses required. The sampling locations to be used and the rationale behind selecting the sites are to be presented in a sample-site plan, which is to be submitted to the State for approval.

### Water Taps

To collect samples from taps connected to water mains the service line must be flushed for a brief period of time before collecting the sample. The following precautions should be taken:

- Do not take samples from drinking fountains, restrooms, or taps with aerators.
- Do not take samples from taps surrounded by excess foliage such as leaves or flowers.
- Do not take samples from taps that are dirty, corroded, or are leaking.
- Never collect a sample from a hose or other attachment fastened to a faucet.

- Care should be taken that the person collecting the sample does not touch the faucet in any way that could contaminate the sample.

Sometimes, as in the collection of samples for lead and copper testing, a ‘first draw’ or ‘first flush’ sample will be required. For this, the water needs to stand in the pipes undisturbed for at least six hours before the sample is drawn. No water is flushed from the faucet before the sample is collected. Usually, this sample will be taken first thing in the morning before any water has been used.

### Distribution Systems

The most representative samples of the water supply would be taken from the water main before any branching off occurs. Analyses of water main samples can be compared to analyses of tap samples to help pin point a possible problem for instance.

Sampling points should be selected so that the pathway of water from the source to the endpoint will be represented. Ideal sampling locations are those that provide a short, direct connection with the main and are made of corrosion-resistant material. Not just any faucet will do, and fire hydrants are not acceptable due to how they are constructed and their infrequent use. Allow the water line to flush long enough to replace the water in the lines twice. About 5 minutes is usually sufficient. Do not turn the faucet on wide open to make flushing quicker as this will stir up any deposits in the lines.

### **Sampling Containers, Preservation and Holding Times**

The type of container used for collecting a sample depends on what tests need to be conducted on that collected sample. The Code of Federal Regulations, Protection of Environment, CFR 40, Part 136.3 contains a complete list of analyses that can be conducted along with information on approved sample containers, volume required, preservatives and maximum holding time between sampling and analysis.

The container must be clean and will usually be supplied by the laboratory performing the analysis. The container must be clearly labeled and at a minimum contain the following information:

- PWS ID Number
- Sample location
- Sample date
- Time of collection (exact time)
- Name of collector

## **BASIC SAMPLING PROCEDURES**

The way you collect, store and transport your drinking water test sample affects the accuracy of your test results. Improper handling may show signs of drinking water contamination where it may not truly exist. The certified laboratory you have hired will give you detailed instructions for handling a drinking water test sample, including:

- Collection procedures;
- Containers to use, including those supplied by the laboratory;
- Labeling of samples;
- Completion and chain of custody forms;
- Transportation of samples; and,
- Time periods for delivery of samples.

Carefully follow the instructions from the laboratory to ensure accurate results.

### **Location of sampling points**

One objective of sampling is to assess the quality of the water supplied by the water purveyor and the point of use, so that samples of both should be taken. Any significant difference between the two has important implications for remedial strategies.

Samples must be taken from locations that are representative of the water source, treatment plant, storage facilities, distribution network, points at which water is delivered to the consumer, and points of use. In selecting sampling points, each locality should be considered individually; however, the following general criteria are usually applicable:

- Sampling points should be selected such that the samples taken are representative of the different sources from which water is obtained by the public or enters the system.
- These points should include those that yield samples representative of the conditions at the most unfavorable sources or places in the supply system, particularly points of possible contamination such as unprotected sources, loops, reservoirs, low-pressure zones, ends of the system, etc.
- Sampling points should be uniformly distributed throughout a piped distribution system, taking population distribution into account; the number of sampling points should be proportional to the number of links or branches.
- The points chosen should generally yield samples that are representative of the system as a whole and of its main components.
- Sampling points should be located in such a way that water can be sampled from reserve tanks and reservoirs, etc.
- In systems with more than one water source, the locations of the sampling points should take into account the number of inhabitants served by each source.
- There should be at least one sampling point directly after the clean-water outlet from each treatment plant.

### **Analytical quality assurance and quality control**

Standard methods for drinking-water analysis should be tested under local conditions for accuracy and precision, agreed at national level, and applied universally by both water-supply and regulatory agencies. However, the use of standard methods does not in itself ensure that reliable and accurate results will be obtained.

In the context of analytical work, the terms quality assurance and quality control are often treated as synonymous. In fact, they are different concepts. Analytical quality control is the generation of data for the purpose of assessing and monitoring how good an analytical method is and how well it is operating. This is normally described in terms of within-day and day-to-day precision.

Analytical quality assurance, by contrast, comprises all the steps taken by a laboratory to assure those who receive the data that the laboratory is producing valid results. Quality assurance thus encompasses analytical quality control but also includes many other aspects such as proving that the individuals who carried out an analysis were competent to do so, and ensuring that the laboratory has established and documented analytical methods, equipment calibration procedures, management lines of responsibility, systems for data retrieval, sample handling procedures, certification, and so on.

### **Field Analysis and Field Instruments**

All field instruments should be calibrated according to the manufacturer's instructions prior to field use and documented in a calibration notebook to be kept with the instrument. Operation of field equipment varies depending on the manufacturer. Care must be taken to assure that each instrument is functioning properly and calibrated according to any calibration schedule.

Field measurements should be made in accordance with equipment manufacturer's instructions and at appropriate times and locations so that valid information is obtained.

### **Chain of Custody Procedure**

Procedures for **Chain of Custody (COC)** require maintenance of permanent records for all sample handling and shipment. COC procedures must be used to ensure sample integrity as well as legal and technically defensible data.

Any samples collected must be submitted with a COC form and a signed affidavit. The lab has stated that one COC form per shipping container (ice chest) is sufficient. The COC form must have each analysis request checked and show a range of collection times.

The sample should be kept in view or in locked storage until custody is relinquished to the shipper and formal documentation of the transfer is completed. The person collecting a sample will start the COC procedure.

In completing the tag, care should be taken to insure that all necessary information is correct and legibly written on the tag with a black waterproof ink pen. The use of a fine point pen is discouraged because of possible problems in making legible photostatic copies.

### **Shipping of Samples**

The water system is responsible for shipment of all routine samples to the laboratories so that analyses can be conducted in accordance with EPA methods. Each sample must be accompanied by a COC form.

When a sample is shipped to the laboratory, it must be packaged in a proper shipping container to avoid leakage and/or breakage. The laboratory must be able to associate each container in the ice chest with a COC form.

COC forms or other documents should be shipped inside the ice chest and must be placed in a plastic bag to prevent water damage. A good method is to use a zip-lock bag taped to the inside of the ice chest lid. All shipping boxes must be taped closed with shipping tape, strapping tape or fiber plastic tape, etc.

The complete address of the sender and the receiving laboratory must legibly appear on each container. When sent by U.S. Mail, register the package with a return receipt requested. When sent by a shipping service, obtain a copy of the bill of lading. Post office receipts and bills of lading may be used as part of the COC documentation.

Certified laboratories must conduct analyses within the prescribed holding times in order to produce valid compliance results. An even flow of samples must be maintained into the labs throughout each sampling period so as to assure that the laboratory capacity is not exceeded. This will require that the Contractor and each shipper carefully plan and coordinate the collection and shipment of samples. Samples must be shipped on a routine daily basis.

It is far better to spend extra funds on ice and shipping costs than to have an entire shipment of samples rejected at the lab because of the failure to meet temperature requirements due to ice melt.

#### **How to store your sample and send it to the laboratory**

- **Submit your drinking water test sample to the certified laboratory as quickly as possible after collection.** To give the most accurate results, testing for bacteria must begin within 30 hours of collecting the drinking water sample. Be sure to obtain clear instructions from the laboratory regarding sample submission drop-off time.
- **Refrigerate samples until ready for shipping.**
- **Ship your sample bottles or containers to the laboratory in coolers, or in foam pack containers, with ice or ice packs.** Don't pack the bottles with loose ice as this may contaminate the sample. If you only have loose ice, encase the sample/container in waterproof packaging or a sealed container. Be sure it is well protected from other samples that you may be sending to the laboratory at the same time (e.g. sewage samples).
- **Don't allow samples to freeze.** In winter, you may want to take advantage of heated shipping offered by some courier companies.
- **Package the completed COC form, provided by the certified laboratory, with the collected sample.** If sending it inside the cooler containing the sample, ensure that the form is enclosed inside a waterproof package (e.g., a new zip-lock bag).

#### **Safety for Laboratory Personnel**

The safety of staff undertaking analytical procedures, both in the field and in the laboratory, is of the greatest importance. All staff should be trained in safety procedures relevant to their work. In the laboratory, individual staff members should be authorized to undertake procedures involving risk of any type only after appropriate training; unauthorized staff should not be allowed to undertake analyses.

All laboratories should formulate and implement a safety policy that should cover cleaning, disinfection, and the containment of hazardous substances. Safety equipment such as fire

extinguishers, safety glasses, and first-aid kits should be suitably located, and readily available; they should be routinely checked and all staff should be trained in their use.

### **Sampling Safety - Preservation Chemicals**

Acids of various types are the most common sample preservation materials that may pose a risk or hazard. Preservation chemicals must be handled with care and all appropriate safety procedures followed. You may feel that safety precautions are a burden; however, no amount of compensation can replace an eye or other body part damaged by acid. Material Safety Data Sheets are available wherever chemicals are stored.

It is your responsibility to use appropriate eye, hand, and clothing protection.

Also, if you are shipping samples that you know or suspect as a health hazard, include a warning note or letter in an appropriate location on the shipping container to minimize laboratory personnel exposure to an unknown health hazard.

### Sample Containers, Preservation and Holding Times for Regulated Parameters

Parameter/ Method	Preservative	Sample Holding Time	Extract Holding Time and Storage Conditions	Suggested Sample Size	Type of Container
Metals (except Hg)	HNO <sub>3</sub> pH<2	6 months		1 L	Plastic or Glass
Mercury	HNO <sub>3</sub> pH<2	28 days		100 mL	Plastic or Glass
Alkalinity	Cool, 4C	14 days		100 mL	Plastic or Glass
Asbestos	Cool, 4C	48 hours		1 L	Plastic or Glass
Chloride	none	28 days		100 mL	Plastic or Glass
Residual Disinfectant	none	immediately		200 mL	Plastic or Glass
Color	Cool, 4C	48 hours		100 mL	Plastic or Glass
Conductivity	Cool, 4C	28 days		100 mL	Plastic or Glass
Cyanide	Cool, 4C, Ascorbic acid (if chlorinated), NaOH pH>12	14 days		1 L	Plastic or Glass
Fluoride	none	1 month		100 mL	Plastic or Glass
Foaming Agents	Cool, 4C	48 hours			
Nitrate (chlorinated)	Cool, 4C non-acidified	14 days		100 mL	Plastic or Glass
Nitrate (non chlorinated)	Cool, 4C, non-acidified	48 hours		100 mL	Plastic or Glass
Nitrite	Cool, 4C	48 hours		100 mL	Plastic or Glass
Nitrate+ Nitrite	H <sub>2</sub> SO <sub>4</sub> pH<2	28 days		100 mL	Plastic or Glass
Odor	Cool, 4C	24 hours		200 mL	Glass
pH	none	immediately		25 mL	Plastic or Glass
o-Phosphate	Cool, 4C	48 hours		100mL	Plastic or Glass

Parameter/ Method	Preservative	Sample Holding Time	Extract Holding Time and Storage Conditions	Suggested Sample Size	Type of Container
Silica	Cool, 4C	28 days		100 mL	Plastic
Solids (TDS)	Cool, 4C	7 days		100 mL	Plastic or Glass
Sulfate	Cool, 4C	28 days		100 mL	Plastic or Glass
Temperature	none	immediately		1 L	Plastic or Glass
Turbidity	Cool, 4C	48 hours		100 mL	Plastic or Glass
502.2	Sodium Thiosulfate or Ascorbic Acid, 4C, HCl pH<2	14 days		40-120 mL	Glass with PTFE Lined Septum
504.1	Sodium Thiosulfate Cool, 4C,	14 days	4C, 24 hours	40 mL	Glass with PTFE Lined Septum
505	Sodium Thiosulfate Cool, 4C	14 days (7 days for Heptachlor)	4C, 24 hours	40 mL	Glass with PTFE Lined Septum
506	Sodium Thiosulfate Cool, 4C, Dark	14 days	4C, dark 14 days	1 L	Amber Glass with PTFE Lined Cap
507	Sodium Thiosulfate Cool, 4C, Dark	14 days(see method for exceptions)	4C, dark 14 days	1 L	Amber Glass with PTFE Lined Cap
508	Sodium Thiosulfate Cool, 4C, Dark	7 days (see method for exceptions)	4C, dark 14 days	1 L	Glass with PTFE Lined Cap
508A	Cool, 4C	14 days	30 days	1 L	Amber Glass with PTFE Lined Cap
508.1	Sodium Sulfite HCl pH<2 Cool, 4C	14 days (see method for exceptions)	30 days	1 L	Glass with PTFE Lined Cap
515.1	Sodium Thiosulfate Cool, 4C, Dark	14 days	4C, dark 28 days	1 L	Amber Glass with PTFE Lined Cap

Parameter/ Method	Preservative	Sample Holding Time	Extract Holding Time and Storage Conditions	Suggested Sample Size	Type of Container
515.2	Sodium Thiosulfate or Sodium Sulfite HCl pH<2 Cool, 4C, Dark	14 days	≤4C, dark 14 days	1 L	Amber Glass with PTFE Lined Cap
515.3	Sodium Thiosulfate Cool, 4C, Dark	14 days	≤4C, dark 14 days	50 mL	Amber Glass with PTFE Lined Cap
515.4	Sodium Sulfite, dark, cool ≤10C fro first 48 hr. ≤6C thereafter	14 days	≤0C 21 days	40 mL	Amber glass with PTFE lined septum
524.2	Ascorbic Acid or Sodium Thiosulfate HCl pH<2, Cool 4C	14 days		40-120 mL	Glass with PTFE Lined Septum
525.2	Sodium Sulfite, Dark, Cool, 4C, HCl pH<2	14 days (see method for exceptions)	≤4C 30 days	1 L	Amber Glass with PTFE Lined Cap
531.1, 6610	Sodium Thiosulfate, Monochloroacet ic acid, pH<3, Cool, 4C	Cool 4C 28 days		60 mL	Glass with PTFE Lined Septum
531.2	Sodium Thiosulfate, Potassium Dihydrogen Citrate buffer to pH 4, dark, ≤10C for first 48 hr, ≤6C thereafter	28 days		40 mL	Glass with PTFE Lined Septum
547	Sodium Thiosulfate Cool, 4C	14 days(18 mo.frozen)		60 mL	Glass with PTFE Lined Septum

Parameter/ Method	Preservative	Sample Holding Time	Extract Holding Time and Storage Conditions	Suggested Sample Size	Type of Container
548.1	Sodium Thiosulfate (HCl pH 1.5-2 if high biological activity) Cool, 4C, Dark	7 days	≤4C 14 days	≥ 250 mL	Amber Glass with PTFE Lined Septum
549.2	Sodium Thiosulfate, (H <sub>2</sub> SO <sub>4</sub> pH<2 if biologically active) Cool, 4C, Dark	7 days	21 days	≥ 250mL	High Density Amber Plastic or Silanized Amber Glass
550, 550.1	Sodium Thiosulfate Cool, 4C, HCl pH<2	7 days	4C, Dark 550, 30 days 550.1, 40 days	1 L	Amber Glass with PTFE Lined Cap
551.1	Sodium Sulfite, Ammonium Chloride, pH 4.5-5.0 with phosphate buffer Cool, 4C	14 days		≥ 40 mL	Glass with PTFE Lined Septum
552.1	Ammonium chloride Cool, 4C, Dark	28 days	≤4C, dark 48 hours	250 mL	Amber Glass with PTFE Lined Cap
552.2	Ammonium chloride Cool, 4C, Dark	14 days	≤4C, dark 7 days ≤-10C 14 days	50mL	Amber Glass with PTFE Lined Cap
555	Sodium Sulfite HCl, pH≤2 Dark, Cool 4C	14 days		≥ 100 mL	Glass with PTFE Lined cap
1613	Sodium Thiosulfate Cool, 0-4C, Dark		Recommend 40 days	1 L	Amber Glass with PTFE Lined Cap

**Reference:** Manual for the Certification of Laboratories Analyzing Drinking Water Criteria and Procedures Quality Assurance, Fifth Edition: US Environmental Protection Agency Office of Water Office of Groundwater and Drinking Water, EPA 815-R-05-004, January 2005.

## TYPICAL CHEMICAL ANALYSIS LABORATORY REPORT

Most laboratories are providing a key on their forms to help explain what various abbreviations and acronyms stand for, but if an owner/operator does not understand what something on the report form means, they will not be able to respond appropriately to questions regarding the analyses. **If you do not understand what something on the report means or the significance of it, ask the laboratory to explain it to you. You are paying for this service; it is your report.** An explanation of the important items is listed below:

1. The time between sampling and analysis can be critical to the validity of the test. This data should be checked for accuracy, especially if the sample is rejected due to holding time problems related to sample preservation.
2. Flag Definitions: This section is provided as a courtesy by the laboratory. It defines the abbreviations and acronyms that appear on the form.
3. Your name, address, etc. **Double check the PWSID # to make sure the sample “belongs to you”. It is also a good idea to give each sample a “client sample ID” that is unique to your system to ensure that the results are definitely for your sample and there was no mix up at the laboratory.** The labs handle hundreds of samples each day and also run samples in groups. They are very careful about tracking samples and maintaining sample integrity, but you should always check this information to make sure sample identification is consistent with your records and PWSID.
4. Parameter: This is the chemical that was analyzed.
5. Result: The result is the concentration that was detected. Note that several do not have a numerical value listed. Instead <MDL is listed this means that for that particular parameter less than the Method Detection Limit was present.
6. Units: Note that the units are all mg/L for this particular analysis.
7. **MDL = Method Detection Limit.** This refers to the test method. All methods have a limit below which the actual concentration cannot be accurately determined. The number in this column lists the detection limit for each parameter using that particular method.
8. **MCL = Maximum Contaminant Level.** This column lists the MCL that is listed in the West Virginia State Drinking Water Regulations. If the number in the Result column exceeds the number in the MCL column, your sample has exceeded the concentration allowed under the regulations for that parameter.
9. Prep Method and Prep Date: If a sample required special preparation before analysis it would be described here.
10. Analysis Method: This column lists the analytical method used. This is important from a regulatory standpoint, because specific methods are called out in the Drinking Water Regulations. If the method used is not an approved method, the sample results will not be valid for compliance purposes. The laboratories in West Virginia are very good about making sure the correct method is used if the sample is to be used for compliance purposes.
11. Analysis Date: This is the day the sample was analyzed.

## **RECORDKEEPING FOR COMPLIANCE SAMPLING**

With a full set of SDWA regulations, the responsibility of keeping a PWS in compliance can seem overwhelming. The most important responsibilities are collecting water samples on schedule, keeping all of the laboratory test results in an orderly filing system, and submitting the proper paperwork. Organization is the key factor.

Here are a few suggestions to help. First, find an extra calendar, or generate a calendar on your computer. Put it up on a bulletin board or just on the wall, somewhere where it will be seen every day. Then go through the whole year and mark down the dates when required sampling needs to be completed. Sampling requirements are different for ground water, surface water and purchaser systems, and for community versus non-transient non-community systems. So look for the sampling guideline that your system receives each year in January or February from the Environmental Engineering Division (EED), central office. For a typical community surface water system you should now be collecting the following:

- Monthly total coliforms: don't forget to follow your sample site plan.
- Lead and Copper: usually one round every three years, between June 1 and September 30.
- Nitrates: be sure to collect the sample in the required calendar quarter.
- Inorganics: any time during the calendar year.
- Regulated VOCs: any time during the year.
- Regulated SOCs: usually only once every three years, but check your individual guidance printout from the EED.
- Disinfection By-Products: depending on your system's population, you may be collecting a quarterly sample or just one sample during the month of August. Be sure to collect the sample from the maximum residence time (MRT) location. You must have the sample analyzed for both TTHMs and HAA5s. Large systems must collect four samples every quarter.
- Raw and Treated Water TOCs: These must be sampled monthly, and reported quarterly on EW-90C.
- Don't forget to submit your Consumer Confidence Report before July 1 each year, and the certification form to confirm that you have distributed it to all of your customers as required, based on your system's population.
- Don't forget to send your monthly operational report in by the 10<sup>th</sup> of each month, including EW-90 (3 pages), EW-90A (2 pages), EW- 90B (1 page), EW-90C (quarterly, 1 page), EW-80 if you fluoridate, EW-103 (2 pages) and EW-210 (2 pages).

Be sure to send the lab results to the EED, central office, as soon as they are received from the lab, and keep a record of when they were sent. Keep each of the above referenced test results and reports in a separate manila folder, and keep all of the test results and reports for a given year in a common hanging file. The file will then be readily available when someone from the EED asks to look at them, and there will not be any more of those aggravating violation notices. A little bit of organization will also go a long way in assuring customers of the dedication and professionalism of the PWS and that they are being provided a safe, high quality drinking water.

## **EFFECTIVE WATER UTILITY MANAGEMENT**

Recent events have highlighted the fundamental importance of sustaining our Nation's water infrastructure. Effective utility management is the key to achieving this goal. Effective management can help utilities enhance the stewardship of their infrastructure, improve performance in critical areas, and respond to other challenges. Addressing the Nation's water and wastewater infrastructure also calls for ongoing collaboration between government, industry, elected officials, and other stakeholders.

PWSs face common challenges, such as rising costs and workforce complexities, and need to focus attention on these areas to deliver quality products and services and sustain community support. Within this context, four primary building blocks of effective water utility management have been identified, which could become the basis of a future water utility sector management strategy. These building blocks, described below, are: Attributes of Effectively Managed Water Utilities, Keys to Management Success, Water Utility Measures, and Water Utility Management Resources.

### **Attributes of Effectively Managed Water Utilities**

Ten attributes of effectively managed water sector utilities have been identified that provide a succinct indication of where effectively managed utilities focus and what they strive to achieve. Further, it was recommended that the water utility adopt and utilize these Attributes as a basis for promoting improved management. The attributes can be viewed as a continuum of, or a set of building blocks for, management improvement opportunities. The attributes, are deliberately not listed in a particular order; since the utility manager will determine their relevance and relative importance based on individual circumstances.

- **Product Quality:** Produces potable water, treated effluent, and process residuals in full compliance with regulatory and reliability requirements and consistent with customer, public health, and ecological needs.
- **Customer Satisfaction:** Provides reliable, responsive, and affordable services in line with explicit, customer-accepted service levels. Receives timely customer feedback to maintain responsiveness to customer needs and emergencies.
- **Employee and Leadership Development:** Recruits and retains a workforce that is competent, motivated, adaptive, and safe-working. Establishes a participatory, collaborative organization dedicated to continual learning and improvement. Ensures employee institutional knowledge is retained and improved upon over time. Provides a focus on and emphasizes opportunities for professional and leadership development and strives to create an integrated well-coordinated senior leadership team.
- **Operational Optimization:** Ensures ongoing, timely, cost-effective, reliable, and sustainable performance improvements in all facets of its operations. Minimizes resource use, loss, and impacts from day-to-day operations. Maintains awareness of information and operational technology developments to anticipate and support timely adoption of improvements.
- **Financial Viability:** Understands the full life-cycle cost of the utility and establishes and maintains an effective balance between long-term debt, asset values, operations and maintenance expenditures, and operating revenues. Establishes predictable rates—consistent with community expectations and acceptability—adequate to recover costs, provide for reserves, maintain support from bond rating agencies, and plan and invest for future needs.

- **Operational Resiliency:** Ensures utility leadership and staff work together to anticipate and avoid problems. Proactively identifies, assesses, establishes tolerance levels for, and effectively manages a full range of business risks (including legal, regulatory, financial, environmental, safety, security, and natural disaster related) in a proactive way consistent with industry trends and system reliability goals.
- **Community Sustainability:** Is explicitly cognizant of and attentive to the impacts its decisions have on current and long-term future community and watershed health and welfare. Manages operations, infrastructure, and investments to protect, restore, and enhance the natural environment; efficiently use water and energy resources; promote economic vitality; and engender overall community improvement. Explicitly considers a variety of pollution prevention, watershed, and source water protection approaches as part of an overall strategy to maintain and enhance ecological and community sustainability.
- **Infrastructure Stability:** Understands the condition of and costs associated with critical infrastructure assets. Maintains and enhances the condition of all assets over the long-term at the lowest possible life-cycle cost and acceptable risk consistent with customer, community, and regulator-supported service levels, and consistent with anticipated growth and system reliability goals. Assures asset repair, rehabilitation, and replacement efforts are coordinated within the community to minimize disruptions and other negative consequences.
- **Stakeholder Understanding and Support:** Engenders understanding and support from oversight bodies, community and watershed interests, and regulatory bodies for service levels, rate structures, operating budgets, capital improvement programs, and risk management decisions. Actively involves stakeholders in the decisions that will affect them.
- **Water Resource Adequacy:** Ensures water availability consistent with current and future customer needs through long-term resource supply and demand analysis, conservation, and public education. Explicitly considers its role in water availability and manages operations to provide for long-term aquifer and surface water sustainability and replenishment.

### Keys to Management Success

Five “Keys to Management Success” were also identified that foster utility management success.

- **Leadership:** Leadership plays a critical role in effective utility management, particularly in the context of driving and inspiring change within an organization. In this context, the term “leaders” refers both to individuals who champion improvement, and to leadership teams that provide resilient, day-to-day management continuity and direction. Effective leadership ensures the utility’s direction is understood, embraced, and followed on an ongoing basis throughout the management cycle.
- **Strategic Business Planning:** Strategic business planning helps utilities balance and drive integration and cohesion across, the Attributes. It involves taking a long-term view of utility goals and operations and establishing an explicit vision and mission that guide utility objectives, measurement efforts, investments, and operations.
- **Organizational Approaches:** A variety of organizational approaches can be critical to management improvement. These approaches include establishing a “participatory organizational culture” that actively seeks to engage employees in

improvement efforts, deploying an explicit change management process, and utilizing implementation strategies that seek early, step-wise victories to build momentum and motivation.

- **Measurement:** A focus and emphasis on measurement is the backbone of successful continual improvement management and strategic business planning. Successful measurement efforts tend to be viewed on a continuum, starting with basic internal tracking.
- **Continual Improvement Management Framework:** A “plan, do, check, act” continual improvement management framework typically includes several components, such as conducting an honest and comprehensive self-assessment; establishing explicit performance objectives and targets; implementing measurement activities; and responding to evaluations through the use of an explicit change management process.

### **Water Utility Measures**

It has been strongly affirmed that measurement is critical to effective utility management. Utility measurement is complicated and needs to be done carefully to be useful. The challenges presented by performance measurement include deciding what to measure, identifying meaningful measures, and making sure that data are collected in a way that allows meaningful comparisons to be made. Consideration of these factors is important if the data are to be used to make real improvements and to communicate accurate information, and help ensure that the information is interpreted correctly.

Within this context, the Committee identified a set of high-level, illustrative example water utility measures related to the Attributes and recommended that, to simply get started on exploring this component of the future sector strategy, these or other example utility measures be made available. These *preliminary* example measures included, for instance, under Operational Optimization, the amount of distribution system water loss; under Operational Resiliency, whether the utility has a current all-hazards disaster readiness response plan; and, under Stakeholder Understanding and Support, whether the utility consults regularly with stakeholders.

It is recommended that a longer-term initiative to identify a cohesive set of targeted, generally applicable, individual water utility measures. The goal would be to provide robust measures for individual utilities to use in gauging and improving operational and managerial practices and for communicating with external audiences such as boards, rate payers, and community leaders.

### **Water Utility Management Resources**

It is believed that water utilities are interested in tools that can support management progress, and that many utilities would benefit from a “helping hand” that can guide them to useful management resources, particularly in the context of the Attributes.

## **CAPACITY DEVELOPMENT**

Capacity Development is a national program to help drinking water systems improve their finances, management, infrastructure, and operations so they can provide safe drinking water consistently, reliably, and cost-effectively. More specifically, the SDWA capacity development provisions establish a flexible framework for OEHS and PWSs to work together to ensure the systems acquire and maintain the technical, financial, and managerial resources necessary to consistently achieve the health objectives of the 1996 SDWA.

West Virginia, in accordance with the 1996 SDWA Amendments, has designed and implements a program to ensure that all new community and new non-transient, non-community water systems commencing operation after August 4, 2000 demonstrate sufficient technical, managerial, and financial capacity to comply with the West Virginia primary drinking water regulations.

Capacity Development is an important component of the SDWA's focus on problem prevention in drinking water systems. The goal of the OEHS Capacity Development program is to assist PWSs to eliminate technical, managerial, and technical capacity weaknesses and thereby ensure the consistent delivery of safe drinking water. The Capacity Development program identifies technical, managerial and financial capacity weaknesses both in systems that are currently in compliance, and in systems that are not in full compliance and provides tools and assistance to remedy these weaknesses.

Technical Capacity is the physical and operational ability of a water system to consistently provide safe drinking water. Technical capacity refers to the physical infrastructure of the water system, including the adequacy of source water and the adequacy of treatment, storage, and distribution infrastructure. It also refers to the ability of system personnel to adequately operate and maintain the system and to appropriately apply technical knowledge to consistently provide safe drinking water.

Managerial Capacity is the ability of a water system to conduct its affairs in a manner that ensures that the system achieves and maintains compliance with the West Virginia primary drinking water regulations. Managerial capacity refers to the system's institutional and administrative capabilities and considers the accountability of the ownership, an effective staffing and organizational structure, and constructive linkages to external entities including customers, regulators and assistance sources.

Financial Capacity is a water system's ability to acquire and manage sufficient financial resources to allow the system to achieve and maintain compliance with the West Virginia primary drinking water regulations. Associated elements include having sufficient revenue to cover costs, access to credit through public or private sources, and use of standardized and accepted accounting, budgeting, and planning techniques.

## **THE NEED FOR ORGANIZATIONAL STRUCTURE**

It doesn't matter if a PWS is large or small; a clear and well-understood organizational plan is vital to its success and long-term viability. Sound organization promotes effective management by uniting the efforts of the governing board, the manager and the employees into the common purpose of operating a successful utility system that meets customer needs. At first glance, the idea of adopting an organizational chart or a chain of command may seem to relate more to larger systems, but in reality, the smaller the system, the more important organization becomes. That is because in a small organization, each employee represents a larger percentage of the staff. Therefore, it is even more important to avoid the duplication of effort and to eliminate confusion.

Developing and implementing a written organizational plan can help achieve those goals. Creating and maintaining an effective organizational plan requires time and careful study. It would be a good idea to involve decision makers, management, and employee representatives into the task. Input from different perspectives can lead to more well- rounded and thorough plan. Following implementation of such a plan, the governing body and management should understand that continuous development, adjustment, and review needs to take place. As the operation changes, the organizational plan should be revised. Any organizational plan needs to consider the ability, needs, and potential of employees. The following are some points to consider when establishing an organizational plan:

- Organization should be based upon the objectives to be achieved and the activities to be performed,
- Each individual should have one "boss" and all directions and guidance should come from that individual,
- Supervisors, at any level, should have a limited number of people for whom they are directly responsible, and
- The number of distinct levels of management should be kept to a minimum.

Delegation of authority should be an objective. This allows decisions to be made by the people who are the closest to the action for which the decision applies. Responsibilities, limits of authority, and the relationship of each organizational department should be clearly stated in approved job descriptions.

In order for any organizational plan to be successful, it must be relatively simple, flexible, and dynamic. That is, it should be a living document and should be regularly reviewed and amended. Once adopted, copies of the plan should be distributed to everyone involved and that includes distributing copies to all board members, managers, and employees. An organizational plan can be an excellent management tool for ensuring that personnel have a clear understanding of their role in the operations of the utility. This plan should be flexible enough to allow job shadowing and continuous staff development.

These elements are important for promoting morale and staff development and in helping employees feel more as a member of the team. Ensuring harmonious relationships while working toward more efficient job performance should be the goal of any organizational plan. Hopefully, the end results will include improved managerial and technical capacity that in turn will lead to improved financial capacity. Any time the three areas of capacity development can advance together in unison, the utility and its employees, and more importantly, the customers, all come out as winners.

## STAFFING AND TRAINING

Even the best designed and constructed treatment facility will not operate at its full capacity without adequate numbers of qualified personnel to manage the processes. In order to plan the staffing of a facility, many things must be considered. Some of these considerations are the number and type of tasks to be performed, the skill level required for those tasks, prior training of personnel, certification of staff and training needs to upgrade skill levels.

### **Staffing**

The numbers and qualifications of staff members will be determined by the size and complexity of operation of the facility.

#### **A. Influences**

1. Plant/System Layout: A plant/system which is compact in nature with centrally located controls will require a much smaller staff than a facility that is spread over a larger area.
2. Processes/Degree of Treatment: Facilities with two to four processes will not require the staffing that six to eight would. A ground-water plant which treats for iron removal, hardness and disinfection will not be as complicated as one treating for iron and manganese, hardness, pH, tastes and odors, turbidity and color with disinfection.
3. Automation: A highly-automated plant may require less staff; however, they must be highly trained and more technically oriented (electricians, instrumentation technicians).
4. Contract Services: A facility which relies upon outside contractors may require less staff. Contracted laboratory services, electrical maintenance, instrumentation maintenance, etc., all will reduce the staff levels and may require staff with less technical capabilities.
5. Operations Schedules: A facility operating on a 24-hour/day, seven-day/week schedule will require four to five times the staff as a facility with an eight hour/day, five-day/week schedule.

**B. Task Classification** (Task classifications identify responsibilities and are broken down into the following general categories).

1. Supervisory/ Management: Supervisors and managers provide the leadership and guidance for the overall operation of a facility. In general, managers plan the operation and supervisors put the plan into effect.
2. Clerical: Clerks manage the data and record keeping of a facility.
3. Laboratory: The laboratory staff performs analyses of water quality for various parameters from which decisions regarding plant operation are based.
4. Operations: The operations staff provide the technical skills required to operate the equipment and processes of a facility.
5. Maintenance: The maintenance personnel provide the skills required to keep the plant equipment in good operating order, and maintain a data base on equipment costs and repairs.
6. Buildings/Grounds: The buildings and grounds personnel keep the buildings and grounds in good repair
7. Distribution Maintenance:
  - a. Foreman

- b. Equipment operator
- c. Truck driver
- d. Laborer
- 8. Customer Service
  - a. Meter readers
  - b. Service personnel (set meters, shut off, turn on, investigate complaints, etc.)

In summary, even though a single staff member may perform more than one task or even all of them, each separate task's responsibilities should be identified.

### **How Are Job Descriptions Prepared?**

After tasks and corresponding qualifications are determined, the tasks can be assigned to certain position titles. The position description will discuss specific duties, supervisory, reporting, and performance level goals.

### **How are position qualifications determined?**

Based upon the description of the position and the tasks involved, certain minimum experience, education and other qualities are necessary for entry level. Listed below are a number of factors which may be considered in determining the qualifications for a particular position.

1. Education (i.e., high school or equivalent, college or technical school)
2. General Abilities
  - a. Reasoning
  - b. Mathematical
  - c. Communication skills
  - d. Mechanical/Technical skills
3. Vocational Training
4. Interests
5. Physical Requirements

### **What are the personnel sources?**

Once the position descriptions are complete and the job qualifications are determined, the utility may obtain people to fill the positions. Primary sources of personnel are listed below.

1. Within the Present Organization
  - a. Promotion
  - b. Transfer
2. Outside Organization
  - a. Related Industries
  - b. Nonrelated Industries

### **Organizational Chart**

The preparation of an organizational chart clearly will define the responsibilities of each position and will provide guidance as to whom to contact for help in emergencies. The organization chart clearly should demonstrate the lines of authority (solid line) and the support channels (dotted line). An organizational chart generally is made up of five major levels.

1. Executive (Authority Board, Council, Commission)
2. Upper Management (Utilities Director, Director of Public Works (Staff Support))
3. Middle Management (Division Manager, Plant Manager (Staff Support))
4. First-Line Management (Foremen, Supervisors)
5. Technical Workforce (Operations, Maintenance, Laboratory, Labor)

## **Certification**

Water system operators must comply with the certification requirements of the Title 64 Series 4.

## **Training Requirements**

Well trained operations and management personnel are essential to the continued successful operation of any facility. Even the best designed and equipped facility will not operate without properly trained personnel. Training provides for compensation of deficiencies in skills and knowledge of entry level employees, remedies for performance deficiencies, and upgrading and/or retraining employees for new equipment, processes and techniques.

A list of training sources available to employees should be prepared by the plant manager. These sources may include:

- OEHS sponsored training programs;
- Local college training programs;
- AWWA
- State water associations (WVRWA, ETC) training programs;
- Private sponsor training programs;
- Organizational (in-house) training programs; and
- Equipment manufacturer.

The list should include a minimum of the following information: Program description; course description; dates, times; and, contact person/organization.

Prior to performing in-house training or recommending outside training programs, it is important that the training accomplish its purpose – improve performance or expand skills. This training analysis is accomplished in three steps.

### 1. Purpose

- a. Improve performance;
- b. Expand skills;
- c. Correct deficient performance.

### 2. Type

- a. Technical
- b. Management
- c. Remedial
- d. Orientation
- e. Certification

### 3. What goals should be met by training?

- a. Set priorities
- b. Establish controls
- c. Provide a basis for evaluation

## **JOB DESCRIPTIONS**

Job descriptions are the building block of organizations. The primary objective of a job description is to help employees and supervisors reach a mutual understanding about important details of a job in order to avoid future problems. This publication discusses the need for job descriptions, how to prepare them, and how to make use of them for more effective human resource management. In addition, some examples of job descriptions for positions in the milking center are included. Job descriptions should never be considered final; they should be open to changes and should be reviewed at least once per year by both employee and supervisor.

There are many reasons for using good job descriptions—some of the most important include the following:

1. **Organization.** The job description helps people understand their responsibilities and how their work contributes to the overall mission of the business.
2. **Training.** It serves as a useful tool for training purposes because it lists the specific tasks that make up the job.
3. **Recruitment.** Clear job descriptions promote an understanding between the employer and the prospective employee. You are more likely to hire the right person if both of you clearly understand the job.
4. **Evaluation.** Employer and employee can compare actual job performance to the expectations outlined in the job description. This helps you recognize a job well done or a need for retraining or discipline.
5. **Defense.** In the unfortunate event that you must terminate an employee for poor performance, the job description gives you a basis for defending your decision.

Job descriptions are really not difficult to write. The best way to begin is by writing your own. This will get you thinking about your responsibilities and how you fit into the organization. It will also help you prepare for questions that your employees might have. Next, take some time to sit down with your current employees and help them to begin writing their job descriptions. Make sure that you explain why you need to develop job descriptions and how you expect employees to benefit from them as well. Your employees might have ideas about parts of their jobs that you might not have thought to include. Finally, you will need to review and make changes to the job descriptions. For new positions you will need to write the job description from scratch. Generally, keep descriptions brief and to the point, but don't leave out important information. Most job descriptions should easily fit on one page. Your goal is to provide a clear picture of the job so that you and your employee will fully understand each other's expectations. A good job description will include the following:

- **Job title.** The job title should accurately describe the job. For example, do not call a job that involves only milking a herdsman position.
- **Summary.** This is a concise definition of the job's major responsibilities, where, and when it is performed. You might use the summary when advertising the position.
- **Qualifications.** A description of any experience, training, or education necessary to perform the job. Also, any physical characteristics essential to perform the job, such as the ability to lift and carry a certain weight. Be sure to avoid statements that might be discriminatory on grounds of race, gender, age, or national origin. Be aware that there are some jobs that young people are not legally allowed to do.
- **Duties or Tasks.** This is the list of all activities that the person will perform. The number of different duties depends on how specialized workers' roles are. Most

employers add at the end of the list “other duties as assigned by supervisor” as a way of including those activities that are not routine. It may be helpful to include the approximate percentage of the worker’s time that each duty will require.

- **Work relationships.** All workers need to know where they fit in the organization. The work relationship section should clearly define who the worker’s supervisor is and how the worker’s position relates to other positions. Be sure that each position only has one supervisor. Job descriptions relate to the staff organization chart—each position that appears on the organization chart should have a job description associated with it. The following two categories are optional. If you use them, don’t be so specific that no changes can be made in the future.
- **Compensation and Benefits.** Include in this section all compensation that is offered. An hourly wage range, insurance, vacation, sick leave, and so on should be clearly stated.
- **Work schedule.** Define work hours as much as possible. Define overtime policy if one applies. If work hours vary with the seasons, make that clear in the description.

Job descriptions are an essential part of the employee-recruitment process. In today’s competitive labor market, water systems need to communicate the image of a well-managed and organized business. Well-constructed job descriptions show that management is aware of specific labor needs and the qualifications and skills that a successful candidate will possess. Job descriptions spell out the specific duties that are required of employees and help candidates to decide if the job will be a good fit for them.

Job descriptions help the manager make effective selections. With the required qualifications and duties clearly specified in the job description, managers can more objectively select candidates based on their potential for job success, rather than on personality traits. Once a candidate is selected, the job description serves as a guide to the skills and knowledge that the new employee will need to perform the job. Those skills that the employee already possesses should be refined and applied in the new position, while skills or knowledge that the employee lacks can be acquired through training.

First, let’s look at some terms. A **job** is a collection of tasks and responsibilities that an employee is responsible to conduct. Jobs have titles. A **task** is a typically defined as a unit of work, that is, a set of activities needed to produce some result, e.g., vacuuming a carpet, writing a memo, sorting the mail, etc. Complex positions in the organization may include a large number of tasks, which are sometimes referred to as **functions**. **Job descriptions** are lists of the general tasks, or functions, and responsibilities of a position. Typically, they also include to whom the position reports, specifications such as the qualifications needed by the person in the job, salary range for the position, etc. Job descriptions are usually developed by conducting a **job analysis**, which includes examining the tasks and sequences of tasks necessary to perform the job. The analysis looks at the areas of knowledge and skills needed by the job. Note that a **role** is the set of responsibilities or expected results associated with a job. A job usually includes several roles.

Typically, job descriptions are used especially for advertising to fill an open position, determining compensation and as a basis for performance reviews. Not everyone believes that job descriptions are highly useful. The cornerstone to any employment decision begins with job analysis. Job analysis is the most basic activity in human resource management. Accurate

information on all jobs is necessary to efficiently direct and/or control the operations of a small business.

Competition and equal employment opportunity legislation has made job analysis a mandatory organizational consideration for small businesses. Because human resources represent the largest cost item for most small businesses, managers must have current and systematized information on all jobs in order to produce products and services efficiently. The myriad of laws, guidelines, and court decisions concerning equal employment opportunity make job analysis necessary. Small businesses have been quite vulnerable on the issue of discrimination in employment practices. One way to defend employment practices is to conduct job analysis and prepare job descriptions.

Job descriptions are the most visible output from job analysis. Comprehensive job descriptions developed from job analysis are used in selection, training, performance appraisal, and compensation. There are many formats used in preparing job descriptions.

### **Job Analysis**

Job analysis is an in-depth study of a job and provides information for job descriptions. The job analyst will gather information about jobs through interviewing employees, observing performance of certain tasks, asking employees to fill out questionnaires and worksheets, and collecting information about a job from secondary sources such as the *Dictionary of Occupational Titles*.

The job analyst will write-up the results of the analysis and review them with the job incumbent. The documentation is then presented to the incumbent's supervisor for review (often the incumbent's supervisor is the job analyst.) The supervisor may add, delete or modify duties, knowledge, skills, abilities, and other characteristics. After supervisory approval is obtained, the documentation is forwarded through channels for final approval. A signed and dated job description is then prepared. This job description becomes the official record for this particular job.

### **Role of Job Incumbent**

The job incumbent has an important role in this process. The following suggestions should help incumbents assist the job analyst:

- Spend some time thinking about the job.
- Make notes, or keep a diary of work related activities;
- At the outset fully explain the incumbents' concept of the job to the analyst;
- Focus on the facts - do not overstate or understate duties knowledge, skills, abilities, and other characteristics;
- Refrain from side issues. The analyst is only concerned with the job itself. Job performance, wages, complaints, relationships with co-workers, etc., are not relevant to this activity;
- Remember that the incumbents' input is critical; however, establishing the boundaries of the job is a management decision; and
- Be aware that there will be no adverse consequences from job analysis. For example, no person's salary will be reduced and no person's job will be eliminated. The analyst may recommend changes in title or other realignments, subject to management decision.

## **Definitions**

The following is a list of commonly used job analysis terms.

- Job duty - a single specific task.
- Knowledge - a body of information applied directly to the performance of a duty.
- Skill - a present, observable competence to perform a learned activity.
- Ability - a present competence to perform an observable behavior or a behavior that results in an observable product.
- Physical characteristic - the physical attributes employees must have in order to perform job duties; unaided or with the assistance of a reasonable accommodation.
- Credentials and Experience - the minimal acceptable level of education, experience, and certifications necessary for employment.
- Other Characteristics - duties, knowledge, skills, and abilities that do not have a logical place in the job description.

## **Writing Style in Job Descriptions**

Job descriptions should be written in brief and clear sentences. The basic structure for sentences in a job description should be "implied subject/verb/object/explanatory phrase." It is best to use action verbs like "types" and "files."

## MANAGEMENT COMPONENTS

Owning and operating a public drinking water system is a big responsibility. There are few things more important to maintaining good health than having access to safe drinking water. The purpose of this section is to assist owners/operators of small water systems to meet the requirements of state and federal drinking water laws, and ultimately to protect the health of their customers.

Much of this guide will be useful on a day-to-day basis. The guide can be used as a filing system for system personnel and can serve many purposes including providing a:

- central location for numerous water system records and system policies;
- process to evaluate present and future system deficiencies and improvements necessary for continued water system operation; and
- a list of operation and maintenance duties that can be reviewed, used and improved as necessary by existing and future water system personnel so they may effectively manage and operate the water system.

This section contains a description of content of the 18 elements. Some elements can be completed quickly (e.g., fill in information that should be readily available or attach documents you should have in your files). Other elements may take more effort (e.g., if one does not exist, create a service area and facility map or develop a cross connection control program).

Working through this section may appear challenging at first, but from the perspective of assuring effective long term management of the system, each element is important. **To help prioritize the efforts, please focus on the first five elements of this section first.** These elements primarily focus on accurate record keeping and water quality monitoring/reporting. They are absolutely essential and need immediate attention. Once these are completed, continue to work through the section and develop the other technical, managerial, and financial elements.

- **Water Facilities Inventory:** Provides information about the water system (e.g., source capacity, number of connections and population served, etc.).
- **Water Quality Monitoring Program:** Identifies the type, frequency and location of baseline water quality monitoring required for each existing, permanent and seasonal source and distribution system.
- **Consumer Confidence Report:** Creates an annual educational water quality report, for distribution to your customers, which summarizes monitoring results.
- **Preparing for Your Sanitary Survey:** Identifies things a system can perform to prepare for sanitary surveys.
- **Annual Operating Permit:** Provides a compliance status report to system to correct any identified problems.
- **Cross-Connection Control Program:** Documents cross-connection control program efforts to protect system from possible contamination.
- **Emergency Response Plan:** Contains phone numbers of parties to contact in case of a system emergency.
- **Service Area and Facility Map:** Contains service area boundaries and lists major system components.

- **Operation and Maintenance Program:** Lists system personnel information (name, title, phone #) and identifies functions, frequency (e.g., weekly, monthly), and location of component maintenance.
- **Wellhead Protection Program:** Summarizes the system's wellhead protection program.
- **Water Right Documentation:** Lists the right (Permit, Certificate, or Claim) that includes the number of acre-feet and gallons per minute allowed to be withdrawn.
- **Record of Source Water Pumped:** Charts the amount of water pumped from system sources.
- **Water Usage:** Charts the number of system users, the average consumption per user, and the estimate of total system usage.
- **Water Conservation Program:** Summarizes the system's conservation efforts that promote the wise use of water.
- **Component Inventory and Assessment:** Verifies component approval status. Inventories system components. Identifies possible system improvements in the next 6 years.
- **List of System Improvements:** Identifies the year, cost, and financing method for anticipated system improvements.
- **Budget:** Includes revenues, expenses and capital improvement financing.
- **System Management:** Documents the system's management practices including the decision making process.

## **FORMAL COMMUNICATION**

Is there a formal communication linkage between the water system operator and one or more members of the governing board or board of directors? Formal communication puts in place a process to allow the governing board to be fully informed and in control of the water system decisions. Management capacity is enhanced when formal communication channels are created between governing board members (usually part time officers) and full time professional operations staff. For example, city councils may require their key operations staff to attend their monthly council meetings to report on water system activities, or a council may designate one of its members as the liaison or “point person” for water system issues.

### **System Policies**

Good management will increase the ability of the system to achieve its mission, as well as reduce liability exposure. System policies help create the frames of reference necessary for the professional staff to determine the scope of authority granted by the governing board. Management teams that create written guidance documents also provide a measure of continuity and guidance for water system personnel. Good business practice demands that the policies listed below should be in written form, adopted and periodically reviewed by the water system management team. What is most important is that the written policy exists, that the content is appropriate for the size of the water system, and that the management team is committed to reviewing and updating the policy periodically. The content of the policies is more important than the structure.

The DWSRF loan application requirements identify the following 6 policies as indicators of management capacity. A general description of each type is also offered below.

### **System Operations Manual or Policy**

This policy provides technical guidance on how the water system is operated. This manual or policy is likely to be the most detailed guidance document of the six listed here. Operations policies also include guidance for monitoring and reporting of water samples and testing results.

### **Board Governance Policy**

The board governance policy reflects the protocols for the governing board’s activities. This policy includes qualifications for election of board members, the number of members who may serve and their terms of office, rules regarding the conduct of meetings, etc. Establishing board protocols can improve the efficiency of board meetings and result in effective use of officers’ time.

### **Personnel Policy**

The personnel policy would include guidance regarding hiring, probation, dismissal and disciplinary procedures; provide detail on employee compensation and fringe benefits; establish requirements for conduct and performance; describe job descriptions and expectations, and explain procedures for employee evaluation.

### **Safety and/or Risk Management Policy**

Accidents, experienced by both the water system staff and the customers they serve, can cause significant disruptions of water service as well as create unexpected financial liabilities. A safety and risk management policy attempts to confine the scope of authority of employees and managers in order to reduce the risk of such negative financial exposure. A water system’s

insurance provider can offer assistance in establishing risk management guidelines to limit liability.

### **Operating Emergency Plan**

Every PWS needs to know how it will react to natural disasters and other emergencies. Specifically, the water system management team needs to know what steps are to be taken and what actions are to be accomplished given a variety of threats to service delivery. Since the events of September 11, 2001, threat readiness and response is absolutely necessary to commit to written policy, especially in the face of terrorist threat to essential facilities such as public drinking water systems.

### **Customer Service Policy**

A water system is in the business of providing service—safe drinking water—to its customers. A customer service policy strengthens the relationship between the water system and its customers because it clarifies how the water system will relate to those it serves. This policy should include public information guidance, complaint resolution procedures, problem response requirements, billing and other notification rules, and other actions the system can take to assure the customers that the water system is being run in the most professional manner possible.

Organizations exist to help provide guidance on the content of each of these policy documents. Water systems with limited staff capacity to create these policies can utilize and modify model policies in each category. Organizations such as the Rural Community Assistance Corporation, the West Virginia Rural Water Association and the American Water Works Association have excellent model policies. In addition, similar sized water systems may be good sources of sample policies.

### **Professional Support Regarding Engineering & Legal Services**

Water system capacity in the areas of engineering and legal services (as well as other professional services such as accounting and auditing) is increasing essential to successful service delivery over time. While water systems can assure such capacity by hiring these professionals, most small systems can gain these capacities by retaining engineering and legal services by contract, or by hiring these professional services as necessary.

Legal and engineering services are specifically identified for capacity assessment purposes by the state of West Virginia. Each profession provides to the water system the capacity to keep pace with regulatory requirements and to advise response to changes in these regulatory requirements.

### **Record Keeping**

A final indicator of management capacity used by the State of West Virginia is record keeping. Well-managed PWSs are expected to have record keeping systems that can easily yield important records for review by the operations staff, the governing board members, customers (where appropriate), and regulatory agency staff of the OEHS and EPA. Record keeping systems create and preserve an important record of the water system's status and activities. For the purposes of **Drinking Water State Revolving Fund (DWSRF)** loan applications, an evaluation of the condition and content of the record keeping system is made by OEHS.

For a water system seeking to demonstrate management capacity relative to record keeping, the following questions should be answered affirmatively:

- Does this water system have current “as built” engineering drawings of the system facilities?
- Does this water system effectively maintain system operating records for operator, board member, customer, EPA and OEHS reference?
- Does this water system effectively maintain records of correspondence with the appropriate agencies?
- Does this water system effectively maintain records of correspondence with the EPA?
- Does this water system effectively maintain records of the results from required water testing as well as CCRs?

## **EMPLOYEE HANDBOOKS**

### **What is an employee handbook and why do we need one?**

The answer to this question is: 1) it lets employees know what is expected of them, 2) it sets the general guidelines of the employment relationship, and 3) it needs to be updated on an annual basis. Should my utility have an employee handbook? The answer is “YES”. The handbook applies equally to all employees and can be a valuable piece of evidence in a lawsuit. It also is a well-written handbook which is a powerful tool for the utility and is a useful guidance to an employer’s policies and procedures.

### **What goes into an employee handbook?**

This can differ with handbooks, but below are some suggestions that could be used:

- A clear statement about the “at will” employment relationship;
- Accepting employment = agreement to conform to the rules and regulations of the employer;
- A disclaimer concerning oral or written statements contrary to what is in the handbook;
- The handbook does not create a contract between employer and employee, but serves as a set of guidelines for employees to follow;
- Is proof that the employee received the handbook and that they acknowledge the content of the handbook;
- Lists the conditions of employment; and,
- And anything else pertinent to the policies and procedures of the utility.

Termination of an Employee – The handbook need to specify the policy for termination of an employee and needs to be followed to the tee. This is important in that more lawsuits are filed for wrongful termination because the procedures listed in the employee handbook weren’t followed exactly. This policy could contain the following:

Pre-termination Evaluation:

- Progressive discipline procedure in place;
- Termination Process in place;
- Documentation supports termination action;
- Potential of lawsuit or discrimination claim; and,
- Supported by solid facts and consistent with prior actions.

Termination Meeting:

- Two employer representatives are present;
- Give explanation/reason for termination;
- Explain benefits due/being withheld/final paycheck;
- Let employee respond; and,
- Document meeting.

### **Employee Handbooks are a Wise Business Practice**

Every water and wastewater utility should have an employee handbook that explains and outlines policies to staff members. Not only should the handbook inform employees about policies and procedures, it should also communicate expected standards of performance and conduct. As a

practical matter, having employee handbooks can prove invaluable in today's legal realm where the inconsistent enforcement of policies can result in discrimination lawsuits.

A well-designed handbook can have a positive influence on morale. It can also introduce new employees to your utility and its mission. Ideally, the handbook should help bring about a consistency of practice that will promote fairness. When there are no written policies, managers are left with an unprofessional 'learn as you go' type of management system. This can be risky at best. There are few issues more destructive to the work place than an employee's belief that management decisions are purely subjective and based on situational ethics depending upon who is affected. The uneven application of rules never promotes unity and teamwork.

An employee handbook should serve as a reference guide to help managers and supervisors take the appropriate actions for specific situations regardless to whom it affects. Without a handbook to rely on, managers can be left to their own reasoning. This can often lead to misinformed and inconsistent actions. Hence, possible illegal decision-making can follow and this is always bad for business.

Above all, a handbook should clearly state policies for hiring and it must include policies against harassment and discrimination. Employee safety should also be prominently addressed in the handbook. Job descriptions should also be included. The handbook should also clearly spell-out disciplinary measures and the steps leading to termination. While state and federal laws sometimes require that certain policies and procedures be posted on employee bulletin boards, the handbook should be presented every staff member. Distributing the handbook to all employees ensures that a utility's most important standards were made available to every staff member. It also allows employees to have their own reference when questions might arise and thus prove to be a time saving document.

There is no single way to write a handbook. The best employee handbooks are organized logically, with the policies grouped into sections. The pages should be numbered, and there should be a table of contents that allows employees to find specific areas with ease. If your utility does not currently have an employee handbook, you can contact West Virginia Rural Water Association and members of our staff will assist you and provide examples from other utilities to help serve as a guide.

Once your handbook is completed, the manager should take steps to introduce the handbook to employees in a non-threatening manner. Staff members might feel overwhelmed when a set of "rules" is handed to them. I would recommend introducing the document at a staff meeting and then follow this initial group meeting with individual conferences with each staff member. Managers should explain that the handbook is documenting the policies that the utility has always had.

It is critically important the handbook include an employee acknowledgement form. Each staff member should sign and return this form for the employee's personnel file. The form must have an acknowledgement that the employee has read the handbook and agrees to adhere to the policies as stated in the document. The importance of this acknowledgement cannot be stressed enough, especially if an employee matter is taken into litigation. With an employee handbook, managers will have another effective tool for communicating with staff and for protecting the utility when a bad hiring decision has been made. Remember, an employee handbook is a smart management decision.

## OPERATING BUDGETS

Financial viability is the ability to obtain sufficient funds to develop, construct, operate, maintain and manage a PWS, in full compliance with local, state and federal requirements on a continuous basis. In short, that means you should run your water system like a business. PWSs should manage their finances to ensure they have enough funds for future needs as well as daily ones. When you have enough money, you are better able to ensure safe and reliable drinking water now and in the future.

This is accomplished by preparing an annual operating budget. A budget is a major tool for tracking all necessary and authorized expenditures to ensure that the water system is operated and maintained in order to deliver safe and pleasant tasting drinking water at a proper pressure to the consumer's tap 100% of the time.

Budgeting is not only a basic financial management tool but it is also an occasion for careful planning for municipal activities for the coming year and making reasoned and balanced decisions on how resources will be spent. Here are some of the significant purposes:

1. The budgeting process allows the elected governing body to express its goals for community services for the coming year in a single document that is readily understandable by the citizens.
2. The budget allocates revenues among various municipal services needs. Careful decisions on what is important have to be made in determining where the limited amount of money available will be spent.
3. The budget provides citizens information on how their tax dollars will be spent, and the process allows citizen input in the making of these decisions.
4. The budget provides a framework for monitoring the performance of revenues and the accumulation of expenditures during the year. If revenues do not match estimates, or if expenditures are significantly higher than planned, quick action must be taken during the year to bring expenses in line with income.

Budgeting is a process to assist the commissioners to anticipate impacts to revenue of costs, any long-term debt, and/or projected capital repairs and improvements. A projected budget will help establish and defend the proper amount of savings in accounts for emergencies, debt payment, and future repairs and improvements. Budgeting will alert the commissioners to an imbalance of expenses to revenue. Budgets are a tool to ensure that the system can live within its means and sustain water quantity and quality.

Major elements of a budget include:

- Revenue
- Operating Expenses
- Debt Service Payments
- Reserves
  - Emergency Operating Expenses
  - Debt Service Reserves
  - Reserves for Asset Replacement

Develop an operating budget with enough income to pay for all regular maintenance and operations needs. Make sure to factor in inflation by multiplying each year's line-item costs by a

2 to 5 percent inflation factor. Remember, inflation is cumulative. You should add inflation to each year's costs based on the previous year's costs. To select the most realistic inflation factor for your area, check the Consumer Price Index that your county or nearest city uses. Your budget should also include debt payments and contributions to your reserves. Because all water systems are different, there is no set formula for how much goes towards each reserve account. Your PWS's operator and board should decide together how much to contribute annually to each reserve based on the water system's needs.

### **Benefits of Financial Viability**

- Predictable Funding for Capital Improvements - Having available funding and a plan for capital improvements will keep your water system running smoothly and efficiently.
- Improved System Efficiency - Financially healthy PWSs have well maintained and regularly replaced equipment that runs better, saving water, electricity and wear and tear.
- Cost Savings - Deferred repair or replacement costs are often much higher when you let equipment age and fail.
- Eligibility for Grants and Loans - Most grant and loan programs require PWSs to demonstrate sound finances. If you spend time up front improving financial health, you are more likely to receive grants or loans.
- Emergency Response - Earthquakes, windstorms, electrical outages, flooding and vandalism are examples of unforeseen emergencies. PWSs must have adequate cash reserves available to pay the costs associated with emergencies, such as providing bottled water to customers and returning to normal operations.
- Peace of Mind - When PWSs have enough funds to pay for daily maintenance and operations, capital improvements, and unforeseen emergencies, their operators, board members and customers do not have to worry or struggle to find means of payment.

## COMPLIANCE MONITORING

Every water system has its own compliance monitoring schedule provided by OEHS by February each year. A general monitoring schedule is provided below. Each PWS is strongly encouraged to contact the OEHS to obtain the most up-to-date version of the chart for their system. It will indicate the most recent monitoring results on record, and subsequent samples that must be collected.

### Monitoring Schedule

<b>TESTING/PARAMETER</b>	<b>HOW OFTEN/HOW MANY/WHERE</b>
BACTERIOLOGICAL	monthly/based on population served/distribution system
FREE CHLORINE RESIDUAL	every 4 hours/based on population served/point of entry
TOTAL CHLORINE RESIDUAL	daily/one/distribution system*
TURBIDITY	Every 4 hours/one/point of entry
NITRATES	annually/one/point of entry
NITRITES	annually/one/point of entry**
MORS	monthly/not applicable/send to OEHS
CROSS-CONNECTION DEVICES	annually/not applicable/distribution system
FLUORIDE	daily/one/distribution system***
LEAD & COPPER	every 3 years/based on population served/distribution
THM&HAA5	quarterly/based on population/distribution
TOC	monthly/two/one at raw and one at point of entry
IOC	annually/one/point of entry
VOC	annually/one/point of entry
SOC	Every 3 years/one/point of entry
RADIONUCLIDES	varies/one/point of entry

\*Total chlorine residuals must be analyzed and recorded with bacteriological samples.

\*\*If 1<sup>st</sup> sample is less than 1 mg/L, no further samples are required.

\*\*\*Once a month a sample must be submitted to a certified laboratory.

## MONTHLY OPERATIONAL REPORTS

The Compliance and Enforcement (C&E) Program of OEHS has noted that many PWSs have not been completing the **monthly operational reports (MOR's)** correctly, which will result in a violation being issued. Under the West Virginia *Public Water Systems* (64CSR3) rule, monthly records are required to be submitted. The specific language of concern to operators is in § 64-3-12, Public Water System Reporting Requirements:

**§ 64-3-12.5. A public water system shall submit a written summary of the public water system operation, test data, and other information as may be required by the commissioner to the commissioner at least once per month. The commissioner may require more frequent reports in cases where there are public health concerns.**

**§ 64-3-12.6 All reports and summaries required by this rule or federal regulations adopted in this rule shall be submitted in a manner or form approved by the commissioner.**

A review of the MOR's have been conducted over the past several months and letters have been mailed with items of concern noted to systems, which has had some positive effects, but there is still a high number of problems. The two major problems associated with the MOR's were inadequate treatment and/or unqualified operators, both having a high potential for adverse public health effects. When a PWS is accused of providing unsafe water, OEHS's position will be detrimental to the PWS if the monthly operational reports indicate that the water was not treated properly, or if an uncertified operator signed the report.

A plan has been devised to address this problem, each month, a number of PWS MOR's will be picked at random from all active systems. These reports will be reviewed in detail, violations issued accordingly, forwarded to the District Offices for one-on-one technical assistance, if appropriate, and forwarded to Certification and Training, if appropriate, for action against the operator. If problems are identified, the system will be tracked until no violations are noted. As systems are noted "in compliance" another system will be picked at random to take the compliant systems' place, until all MOR's have been reviewed, and systems are submitting satisfactory MOR's.

For your information, here is a breakdown of the top ten problems:

1. Inadequate free chlorine residual;
2. Chlorine residual not monitored daily;
3. All sheets required not submitted (EW-90);
4. Inadequate total chlorine residual;
5. Questionable location where a total chlorine residual was obtained;
6. Improper Operator Classification;
7. No location total chlorine;
8. No exp. date and/or classification noted;
9. No free chlorine recorded; and,
10. Expired certification.

A typical ground water system problem is minimum free chlorine residual, after the 30 minute contact time, is tied to the pH of the treated water. If no pH is measured, the minimum required free chlorine residual is 1.0 mg/L. Total chlorine residual is required to be monitored every day

that water is available to the public. Free chlorine residual is required to be measured every day that water is treated.

A typical surface and ground water under the influence system problem is the EW-90A and/or EW-90B is not completed or not attached.

A minimum total chlorine residual of 0.2 mg/L is required throughout the distribution system. Many systems are reporting 0.0 mg/L or 0.1 mg/L.

The location is being asked to verify that it would represent a good location in the distribution system for District Office personnel, when a site visit is conducted. Most of these problems are where the location appears to be at the plant or entry point (or before), which would not represent the total chlorine residual in the distribution system.

Another typical problem is a Class II water system MOR signed by a Class I or 1D. It is also a problem if no location was indicated on the MOR or if the MOR was signed, but no classification and/or no expiration date was noted. The assumption by C&E will be that the person signing does not hold a current certification. Similarly, if the MOR was signed, but based on the expiration date, the operator's certificate is not current, it is not considered within compliance.

Free chlorine residual is required to be measured each day that water enters the distribution system.

Other common problems include:

- No free chlorine residual recorded at all;
- The wrong form was submitted;
- The sampler's initials were not indicated;
- The MOR was not signed at all;
- No total chlorine residual was recorded at all;
- The chlorine residuals were placed in the amount of chlorine added;
- The chlorine residuals did not have a decimal;
- A rubber stamp for the operator's signature; and,
- One report with exceptionally high chlorine residuals (over 5.0 mg/L).

## **MONTHLY OPERATIONAL REPORT FORMS**

Copies of these forms must be made and retained by the system and the original is sent to OEHS by the 10<sup>th</sup> of the next month. Remember all forms must be complete, legible, signed and dated. **The original must be signed by a certified operator in ink.** Also remember to use the most current version of each form. All forms are available on the OEHS website at <http://www.wvdhhr.org/oehs/eed/dm/mor.asp> or by phone request from the Certification and Training Program at (304) 558-2981.

- [EW-103](#) Groundwater Systems Form
- [EW-210](#) Purchase Systems Form
- [EW-90](#) Surface Water Series Form
- [EW-80](#) Fluoride Form

## MINIMIZING REPORTING VIOLATIONS

According to Federal regulations, PWSs are required to submit test results (and reports) to the OEHS no later than ten (10) calendar days from the end of each applicable monitoring period. Here are some ways your system can minimize the chance of receiving a reporting violation.

- Sample early in the monitoring period. This gives your system time to take another sample in the event the lab, post office, or both fail to provide test results in a timely manner.
- Submit your system's results via Certified Mail. If there are problems with delivery reliability in your area, consider sending us your results via Certified Mail, which provides the sender with a mailing receipt from the US Postal Service.
- Make sure results are mailed to the correct address and be sure the "ATTN" line is addressed to Data Management.
- Always include the following information on each test result (or report sheet):
  - PWSID number;
  - Water system name;
  - Treatment plant name (if you have multiples); and,
  - Sample location name.
- Call Data Management to confirm receipt of test results.
- All test results must be submitted to the OEHS central office in Charleston, WV to receive credit for compliance.
- Make sure your chief operator receives a copy of the current year's monitoring schedule. Monitoring schedules are mailed in late January each year. Your chief operator is responsible for arranging appropriate and timely testing during the correct compliance period and ensuring results and reports are submitted to the OEHS on time.

## **SAFE DRINKING WATER INFORMATION SYSTEM**

Public drinking water information is stored in the Safe Drinking Water Information System (SDWIS), the EPA's Safe Drinking Water Information System. SDWIS contains information about PWSs and their violations of EPA's drinking water regulations, as reported to EPA by the states. These regulations establish maximum contaminant levels, treatment techniques, and monitoring and reporting requirements to ensure that PWSs provide safe water to their customers. This query will help you to find your drinking water supplier and view its violations and enforcement history since 1993.

Information in the SDWIS database can be freely accessed at the following website: [www.epa.gov/enviro/html/sdwis/sdwis\\_query.html](http://www.epa.gov/enviro/html/sdwis/sdwis_query.html) through the use of a query. Queries that return a large volume of data may terminate prematurely due to system limitations. A few examples of constraints for a query are: a single session can be 15 minutes in duration; and a session may stay idle for 7.5 minutes, at which time it will be terminated. So it is important to develop queries that return small batches of data and terminate the session as soon as your queries have been executed, so others can access the database.

This query form allows you to retrieve Safe Drinking Water data from the SDWIS database in Envirofacts. This is a brief description to the Safe Drinking Water Query Form. For help understanding and using the data in this system, consult the [User's Guide](#). For national and state-by-state information, please see the [drinking water facts and figures page](#).

### **How to get information about your PWS?**

#### **Step 1: Find your water system**

- Select the state where you live.
- At the line that says "Water System Name" select "containing" and then type the name of your water system is (it doesn't need to be the whole name) and press the search button, e.g. "Jonesville".
- Scan the list of PWSs. Do any of these appear to be your system? Look carefully at the Water System Name, Principle County Served, and Population Served to determine if this is your water system.
- If this search also fails, try either a county search (which will show you all the PWSs which principally serve a specific county) or a search by system size (where you can locate, for example, all the PWSs in your state that serve over 100,000 people).
- If neither of these two searches work, try a water system name search again using less specific words, e.g., "Jones"

#### **Step 2: View your water system**

- Once you have located your water system, select it by clicking on the Water System ID number. This will take you to a screen which will list any violations your system has had of EPA safety standards for drinking water.
- If there aren't any violations listed, your water system meets all federal drinking water safety standards, and your water should be considered safe to drink.

### **Step 3: What if there are violations?**

If there are violations, there are several key things you should look at:

- When did the violation occur? (Look at beginning and ending dates of the violation period to give you the time frame the violation occurred in.) Was the violation recent or did violations several years ago and not since then? Is there a pattern of violations?
- What type of violation occurred? Violations will be displayed in two tables. The first table lists "health-based violations." These violations occur when a PWS detects levels of a contaminant exceeding the safety level (called the maximum contaminant level) or when the water system fails to treat the water as required to remove particular contaminants (called a treatment technique violation). Other violations include monitoring and reporting violation (which indicate that the water system failed to complete are required sampling or to do so in a timely manner). Specific definitions for what each violation means are available by clicking on the column [Type of Violation](#).
- What contaminant was the violation for? Click on the contaminant name to see why each is regulated by EPA and what its health effects are at levels above EPA's safety standards.

Notes: For many contaminants, an exceedence of the EPA safety level (MCL) may not by itself be a cause for immediate concern. Many contaminants are only a concern if ingested at levels well in excess of the safety standards over many years.

Monitoring violations do not necessarily indicate that the drinking water is not safe. Monitoring violations can occur for many reasons; the best way to find out why your system has monitoring violations is to call your water system directly.

### **Step 4: If there were violations, what has been done about it?**

This question is answered in the follow-up action section following each violation. Look to see if any actions have been taken. Actions can be taken by either the Federal Government (EPA) or by states. If no action has been taken for a violation, as recorded in SDWIS, one of four things has occurred: an informal action (not federally defined) was taken to correct the problem, a formal action (federally defined) was taken to correct the problem but not reported to EPA, no action was taken to correct the problem, or an action to correct the problem is pending.

If action has been taken and reported, look at:

- What action was taken? (By clicking on the column heading, [Action Taken](#), you can see what each individual action means).
- When was the action taken? (Enforcement Action Date)

### **Step 5: How can I find out more?**

If you are concerned about the violations your system has, there are several things you can do to find out more information.

- Contact your water system to find out the latest testing results and what steps it may be taking to address violations. Look in the mail for a new annual water quality report (sometimes called a consumer confidence report) that your water system is required to prepare if it serves more than 25 people year-round.
- Contact OEHS and ask what the state is doing to address violations.

- Find out more about the Safe Drinking Water Act and EPA's Drinking Water Program by calling the Safe Drinking Water Hotline at 1-800-426-4791 or by looking at the Office of Ground Water and Drinking Water web site.
- Find out how you can get involved in protecting your drinking water.

**NOTICE:** EPA is aware of inaccuracies and underreporting of some data in the Safe Drinking Water Information System. We are working with the states to improve the quality of the data.

**Reference:** [www.epa.gov/enviro/html/sdwis/](http://www.epa.gov/enviro/html/sdwis/)

## RECORD KEEPING

Keeping of adequate records of performance is an integral part of good water treatment plant operation. Only by making a clear and concise memorandum of what has happened and what has been accomplished will the experiences be of assistance in meeting future operation situations. Pertinent and complete records are a necessary aid to control procedures. Above all, records should be used as a basis for plant operation and for interpreting the results of water treatment.

Records also provide an excellent check on things done or to be done, especially regarding maintenance problems. Equipment in water treatment plants requires periodic services; some daily, some weekly, and others monthly or yearly. Adequate records show when service was last performed and when the time for service approaches. Thus a schedule can be maintained, with nothing overlooked or forgotten.

Significant details of day-to-day experience provide a running account of plant operation and thus have an important historical value. When accurately kept, records provide an essential basis for the design of future changes or expansions of the treatment facilities for other locations where similar problems may be encountered. In the event of legal questions in connection with water treatment or plant operations, accurate and complete records would be urgently required as evidence of what actually occurred at any given time or over any particular period of time. Thus, records and their proper maintenance are essential in any type of water treatment. However, only those records should be kept which are known to be useful; the temptation to accumulate minutiae of no significant value must be guarded against.

In summary the main functions of records are to:

- Satisfy legal requirements;
- Aid the operator in solving treatment problems;
- Provide an alert for changing raw water quality;
- Show that the final product is acceptable to the consumer;
- Show that the final product meet plant performance standards;
- Show that the final product complies with the WV Drinking Water Standards;
- Determine equipment, plant, and unit process performance;
- Aid in answering complaints;
- Anticipate routine maintenance;
- Provide cost analysis data;
- Provide future engineering design data; and,
- Provide the basis for monthly or annual reports.

### **Information To Be Included**

The extent to which record keeping should be practiced depends entirely upon their potential use. The type of treatment, the volume of water treated, and the kind and importance of installations auxiliary to the treatment plant will control the amount of necessary record keeping. Some of the basic items of information to be recorded are:

#### **Source Water**

Raw water temperature

Raw water quality

Air temperature  
Rainfall data  
Raw water quantity used  
Capacity

### **Treatment**

Amount of water treated  
Chemical dosages  
Total amount of chemical used  
Amount of water filtered  
Number of filters in service  
Number of hours filters are in service  
Final loss of head before filter was washed  
Amount of wash water used  
Length of backwash  
Rate of backwash  
Daily results of laboratory tests

### **Pumping Stations**

Total amount of water delivered by each pump  
Suction and discharge pressure  
Number of hours of pump operation  
Tank levels

### **Other**

Maintenance schedules  
Distribution system pressures  
Master and individual meter readings  
Valve and hydrant operation and maintenance

In addition to these basic data items, each water supply system should have:

- hydrant and valve maps for the distribution system
- a list of material and equipment suppliers
- a central file of instruction manuals for treatment equipment or processes
- all records required by the PWS Regulations
- a description of the basic functions of automatic control systems
- a safety program
- a cross-connection control plan
- engineering plans and specifications for past construction
- names, addresses, and telephone numbers of nearby operators and personnel of the city council, district, or regional health office
- copies of the watershed rules and the latest watershed inspection report
- the procedure for adjustments necessary in case of a major fire

The above are just a few of the many data items that make up good records. Each PWS has its own critical areas for which data are necessary.

When laboratory determinations are made, it is essential that not only the final results of each test be recorded, but also that all of the test data, frequently called the working data, such as buret readings and the necessary computations, be noted for future reference. Although such details may seem superfluous, should any question arise as to the accuracy of final data obtained in the laboratory, the notes on technical procedures, if available, will be evidence of the accuracy or inaccuracy of the final result reported. Thus, for his own protection in maintaining the integrity of his work, the analyst in the laboratory should keep complete records in most cases. This means that full records of tests must be maintained in the laboratory, although the separate plant operation records will contain only the final result of such laboratory determinations.

Frequently, state and municipal regulations govern the operation of water treatment installations. These regulations require that certain operating records be maintained and reported to the supervising agency at specified intervals. These records must be kept, but should be in addition to adequate plant operating data and should not be considered a substitute for plant records.

## **MAINTAINING RECORDS & REPORTS**

It is important that water system personnel maintain various reports and records for planning and proper management of the system operation. It is equally important to know the significance of each report and record because the operator is responsible for them. Technical reports and records are generally viewed as those dealing with the physical operation and maintenance of the water system's facilities. These reports, like financial reports, can be valuable tools for good decision-making and good day-to-day management, and can be used as a gauge to help determine the financial integrity and condition of the system.

Good records also allow operators to react to potential problems and plan for future expansion. Accurate historical data allows Board Members to make more informed decisions regarding projections for system improvements. This data can also be an invaluable asset in helping to recognize areas of preventative action. The following reports or records should be used by systems:

### **Daily Operating Report**

This report lists such things as the amount of water purchased or produced, meter readings, and the amount of chemicals used in the treatment process. The report is completed on a daily basis. It is advisable to maintain these records in the files for ten years.

### **Water Loss Report**

The term "water loss" is generally defined as the difference between the amount of water produced or purchased and the amount of water sold to the customers (as described above).

### **Operation and Maintenance Records**

It is essential to know when equipment was installed or repaired, the number of hours operated or other maintenance performed. Operation and maintenance records cover all the physical facilities of the water system including storage tanks, meters, pumps, vehicles, fire hydrants, valves, etc. Operation and maintenance manuals should be available for all appurtenances.

### **Emergency Response**

Emergency planning is an important responsibility for governing bodies of PWSs. Mayors/Board Members should make sure that the PWS has contingency plans to handle emergency situations. Good emergency planning includes guidelines to help the system initiate preventive measures directed toward potential emergencies. Several areas in which Mayors/Board Members should plan for emergency response and prevention include the following:

- Emergency and standby systems including supply options for contamination, main breaks, drought, flood, or other disasters;
- Mayors/Board members should have access to all federal and state disaster emergency service numbers in the event of an emergency;
- Emergency conservation plans; and,
- Plans for emergency staffing.

## **TOTAL COLIFORM RULE**

**The Total Coliform Rule (TCR)** is the Federal regulation establishes a maximum contaminant level (MCL) based on the presence or absence of total coliforms and monitoring requirements for coliforms in drinking water. It requires every regulated system to periodically collect samples and analyze them for coliforms. The number of routine samples required each month depends on system size. Samples must be collected according to a written “Sample Site Plan” approved by the OEHS. The TCR applies to all public water systems.

Coliform bacteria and chlorine residual are routine sampling and monitoring requirements for all PWS in WV. The coliform bacteriological sampling is governed by the TCR of the SDWA. The TCR requires all PWSs to monitor their distribution system for coliform bacteria according to the written sample site plan for that system. The sample site plan identifies sampling frequency and locations throughout the distribution system that are selected to be representative of conditions in the entire system. Coliform contamination can occur anywhere in the system, possibly due to problems such as; low pressure conditions, line breaks, or well contamination, and therefore routine monitoring is required. A copy of the sample site plan for the system should be kept on file and accessible to all who are involved in the sampling for the water system.

The number of samples to be collected monthly depends on the size of the system. The TCR specifies the minimum number of coliform samples collected but it may be necessary to take more than the minimum number in order to provide adequate monitoring. This is especially true if the system consists of multiple sources, pressure zones, booster pumps, long transmission lines, or extensive distribution system piping. Since timely detection of coliform contamination is the purpose of the sample site plan, sample sites should be selected to represent the varying conditions that exist in the distribution system. The sample site plan should be updated as changes are made in the water system, especially the distribution system.

The sample site plan must be followed and all operating staff must be clear on how to follow the sampling plan. In order to properly implement the sample site plan, staff must be aware of how often sampling must be done, the proper procedures and sampling containers to be used for collecting the samples, and the proper procedures for identification, storage and transport of the samples to an approved laboratory. In addition, proper procedures must be followed for repeat sampling whenever a routine sample result is positive for total coliform.

Each water system should have specific procedures for TCR sampling to address the issues described. The sample site plan and sampling procedures must be readily available to all operations personnel at the facility. In order to prevent obtaining inaccurate sample results that could cause compliance problems, it is critical that the operator be aware of some key issues relating to the collection and transport of the total coliform samples.

## **HOW COMPLIANCE IS DETERMINED FOR THE TCR**

- Compliance is based on the presence or absence of total coliforms.
- Compliance is determined each calendar month the system serves water to the public (or each calendar month that sampling occurs for systems on reduced monitoring).
- The results of ROUTINE and REPEAT samples are used to calculate compliance.

### **A Monthly MCL Violation is Triggered if:**

- A system collecting fewer than 40 samples per month . . .Has greater than 1 ROUTINE/REPEAT sample per month which is total coliform-positive.
- A system collecting at least 40 samples per month . . . Has greater than 5.0 percent of the ROUTINE/REPEAT samples in a month total coliform-positive.

### **An Acute MCL Violation is Triggered if:**

- Any public water system . . . Has any fecal coliform- or *E. coli*-positive REPEAT sample *or* has a fecal coliform- or *E. coli*-positive ROUTINE sample followed by a total coliform-positive REPEAT sample.

### **What are the Public Notification and Reporting Requirements?**

- For a Monthly MCL Violation . . . The violation must be reported to the state no later than the end of the next business day after the system learns of the violation. The public must be notified within 30 days.
- For an Acute MCL Violation . . . The violation must be reported to the state no later than the end of the next business day after the system learns of the violation. The public must be notified within 12 hours.

### **TCR Sampling Considerations**

- Samples must be collected in sterile containers provided by the approved laboratory that will be doing the coliform analysis. .
- All sample containers should be labeled with the date, time, and location of sample collection as well as the sign of the person who collected the sample.
- Use only clean sample taps. If cleanliness is questionable, apply a solution of sodium hypochlorite to the surface the tap before collecting the sample.
- The sample should be taken from a smooth nosed cold water tap if possible.
- Aerators, strainers, and hose attachments should be removed before collecting a sample.
- Samples should not be taken from:
  - Leaky taps that allow water to flow from around the stem and over the outside of the faucet;
  - Swivel faucets;
  - Houses with home treatment units; or
  - Taps with non-removable aerators, strainers, or hose attachments.
- The spout of the sampling tap should face the ground so that water cannot stand in the spout when the tap is shut off.
- Prior to collecting the sample, open the tap fully and flush to clear the service line.
- Ensure that there is a total chlorine residual before collecting the sample.

- Reduce the flow enough to prevent splashing, open and fill the sample container without rinsing, leaving a 1 inch space in the container.
- Do not rinse out the bottle, while collecting a bacteriological sample. The bottle contains sodium thiosulfate, which is a preservative used to neutralize the chlorine present in the sample.
- If sample will be in transport to the laboratory for more than 1 hour, use an iced cooler to maintain sample temperature of 4°C. Do not submerge the tops of the sample containers.
- Samples can be held for up to 30 hours before analysis if kept refrigerated.
- It may be necessary to mail the sample to a lab if the PWS is in a remote location. Insulation and mailing is acceptable as long as the time from collection to analysis is less than 30 hours and a chain of custody is maintained.

All of the information described above, relating to the TCR requirements, is readily available from local, state, and federal regulatory agencies. Include your state's monitoring requirements and policies on file with your sample site plan. There are a number of operator guidance manuals available describing the detailed requirements and procedures necessary to comply with the TCR. It is the operator's responsibility to obtain the necessary information to insure compliance.

### **Chlorine Residual Monitoring**

The state of West Virginia requires total chlorine monitoring at the time of bacteriological sampling. Results of all microbiological quality samples must be submitted to OEHS. Certified laboratories must perform coliform analyses. **It is the responsibility of the owner or operator to send OEHS a copy of the results by the 10<sup>th</sup> day of the next month.** For example, results must be submitted by February 10<sup>th</sup> for samples collected in January. If the results are not received your system will receive a violation for failing to monitor. This shows how important it is to keep copies of all laboratory results. In West Virginia, copies of all microbiological monitoring results must be kept for a minimum of 5 years.

## COLIFORM SAMPLING PLANS

A coliform sampling plan is a written document that PWSs should use to consistently and accurately perform sampling that is representative of drinking water in the system's distribution system. All PWSs must develop and implement a written coliform sampling plan. These plans need to be reviewed and approved by OEHS District Office Engineers during the on-site sanitary survey inspection.

The sampling sites should be representative of and provide adequate coverage of the distribution network and pressure zones. It is also important to select sampling sites that provide the least amount of negative influence on the water sample. Examples of sites to avoid include leaky or dirty faucets, sampling points in areas with little or no water use, swivel faucets, custodial or industrial use sinks, or any location you believe to be questionable. Many water systems utilize dedicated sampling stations in the distribution system that are used exclusively for sampling purposes, eliminating many outside influences that may potentially impact water samples. If, when you go to collect your routine sample, you find the water tap has been damaged or is leaking, use one of your alternate sites until you can repair the original. Likewise, if the sample bottle is damaged or you believe you may have contaminated it, do not use it. Select a clean one for your sample and return the other to the lab empty.

The plan should include the following elements.

- A brief **narrative** of the water system that includes source, treatment, storage, distribution system maintenance, pressure zones, number of connections, population, etc.
- A **map** of the distribution system with the routine and repeat sampling sites identified, distribution piping locations, entry points, etc.
- A **sample site plan** that includes sample site addresses, the minimum number of samples collected, rotation schedule of sample sites, chlorine residual monitoring, contact person and phone number, sampling procedure or protocol, etc. In the event that a routine site sample tests positive for coliform or *E. coli*, the plan should list repeat sites for each routine site and should include a written procedure of what steps the water system will follow to investigate a positive sample.

## **TYPES OF COLIFORM SAMPLES**

Testing for total coliforms is performed by collecting water samples. There are five types of samples that a NCWS generally takes. These are routine samples, repeat samples, additional routine samples, replacement samples, and special samples.

### **Compliance Samples**

**Routine Samples:** Routine samples are those that you are required to take on a routine basis, whether that is monthly or quarterly. These samples, as well as the other types of samples noted below, are collected from representative locations throughout your water system in 125mL containers. These samples, as with all coliform samples, should be submitted to a certified laboratory for testing within **30 hours** after collection.

**Repeat Samples:** These compliance samples are required each time a coliform positive sample is detected and must be collected within 24 hours after you receive notification of a positive coliform result. These samples confirm any positive detection of coliform bacteria and help to identify the extent of the coliform contamination within your system, the type of coliform present, and the location or source of the contamination. Samples above and beyond the repeat sample requirement may be collected until either the system no longer detects the presence of any coliform bacteria or until the source of the contamination has been identified, eliminated, and/or prevented.

### **If any routine sample is total coliform-positive, repeat samples are required.**

Within 24 hours of learning of a total coliform-positive ROUTINE sample result, at least 3 REPEAT samples must be collected and analyzed for total coliforms:

- One REPEAT sample must be collected from the same tap as the original sample.
- One REPEAT sample must be collected within five service connections upstream.
- One REPEAT sample must be collected within five service connections downstream.
- Systems that collect 1 ROUTINE sample per month or fewer must collect a 4th REPEAT sample anywhere in the system.

If any REPEAT sample is total coliform-positive:

- The system must analyze that total coliform-positive culture for fecal coliforms or *E.coli*.
- The system must collect another set of REPEAT samples, as before, unless the MCL has been violated and the system has notified the state.

Additional ROUTINE Sample Requirements

- A positive ROUTINE or REPEAT total coliform result requires a minimum of five ROUTINE samples be collected the following month the system provides water to the public unless waived by the state.

### **Non-Compliance Samples**

**Additional Samples:** This type of sample refers to any additional non-compliance samples required by your state primacy agency in order to help identify the extent of the contamination, provide better information about water quality, or to provide further monitoring of the water within the PWS.

**Replacement Samples:** If a compliance sample is collected and does not get analyzed, it may be replaced by a new sample. There are several reasons why a certified laboratory may not analyze samples:

- The sample may be outdated or too old;
- The sample container may be broken upon arrival at the lab;
- The sample container may have leaked;
- The sample amount may be not be enough (remember, 100mL is the minimum);
- The sample does not indicate a date or time to tell the lab how old it is; and
- The sample may have been frozen.

**Special Samples:** These, too, are non-compliance samples that are collected due to repairs, complaints, or maintenance reasons. Collection of these types of samples is often necessary to ensure that coliform has not entered your distribution system as a result of events such as water line repairs, line breaks, or routine maintenance.

## WATER AUDITS

The records for most water systems show that more water enters the system than leaves it. The meters register more water "in" than water "out." It seems that some water just disappears! How? That's what this training guide is about. It will show you how to solve the mystery of disappearing water with the help of a water audit.

A water audit is a management tool. It can tell you how efficiently your system is operating and where some of your losses may be occurring.

A water audit involves:

- Collecting records for a water audit review period (such as the past 12 months);
- Calculating how much water entered and left the system during the review period;
- Testing meters for accuracy estimating the amount and cost of "unaccounted for" water; and,
- Analyzing the data.

"Unaccounted for" water is the difference between water "in" and water "out" for a system. For example, a system's records may show 10 million gallons entering the system and only 8 million gallons leaving the system. The difference of 2 million gallons is "unaccounted for" water.

The second cause of unaccounted for water is water loss. This is water that actually leaves the system without passing through a meter. Lost water may have been stolen or given away. It could also have leaked out of the system.

### **What are the benefits of a water audit?**

There are many good reasons to perform a water audit. For example, a water audit can help you find errors in records and meters. With this information, you can be sure that you are billing for all the water your customers use.

A water audit is also the first step in solving water loss problems. Water audits can tell you how serious your water loss is. By lowering your system's water loss, you can reduce wear on equipment. You can also lower electricity bills and other operating costs for treating, pumping, and storing water. Lower operating costs mean lower rates for customers. Also, reducing water loss helps protect the public health. For example, by fixing leaks you may also lower insurance costs and the risk of lawsuits.

A successful water audit can even improve public relations by helping you lower rates and improve service. If your system is operating more efficiently, you may eliminate the need for costly capital improvements. You may also be able to expand service. Perhaps the most important benefit of a water audit is that it can help you save a precious resource. Because of pollution and increasing demands, saving water is becoming more important each year.

### **What makes a successful water audit?**

A successful water audit depends on the hard work and good judgment of a team. Decision-makers, operators, managers, bookkeepers, secretaries, and consultants must use their special skills together to make the audit work. Encourage each person involved to ask questions at every step. Look for the causes of unaccounted for water and try to determine if they result from record errors or water loss. Questions may include:

- Does the system seem to have a problem with unaccounted for water?
- If so, when did the problem start?
- Where does the problem seem to be?
- Has there been an unusual use of water, such as for fighting a fire or for a county fair?
- Have there been customer complaints about low pressure?
- Have there been cases of water theft?
- How has the weather affected water use?

## UNACCOUNTED-FOR WATER

Unaccounted-for water is water which is produced but is not used or sold to the consumers. There are many factors which are considered in the determination of the percentage of unaccounted-for water. This percentage is a measure of the efficiency of the operation of the system.

### **Factors to Consider**

Factors to consider in the determination of the unaccounted-for water are:

- The water produced - Is this quantity accurately determined, has the meter been calibrated, and does the meter measure all of the water?
- The water used for water system purposes such as chemical feed water, backwash water, fire hydrant and blow-off flushing - How is each of these uses measured? Careful accounting in the treatment plant is necessary because, in some plants, plant use water is used before the master meter, and in other plants, it is used after the master meter.
- The water sold or used by the consumer - A meter testing program should be in place to periodically test the accuracy of the meters. All consumer use must be accounted for. For example, free water may be provided for parks, cemeteries, or for municipal purposes at sewage treatment plants, borough buildings, and fire companies. All of this water must be measured and accounted for.
- Water used for fire fighting purposes - This water only can be estimated, but some careful calculations by the fire company and the water system can develop a reasonable value.

### **Basic Calculation**

The basic calculation is:

$$\frac{(\text{Water Available for Sale}) - (\text{Water Sold or Used})}{\text{Water Available for Sale}} \times 100 = \text{Percent of Unaccounted for Water}$$

1. The water available for sale is the water produced, adjusted for the company uses of water, as follows:
  - Subtract any plant use water that is taken off the system after the master meter,
  - Subtract any water used on the distribution system for flushing fire hydrants and blow-offs and for fire protection.
2. The water sold or used is the total quantity of water sold to customers through meters plus an estimate of all unmetered uses either to flat rate customers or for public purposes.
3. When making the calculation, the time interval must be considered since the amount of water sold only may be determined monthly, quarterly, or annually, and usually all meters are not read on the same day or at the same time. It is recommended that a one-year (four-quarters or 12-months) period be considered since this will level off the variables for meter reading, and seasonal variations. This calculation can be made on a monthly basis by using the totals for the previous 12 months.

### **Normal Operating Ranges**

The normal operating range should not exceed 15% for a well maintained system. There are many factors which should be considered when determining what an acceptable percent of unaccounted-for water is for a particular system. These are:

1. The age and condition of the system. A very old water system which has deteriorated pipe will have many undetected leaks at joints. Although the goal may be the 15%, it only can be accomplished by replacing large segments of the system. Therefore, a range of 35 to 40% may not be unusual until funds for replacement of mains are available.
2. The pressure in the system can affect the rate of leakage. Thus high pressure systems may have a higher percentage of unaccounted-for water.
3. The number of customers per mile of main can affect the unaccounted-for-water. Therefore, if a system has a high ratio of miles of pipeline to the number of customers, the percentage of unaccounted-for water will increase.
4. Under-registration of customer meters or unauthorized use can increase the percentage of unaccounted-for water.

### **Control of Unaccounted-for Water**

To reduce the percentage of unaccounted-for water, the following are suggested actions:

1. Calculate the cost of producing 1,000 gallons or 100 cubic feet of water and then calculate the amount of money which is being "lost" as unaccounted-for water each month. By identifying this cost, you can justify the cost of the programs to correct the problem.
2. A meter testing program should be installed to test the master meter and other system meters at least annually and to test all customer meters (on a continuing basis) at least once every 10 years.
3. An adequate leakage control program includes:
  - A program of listening to all fire hydrants valves and services to detect leaks;
  - The use of detector type meters on fire lines;
  - Training personnel to listen for leaks and to detect unauthorized use of water; and
  - Review of meter readings to detect stopped meters or obvious under-registering meters.
4. A record of leaks repaired and the estimated amount of water lost at each leak can help to justify replacement of sections of mains which have a high incidence of leakage.

## WATER METER PROGRAM

What is the purpose of a water meter? To measure and track the amount of water delivered through a distribution system. More importantly a water meter registers the amount of water delivered to a customer so an appropriate bill for that water can be charged. That charge determines the amount of revenue a system receives. The potential for revenue loss can be staggering if the system has a large number of meters significantly under-registering. Loss of revenue is more significant particularly for systems that have a high water production cost or high purchase water costs. Consideration must also be given for customer billing equity. Major differences in meter accuracy translates to unequal customer billing. A water system with a high unaccounted for water loss may have leaks or other distribution problems that must be addressed. Without accurate meters the degree of these problems cannot truly be known. The accuracy of a utilities water meters should be high priority and efforts made to maintain all meters at a high and uniform level of efficiency. An alert meter reader should be able to spot an under-registering meter by a quick comparison with past reading. Meter stoppages should be noted immediately at the time of the meter reading and scheduled replacement planned.

Why does the accuracy of a water meter diminish? A water meter like any mechanical device is subject to wear and deterioration over time. The deterioration would be accelerated by poor water quality such as corrosive or abrasive water. Water meters can register over register but this rarely occurs because wear on internal meter parts generally cause lower measurements. It can be assumed that after a certain age the inaccuracy of the meter due to deterioration becomes an economical liability.

When should a water meter be replaced? There is no study that can show or recommend the exact age when a water meters accuracy is diminished to such a degree that replacing is economical. How long water meters retain their overall accuracy depends on many factors, such as the quality of the water being passed through the meter, the rate of flow and the total quantity of water that has been measured. Various conditions that water meters are exposed to prevent any exact time frame for water meter decay due to differences in water chemical composition, temperature and humidity. Most studies do conclude residential meters should be repaired or replaced after 15 or 20 years. At this age the accuracy would have diminished to the point that the cost of meter replacement is less than loss of revenues with continued use of the meter.

It is important that all water systems establish a meter program to insure that the system is able to track water production and distribution. There are essentially three levels or types of meter programs:

- A comprehensive meter testing program
- A meter testing and repair program
- A comprehensive meter replacement program

A meter testing program would consist of periodically testing meters within the system to determine their accuracy. The meter testing would be based on meter age, meter use, water quality, cost of testing and water revenue loss. Older meters and those carrying the largest volumes should be given the highest priority. According to the WV Public Service Commission, small meters should be tested once every ten years and larger meters every one year. In theory new meter should be tested before installation although only a fraction of utilities perform such tests. Meters have an inherent variation of 2 to 3 percent in registration over the entire range of flows, except very low flows just above those that the meter will not register. Meters are to be

considered to be satisfactory if measurements are 95% accurate at low flows and 98.5 % accurate during normal flows. Those meters that fall outside of these ranges should be serviced or replaced. Whenever, on installation, periodic or any other test, a meter is found to exceed a limit of two percent (2%) fast or slow, it must be adjusted so as to register as nearly one-hundred percent (100%) as is commercially practicable. Establishing a meter testing program is often difficult, as it involves repetitive testing and manpower. Obviously the only way to determine whether a specific meter is operating efficiently is to test it. Probably no phase of water utility operation has been handled in so many different ways as that of testing water meters. There have been no nationally recognized water meter testing procedures however accuracy requirements are contained in the various AWWA meter standards and these standards have been widely used as a basis for establishing individual testing methods.

Repairing meters is an option that may be economical for larger systems that have the equipment and expertise for such a program. Meter repair work is not considered acceptable if repaired meters do not register 90 percent on the test. Most modern meters have sealed registers and easily changed measuring chambers. These meters are usually maintained and repaired by the utility. Older style meter with heads that must be worked on should be returned to the manufacturer for maintenance and repair if they are not to be replaced.

A meter replacement program is generally the best and most cost effective method for smaller systems due to the lack of manpower, equipment and expertise. An initial service period must first be established. This period may be 20, 15 or even 10 years. Once the service period is reached the meters are replaced with new meters creating a reasonable economic balance between the cost of replacing the meter versus loss of revenue incurred with continued use of the old meter. It is obviously economical if the cost of the replacing a meter is less than the loss of revenue that would occur if the meters were to be used longer than there established service period. Essentially the meter program would more than pay for itself.

A comprehensive meter program not only benefits the system creating a more efficient operation but allows the system to maintain the lowest possible water rates.

## TESTING LARGE METERS

Water meter testing can be just as important as metering itself as a tool for unaccountability due to an accounting error, leak, pump inefficiencies or an illegal cross-connection. Turbine meters two inches and larger must always be tested after installation. Three inch meters must be tested once every three years. Meters four inches and larger must be tested each year. It is recommended that these meters always have a screen directly upstream not only to protect the meter but to help ensure its accuracy. These screens should be cleaned each time the meter is tested; however, this may not be often enough. After a large line break on either side of the meter, line flushing or any other disturbance in the distribution system, it is always a good idea to check the screens on large meters. A partially blocked screen on a turbine meter usually makes the meter record fast. If a meter is found to be more than two percent fast, the utility must refund the overcharge. Based on the corrected meter, the time for calculating the payback will be half the time elapsed since the last test, but not to exceed six months. However, if a date can be determined when the error began, the payback should be calculated retroactively to that date. If, the meter has not been tested in accordance with Rule 6.4, the period beyond the test period will be added to the six months.

For example, assume one utility is selling water to another through a four inch master meter. The purchase system has 1,000 customers averaging 100 gallons per day usage giving an annual purchase, including 15 percent water loss, of 41,975,000 gallons. At \$1.50 per 1,000 gallons, the annual cost for water would be \$62,962. In the first case during its annual test, the meter is found to be reading five percent fast. The seller would be required to refund the purchaser \$1,574:

$41975(\text{M gallons}) \times 5\% = 2098 \text{ gallons}$   
 $2098 \text{ M gallons at } \$1.50/\text{M} = \$3147$   
 $\$3147 / 2 \text{ (6 months)} = \$1574$

If it could be agreed that, due to a line break or other recognized incident, the meter started reading fast three months prior, the payback would be \$787. If the meter had not been tested for the past three years, for example, the required payback would be \$7,868. Although it's the sellers' responsibility to own, operate, repair, maintain and test the meter, the purchaser should always see to it that the meter is tested and that they receive a copy of the test report.

## **THE LEAK ADJUSTMENT INCREMENT**

The Leak Adjustment Increment is used to calculate charges for consumption over and above the customer's historical average usage. This rate is equivalent to the rate per thousand gallons of water sold to customers whose bills reflect unusual consumption attributable to eligible leakage on the customer's side of the point of service. However, there have been some misunderstandings regarding the incremental cost for water and sewer utilities and its applicability in accordance with water and sewer rules.

All water utilities (150CSR7, Section 4.4.c.1) shall develop and implement a written leak adjustment policy. The Commission, at the time it promulgated and enacted its leak adjustment policy requirement, established average or "typical incremental costs" of \$0.75 per thousand gallons for water utilities. The Commission established leak adjustment increments (in accordance with 150CSR7, Section 4.4.c.3) may be used as an alternative to the water company's incremental cost of producing water or treating sewage. The rules further state that the Commission shall, from time to time, establish its estimate of "typical incremental cost" by order.

The other method for determining the leak adjustment increment is through a rate case proceeding. 150CSR7, Section 4.4.c.4 state that, in future rate cases, the utility's incremental cost of water treatment be placed in the appropriate water tariff as the leak adjustment rate. It is important to note that once this leak adjustment charge is determined in a rate case, the water utility company will not have the option of using the Commission's estimate of "typical incremental cost" found in 150CSR7, Section 4.4.c.3.

Some utilities have reverted back to charging the Commission's "typical increment cost" after the company's charge has been determined in a rate case. Clearly this is a violation of the applicable water and sewer rules. It is important for water and sewer utilities to understand these rules and apply them accordingly.

## PUBLIC RELATIONS

Public relations is a way of promoting understanding, support, and goodwill between your water system and the public. You can influence the public's image of your system by following the public relations steps presented in this training guide.

Good public relations doesn't happen overnight. It must be developed over time. Moreover, once your system has gained the community's confidence, you must continue your efforts to ensure that the support you need will always be there.

The main purpose of public relations is to gain and keep the public's confidence and support. Good relations with the public can also:

- Strengthen the system's position in the community;
- Help the system form fair guidelines and policies;
- Promote goodwill between employees and customers;
- Educate the public about water use;
- Overcome misconceptions about the water system;
- Gain the support of local government;
- Weaken the impact of any negative publicity the system may receive; and
- Justify reasons for capital improvements or rate hikes.

Once you know *where you are* and *where you are going*, you need to determine the *public image* your system needs to have to accomplish your goals. Your public image is an accurate picture of your operation that spotlights key aspects of your work.

For example, if your system needs public support for a major purchase, it may help to let customers know about the complexity of water system operation. Most people don't realize that water system operation can be very difficult. Customers may be more likely to support water system improvements if they understand that water system operation is a demanding job that requires the best equipment available.

A different goal may be to build public confidence in your system. To do this, **let people know about the good work you are doing!** Assure them that system employees are well trained. You may wish to inform the public of any continuing education classes your employees have attended. Also make sure the public knows that their water is tested. You may even want to report the positive findings from state health agencies or labs.

Even though most water systems are organized as "nonprofits," they must operate like any business. Because the success of any business relies on its customers, systems should keep customers informed and respond promptly to their needs.

A good public relations practice to develop is to always let customers know when their service may be affected. This might include:

- Interruption of service;
- Repairs (especially when the streets are affected);
- Changes in water taste, odor, or pressure;
- Unusual findings during state health inspections;
- Proposed changes in rates; and

- New construction.

Explain what is happening, apologize for any inconvenience, and reassure the public that what is happening is in their best interest.

Early in this step of the public relations cycle, your system needs to select a representative. Your representative should be someone from the system that can communicate well with the public. This representative should also:

- Be well-respected in the community;
- Have a pleasant appearance;
- Be a good speaker;
- Get along with people; and
- Be knowledgeable about your system.

Select your representative carefully. In some cases, you may wish to choose more than one. Make sure the person you choose reflects the image you want for your system.

The two main forms of communication are **personal communication and written communication**. Personal communication is more than just talking to the public. A person's appearance, behavior and work habits are also important elements of personal communication. Specifically, personal communication is any direct professional contact between system personnel and the public they serve. Personal communication can occur in the office, in the field, or in any other public setting. Always practice positive personal communication in the office. Ask office staff to greet customers promptly and give them full attention.

The telephone is a powerful public relations tool. Not only is it much faster than written messages, but it also often eliminates the need to travel. A major disadvantage of the phone is that you can't see the person you're talking to. This may make it more difficult to tell how a caller is reacting to your conversation. You have to rely totally on the person's spoken message. Because the spoken message is so important, employees should be aware of how they answer and use the phone. Some guidelines for effective telephone communication are listed below.

### **Answering the Telephone**

1. *Always answer the phone promptly.* Clearly state your name and the name of your system.
2. *Try to sound pleasant you are talking.* Some people actually smile when they are on the phone because it makes them sound more pleasant.
3. *Never interrupt callers.* This makes them feel that you are bored or disinterested.
4. *Listen carefully.* If you are unsure of what callers are talking about, repeat what they have said to make sure you have understood them.
5. *Don't put customers on hold for more than 30 seconds.* If you must search through records or discuss the subject with someone else, take the caller's name and number and call back as soon as you can.

### **Handling customer complaints**

Complaints present an excellent opportunity to build positive customer relations. A customer whose complaint receives prompt attention can become a valuable supporter. When dealing with complaints in the office or on the phone:

- Listen and sympathize;
- Do NOT argue;
- Ask questions;
- Work to find an acceptable course of action for both sides; and
- Follow-up the complaint to make sure the problem is resolved.

No one enjoys receiving complaints, but resolving a complaint quickly and professionally can actually improve your image with the public.

### **Personal communication in the field**

The way system employees act and appear when they are working can have a big impact on your system's public image. Employees should appear neat and clean whenever possible. They should also be encouraged to be patient and courteous to every customer. Pay special attention to the way employees work at construction sites:

- Has the system constructed barriers to prevent possible accidents?
- Have employees completed the job quickly and safely?
- What was the condition of the area after the work was finished?
- Did the system replace or repair any property that was affected by the job?

Each employee represents your system. Only by behaving and dressing professionally can they reflect a positive public image.

### **Personal communication door-to-door**

The most visible people working for your system are the meter readers. Because of this, it is especially important that they have a professional appearance and a positive attitude. Sometimes it is necessary for other employees to go door-to-door. For example, they may need to inform customers when service is going to be interrupted. Ask them to take the time to explain what is happening and answer any questions the customer might have.

The condition of your system's facilities and equipment also affects your public image. Check all visible parts of the system. One of the first things visitors see is the storage tank. Keep it painted and free from graffiti. Hydrants are another highly visible part of the system. Make sure they are painted and free from obstructions such as weeds and trash. It is also important that vehicles and equipment are clean and in good repair. Check the system office and other buildings as well, such as garages, pump and well houses, and storage sheds. Keep these neat and well-maintained.

### **Reporting bad news**

One of the hardest parts of public relations is giving customers bad news. Business letters can be an effective way to report bad news and make customers feel that their individual concerns are taken seriously. Report honestly and openly what has happened. Reassure people that their water system is working to correct the problem. It is up to you to work with the media and use other communication techniques to make sure the public really knows what has happened.

If you have a good working relationship with the media, you may also be able to participate in a feature story or an interview about the event. In either case, you have an opportunity to give your system's response to the situation and to reassure the public that you are working to solve the problem.

**Interview tips**

Whenever television or newspaper reporters create their own stories, they often prefer to conduct interviews. If you are going to be interviewed:

1. Be prepared. Make sure you know the subject you are supposed to talk about. Have the facts and figures to support your comments.
2. Stick to the subject.
3. Try not to answer questions with just "yes" or "no." These may cut your interview short.
4. Stay calm. Don't lose your temper or get pulled into an argument.
5. Keep your answers short but include all necessary information.
6. Speak in generalities whenever possible.
7. Keep in mind that you are reflecting your water system, not yourself.
8. Never lie or try to bluff the interviewer. If you don't know, say so.
9. If possible, practice. Sometimes the interviewer will rehearse with you if you ask.

Public relations work never ends. As long as your system is providing an essential service, you will need to communicate with customers and other members of the public about the good work you do.

## COMMUNICATION

The two main forms of communication are personal communication and written communication. Personal communication is more than just talking to the public. A person's appearance, behavior and work habits are also important elements of personal communication. Specifically, personal communication is any direct professional contact between system personnel and the public they serve. Personal communication can occur in the office, in the field, or in any other public setting. Personal communication in the office Always practice positive personal communication in the office. Ask office staff to greet customers promptly and give them full attention. If the system is involved in a special project, make sure employees are aware of this and can explain the project to customers. For instance, if your system is making extensive repairs, the office staff should either be able to explain the situation or let customers know who can. Your system must make sure that customers know what is going to happen and how they will be affected.

The telephone is a powerful public relations tool. Not only is it much faster than written messages, but it also often eliminates the need to travel. A major disadvantage of the phone is that you can't see the person you're talking to. This may make it more difficult to tell how a caller is reacting to your conversation. You have to rely totally on the person's spoken message. Because the spoken message is so important, employees should be aware of how they answer and use the phone. Some guidelines for effective telephone communication are listed below.

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- *Don't put customers on hold for more than 30 seconds.* If you must search through records or discuss the subject with someone else, take the caller's name and number and call back as soon as you can.

### **Placing calls**

- *Consider the purpose of your call.* If possible, jot down the main ideas you want to discuss before you pick up the phone. This will help you communicate clearly and save time when you are on the phone.
- *Call at a convenient time.* Consider the listeners' work schedule. If you are calling someone at a business, call when you know the person will be there. Don't wait 10 minutes before lunch or closing time before you call. If you are calling customers in the evening, call between 7 pm and 9 pm. By doing this, you probably won't interrupt their dinners or wake them up.
- *Take notes during your conversation.* This may keep you from having to call someone again. Before you hang up, repeat the main ideas of your conversation. Make sure you each understand what was discussed.

### **Handling customer complaints**

Complaints present an excellent opportunity to build positive customer relations. A customer whose complaint receives prompt attention can become a valuable supporter. When dealing with complaints in the office or on the phone:

- Listen and sympathize.
- Do NOT argue.
- Ask questions.
- Work to find an acceptable course of action for both sides.
- Follow-up the complaint to make sure the problem is resolved.

No one enjoys receiving complaints, but resolving a complaint quickly and professionally can actually improve your image with the public.

### **Personal communication in the field**

The way system employees act and appear when they are working can have a big impact on your system's public image. Employees should appear neat and clean whenever possible. They should also be encouraged to be patient and courteous to every customer. Pay special attention to the way employees work at construction sites:

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- What was the condition of the area after the work was finished?
- Did the system replace or repair any property that was affected by the job?

Each employee represents your system. Only by behaving and dressing professionally can they reflect a positive public image.

### **Personal communication door-to-door**

The most visible people working for your system are the meter readers. Because of this, it is especially important that they have a professional appearance and a positive attitude. Sometimes it is necessary for other employees to go door-to-door. For example, they may need to inform customers when service is going to be interrupted. Ask them to take the time to explain what is happening and answer any questions the customer might have.

### **Other opportunities for personal communication**

There are usually many opportunities for you to communicate with people in your area. Some of the public relations opportunities you may have include:

- speeches for local civic organizations, such as Lions, Rotary, Kiwanis, American Legion, Jaycees, and the Chamber of Commerce;
- exhibits at public events, such as county fairs and festivals;
- school tours of the water system office and treatment facilities;
- poster or essay contests for local students;
- training sessions for area water professionals hosted by your system; and
- open house for holidays or on completion of new construction

Whenever preparing to deliver a personal message, remember that appearance and behavior are just as important as the message you are presenting. Try to represent your system in a professional, friendly manner.

## **System facilities and equipment**

The condition of your system's facilities and equipment also affects your public image. Check all visible parts of the system. One of the first things visitors see is the storage tank. Keep it painted and free from graffiti. Hydrants are another highly visible part of the system. Make sure they are painted and free from obstructions such as weeds and trash. It is also important that vehicles and equipment are clean and in good repair. Check the system office and other buildings as well, such as garages, pump and well houses, and storage sheds. Keep these neat and well-maintained.

## **Written communication**

There are also many kinds of written messages you can deliver to the public. Written communication can range from business letters to bill stuffers, newsletters, and press releases.

### **Business letters**

Business letters are one of the most effective tools in public relations. If you follow a few simple rules, your letters can effectively communicate your message.

- Decide what you want to say. Before you begin to write, decide exactly what you want to say to your reader. Generally, the most effective letters make only one or two main points and are no more than one page long. Remember not to ramble! It is tempting to include excessive information in a letter, but this weakens the impact. Short business letters are more effective than long ones.
- Remember your reader. Keep in mind who your reader is. Try to think about the reader's level of knowledge and understanding about the system. The letter you send to a typical customer about your system should be very different from one you would send to a consulting engineer.
- Be polite. Some business letters are written in response to difficult problems. Do not let emotion creep into your letter. Always remain polite and professional.
- Outline your letter before you write. Before you begin to write, jot down an outline of what you want to say. Good business letters:
  1. Explain the current situation.
  2. State the reason for the letter.
  3. Explain what is being done about the situation.
  4. Suggest what the reader should do.

For example, many systems send letters about overdue water bills. Begin a collection letter by explaining your system's current situation. Tell the reader that the system is expensive to operate and maintain to ensure safe water. Next state the reason for the letter. Let the reader know that according to your records, the reader's bill is past due. Then explain what you are doing about the problem. State that you are writing to remind the customer about the bill. Also state that you may have to discontinue service according to your system's policy if the bill isn't paid by a given date. Finally, state what the customer should do. Suggest that payment may be mailed or paid in person at the system office. Give the office hours and times the office is open.

## CUSTOMER COMPLAINTS

When dealing with a customer complaint, a water utility must keep a full and complete record of all relative information. At a minimum, keep the:

- Date of the complaint;
- Name of complainant;
- Nature of complaint; and,
- What the utility did to resolve it.

If an informal complaint becomes a formal complaint case, the PSC will attempt to determine what the utility did during the informal complaint stages. Without proper documentation, there is not much of a defense.

The PSC frequently sends a representative to investigate or may ask the utility to send copies of their records. The PSC will want to look at the records to determine what the utility has already done. If the utility's actions seem to be complete and proper the PSC will be prone to join the utility in a statement that no further action is necessary, but if no record exists to show that the complaint has been investigated by the utility, the utility may lose because no investigation can be proven. Complaint records are kept primarily to protect the utility. The required information for water customers is in Water Rule 4.5. Once a formal complaint is filed against a utility, the Commission will issue an order for the utility to respond to the complaint within 10 days.

Based on the utility's response, PSC will conduct its investigation which may include a field investigation and/or a request for additional information from the complainant and/or the utility. If there is no settlement of issues, then the case will be set for an evidentiary hearing. Also, any formal complaint can result in a general investigation of the utility. One can easily see where good record keeping will be invaluable in such situations. Utilities are not required to keep a record of inquiries. The difference between a complaint and an inquiry hinges on whether the utility has to take some investigative or corrective action. If a customer calls and states that his/her water is off, to fix a leak or to flush lines, for example, then it is not a complaint. If a customer calls and says his/her bill is incorrect and in a phone conversation, it is determined that the customer was correct and the utility has to issue a corrected bill, then it was a complaint.

When handling complaints either over the phone or in person, it is a good idea to take notes. Another important point to remember is that after the customer has finished airing the complaint, repeat back the alleged complaint. This ensures that the problem has been identified correctly. Remember it is beneficial to practice good public relations (PR) to keep complaints at a minimum. Surprisingly, handling customer complaints can be one of the most effective opportunities to build positive customer relations. Handling a complaint promptly and courteously can turn a negative situation into a positive one and can cause an unhappy customer to become a valuable supporter. In this regard, when dealing with complaints, always strive to:

- Listen and sympathize;
- Do not argue;
- Negotiate to find an acceptable solution; and
- Follow up to make sure customer is satisfied and problem is resolved.

Complaint records are also a valuable management tool as it is a good idea to go through such records from time to time or at the end of the year to see what types of complaints were received and note any patterns that may have developed. For example, several water quality complaints from the same area may indicate a problem that has gone undetected until the number and

frequency of complaints are acknowledged. By dealing with one customer at a time, the immediate problem may be solved, but if that problem keeps recurring, then the underlying problem is not being identified or corrected.

All individual complaint records are to be kept until a year end summary has been prepared which is to be used as a permanent record. The summary has to show the character of the complaints made, the number of each type received in each month, and the disposition of the complaints.

## **POTABLE VS. PALATABLE**

The purpose of municipal water treatment is to produce potable, palatable drinking water. Potable water is safe to drink; palatable water has acceptable taste, odor and color. The conventional steps in treatment are designed to address: taste, odor, color, turbidity, and pathogens. To be palatable water should be free of detectable taste and odors. Turbidity, sediment, and color also play important roles in determining whether water is palatable.

Various odors and tastes may be present in water. They can be traced to many conditions. Unfortunately, the causes of bad taste and odor problems in water are so many, it is impossible to suggest a single treatment that would be universally effective in controlling these problems.

Tastes are generally classified in four groups -- sour, salt, sweet and bitter. Odors, on the other hand, possess many classifications. There are some 20 of them commonly used, all possessing rather picturesque names. In fact, the names in many cases, are far more pleasant than the odors themselves, to name a few of them -- nasturtium, cucumber, geranium, fishy, pigpen, earthy, grassy, and musty. Authorities further classify these odors in terms of their intensity from very faint, faint, distinct and decided to very strong. All taste buds and olfactory organs are not necessarily of the same acuteness, but generally you should not be aware of any tastes or odors in water if there is to be pleasure in drinking it. If you are conscious of a distinct odor, the water is in need of treatment.

In many cases it is difficult to differentiate between tastes and odors. Both the taste buds and olfactory organs work so effectively together it is hard to determine where one leaves off and the other begins. To illustrate: hydrogen sulfide gives water an "awful" taste, yet actually it is the unpleasant odor of this gas that we detect rather than an unpleasant taste. Unfortunately there is little in the way of standard measuring equipment for rating tastes and odors. Tastes and odors in water can be traced to a number of factors. They include:

- Decaying organic matter;
- Living organisms;
- Iron, manganese and the metallic products of corrosion;
- Industrial waste pollution from substances such as phenol;
- Chlorination;
- High mineral concentrations; and,
- Dissolved gases.

In general, odors can be traced to living organisms, organic matter and gases in water. Likewise, tastes can be traced generally to the high total minerals in water. There are, however, some tastes due to various algae and industrial wastes. Now how can these objectionable tastes and odors be removed from water?

Some tastes and odors, especially those due to organic substances, can be removed from water simply by passing it through an activated carbon filter. Other tastes and odors may respond to oxidizing agents such as chlorine and potassium permanganate. Where these problems are due to industrial wastes and certain other substances, some of the above types of treatment may completely fail. In some cases, for example, chlorination may actually intensify a taste or odor problem. Potassium permanganate has been found to be extremely effective in removing many musty, fishy, grassy and moldy odors. Two factors make this compound valuable: it is a strong

oxidizing agent; and it does not form obnoxious compounds with organic matter. However, a filter must be used to remove the manganese dioxide formed when the permanganate is reduced.

In any case, you may have to try a number of methods in an attempt to rid a water of objectionable tastes and odors. If methods considered here do not work, it may be more economical to seek out a new source of drinking water.

## COMMON INQUIRIES

At times, water can have an unusual odor, taste or appearance. In most cases, these aesthetic characteristics do not pose a public health threat. The first step in solving a water quality problem is to identify whether it originates from the household plumbing or the water utility. One way to tell is to ask others in the service area if they have a similar problem. Below are typical concerns, their most common causes, and what to do about them.

### **Discolored Water**

If the water changes color suddenly – no matter what color it becomes – it could indicate a public health concern. Do not use the water. Something likely has disturbed the direction or rate of water flow in the water main, such as a water surge caused by a power outage or use of a fire hydrant.

Avoid running hot water if the cold water is discolored. This will prevent filling the hot water tank with discolored water. If you are washing clothes, you can minimize the potential for staining by stopping the washer while it is full and waiting until clear water is available to finish.

Green or blue water is usually caused by corrosion of copper plumbing. If corrosion is occurring, dripping water will leave a bluish-green stain on porcelain fixtures. Certain metals, such as copper, that get into drinking water from corrosion may pose a health concern. The problem could be in the home's piping or corrosive water from the utility.

Black or dark brown water is usually due to manganese or pipe sediment and should clear up without further action when the sediment settles in the water main. Manganese does not pose a threat to human health. If it doesn't clear after a few minutes of flushing the cold water faucets and toilets, wait about an hour and try again.

Brown, red, orange or yellow water is usually caused by iron rust. Rusty water can be caused by galvanized iron, steel or cast iron pipes either in a home or business, or the water main. While unpleasant and potentially damaging to clothes and fixtures, iron in drinking water is not a human health concern.

Milky white or cloudy water is almost always caused by tiny air bubbles. If the water is white, fill a clear glass with water and set it on the counter. If the water starts to clear at the bottom of the glass first, the cloudy or white appearance is a natural occurrence. It is not a health threat and should clear in about 5 minutes.

### **Taste and Odor Problems**

If the taste or odor occurs at every water faucet on the property, the cause could be the water supply. If it occurs only in certain faucets, the problem is with the fixture and pipe supplying those specific faucets. If the problem goes away after running the water for a few minutes, the problem is somewhere in your plumbing system.

Petroleum, gasoline, turpentine, fuel or solvent odor is rare and potentially serious. It is possible a leaking underground storage tank may be near your water supply. Do not use the water.

Metallic taste is usually due to minerals, such as iron or copper that can leach into water from pipes. Metals such as zinc and manganese are less common causes. Only a certified laboratory

can analyze the water to determine if metals are present. Certain metals may have human health effects if consumed over long periods of time.

Chlorine, chemical or medicinal taste or odor is usually caused by the addition of chlorine to the water by your PWS, or the interaction of chlorine with a build-up of organic matter in your plumbing system. This is not a health threat. The best way to reduce taste and odor is to run the faucet for several minutes, put some water in a container, and store it in the refrigerator.

Sulfur or rotten egg taste or odor is most commonly caused by bacteria growing in your sink drain or water heater. But, in some cases, this smell is caused by naturally occurring hydrogen sulfide. To problem-solve the cause, put a small amount of water in a narrow glass, step away from the sink, swirl the water around inside the glass and smell it. If the water has no odor, then the likely problem is bacteria in the sink drain. If the water does have an odor, it could be your water heater. This occurs if the hot water has been unused for a long time, the heater has been turned off for a while, or the thermostat is set too low. If the drain or water heater have been ruled out, and the odor is definitely coming from the tap water, do not use the water.

Moldy, musty, earthy, grassy or fishy taste or odor is commonly caused by bacteria growing in a sink drain or from organic matter such as plants, animals or bacteria that are naturally present in lakes and reservoirs. To problem-solve the cause, put a small amount of water in a narrow glass, step away from the sink, swirl the water around inside the glass and smell it. If the water has no odor, then the likely problem is the sink drain. If it does have an odor, the source could be organic matter in your drinking water. Although harmless, it can affect the taste and smell of your drinking water even at very low concentrations. The best way to reduce taste and odor is to run the faucet for several minutes, put some water in a container, and store it in the refrigerator.

## STANDARD OPERATING PROCEDURES

A **Standard Operating Procedure (SOP)** is a set of instructions or steps someone follows to complete a job safely, with no adverse impact on the environment (and which meets regulatory compliance standards), and in a way that maximizes operational and production requirements. Write SOPs for any processes an individual or group performs: unloading raw materials, manufacturing products, shutting down an operation, repairing a faulty electrical circuit, and thousands of other workplace activities.

Write different SOPs for people who perform jobs by themselves, people who work together on a job, and people who supervise other people doing a job. The primary audience for an SOP, however, is the person who will perform a particular job. Consider such factors as the age, education, knowledge, skills, experience and training of a person who will perform a job, and the "social culture" or work history within which the individual works. Some work cultures disdain SOPs so you must work to overcome rejection.

SOPs also can be used by managers, government safety inspectors, environmental regulators, lawyers, engineers, planners, vendors, contractors and customers. Sometimes the same SOP material is used to write a description of how a job is done—a process—which can be useful if a company representative must explain operations to the media and public.

Ideally, SOPs should be written before a job is begun. Test SOPs before putting them into final application. Revise SOPs after an on-the-job trial. Also revise SOPs when any changes or modifications are made to equipment, machinery, buildings or other structures, or procedures within the immediate work area that might affect performance of a job or the "environment" in which it is performed.

You can't write SOPs for every job overnight, so set priorities. Write SOPs when new equipment or processes create new work situations. Write or rewrite SOPs when new information suggests benefits from modifying work practices to improve performance. Accident investigations might show you that procedural, safety and environmental guidelines are insufficient, incomplete, or even missing for certain jobs or parts of jobs.

Systematically update all safety and environmental guidelines by asking workers to evaluate existing SOPs, work practice guidelines and other documents that contain work, safety and environment guidelines. Then rank these jobs as to which should be revised first through last. These procedures could be revised, perhaps by the groups that ranked them.

SOP writers often don't know how long an SOP should be. Sometimes writers are pressured by operations supervisors to "make it short" rather than comprehensive. Clearly these supervisors don't understand the purposes and audiences an SOP serves.

SOPs can be either long, short or both. Because SOPs are used for a variety of reasons and audiences, they first must be comprehensive, which means they are as long as necessary to cover a job. For long SOPs or for jobs performed infrequently, it pays to keep the long-form SOP handy. Once an employee is familiar with a process, he or she will most likely be able to perform a series of short SOP steps from memory. These steps can be written as a short-form SOP. If someone is going to use a short-form SOP, it should be prepared after a full long-form SOP has

been tested and approved and should be handed out after an employee has passed the appropriate training.

- Keep in mind that the average person is uncomfortable following a long list of steps for the following reasons:
- A long list looks formidable, which makes the task daunting and tedious for many people who then don't want to perform the steps.
- A long list is difficult for your eyes to follow. You forget where you are on the list and forgetting leads to mistakes.
- A long list scares people and makes them nervous or anxious to "get it over with."
- A long list can hide steps that should be done with caution.
- A long list is difficult for writers to write while ensuring that the step sequence is clear.

The solution to SOPs that involve a long list of steps is to break the steps into logical sections of about 10 steps per section, such as "Getting ready for the process," "Initial steps," "Final steps."

Most importantly, SOPs should be reviewed by several people qualified to evaluate the SOP in terms of its completeness and clarity of safety, environmental and operational components.

Write SOPs for the following reasons:

1. To provide individuals who perform operations with all the safety, health, environmental and operational information required to perform a job properly;
2. To ensure that operations are done consistently to maintain quality control of processes and products;
3. To ensure that processes continue and are completed on a prescribed schedule;
4. To ensure that no failures occur in manufacturing and other processes that would harm employees or anyone in the surrounding community;
5. To ensure that approved procedures are followed in compliance with company and government regulations;
6. To serve as a training document for teaching users about a process;
7. To serve as a historical record of the how, why and when of steps in a process for use when modifications are made to that process and when a SOP must be revised; and,
8. To serve as an explanation of steps in a process that can be reviewed in incident investigations that seek to improve safety practices and operating conditions.

Here are suggestions for what to include in an SOP. Be sure to modify as necessary. Use an organization that favors simplicity and ease of reading.

1. Write a title (with a descriptive verb) that defines the purpose of the SOP. Include the word "safety" in the title, if applicable.
2. Use document reference numbers and revision dates on the title or cover page and a second page such as the table of contents or first page of text.
3. Identify general and specific points of activity for which an SOP has been written.

4. State the purpose of the SOP including the specific audience (user) in one or two sentences. Include information about process and regulatory standards, and both desirable and undesirable consequences.
5. Write a "scope" statement that tells what related subjects the SOP will not cover if there is any chance someone will be confused and make a mistake. Use scope statements for two reasons: to focus your attention as a writer and to clarify things for a reader. Many SOPs do not require scope statements, but consider the value of one before dismissing it as too much trouble to write.
6. List by category, any items or tools required for following the SOP whenever they apply. Think of this list as being a "tools and parts kit" for doing a job. Use general terms for common tools and equipment. For example, instead of listing every tool, a chemist or technician might simply list "gas cylinder tools." Add other categories or subcategories as desired. Sometimes a table instead of a paragraph is an appropriate format for this information.
7. Give an overview of the steps in the SOP that describes the process in terms of its major functions. Include anticipated safety, health, environmental and operational results.
8. Describe the machinery, mechanism, processing system and major components. Complete operating instructions contain overall descriptions of the major system and its components so that readers can orient themselves to the system as a whole and to its major parts.
9. Define terms and concepts. If the SOP contains terms and concepts that readers may be unfamiliar with, define these in their own paragraph so that readers (1) know that there are unusual words or concepts, and (2) can find them easily for use when needed. A long list of terms may fit better in a glossary at the beginning of a document. If you decide that a simple list of terms and definitions is better, include the list within the write-up, perhaps right before the list of steps to be performed.
10. Place safety warnings, cautions and notes prominently within the SOP before the actual step to be described. Never place safety items at the end of a step. Depending on the SOP, a writer might include an overall warning or caution that describes the general safety concerns. This should be placed at the beginning of an SOP where it is the first thing read after the title on the first page of text. If more than one safety warning, caution or note exists, list them in boldface type at the beginning of the SOP. The purpose of placing the cautions first is to alert the reader to read the warnings first. Often a page of safety cautions appears immediately after the title page and before the first page of text. Write warnings and cautions in clear sentence form. If there are only one or two warnings, these might be best placed at the top of the first page of text rather than on a separate page. The goal is to place warnings where the reader will read them. Sometimes this placement is determined by the size of the final printed version of an SOP. It is easy to place several warnings on an 8-1/2"x11" sheet of paper, but not so easy to do on a pocket-size handbook. Write Notes to provide people with information that can help them satisfy safety, health, environmental and

operational procedural requirements. For example, if it is permissible to use an extension cord of a certain length, this information should be stated in the SOP.

11. List and explain the process steps in sequential order in which an SOP user should perform the steps.
12. If two steps must be done at once, explain them in a sentence that clearly says so. You may wish to highlight (with italics or underlining) the first part to differentiate it from the actual step.
13. Provide a more detailed explanation if a reader needs more information to fully understand the reason for performing a step.
14. Provide readers with alternative steps to take in case a desired step does not work.
15. When an SOP is time-dependent, indicate the times clearly.
16. When a step depends on informational input (data), include the source, reference document number and date if possible.
17. Decide where to use graphics (drawings, photographs and thumbnail icons) to communicate clearly. Well-labeled drawings often are better than text. Use drawings of labeled (named) parts of objects to show proper relationships and orientations among the parts or other objects. Show the positioning of hand tools, other tools and even hands and feet if applicable when work is to be performed. For example, show the positioning of a wrench or direction for turning a valve. Show the individual parts of a device in a final assembled position. Consider using thumbnail graphics to visually alert readers that they have come to a safety item.
18. Write a reference and writers' section that includes a complete list of source material used for the SOP. If someone wants to confirm something, they will know where to look. List the names of those who wrote the SOP.
19. Test the SOP in the field and then develop troubleshooting instructions. Anyone who has ever assembled a consumer product knows there are always problems to solve either while trying to assemble something or after it has been assembled. Anticipate all these problems for a reader and include them in a troubleshooting section. Also incorporate troubleshooting tips at each step in a process where they actually occur.
20. One way to anticipate safety, health, environmental and operational problems is to ask an inexperienced person to "walk through" a mock (inactive) process (under close supervision of an expert) and try the steps. Such unknowledgeable person could ask questions or demonstrate behaviors that an experienced or familiar person would not.

## **SAFETY PROGRAM**

Every water system, regardless of size, needs to develop and implement a safety program to prevent injury to its employees and to avoid accidents involving the public. The development of a safety program should include information regarding potential job hazards, preventive safety measures, proper safety and emergency procedures for the use and operation of tools and equipment, and the proper methods of handling and reporting accidents and injuries. One person should be designated the responsibility for overseeing and maintaining the safety program.

A safety program is designed to maintain a safe workplace. All employees will be required to comply with all aspects of the safety program. The safety program should include a written safety plan designed to promote employee participation in the safety program. The Safety Plan should list procedures which have been established as part of the water system's safety program which identifies and describes water system hazards and provides safety measures.

The following sections will not outline the exact safety procedures that should be written in the Safety Plan. Rather, it will serve as a guide for recommended job activities for which safety procedures should be established and listed, as well as other general topics related to the safety program.

### **Identification and Description of Hazards**

The safety hazards associated with water supply systems are numerous and varied. Water system personnel should be made aware of all hazards, where these hazards are present in the water system, and how they may affect the employees. The following list identifies some of the general hazards faced by water system employees:

1. Bodily injury caused by falls, improper lifting, improper use of tools and equipment, and accidents involving moving mechanical equipment;
2. Electrical shock and burns;
3. Injury caused by improper chemical handling;
4. Exposure to chlorine gas;
5. Injury caused by improper entrance into confined spaces; and,
6. Trenching and shoring cave-ins.

The Safety Plan also should include a detailed description of each hazard, including where each hazard may be present and what the health risk from each hazard may be to the employee.

### **Recommended Safety Program**

Once the job hazards have been identified and described, it is important to outline the proper safety procedures which should be used when performing each job task to reduce these hazards as much as possible. Therefore, the Safety Plan should provide detailed safe operating procedures for specific aspects of water system employee job responsibilities. Recommended safety procedures for each of these water system job tasks can be found in the AWWA's Manual M3, Safety Practices for Water Utilities, as well as in other reference materials on water supply system operation. Manufacturer's literature also may be a good source of safety procedures for some of the tools, equipment, and machinery.

## **SAFETY MANUAL**

Every water system, regardless of size, needs to develop and implement a safety program to prevent injury to its employees and to avoid accidents involving the public. The development of a safety program should include the preparation of a safety manual which provides employees with guidance on all aspects of the safety program. This includes information regarding potential job hazards, preventive safety measures, proper safety and emergency procedures for the use and operation of tools and equipment, and the proper methods of handling and reporting accidents and injuries. The safety manual, once written, should be included as a chapter of the O&M Plan and should be distributed to each employee.

The following section will serve as a guide to the development of a water system safety program, as well as for the preparation of a safety manual for inclusion in the O&M Plan.

### **Start-Up and Maintenance of a Safety Program**

The process by which a safety program is established and implemented will differ for every water system. However, there are key elements which should be included as part of the start-up and maintenance of any safety program. Some of these key elements are suggested as follows:

1. **Designate a Safety Officer**

For large systems, a safety officer should be assigned; while in smaller systems, the manager or superintendent should assume the responsibilities of overseeing the safety program. The safety officer should possess a thorough knowledge of safety procedures and standards, and should be responsible for the development of safety programs for specific job activities and their incorporation into the safety manual. The maintenance of safety records and reports also would be among the responsibility of the safety officer.

2. **Issue a Policy Statement**

This statement should outline the water system's policy on safety and give its objectives concerning the employees' welfare. The objectives outlined in the policy statement can help the system gain the loyalty and respect of its operators and achieve efficient system operation.

To be effective, the policy statement should stress the system's recognition of the need for safety and emphasize the responsibility of workers at all levels to perform the job safely. The policy statement should be included in the chapter on safety in the O&M Plan and reinforced by the supervisory staff.

3. **Form Safety Committees**

Safety committees are important tools in the development of a safety program because they enable different groups of people at different employee levels to meet and discuss safety issues as they relate to the various job responsibilities. Three possible committees are the management committee, working committee, and accident review board. The management committee can advise and assist management in the implementation of the safety program, while the working committee creates interest in safety within the work force. The accident review board would be responsible for the investigation and determination of accident causes. In smaller systems, one committee could be formed to perform the functions of these three committees with the superintendent acting as committee chairman.

#### 4. Establish a Recordkeeping and Reporting System

A method of reporting and recording accidents and injuries must be established and maintained so that proper investigations can be made (i.e., the types, sources, and personnel involved in accidents and injuries recorded, and the causes determined). From these reports and records, corrective measures may be taken to prevent similar accidents or injuries in the future.

Some of the types of reports and records which should be incorporated into the safety program are:

- Employee Record;
- Occupational Injury Report;
- Vehicle Accident Report;
- Public Injury Reports.

Summary reports for the safety program should be submitted by the safety officer to the supervisors and upper management on a quarterly basis and should be cumulative during the year. These reports should provide a summary of the occupational injury, vehicle accident, and public injury reports, and should compare the current year's data to the data from the previous year so that the effectiveness of the safety program may be evaluated. The method for preparing the summary reports may be included in the O&M Plan for easy reference.

#### 5. Institute a Safety Education and Training Program

Institution of a safety education and training program is needed to bring the importance of safety to the attention of the employees and to continually remind them of that importance. The program should include:

- The development of a safety manual for all employees;
- Conducting training sessions on all of the subjects covered in the safety manual;
- Scheduling safety meetings, seminars, and talks to reinforce any safety training previously provided.

### **O&M Safety Plan**

As noted previously, the safety chapter of the O&M Plan also can serve as a safety manual for water system employees. It should be a compilation of the policies and procedures which have been established as part of the water system's safety program. Therefore, this chapter should include the water system's safety policy statement, the identification and description of water system hazards, a recommended safety program, accident and injury response and reporting, and fire prevention and first aid procedures.

The following sections will not outline the exact safety procedures that should be written in the O&M Plan. Rather, it will serve as a guide for recommended job activities for which safety procedures should be established and included in the O&M Plan, as well as other general topics related to the safety program that also should be included.

#### *Introduction*

The introduction to this chapter of the O&M Plan is a good place to include the water system's safety policy statement. In doing so, the system's policy on safety and the purpose of the chapter are clearly stated at the outset.

### *Identification and Description of Hazards*

The safety hazards associated with water supply systems are numerous and varied. Water system personnel should be made aware of all hazards, where these hazards are present in the water system, and how they may affect the employees. When writing the safety chapter of the O&M Plan, emphasis should be placed on the hazards within the specific system for which the plan is being written. The following list identifies some of the general hazards faced by water system employees. The O&M Plan should include a similar list which identifies the specific hazards of the system for which the plan is being written.

In a water treatment plant or in water pumping stations, the most common safety hazards are the following:

- Bodily injury caused by falls, improper lifting, improper use of tools and equipment, and moving mechanical equipment;
- Electrical shock and burns;
- Drowning;
- Injury caused by improper chemical handling;
- Exposure to chlorine gas;
- Laboratory accidents; and,
- Injury caused by improper entrance into confined spaces.

In a water distribution system and in storage tank facilities, the most common safety hazards are the following:

- Bodily injury caused by falls, improper lifting, improper use of tools and equipment, motor vehicle accidents, automobile traffic at work sites, improper pipe handling and improper trenching and shoring;
- Exposure to dangerous gases; and
- Electrical shocks and burns.

This section of the safety chapter of the O&M Plan also should include a detailed description of each hazard, including where each hazard may be present and what the health risk from each hazard may be to the employee.

### *Recommended Safety Program*

Once the job hazards have been identified and described, it is important then to outline the proper safety procedures which should be used when performing each job task to reduce these hazards as much as possible. Therefore, this section of the safety chapter of the O&M Plan should provide detailed safe operating procedures for specific aspects of water system employee job responsibilities. Recommended safety procedures for each of these water system job tasks can be found in the American Water Works Association's (AWWA's) Manual M3, Safety Practices for Water Utilities, latest edition, as well as in other reference materials on water supply system operation. Additional excellent references are the Chlorine Institute for chlorine safety, and OSHA which provides general safety information and safety sheets for chemicals used in the water industry. Manufacturers' literature also may be a good source of safety procedures for some of the tools, equipment, and machinery used by the particular water system for which the O&M Plan is being written.

The following sections discuss some of the recommended job-related activities for which safety procedures should be provided in this section of the safety chapter of the O&M Plan.

1. **General Safety Practices and Equipment.** Safe work procedures for all jobs performed by the water system employees should be established and standardized if the maximum benefits of the safety program are to be obtained. Some general topics of safety practices and equipment are:
  - a. **Personal Protective Equipment.** The type of personal protective equipment required for each job activity should be outlined. When the wearing of personal protective equipment is specified, it should be made mandatory. The types of personal protection equipment that should be discussed are:
    - i. Face and eye protection;
    - ii. Hand protection;
    - iii. Body protection;
    - iv. Head protection;
    - v. Foot protection;
    - vi. Respiratory equipment; and,
    - vii. Safety belts.
  - b. **General Safety Procedures.** There are some activities that, even though they are performed routinely, can result in serious injury if not carried out in the proper way. Therefore, the correct procedures for lifting and lowering objects, fall prevention, and the use of stairways and handrails should be outlined in the O&M Plan.
2. **Use of Tools and Equipment.** It is important that the need for learning and using the proper care and handling of tools and equipment be stressed in this chapter. By establishing safety procedures for all tools and equipment used by water system personnel, some serious accidents and injuries may be avoided.
3. **Motorized Vehicle Operation.** In order to avoid as many motor vehicle accidents as possible, it is important that:
  - a. The employees who are responsible for operating each vehicle are made aware of and trained in the proper operation of the vehicles; and
  - b. The vehicles are properly maintained according to the manufacturers' recommendations.Therefore, the O&M Plan should include procedures for the safe operation of each motor vehicles driven by water system employees. It also should include a safety checklist which lists items that should be checked prior to operation of the vehicle (e.g., headlights, turn signals, horn, windshield wipers, mirrors, brakes, etc.). The employees should be provided with training in the safe operation of the vehicles and periodically evaluated on safe driving skills.
4. **Distribution System and Storage Facilities.** To reduce the distribution system and storage facility hazards, employees should be provided with the proper procedures for performing the job activities related to working in the distribution system and storage facilities. Some of the job activities for which safety procedures should be included are:
  - a. Entering and working in confined spaces;
  - b. Trench excavation;
  - c. Blasting operations;
  - d. Barricades and warning signs;
  - e. Pipe handling, installation, and storage; and

- f. Climbing, entering, and repairing storage tanks and standpipes.
5. **Water Treatment Plant, Well, and Booster Pump Stations.** The purpose of this section of the safety chapter is to inform the employees who are responsible for working in and around water treatment plants, well houses and booster pumping stations of the proper procedures for performing job activities in these areas. Safety precautions should be outlined for maintenance work on treatment units, pumps and related equipment, placement of equipment guards, and working on or near electric switch panels. Employees should be instructed to refer to the applicable sections of the safety chapter for special instructions on electrical safety and chemical handling. Some areas for which safety procedures for treatment plant and pump station personnel are as follows:
- a. **Electrical Safety** - Although water system operators should not be performing major electrical repairs or installations, there are times when minor repairs or routine inspections are needed. Also, since much of the equipment routinely used by the operators is powered by electricity, as are most of the water system facilities themselves, it is important for the employees to be well informed on the proper procedures for working with or around electrically-powered tools or equipment. The electrical safety guidelines for electric hand tools and electric equipment should be included in the safety procedures for the specific pieces of equipment to be used for each job. This section of the O&M Plan should outline preventive measures which must be taken to ensure the safety of the operators while they are performing maintenance, installation, or inspection of electrical systems in the water treatment plant, in well or booster pumping stations, or in the distribution system. It also should outline safety precautions to be taken when working with or in the vicinity of electrically-powered tools or equipment. In distribution systems, electrical hazards (when excavating) must be stressed due to the current practice of buried electrical lines. Locations of underground utilities must be obtained prior to excavation. When changing water meters, care must be taken to provide an electrical continuity across the meter space because the residential wiring systems may be grounded to the water system and the water system employee could receive a severe shock.
  - b. **Chemical Handling and Storage**-Water supply system personnel are responsible for handling a variety of chemicals, the nature of which depends on the complexity of the water system. In a simple well system, hypochlorite solution may be the only chemical used; while in a complex filtration plant, chemicals used can range from lime and alum to powdered activated carbon and gas chlorine. Regardless of the size or complexity of the system, it is important that the employees responsible for handling chemicals are well informed and thoroughly trained in the proper handling and storage procedures for all chemicals used in their particular water treatment process. When preparing the chemical handling section of the O&M Plan, each chemical used by the water system in any capacity -- from water treatment to window cleaning - -should be included. If any chemicals are added to or deleted from the treatment schematic, the manual should be revised to include or delete that chemical. The following information should be provided for each chemical:
    - i. Safety hazards posed by the chemical;
    - ii. Special precautions to be taken;
    - iii. Proper handling procedures and storage methods;
    - iv. Protective equipment;

- v. Control of leaks (for liquids and gases) and dust (for powders); and
- c. Right to Know Act - The purpose of this law is to ensure that information concerning the hazards of all chemicals is transmitted to employees who must work with them so as to reduce the incidence of chemically-related illnesses and injuries. In other words, workers have a right to know about chemical hazards to which they may be exposed. This is to be accomplished by providing information about chemical hazards to the water system employees by the following means:
  - i. Labels. Labels must be placed on each container present in the work areas and should list precautions in the following categories:
    1. Basic warnings;
    2. First aid;
    3. Fire;
    4. Spills;
    5. Handling and storage; and,
    6. Disposal.
  - ii. Material Data Sheets. A material safety data sheet (MSDS) or similar informational reference for each hazardous chemical used must be maintained in each work place. These material safety data sheets must be made available to the employees during all hours of operation. The material safety data sheets must contain information for each hazardous chemical in the following categories:
    1. Chemical identification - Chemical name, trade names, manufacturer's name and address, and an emergency phone number;
    2. Hazardous ingredients - What harmful ingredients the chemical contains and safe exposure levels;
    3. Physical data - Describes the chemical's appearance, odor, and other characteristics;
    4. Fire and explosion data - Identifies temperature at which the chemical ignites (flash point) and what will extinguish the fire;
    5. Health hazards - Lists symptoms of overexposure, first aid and emergency procedures in the event of overexposure, and medical conditions that may be aggravated by exposure to the chemical;
    6. Reactivity data - States whether the chemical reacts with materials or conditions:
      - a.  Incompatibility - Lists materials that cause the chemical to burn, explode, or release dangerous gases,
      - b.  Instability - Lists the environmental conditions, such as heat or direct sunlight, that cause a dangerous reaction;
    7. Spill or leak procedures - Outlines what method to use to clean up a spill or leak, required protective clothing and chemical disposal method;
    8. Special protection - Lists any personal protective equipment needed to work safely with the chemical; and
    9. Special precautions - Lists any other special precautions to follow when handling the chemical and any health and safety information not covered in other parts of the MSDS.

- d. Employee Information and Training. The water system must provide employees with information and training on hazardous chemicals in their work areas. This training must begin before the employee's initial assignment and additional training shall be provided when new chemicals are used or new information indicates the need for additional protective measures. The training programs should be conducted during the employee's regular working hours. The information and training program shall include the following:
  - i. Provisions of the act;
  - ii. Discussion of operations in the work area where hazardous chemicals are present;
  - iii. Methods of detecting the presence or release of hazardous chemicals in the work area;
  - iv. The location and availability of the written hazard communication program and related documents;
  - v. Protective measures the employees may take, including the purpose, proper use, and limitations of personal protective equipment;
  - vi. Explanation of labeling system and material safety data sheets; and,
  - vii. Emergency procedures, methods, and observations that employees can use to detect the presence of a hazardous chemical.
- e. Access to Written Records and Prohibited Practices. All chemical identification lists and material safety data sheets required by the act and any exposure measurements taken to monitor employee exposure to chemicals in the work area must be made available upon request to any affected employee or former employee, authorized employee representative, designated physician or representative. Furthermore, it is unlawful for the water system to discharge, discipline, or otherwise discriminate against any of its employees who assist in the enforcement of the act.
- f. Laboratory Operations - The water system employees who work in the laboratory also face job-related hazards because they must work with glassware; toxic, hazardous, and flammable chemicals; corrosive chemicals; acids; alkalines; and bacteriological agents. As a result, the inclusion of correct procedures for safe laboratory operations in the safety chapter of the O&M Plan is vital for laboratory worker safety. The laboratory safety section of the chapter should include safety guidelines related to the following activities:
  - i. Handling and cleaning of glassware;
  - ii. Chemical handling guidelines for chemicals used in the laboratory;
  - iii. Personal protection equipment;
  - iv. Correct use of pipettes;
  - v. Proper use of laboratory equipment, including hot plates, water stills, centrifuges, etc.;
  - vi. Personal hygiene; and,
  - vii. Use of the laboratory safety equipment.
- g. Office Worker Safety. Since the purpose of the safety program is the elimination of all hazards, regardless of where they exist, safety guidelines should be established for water system office employees and incorporated into the safety chapter. Some areas of concern which should be considered when preparing the

office safety measures include wet or newly waxed floors, aisles and stairs, doors, adequate lighting, electrical safety, proper material storage, office fans, fire extinguishers, emergency plans, chairs, file cabinets, and proper use of office equipment (i.e., staplers, paper clips, scissors, etc.).

- h. **General Maintenance:** Water system maintenance involves some hazardous job responsibilities. Therefore, the proper procedures for performing some of the more hazardous maintenance duties at the water supply system should be outlined in the O&M Plan. Some of these maintenance duties include window cleaning; cleaning, scrubbing, and waxing floors; and painting.
  - i. **Fire Protection:** Methods for the protection of the water system and employees from fire hazards should be included in this chapter of the O&M Plan. This section should include information regarding:
    - i. **Fire prevention measures** - Include guidelines on housekeeping activities that relate to fire prevention, such as proper disposal of cartons, crates, trash, etc.
    - ii. **Fire extinguishers** - Include number of extinguishers, types, locations, installation, inspection and maintenance requirements, and the type of extinguisher used on each type of fire (i.e., foam-type extinguisher on a Class B (flammable liquid) fire).
    - iii. **Flammable storage** - Outline proper storage methods and instructions on where and how flammable materials and chemicals should be stored.
    - iv. **Telephone numbers of fire and police departments.**
6. **Accident and Injury Response and Reporting.** Because accidents do sometimes happen even when safety procedures are followed, the safety program also should include a section which provides guidance on procedures which should be followed in the event of an accident or injury. This section should include procedures on accident response, first aid, and accident and injury reporting.
- a. **Accident Response** - Prepare instructions on procedures to follow when an accident happens (i.e., who should be notified, administration of first aid and reporting requirements). Include telephone numbers of the safety officer and/or supervisor, fire department, ambulance, police department, physician, and poison center.
  - b. **First Aid** - All employees should be encouraged to become trained in the administration of first aid and cardiopulmonary resuscitation (CPR) and advised of where such training is available. In addition, emergency first aid procedures for different types of injuries should be outlined in this section of the safety chapter. Some injuries for which emergency procedures should be provided are exposure to dangerous gases, electrical shock and burns, bodily injury, drowning, injury caused by dangerous chemicals, and miscellaneous first aid measures. A good reference for first aid procedures for all of these injuries is the American Red Cross First Aid Textbook, which may be obtained from local Red Cross offices.
  - c. **Accident and Injury Reports** - An important part of the success of the safety program is an established accident and injury reporting program. An accident and injury report should be developed and a copy of the form, as well as instructions for completion, should be included in this section of the O&M Plan safety chapter. Employees should be provided with instructions on when and how the form should be completed.

## **STEPS TO COMPLIANCE WITH THE EMPLOYEE RIGHT TO KNOW**

The following steps provide employers with a guide to achieving compliance with the law and to promoting safe and healthy working conditions for employees.

### **STEP 1. Make an inventory of all materials.**

- Walk around your workplace and prepare a written inventory of all materials that may be hazardous, regardless of quantity.
- As you prepare your inventory, read the container labels and note the name of the product; information about the manufacturer or distributor, such as the name, telephone number, and location; and the general work area where the product is found.
- Do not forget such things as compressed gasses, welding rods and alloy metals. Also check for by-products and intermediate products that may result from a process your company uses.
- Check with the person who purchases supplies to be sure that these materials are included on your list.

### **STEP 2. Obtain Material Safety Data Sheets (MSDS).**

- When your company places its first order for a hazardous chemical, the manufacturer should send an MSDS with the initial shipment. Manufacturers and importers are required to provide an MSDS with the initial shipment of a product to distributors and purchasers, and must provide updated information with the first shipment after each update. You may have received an MSDS previously and, not knowing what it was, thrown it away.
- For each substance noted during the survey for which you do not have an MSDS, request a material safety data sheet from the manufacturer or distributor. If the request is made verbally, follow up with a letter to document your request.
- If you are a manufacturer, you must conduct a hazard determination and develop an MSDS for products manufactured at your facility.

### **STEP 3. Use the information on the material safety data sheet to determine the chemical name and to identify the hazards of the substance.**

### **STEP 4. Prepare a chemical information list.**

- Arrange the material safety data sheets in alphabetical order by common or trade name.
- Review your inventory to be sure that you include all hazardous materials, even if you have not received a material safety data sheet from the manufacturer or distributor.
- Using the material safety data sheets and the inventory, prepare a chemical information list for your workplace. The list must:
  - be arranged in alphabetical order according to common name;
  - contain the chemical name; and
  - identify the work area in which the hazardous chemical is found.
- Be sure that the same name or *identity* is used on the label, the MSDS and the chemical information list to facilitate access to hazard and emergency information.
- If a product is a consumer product, be sure to consider the frequency of exposure that a typical consumer would have and compare it to the frequency of exposure of your employees. If your employees are exposed more frequently or in greater amounts than the typical consumer, the consumer product must be included on the list.

**STEP 5. Develop a system for updating the list.**

- As each new substance arrives in your workplace, be sure to obtain the MSDS. It may be appropriate to include on the initial purchase order for a hazardous chemical, as a condition of purchase, the requirement to provide an appropriate MSDS. Be sure that purchasing personnel notify you of any new products.
- When new materials are obtained, you must add them to the chemical list within 30 days. Be sure to include the date the chemical is added to the list.
- Re-alphabetize the chemical list every two years.

**STEP 6. Conduct a hazard assessment.**

- Go through your plant and identify each process in which a hazardous chemical is used.
- Using the hazard information on the MSDS, consider whether appropriate engineering controls, work practices, personal protective equipment, emergency procedures, and fire control procedures are in place to ensure the safety and health of your employees.

**STEP 7. Check to see that all containers are labeled.**

- Ensure that all containers of hazardous substances in the workplace are labeled, tagged, or marked. The label must include both the identity of the hazardous chemical and the appropriate hazard warnings. Container labels for hazardous substances you purchase also must include the name and address of the manufacturer, importer, or other responsible party.
- Check all incoming shipments of hazardous substances to be sure that they are labeled.
- If a container is not labeled, obtain a label from the manufacturer, importer, or other responsible party, or prepare a label using information obtained from these sources. Employers are responsible for ensuring that containers in the workplace are properly labeled, tagged, or marked.
- Do not remove or deface existing labels on containers unless the container is immediately re-marked with the required information.
- Instruct employees on the importance of labeling portable receptacles into which they have poured hazardous substances. If the portable container is only for the immediate use of the employee pouring the substance, then the container does not have to be labeled. If the container is used by more than one person, or on more than one shift, or if it may be left unattended by the person using it, it must be labeled.

**STEP 8. Develop an employee training and notification program.**

- Employers must develop an employee training and education program that informs employees of the requirements of the law, the employer's hazard communication methods, and the employee's rights.
- The program also must include information about the nature of the hazards, appropriate work practices, control programs, protective measures, and emergency procedures.

**STEP 9. Train and educate employees.**

- Initial training must be given to all current employees, and to new employees prior to their first assignment.
- Additional training must be provided when:
  - new hazards are introduced into the workplace;
  - exposure to hazardous chemicals changes;
  - employees are subject to increased exposure due to changes in work practices, processes or equipment; and

- additional information about hazardous substances in the workplace becomes available.

**STEP 10. Document the training given.**

- Be sure to keep records such as:
  - names of persons trained;
  - date and length of training session;
  - who conducted the training;
  - type of training, and
  - an outline or lesson plan.

**STEP 11. Develop a written hazard communication program.**

This program must include:

- Information about where your chemical information list and MSDS are maintained and how employees may access them;
- A description of your labeling system and other forms of warnings;
- How you provide employees with information about hazardous, non-routine tasks; and
- How employees receive information about hazardous chemicals in unlabeled pipes.

## **SAFETY**

Based on past studies, the water and wastewater industry has one of the highest injury rates in the nation. Workers in these areas are involved in construction and excavations, confined spaces, hazardous chemicals, and mechanical equipment that pose a serious injury risk when proper training, equipment, and procedures are not utilized. The **Occupational Safety and Health Administration (OSHA)** is responsible for developing regulations regarding worker safety and protection.

This section will introduce the topic of safety but is not intended to provide detailed information on all the safety topics important to operators. Each of us is responsible for his/her own safety and for the safety of others working in or entering our facilities. The water industry is one of the most hazardous, so it is very important for operators to be informed about situations that pose a safety risk.

### **Safety Conditions**

You may encounter potentially hazardous conditions on a regular basis while operating, maintaining, and repairing water system equipment. You should be aware of these hazards and use good judgment when you encounter a potentially hazardous situation. The life you save may be your own.

Accident prevention is everyone's job, but it is the employer who is ultimately responsible for providing a safe workplace. Some of the hazards an operator may encounter include, but are not limited to:

- Lifting injuries
- Electric shock
- Slips and falls
- Chemical burns
- Eye injuries
- Excavation accidents (cave-ins)
- Construction accidents
- Inhalation accidents (dust, toxic gases and vapors)
- Oxygen deficient confined spaces (less than 19.5% oxygen)

Accidents are the result of unsafe actions by employees or unsafe conditions that exist in the water system. Unsafe actions include, but are not limited to:

- Removing or disabling machinery safety devices
- Failure to wear personal protective equipment
- Using equipment or tools not designed for the job
- Using defective equipment or tools
- Standing on or riding the outside of moving equipment
- Failure to secure or tie down heavy loads
- Operating vehicles, including heavy equipment, at an unsafe speed
- Failure to use lockout/tagout devices

Some of the more common unsafe conditions found at a small water system may include, but are not limited to:

- Poor housekeeping

- Improper storage of chemicals
- Doors removed from electrical panels
- Machinery guards or safety devices missing
- Fire and explosion hazards
- Low clearance hazards
- Improperly secured ladders or scaffolds
- Protruding objects
- Inadequate lighting
- Noise above safe decibel levels
- Lack of warning placards
- Confined spaces

You should keep your water system facilities clean and orderly. Emergency equipment and doorways should be kept clear and machine guards replaced after repairing equipment. Doors should be replaced on the electrical panels when you complete a wiring job or replace a breaker.

The door to the pump house or chlorine room should open outward for ease in entering and leaving the structure. Abnormal machine or equipment operation, electrical hazards or other unsafe conditions should be corrected promptly. Do not let unsafe conditions become commonplace. Eventually, an unsafe condition will result in an accident.

Unfortunately, it is often the 5 minute task that causes many injuries. Quick fixes usually promote unsafe acts. Do not let 5 minute tasks result in an injury to yourself or an employee.

Become skilled at recognizing unsafe conditions. Your knowledge of unsafe conditions and unsafe acts gives you foresight to correct a hazardous situation before an accident occurs. Together materials handling, falls, falling objects and machinery cause more than 60% of all workplace injuries.

Employers are responsible for providing employees with the proper safety equipment and training in its use. They are also responsible for development and implementation of safety policies for their workplace. The employees, after proper training, are responsible for recognizing the safety issues; following approved safety procedures, and properly utilizing the associated safety equipment.

### **Personal Protective Equipment**

**Personal Protective Equipment (PPE)** may be uncomfortable and increase stress, but is for your protection. When wearing PPE, the body's ability to cool is usually diminished. Nevertheless, PPE is frequently required to reduce the risk of injury. PPE includes steel-toed boots, safety glasses or goggles, face shields, earplugs, gloves or chemical protective clothing. The employer is responsible for providing PPE for their employees.

Respiratory protection equipment is commonly used because of the danger of inhalation, which provides a route of entry into the bloodstream for dangerous volatile chemicals. There are 2 types of respiratory protection devices called respirators: air purifying and air supplying. Both consist of a face piece connected to either an air source or an air-purifying device. The air-purifying respirator uses cartridges with filters to purify air before it is inhaled. This type of protection is not adequate in an oxygen deficient atmosphere.

## **Hazard Communications**

OSHA established the Hazard Communication Standard in 1986. The standard was created to provide an information system on hazardous chemicals for both employers and employees. The Haz-Com Standard requires employers to ensure their employees know what hazardous materials exist in the workplace, how to safely use these materials, and how to deal with any emergencies that arise during use. Employers are required to provide the proper safety equipment, train employees in the safe use of any hazardous materials on a jobsite, and maintain records of both.

Producers of hazardous materials are required to provide customers with a **Material Safety Data Sheet (MSDS)** for each individual chemical or material. MSDS's must be kept on file and available to employees. Employee training should also include how to read and understand the information on the MSDS. The hazards that are involved fall into two basic categories: Health Hazards and Physical hazards.

Health hazards refer to immediate or long-term harm to the body caused by exposure to hazardous chemicals. Physical hazards like flammability or corrosivity can also cause injury to skin, eyes and the respiratory system. MSDS's are divided into 8 sections.

1. Manufacturers Contact Information
2. Hazardous Ingredients/Identity Information
3. Physical/Chemical Characteristics
4. Fire and Explosion Hazard Data
5. Reactivity Data
6. Health Hazard/First Aid Information
7. Precautions for Safe Handling and Use
8. Control/Cleanup Measures

## **NFPA Color-Code Warning System**

OSHA uses a system based on the **National Fire Protection Association (NFPA)** diamond warning symbol as part of the MSDS information. This code is also required for all container labels. The NFPA symbol has four color-coded diamond-shaped sections. The top (Red) diamond is the Flammability Hazard rating. The left (Blue) diamond is the Health Hazard rating. The right (Yellow) diamond is the Reactivity Hazard rating. The bottom (White) diamond contains special symbols to indicate properties not explained by the other categories. A number-based rating system is used for each section, ranging from 0 – least dangerous to 4 – extremely dangerous.

## **Lock Out/Tag Out**

**Lock out/tag out (LOTO)** regulations deal with the need to isolate a machine from its energy source to prevent it from starting while work is being done in and around the equipment. Energy sources can include electrical energy, hydraulic energy, pneumatic energy, thermal energy, and chemical energy. This can be either active energy or stored energy. Stored energy can take many forms. Some examples of stored energy are; electrical energy stored in capacitors, pneumatic energy stored in a compressor tank, and hydraulic water pressure in an isolated line. Any stored energy must be dissipated prior to working on the equipment. Employers are responsible for establishing an “Energy Control Plan” for LOTO work and supply each worker with their individual LOTO locking devices.

LOTO requires workers to isolate and de-energize these sources and lock and tag them prior to working on the equipment or process. Only trained personnel should conduct lock out/tag out procedures. Each individual involved in the work should attach their personal LOTO lock to the disconnect or isolation device. This assures that the equipment cannot be restarted until each individual is finished with their task and is clear of the equipment. Tags are used to provide information regarding the date and nature of the lockout and the individual responsible for removing the lockout. Tags are not substitutes for locks. Any isolation that can be locked must be locked and tagged. Lockout devices may also include chains, valve clamps, wedges, jacks, or key blocks.

Anyone who enters a LOTO work area must be informed that a LOTO situation exists. If they are to be involved in the work, they must also apply their own LOTO locks. Workers that leave a LOTO site must take their LOTO locks with them. If work is not completed at the end of a shift, all LOTO locks must be removed and be replaced with an equipment protection lock until work resumes. If equipment must be temporarily restarted, the LOTO must be removed during the restart and reapplied before work can continue.

### **Confined Space Entry**

The water and wastewater industry has one of the highest numbers of confined space injuries per capita in the country. The vast majority of confined space related injuries result in fatalities. Another disturbing fact is that 40% of the confined space related fatalities are people who tried to rescue someone else from a confined space.

A confined space is defined by the following parameters. It must be large enough for a person to enter and do work. It has openings that make entry or exit difficult. It is not intended for continuous occupancy. Any open surface tank that is deeper than four feet is also considered a confined space. Confined spaces fall into two categories; permit required and non-permit required. A confined space becomes permit required when it has potential for a hazardous atmosphere, potential for engulfment, a hazardous internal configuration, or other recognized hazards such as dangerous equipment or hot work (welding, cutting torch, etc.) that is in progress.

All employees involved in confined space entries must have the proper training in entry procedures and use of safety equipment. An entry supervisor is responsible for conducting the testing and completing the permit. Atmospheric testing should include oxygen concentration, Lower Explosive Limit for explosives, and any toxic gases that may be present. The oxygen concentration must be between 19.5-23.5%. The alarm point for explosives is 10% of Lower Explosive Limit (LEL).

An attendant must be present and stationed outside the confined space to monitor the entrants while they are working. The attendant must maintain constant verbal and visual communications with the entrants. The attendant must also be prepared to instruct the entrants to exit the confined space should the equipment fail or the entrants exhibit impaired judgment.

Any confined space must be tested for a hazardous atmosphere before the entry. Monitoring must continue while the entrants are in the confined space. Permit required confined spaces also require ventilation during the entry and self-contained or supplied air must be used if ventilation fails to produce a safe atmosphere. Permit required confined space entries also require rescue equipment such as a harness and tripod for emergency rescues. If the space is configured in a way that prevents the use of self-rescue equipment, an emergency rescue team must be on-site

during the entry. When the entry is completed, the entry supervisor must complete the permit form and file a copy with the appropriate supervisor and a confined space entry master file. Non-permit confined spaces must be reassessed periodically. Any non-permit space can be reclassified, as permit required, based on the results of these assessments.

### **System security**

The three “D”s of security are: Deter, Detect and Delay. Intrusion should be deterred, and detected if it occurs. Intruders should be slowed down (delayed) as much as possible to allow more time for their apprehension.

Water system security steps include:

1. Vulnerability assessment - Identify vulnerabilities such as doors, windows, hatches and locations in remote areas.
2. Eliminate or mediate vulnerabilities - Install locks and use them. Install fences, alarms and security lights. Ask for police patrols. Consider asking neighbors to watch over your facilities for you (adopt-a-facility).
3. Emergency response - Know who to call in an emergency. Create a list of emergency telephone numbers.
  - Fire
  - Police
  - IDEM
  - Local health department
  - Critical users
  - Your boss
  - Government officials
  - Nearby water systems
  - Laboratories
  - Contractors
  - Chemical suppliers
  - Parts/equipment suppliers
  - Insurance agent
  - Local media (radio, TV and newspaper)

Plan ahead for your emergencies. Think about what might go wrong, and try to plan for it. Like a good scout, “be prepared.” Always remember, people come first, then property. Be safe and do not take unnecessary risks.

## PERSONAL SAFETY

Sometimes you may be working in remote areas that could potentially put you at risk of getting lost or hurt. You should take the following steps to ensure you can work safely when conducting sanitary surveys and field visits in remote locations:

### **Plan Ahead**

- Notify your supervisor or a fellow worker that you will be working in a remote area.
- Have a check-in time set up before you leave. A check-in/check-out procedure can be used so that it is known where you are and when you have safely returned at the end of the day.
- Carry a fully charged cell phone (available for checkout at the regions).
- Know your site's emergency call-in number or your supervisor's pager number.
- Always wear your ID badge to clearly identify yourself.
- Wear appropriate footwear for the conditions, such as non-slip soled shoes for rough trails, mossy or slippery rocks, uneven or slippery floors, ladders, etc.
- If you are injured or involved in an accident, report to your supervisor immediately and submit an Accident/Incident Report Form.

### **Vehicle Safety**

- Always drive defensively and safely. Obey all driving laws, including wearing your seat belt. Be aware of other vehicles and surroundings.
- Know who to call if your vehicle breaks down.
- If someone bumps you from behind or is following you, don't pull over at that spot, especially if it is isolated. Go to a public place with lots of lights and people and report to your supervisor immediately or call 911.
- Driving precautions in rural areas: watch for debris and potholes; lanes are narrow, be aware of oncoming traffic; watch for surface changes; watch for slow going vehicles; be aware of unguarded railroad crossings; and watch for animals.

### **Methamphetamine (Meth) Labs**

- Be alert to homes whose view to the interior is obstructed in some manner by blinds, or the windows are boarded over, etc. Some drug labs have excessive security (more than one deadbolt, metal security doors, bars on windows, or vicious dogs). They also may have yards filled with discarded propane tanks and glassware that could have been used in a meth lab operation.
- Meth labs can be identified by their strong smell, similar to stale cat urine.
- Be careful when walking in yards with discarded glassware that could have been used in a meth lab operation because the chemicals they contained can contaminate you. Also, there may be booby traps set around the premises of the building.
- You **SHOULD** leave if you suspect the area is a meth lab operation.

### **In the Event of an Assault**

If you are attacked or threatened you have the right to defend yourself in any manner necessary proportionate to the threat. How you choose to defend yourself will depend on the circumstances of the assault and your abilities. Consider that you could be attacked and think about what you can or are willing to do to protect yourself. There is no one guaranteed method of defense. You will need to consider alternatives and optional responses.

### **Trust Your Instincts**

If you are feeling uncomfortable, cancel the visit, reschedule, or request back-up from another staff member or the police. If you are in a tight situation:

- Don't show fear. Watch their body language.
- Try not to show any facial expression.
- Control your breathing.
- Speak slowly and lower the pitch of your voice, talk from your diaphragm.
- Watch your hands so they don't move nervously. Maintain personal space.
- Maintain eye contact, but don't try to stare anyone down.
- Don't challenge, but be assertive, especially if lewd comments are made.
- Check your watch; say you need to call your office because they are waiting for your call.
- Repeat what you are there for.
- Stand up and leave.

## INCOMPATIBLE CHEMICALS

The purpose of this section is to assist with the identification of chemicals in use at water treatment plants that should be stored separately. Several chemicals commonly used in water treatment are considered “incompatible” with one another. **The term “incompatible” applies to chemicals that could create a hazardous reaction (such as production of toxic gas, accelerated corrosion, or generation of excessive heat through an exothermic reaction, which could result in an explosion and fire) if mixed together in their concentrated form.** Depending on the type, form, concentration, and amount of chemical, this reaction could be catastrophic, resulting in a loss of life and rendering the water plant inoperable. It is therefore important to store chemicals in a manner that will prevent incompatible substances from coming into contact with one another.

Chemicals commonly used at water treatment plants can be divided into 6 broad groups of “incompatible” chemicals. To ensure the safety of system personnel and the system itself, each of these groups of chemicals is considered incompatible with the other and therefore should be stored separately. These groups are listed in the table below.

<b>Group I</b>	<b>Acids</b>
<b>Group II</b>	<b>Bases</b>
<b>Group III</b>	<b>Salts &amp; Polymers</b>
<b>Group IV</b>	<b>Adsorption Powders</b>
<b>Group V</b>	<b>Oxidizing Powders</b>
<b>Group VI</b>	<b>Compressed Gases</b>

Examples of chemicals that should not be stored near each other, and the resulting consequence of improper storage including the following:

<b>Incompatible Chemicals - Examples</b>	<b>Hazardous Reactions</b>
Powdered Activated Carbon - PAC (an adsorption powder) mixed with Potassium Permanganate (an oxidizing powder.)	Excessive heat generation, with the possibility of explosion and fire. <b>Note:</b> PAC alone is extremely combustible
Calcium Hypochlorite (a combination base/oxidizer) exposed to moisture or mixed with a viscous fluid such as oil.	Excessive heat, fire or explosion possible. Can provide an ignition source for combustible materials
Concentrated Sulfuric Acid (a strong acid) mixed with Concentrated Sodium Hydroxide (a strong base)	Excessive heat and liquid explosion. <b>Note:</b> Highly concentrated acids and bases when mixed together, will have a much more hazardous reaction than weak acids and bases.
Calcium Oxide (a strong base that is only available in powdered form) exposed to moisture	Excessive heat, fire. Can provide an ignition source for combustible materials.

**Liquid chemicals should be stored separately from dry chemicals, regardless of which their compatibility group.** Certain concentrated dry chemicals will produce an exothermic reaction when exposed to liquid or even small amounts of moisture. All chemicals should be stored in secure, well-ventilated areas that are free of moisture (especially dry chemicals), freezing

conditions (especially liquid chemicals), excessive heat, ignition sources, and flammable/combustible materials. Products such as paint, antifreeze, detergent, oil, grease, fuel, solvent, and beverages should never be stored in the same area as water treatment chemicals.

Listed below are a number of chemicals commonly used in water treatment, listed by their compatibility group. Because there is a wide range of chemicals available and in use today, all chemicals used in the water industry may not be included on the following tables. OSHA Regulation 29.CFR.1910.1200 (Hazard Communication) requires that all organizations that handle hazardous chemicals, including PWSs, maintain a MSDS in their files for each chemical stored onsite. If there is a question regarding the properties or incompatibility of any chemical encountered at a plant, the appropriate MSDS should be reviewed.

### Group I: Acids

Name	Common Name	Available Forms <sup>(1)</sup>
Acetic Acid	Ethanoic Acid	Liquid
Hydrofluosilicic Acid	Fluosilic Acid	Liquid
Hydrogen Fluoride Acid	Hydrofluoric Acid	Liquid
Hydrochloric Acid	Muratic Acid	Liquid
Nitric Acid	Nitric Acid	Liquid
Sulfuric Acid	Sulfuric Acid	Liquid

### Group II: Bases

Name	Common Name	Available Forms <sup>(1)</sup>
Calcium Hydroxide	Hydrated Lime	Dry
Calcium Oxide	Quicklime	Dry
Calcium Hypochlorite	HTH	Dry
Sodium Bicarbonate	Sodium Bicarbonate	Dry
Sodium Carbonate	Soda Ash	Dry
Sodium Hydroxide	Caustic Soda, Lye	Liquid, Dry
Sodium Hypochlorite	Bleach	Liquid
Sodium Silicate	Water Glass	Liquid

### Group III: Salts/Polymers

Name	Common Name	Available Forms <sup>(1)</sup>
Aluminum Sulfate	Alum	Liquid, Dry
Copper Sulfate	Blue Stone	Liquid, Dry
Ferric Chloride	Ferrichlor	Liquid, Dry
Ferric Sulfate	Ferrifloc	Dry
Ferrous Sulfate	Coppras	Liquid, Dry
Polyaluminum Chloride	PAC or PACl	Liquid
Polyelectrolytes (Cationic, Anionic, Non-ionic)	Polymer	Liquid, Dry
Sodium Aluminate	Soda Alum	Liquid, Dry
Sodium Fluoride	Sodium Fluoride	Liquid, Dry
Sodium Hexametaphosphate	Glassy Phosphate	Dry
Sodium Phosphate	Sodium Phosphate	Liquid, Dry
Zinc Orthophosphate	Zinc Ortho	Liquid

(1) Liquid and Dry chemicals should be stored separately even if they are in the same compatibility group. Certain concentrated dry chemicals, like calcium hypochlorite and calcium oxide (quicklime) will produce an exothermic reaction when exposed to liquid or even small amounts of moisture.

**Group IV: Adsorption Powders**

Name	Common Name	Available Forms
Powdered Activated Carbon	PAC	Dry
Granular Activated Carbon	GAC	Dry

**Group V: Oxidizing Powders**

Name	Common Name	Available Forms
Potassium Permanganate	Permanganate (PotPer)	Dry

**Group VI: Compressed Gases<sup>(2)</sup>**

Name	Common Name	Available Forms	Incompatible Chemicals Within This Category <sup>(3)</sup>
Ammonia	Ammonia	Liquid, Gas	Chlorine
Chlorine	Gas Chlorine	Liquid, Gas	Ammonia
Carbon Dioxide	Dry Ice	Liquid, Gas	-
Sulfur Dioxide	Sulfur Dioxide	Liquid, Gas	-

(2) Each compressed gas should have its own separate storage / feed area

(3) Chlorine and Ammonia

## **WATER SECURITY**

Security practices should be incorporated into a utility's every day business functions. Activities such as fence cutting and lock picking, often dismissed as harmless, may be indications of more serious threats to a water or wastewater system. Utilities must be prepared to respond to this type of threat, as well as a wide range of other emergencies, including natural disasters. Improved security preparations provide for a more effective and efficient response.

Water and wastewater utilities are responsible for taking action to protect their infrastructure. The federal government and EPA are helping utilities to accomplish these actions by providing tools, trainings, and technical assistance.

Several resources designed specifically to help small drinking water and wastewater utilities better protect their systems are available through this site.

**BIOTERRORISM ACT** - On June 12, 2002, President Bush signed into law the Public Health Security and Bioterrorism Preparedness and Response Act of 2002 (PL 107-188, referred to as the Bioterrorism Act). In the Bioterrorism Act, Congress recognizes the need for drinking water systems to undertake a more comprehensive view of water safety and security. The Act amends the SDWA and specifies actions CWSs and the EPA must take to improve the security of the Nation's drinking water infrastructure.

The Bioterrorism Act defines small community drinking water systems as those serving a population of more than 3,300 but less than 50,000. If a community drinking water system serves more than 3,300 people, that utility must:

- Conduct a vulnerability assessment
- Certify to EPA that the assessment has been completed
- Send a copy of the assessment results to EPA
- Certify that the system has an emergency response plan.

**VULNERABILITY ASSESSMENTS** - Vulnerability assessments help PWSs evaluate susceptibility to potential threats and identify corrective actions that can reduce or mitigate the risk of serious consequences from adversarial actions (e.g., vandalism, insider sabotage, terrorist attack, etc.). Such an assessment for a water system takes into account the vulnerability of the water supply (both ground and surface water), transmission, treatment, and distribution systems. It also considers risks posed to the surrounding community related to attacks on the water system. An effective vulnerability assessment serves as a guide to the water utility by providing a prioritized plan for security upgrades, modifications of operational procedures, and/or policy changes to mitigate the risks and vulnerabilities to the utility's critical assets. The vulnerability assessment provides a framework for developing risk reduction options and associated costs. PWSs should review their vulnerability assessments periodically to account for changing threats or additions to the system to ensure that security objectives are being met. Preferably, a vulnerability assessment is "performance-based," meaning that it evaluates the risk to the water system based on the effectiveness (performance) of existing and planned measures to counteract adversarial actions.

The following are common elements of vulnerability assessments. These elements are conceptual in nature and not intended to serve as a detailed methodology:

1. Characterization of the water system, including its mission and objectives;
2. Identification and prioritization of adverse consequences to avoid;
3. Determination of critical assets that might be subject to malevolent acts that could result in undesired consequences;
4. Assessment of the likelihood (qualitative probability) of such malevolent acts from adversaries;
5. Evaluation of existing countermeasures; and
6. Analysis of current risk and development of a prioritized plan for risk reduction.

The vulnerability assessment process will range in complexity based on the design and operation of the water system itself. The nature and extent of the vulnerability assessment will differ among systems based on a number of factors, including system size, potential population affected, source water, treatment complexity, system infrastructure and other factors. Security and safety evaluations also vary based on knowledge and types of threats, available security technologies, and applicable local, state and federal regulations.

**EMERGENCY RESPONSE PLANS** - An **Emergency Response Plan (ERP)** is a documented plan that describes the actions that a CWS would take in response to various major events. A major event refers to:

- Credible threats, indications of terrorism, or acts of terrorism;
- Major disasters or emergencies such as hurricanes, tornadoes, storms, earthquakes, fires, flood, or explosion regardless of cause; and
- Catastrophic incidents that leave extraordinary levels of mass casualties, damage, and disruption severely affecting the population, infrastructure, environment, economy, and government functions.

Protecting public health is the primary goal of community drinking water systems, and having an up-to-date and workable ERP helps achieve this goal in any crisis situation. The Bioterrorism Act amends the SDWA by adding, among other requirements, section 1433. Section 1433(b) requires community water systems serving populations greater than 3,300 to either prepare or revise an ERP that incorporates the results of its Vulnerability Assessment (VA). The ERP must include “plans, procedures, and identification of equipment that can be implemented or utilized in the event of a terrorist or other intentional attack” on the CWS. The ERP also must include “actions, procedures, and identification of equipment which can obviate or significantly lessen the impact of terrorist attacks or other intentional actions on the public health and the safety and supply of drinking water provided to communities and individuals.”

Core elements form the basis, or foundation, for responding to any major event. EPA has identified 8 core elements common to an ERP that you should plan to utilize or bring to bear during water emergencies:

1. System Specific Information;
2. CWS Roles and Responsibilities;
3. Communication Procedures: Who, What, and When;
4. Personnel Safety;
5. Identification of Alternate Water Sources;

6. Replacement Equipment and Chemical Supplies;
7. Property Protection; and
8. Water Sampling and Monitoring

Your ERP may contain sensitive information, so you should consider steps you need to take to ensure the security of your ERP. Sensitive information should be placed in appendices, or in sections that are not readily available to unauthorized personnel. The ERP, however, should be easily accessible to authorized personnel and should be easily identifiable during a major event. Steps taken to limit access by unauthorized persons should consider local and state **Freedom of Information Act (FOIA)** laws. Alternatively, you can opt to make your ERP general in nature so that everyone can use it and not include specific information about system vulnerabilities. A secure copy of your ERP should be maintained in an off-premises location in the event that your primary copy cannot be accessed.

## **WATER SYSTEM SECURITY: Threat & Emergency Response Guide Manual**

### **What is an Emergency?**

An emergency is an unplanned event which disrupts or impacts your water system.

### **What Causes an Emergency?**

- Cross-connections
- Mis-communication
- Unspecified Responsibilities
- Equipment Failure
- Safety Violations
- Inadequate Maintenance
- Accidents
- Natural Disasters
- Acts of Vandalism or Terrorism
- Insufficient or Contaminated Source Water

### **How Can You Minimize the Impact of an Emergency?**

Quick, responsible action is necessary during an emergency. Developing and implementing a written emergency plan and procedures, along with having trained personnel, will help your water system achieve this goal. This guide offers information which can be used to create such a plan for your system.

### **Guidelines to Determine Impact of an Emergency:**

#### **LEVEL 1—NORMAL**

Trouble that can be handled routinely, including normal operator activity.

#### **LEVEL 2—ALERT (Minor Emergency)**

Trouble which can be handled by the system with oversight and guidance from OEHS and/or Rural Water Association. This could be an early sign to indicate that a system or part of a system could be lost.

#### **LEVEL 3—Major Emergency**

Problem(s) that are somewhat beyond the capability of system personnel and association capabilities. May require a declaration of emergency in order to authorize shortcut procedures. Would require mobilizing all system personnel who might seek help through activating mutual aid agreements or contacts. This level of emergency leaves no doubt that outside help is required because of a serious threat to the facilities of a system and the public health.

#### **LEVEL 4—PROBLEMS CLEARLY AND IMMEDIATELY BEYOND THE CAPABILITY OF THE UTILITY**

Recovery time will exceed one week. Cost will be great and large amounts of mutual aid will be required. A request for a declaration of emergency will be required. This level would normally affect many different services that may be lifelines to a water and/or wastewater system. Natural or man-made disasters at this level will cause both disruption over a large area of service and a severe health risk to the public.

## **HOMELAND SECURITY ADVISORY SYSTEM**

### **Threat Condition Levels**

The Homeland Security Advisory System consists of five Threat Condition Levels, each identified by a brief description and corresponding color. From lowest to highest, they are as follows:

**LOW =GREEN**  
**GUARDED= BLUE**  
**ELEVATED = YELLOW**  
**HIGH = ORANGE**  
**SEVERE = RED**

The higher the Threat Condition, the greater the risk of a terrorist attack. (Risk includes both the probability and severity of such an event.) The EPA has created a series of suggested preventive measures for PWSs to use at each of these levels.

## **EIGHT COMPONENTS OF EMERGENCY RESPONSE PLANS** (Suggested by the EPA)

### **1) System Specific Information**

- PWSID Number
- System Name
- Physical Address
- Phone Numbers, etc.

### **2) Water System Responsibilities**

- Designate an Emergency Response Lead (ERL)
- Name an alternate ERL
- ERL's should be individuals who can be on call 24/7
- Maintain contact information for ERL's

### **3) Communication Procedures**

- Details WHO, WHAT, and WHEN for distributing information
- Communicates with both internal and external customers
- Special plans for contacting various contingencies (first responders, hospitals, schools, etc.)

### **4) Personnel Safety**

- Shelter in place procedures
- Evacuation of employee procedures
- Other actions to ensure safety of water system personnel during emergencies

### **5) Identify Alternate Water Sources**

- List other water utilities or agencies which could be utilized in emergencies

### **6) Replacement Equipment and Chemical Supplies**

- Sources for replacing equipment damaged as a result of emergency situation
- Sources of chemical supplies

### **7) Property Protection**

- Measures taken to protect water system physical facilities

### **8) Water Sampling/Monitoring**

- Listing of companies and facilities which can provide sampling and monitoring

### **WHAT SHOULD YOU DO IF...**

- A threat is made against your water system?
- There is suspicious activity at your facilities?
- An intrusion or act of vandalism has occurred at your system?

### **IMMEDIATELY**

#### **1) CALL 911**

If your area does not have 911 service, Then contact your local law enforcement agency

**2) CALL WV WATCH: 1-866-989-2824**

This number will connect you with the WV State Police

**3) CALL THE OEHS DISTRICT OFFICE SERVING YOUR AREA**

See Phone Numbers below. Ask to speak directly to a district office Representative

**OFFICE OF ENVIRONMENTAL HEALTH SERVICES  
District Offices/Counties Served**

**Beckley (District 1) Phone: (304) 256-6666**

COUNTIES SERVICED: Fayette, Greenbrier, McDowell, Mercer, Monroe, Nicholas, Raleigh, Summers, Wyoming

**St. Albans (District 2) Phone: (304) 722-0611**

COUNTIES SERVICED: Boone, Cabell, Calhoun, Clay, Jackson, Kanawha, Lincoln, Logan, Mason, Mingo, Putnam, Roane, Wayne, Wirt

**Kearneysville (District 4) Phone: (304) 725-9453**

COUNTIES SERVICED: Berkeley, Grant, Hampshire, Hardy, Jefferson, Mineral, Morgan, Pendleton

**Wheeling (District 5) Phone: (304) 238-1145**

COUNTIES SERVICED: Brooke, Doddridge, Hancock, Marshall, Ohio, Pleasants, Ritchie, Tyler, Wetzel, Wood

**Philippi (District 6) Phone: (304) 457-2296**

COUNTIES SERVICED: Barbour, Braxton, Gilmer, Harrison, Lewis, Marion, Monongalia, Pocahontas, Preston, Randolph, Taylor, Tucker, Upshur, Webster

**Charleston (Central Office) Phone: (304) 558-2981**

## **THREAT AWARENESS**

### **What Is A Threat?**

A threat is any event which could result in contamination of your water system or cause a loss of water volume or pressure.

### **Types of Threats**

- Intentional Acts from an EXTERNAL source (Example: Activist groups, Criminals, Cults, Domestic or International Terrorist Groups, Vandals)
- Intentional Acts from an INTERNAL source (Example: Disgruntled present or former employee of a system)
- Natural Disaster (Example: Acts of God or Nature, such as a flood)
- Unintentional Acts/Accidents/Incidents (NON-DELIBERATE acts due to such causes as equipment failure, human error, or other unplanned acts)

### **How Can A Threat Be Communicated?**

- E-Mail (Example: Virus which can damage system)
- Fax
- In-Person (Example: A disgruntled employee threatens to damage a treatment plant)
- Phone (Example: Bomb threat)
- Suspicious openings or evidence of tampering involving structures such as manhole covers, buildings, or other equipment.

### **How Can I Increase Awareness?**

- Encourage customers to communicate with you and your staff as to how they can be involved in protecting their water system.
- Work with the public and other local agencies such as law enforcement or citizens/neighborhood watch groups.
- Watch for suspicious activity involving system facilities, personnel, or vehicles.

### **Examples of Suspicious Activity**

- Unidentified or unmarked vehicles (cars, trucks, etc.) parked or left near waterways or facilities for no apparent reason.
- Unidentified persons photographing or videotaping water system facilities, structures, equipment, dams, etc.
- People atop water tanks or climbing or cutting a utility fence.
- Unknown persons hanging around locks or gates.

### **IF YOU SUSPECT A THREAT, IMMEDIATELY:**

1. CALL 911  
If you do not have 911 in your area, call your local law enforcement agency.
2. CALL WV WATCH  
1-866-989-2824 (WV State Police)
3. CALL THE OEHS DISTRICT OFFICE SERVING YOUR AREA  
Ask to speak directly to a District Office Representative.

## MAINTENANCE PROGRAM

An important aspect of any effective and efficient water service organization is a maintenance program. The objectives of a maintenance program should be to eliminate the interruption of service caused by equipment failure and to extend the service life of all equipment for as long as practically possible and economically feasible. With this in mind, a good maintenance program will consist of a preventive maintenance plan, a general maintenance plan, an emergency maintenance plan, and a program evaluation. While each of these program topics will be discussed separately below, it is important to remember the effectiveness of the overall maintenance program will be determined by how closely each plan fits together.

Preventive maintenance provides a water system with three basic benefits:

1. Better service to all customers;
2. Increased equipment service life; and,
3. Efficient use of resources.

A preventive maintenance plan can be established by the use of planned work orders, planned work schedules and an evaluation process for all water system equipment. The use of planned work orders is an integral part of any preventive maintenance plan. Planned works orders should include the complete procedures to be performed, the total manpower (number of personnel, skill type, and total time) needed, and a list of materials required for the each preventive maintenance job. Compiling all planned work orders in an organized work schedule provides an efficient way of using the resources available to the water system, completing the work in a timely manner, and producing a framework for quality maintenance records. Equipment evaluation is one area overlooked when discussing a preventive maintenance plan. In order to evaluate the effectiveness of any preventive maintenance plan, a benchmark of the existing conditions of all equipment is required. When preventive maintenance work is completed, the water system should have the ability to evaluate equipment performance on both a short term and long term basis. Also, the preventive maintenance work itself can be evaluated to better improve the individual components of the plan. Preventative maintenance can be considered a time efficient and cost effective way of maintaining a water system. Scheduled preventative maintenance can lower total maintenance costs by allowing the system to purchase quality materials when time is available to obtain the best price. Scheduled preventative maintenance can be time efficient by the productive use of manpower and work schedules to complete the work while retaining some control over both the maintenance and operation of the equipment.

General maintenance is usually the largest component of any maintenance program. A general maintenance plan can be established by developing planned work orders, prioritizing work within daily, weekly, and monthly schedules, developing a material purchasing system, and evaluating the overall performance of all general maintenance work. As with the preventive maintenance plan, the use of planned work orders is vital to an effective general maintenance plan. Planning work in advance can assure that proper procedures are followed by each staff member, correct materials and supplies are available to complete the work, and a record of the completed work is available for filing in project and equipment files. Reviewing planned work orders will provide the water system with a means of fine tuning their general maintenance plan. Another key is a prioritized work schedule. Prioritizing work on a daily, weekly, and monthly basis creates a productive working environment for personnel. This results in more maintenance being completed at a much lower overall cost. Efficient maintenance requires that adequate materials and supplies be available for use at a moment's notice. It is important that water

systems realize the need for developing a material purchasing system. This system would include a complete material and supply inventory, standardized purchasing procedures, and a tracking method of all materials used by the water system. It is important to have a centralized area designated for the storage of all materials and supplies used by the water system. An evaluation process should be developed to determine the overall performance of all maintenance work along with its effectiveness over the service life of the equipment. Changes in the types of procedures and materials used can be detected and corrected during the evaluation process. Also, the efficiency of a water system's use of resources and manpower as they pertain to the general maintenance plan can be determined.

An emergency maintenance plan is an invaluable component of most maintenance programs. This specialized plan will save both time and money when utilized properly. The foundation in developing an emergency plan is knowing the capabilities and limitations of the water system's staff and resources. The next step is to formulate contingencies for all types of emergencies that your water system has encountered in the past or could encounter in the future. It is important to be as specific as possible in identifying the many emergencies that could occur. Finally, a comprehensive list of consulting engineers, contractors, technical sales representatives, and material supply companies should be developed. This list should contain information as to the contact people, phone numbers (business and emergency), and the specific time and reasons each would be contacted. This contact list and a material/supply inventory list should be updated as often as possible and readily available for use at any time. Experience and planning are the keys to assuring the emergency maintenance plan operates properly. When the dust has settled and normal operation has resumed, a comprehensive evaluation of all actions taken as a part of the emergency plan should occur in a timely manner. At this point, evaluating the actions taken will hopefully result in a better emergency plan and, thus, an improved response to the next emergency.

The final component of a comprehensive maintenance program is a program evaluation. The only way to improve a water system's maintenance program is to periodically evaluate it to ensure the main objectives of eliminating the interruption of service caused by equipment failure and extending the service life of all equipment for as long as practically possible and economically feasible are being met. By applying the knowledge and experience gained from successful and unsuccessful maintenance work along with proper planning and training, the evaluation process will improve the overall maintenance program by strengthening the individual preventive, general, and emergency plans. As more evaluations are conducted, the water system will find itself gaining more experience, performing improved maintenance work, increasing the service life of all equipment, benefiting from more productive work, saving more money, and providing the best possible water service to the customers.

### **Preventive Maintenance**

Preventive maintenance involves the regular inspection, testing, and replacement or repair of equipment and operational systems. As a **best management practice (BMP)**, preventive maintenance should be used to monitor and inspect equipment and other conditions that could cause breakdowns or failures of structures and equipment. A preventive maintenance program can prevent breakdowns and failures through adjustment, repair, or replacement of equipment before a major breakdown or failure occurs.

Preventive maintenance procedures and activities are applicable to almost all facilities. This concept should be a part of a general good housekeeping program designed to maintain a clean

and orderly work environment. Preventive maintenance takes a proactive approach and seeks to prevent problems before they occur. Preventive maintenance programs can also save a facility money by reducing the likelihood of having a system breakdown. In addition, a preventive maintenance program can be an effective community relations tool.

The primary limitations of implementing a preventive maintenance program include:

- Cost;
- Availability of trained preventive maintenance staff technicians; and,
- Management direction and staff motivation in expanding the preventive maintenance program.

### **Key Program Components**

Elements of a good preventive maintenance program should include the following:

- Identification of equipment or systems that may malfunction.
- Establishment of schedules and procedures for routine inspections.
- Periodic testing of plant equipment for structural soundness.
- Prompt repair or replacement of defective equipment found during inspection and testing.
- Maintenance of a supply of spare parts for equipment that needs frequent repairs.
- Use of an organized record-keeping system to schedule tests and document inspections.
- Commitment to ensure that records are complete and detailed, and that they record test results and follow-up actions. Preventive maintenance inspection records should be kept with other visual inspection records.

### **Implementation**

The key to properly implementing and tracking a preventive maintenance program is through the continual updating of maintenance records. Update records immediately after performing preventive maintenance or repairing an item and review them annually to evaluate the overall effectiveness of the program. Then refine the preventive maintenance procedures as necessary.

No quantitative data on the effectiveness of preventive maintenance as a BMP is available. However, it is intuitively clear that an effective preventive maintenance program will result in improved water system.

### **Costs**

The major cost of implementing a preventive maintenance program is the staff time required to administer the program. Typically, this is a small incremental increase if a preventive maintenance program already exists at the facility.

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## EXAM PREPARATION

The following is some information about the certification exam to hopefully make you a little less apprehensive. Use common sense when studying for the exam. Exams are not written by a disgruntled person trying to fail everyone, nor are 100% pass rates the goal. The Drinking Water Exam Review Committee (DWEREC), which includes state regulators (OEHS Certification and Training Program staff), educators (WV Environmental Training Center and WV Rural Water Association representatives) and current Class IV water operators, develop all PWS operator certification exams to increase training and testing relevance and comply with EPA Operator Certification Program requirements. The DWERC continues to work towards multiple complete versions of each classification exam with references, organized by content areas to ensure all exam questions are based on what operators actually “need to know” to adequately prepare for and perform job duties and responsibilities associated with the treatment and distribution of drinking water. As new federal and state regulations and drinking water treatment technology advances are made, the DWERC will continue to review and revise all required PWS operator exams to ensure they are valid and relevant.

Also, if a person is familiar with how the exam is conducted, he/she will be more comfortable with the exam process and more likely to pass the exam. This list will help you familiarize yourself with the certification exam.

1. Most exams have 100 questions, with each question worth one point. A score of 70 or above is passing.
2. All questions are multiple-choice. You will receive partial credit on the math problems, so make sure you **show all of your work**. It could mean the difference between passing and not passing.
3. You will be given 4 hours to complete the exam. This has proven to be plenty of time for people to complete the exam.
4. The exam is a closed-book exam. All equations and conversions needed for math problems will be given on a formula sheet with each exam so there is no need to memorize equations.
5. Overall, the percentage of people passing a given exam is good.
6. All applicants must complete and submit form EW-102C at least thirty (30) days prior to the requested exam date.
7. If you have any special learning needs, please notify the Certification and Training Program so appropriate accommodations can be arranged in advance.
8. OEHS is required to notify applicants before the exam date with a confirmation letter by mail. Bring this confirmation letter, a photo ID, a pencil, and a calculator to the exam with you.
9. Exam scores are valid for 2 years, so you must fulfill the experience requirement to upgrade to a Class II within that timeframe or reapply and retake the exam.
10. If you do not make a passing grade on the exam, you must wait at least 60 days before reapplying for reexamination.
11. Once certified, a Class II operator must acquire at least 24 hours of continuing education credits (CEHs) every two years to maintain certification.
12. CEHs are training classes pre-approved by the OEHS based on their relevancy to the drinking water industry. Operators must provide copies of class certificates with their renewal application (EW-102D).

**HERE'S A QUICK SUMMARY OF TEST-TAKING STRATEGIES  
YOU NEED TO KNOW!**

- ◆ Be on time and try to relax.
- ◆ Pace yourself, so you have time to answer all of the questions.
- ◆ Read the instructions carefully and look at both side of each page.
- ◆ Consider doing easier questions first and coming back to harder, more time-consuming questions such as those with calculations.
- ◆ Read each question carefully.
- ◆ Read all of the answers so that you can pick the best one.
- ◆ There's no penalty for wrong answers, so answer every question, even if you have to guess.
- ◆ If you have to guess, improve your odds by eliminating obviously wrong answers.
- ◆ Take a break if you need one.
- ◆ Recheck your answers after you've finished the exam.
- ◆ Watch out for distracting information in the questions and answers. Some of the information you're given may be irrelevant or may even lead you to the wrong answer. Make it a point to determine what the question is really asking.
- ◆ Beware of extreme modifiers (like "all" or "never"). There are exceptions to most rules, so be careful about any statement that expresses an absolute truth.
- ◆ Some answers may be partially correct, so be sure that you read every answer and then pick the best one.
- ◆ Make a drawing or sketch if it will help you understand the question.
- ◆ Be aware that another question may contain the answer to a question you are not sure of.
- ◆ Underline key points in a question such as variables in a math problem.

## GLOSSARY

**ABSORPTION** - Taking in or soaking up of one substance into the body of another by molecular or chemical action (as tree roots absorb dissolved nutrients in the soil).

**ACCOUNTABILITY** - When a manager gives power/responsibility to an employee, the employee ensures that the manager is informed of results or events.

**ACCURACY** - How closely an instrument measures the true or actual value of the process variable being measured or sensed.

**ACIDIC** - The condition of water or soil which contains a sufficient amount of acid substances to lower the pH below 7.0.

**ACTION LEVEL** - The level of lead or copper which, if exceeded in over 10% of the homes tested, triggers treatment or other requirements that a water system must follow.

**ACTION PLANS** - Specific plans designed to be used during the response to a threat or incident. Action plans should be easy to use and contain forms, flow charts, and simple instructions to support staff in the field or decision officials during management of a crisis.

**ACTIVATED CARBON** - Adsorptive particles or granules of carbon usually obtained by heating carbon (such as wood). These particles or granules have a high capacity to selectively remove certain trace and soluble materials from water.

**ACUTE** - Effects of an exposure which causes severe symptoms to occur quickly.

**ACUTE CONTAMINANT** - A harmful substance that has a rapid effect on humans and/or animals.

**ACUTE HEALTH EFFECT** - An immediate (i.e., within hours or days) adverse health effect that may result from exposure to certain drinking water contaminants (e.g., pathogens).

**ADSORPTION** - The collection of a gas, liquid, or dissolved substance on the surface or interface zone of another material.

**AERATION** - The process of adding air to water. Air can be added to water by either passing air through water or passing water through air.

**AEROBIC** - A condition in which “free” (atmospheric) or dissolved oxygen is present in the water.

**AESTHETIC** - Attractive or appealing.

**AESTHETIC QUALITIES** - The taste, odor and appearance of drinking water.

**AIR BINDING** - A situation where air enters the filter media. Air is harmful to both the filtration and backwash processes. Air can prevent the passage of water during the filtration process and can cause the loss of **altar** media during the backwash process.

**AIR GAP** - An open vertical drop of vertical empty space that separates a drinking (potable) water supply to be protected from another water system in a water treatment plant or other location. This open gap prevents the contamination of drinking water by backsiphonage or backflow because there is no way raw water or any other water can reach the drinking water.

**AIR STRIPPING** - A treatment process used to remove dissolved gases and volatile substances from water. Large volumes of air are bubbled through the water being treated to removed (strip out) the dissolved gases and volatile substances.

**ALGAE** - Microscopic plants which contain chlorophyll and live floating or suspended in water. They also may be attached to structures, rocks or other submerged surfaces. Excess algal growths can impart tastes and odors to potable water. Algae produce oxygen during sunlight hours and use oxygen during the night hours. Their biological activities appreciable affect the pH and dissolved oxygen of the water.

**ALGAL BLOOM** - Sudden, massive growths of microscopic and macroscopic plant life, such as green or blue-green algae, which develop in lakes and reservoirs.

**ALKALINE** - The condition of water or soil which contains a sufficient amount of alkali substances to raise the pH about 7.0

**ALKALINITY** - The capacity of water to neutralize acids. This capacity is caused by the water's content of carbonate, bicarbonate, hydroxide, and occasionally borate, silicate, and phosphate. Alkalinity is expressed in milligrams per liter of equivalent calcium carbonate. Alkalinity is not the same as pH because water does not have to be strangely basic (high pH) to have a high alkalinity. Alkalinity is a measure of how much acid can be added to a liquid without causing a great change in pH.

**ALTERNATING CURRENT** - An electric current that reverses its direction (positive/negative values) at regular intervals.

**ALTITUDE VALVE** - A valve that automatically shuts off the flow into an elevated tank when the water level in the tank reaches a predetermined level. The valve automatically opens when the pressure in the distribution system drops below the pressure in the tank.

**AMBIENT TEMPERATURE** - Temperature of the surrounding air (or other medium). For example, temperature of the room where a gas chlorinator is installed.

**AMPERE** - The unit used to measure current strength. The current produced by electromotive force of one volt acting through a resistance of one ohm.

**ANAEROBIC** - A condition in which "free" (atmospheric) or dissolved oxygen is NOT present in water.

**ANALYZER** - A device which conducts periodic or continuous measurement of some factor such as chlorine, fluoride turbidity. Analyzers operate by any of several methods including photocells, conductivity or complex instrumentation.

**ANNULAR SPACE** - A ring-shaped space located between two circular objects, such as two pipes.

**ANODE** - The positive pole or electrode of an electrolytic system, such as battery. The anode attracts negatively charged particles or ions.

**ANTHRACITE** - A dense, shiny coal that has high carbon content and little volatile matter and is often used on top of sand water treatment filters for iron removal.

**AQUIFER** - A natural underground layer of porous, water-bearing materials (sand, gravel) usually capable of yielding a large amount or supply of water.

**ARSENIC RULE** - U.S. Environmental Protection Agency has issued a rule that applies to all community water systems and non-transient, non-community water systems, which sets the maximum contaminant level of arsenic at 10 milligrams per liter.

**ARTESIAN** - Pertaining to groundwater, a well, or underground basin where the water is under a pressure greater than atmospheric and will rise above the level of its upper confining surface if given an opportunity to do so.

**AS-BUILT MAPS** - Maps or drawings depicting the actual installation of pipes and equipment. Also called record drawings. As-builts often differ from original plans.

**ASSIMILABLE ORGANIC CARBON (AOC)** - The portion of DOC that is easily used by microorganisms as a carbon source.

**AUDIT, WATER** - A thorough examination of the accuracy of water agency records or accounts (volumes of water) and system control equipment. Water managers can use audits to determine their water distribution system efficiency. The overall goal is to identify and verify water and revenue losses in a water system.

**AVAILABLE EXPANSION** - The vertical distance from the sand surface to the underside of a trough in a sand filter. This distance is also called FREEBOARD.

**AVAILABLE SUPPLY** - The maximum amount of reliable water supply, including surface water, groundwater, and purchases under secure contracts.

**AVERAGE-DAY DEMAND** - A water systems average daily use based on total annual water production (total annual gallons or cubic feet divided by 365); multiple years can be used to account for yearly variations.

**AVERAGE DEMAND** - The total demand for water during a period of time divided by the number of days in that time period. This is also called the AVERAGE DAILY DEMAND.

**BACK PRESSURE** - A pressure that can cause water to backflow into the water supply when a user's water system is at a higher pressure than the PWS.

**BACKFILL** - To refill an excavated area with removed earth; or the material itself that is used to refill an excavated area.

**BACKFLOW** - A reverse flow condition, created by a difference in water pressures, which causes water to flow back into the distribution pipes of a potable water supply from any source or sources other than an intended source. Also see BACKSIPHONAGE.

**BACKFLOW PREVENTION** - The best defense for backflow is a proactive backflow prevention program requiring backflow preventers in areas where backflow can occur.

**BACKFLOW PREVENTION ASSEMBLY INSTALLER/TESTER (BPAIT)** - An individual who meets all the requirements of 64CSR25 and is certified to inspect and test backflow prevention assemblies or methods.

**BACKSIPHONAGE** - A form of backflow caused by a negative or below atmospheric pressure within a water system. Also see BACKFLOW.

**BACKWASH** - The up flow or counter-current flow of water through a filter or ion-exchange medium, lifting the mineral bed and flushing away to the drain the particles of foreign matter that have been filtered from the water supply during the filter cycle.

**BACKWASHING** - The process of reversing the flow of water back through the filter media to remove the entrapped solids.

**BACTERIA** - Bacteria are living organisms, microscopic in size, which usually consist of a single cell. Most bacteria use organic matter for their food and produce waste products as a result of their life processes.

**BAFFLE** - A flat board or plate, deflector, guide or similar device constructed or placed in flowing water or slurry systems to cause more uniform flow velocities, to absorb energy, and to divert, guide, or agitate liquids (water, chemical solution, slurry).

**BASE** - Any substance which contains hydroxyl (OH) groups and furnishes hydroxide ions in solution; a molecular or ionic substance capable of combining with a proton to form a new substance; a substance that provides a pair of electrons for a covalent bond with an acid; a solution with a pH of greater than 7.

**BATCH PROCESS** - A treatment process in which a tank or reactor is filled, the water is treated or a chemical solution is prepared, and the tank is emptied. The tank may then be filled and the process repeated.

**BED EXPANSION** - During backwashing, the water pushes the media up until it is suspended in the water. The height to which the media rises during backwashing is known as the bed expansion. For example, if the filter media is 2 feet deep, it may rise up to 3 feet deep during backwashing. This is a 50% bed expansion

**BENTONITE** - Bentonite is a type of clay used as a coagulant aid in water high in color and low in turbidity and mineral content. This type of water usually would not form floc large enough to settle out of the water. The bentonite joins with the small floc, making the floc heavier and thus making it settle more quickly

**BEST AVAILABLE TECHNOLOGY (BAT)** - The water treatment(s) that EPA certifies to be the most effective for removing a contaminant. The best technology treatment techniques, or other means which the Administrator finds, after examination for efficacy under field conditions and not solely under laboratory conditions, are available (taking cost into consideration). For the purposes of setting MCLs for synthetic organic chemicals, any BAT must be at least as effective as granular activated carbon.

**BEST MANAGEMENT PRACTICES (BMPs)** - Structural, nonstructural and managerial techniques that are recognized to be the most effective and practical means to control nonpoint source pollutants yet are compatible with the productive use of the resource to which they are applied. BMPs are used in both urban and agricultural areas.

**BIOFILM** - Organic or inorganic surface deposit consisting of microorganisms, microbial products, and detritus.

**BIOLOGICAL GROWTH** - The activity and growth of any and all living organisms.

**BIOTERRORISM ACT** - The Public Health Security and Bioterrorism Preparedness and Response Act of 2002.

**BLOWOFF** - A controlled outlet on a pipeline, tank, or conduit which is used to discharge water or accumulations of material carried by the water.

**BOIL WATER NOTICE** - A directive issued to water system users to boil their water because of known or suspected bacteriological contamination.

**BREAKPOINT CHLORINATION** - Addition of chlorine to water until the chlorine demand has been satisfied. At this point, further addition of chlorine will result in a free residual chlorine that is directly proportional to the amount of chlorine added beyond the breakpoint.

**BREAKTHROUGH** - A crack or break in a filter bed allowing the passage of floc or particulate matter through a filter. This will cause an increase in filter effluent turbidity. A breakthrough can occur (1) when a filter is first placed in service, (2) when the effluent valve suddenly opens or closes, and (3) during periods of excessive head loss through the filter (including when the filter is exposed to negative heads).

**BUFFER** - A solution or liquid whose chemical makeup neutralize acids or bases. This is a measure of the capacity of water for offering a resistance to changes in pH.

**C FACTOR** - A factor or value used to indicate the smoothness of the interior of a pipe. The higher the C Factor, the smoother the pipe, the greater the carrying capacity, and the smaller the friction or energy losses from water flowing in the pipe. To calculate the C Factor, measure the flow, pipe diameter, distance between two pressure gages, and the friction or energy loss of the water between the gages.

**CALCIUM CARBONATE (CaCO<sub>3</sub>) EQUIVALENT** - An expression of the concentration of specified constituents in water in terms of their equivalent value to calcium carbonate. For example, the hardness in water which is caused by calcium, magnesium and other ions is usually described as calcium carbonate equivalent.

**CALIBRATION** - A procedure which checks or adjusts an instrument's accuracy by comparison with a standard or reference.

**CAPACITY DEVELOPMENT** - The process through which your water system can acquire and maintain technical, managerial, and financial capabilities to consistently provide a safe and reliable source of drinking water

**CARBONATE HARDNESS** - Hardness caused by metals combined with a form of alkalinity. Carbonate hardness is the most common type of hardness and is responsible for the deposition of calcium carbonate scale in pipes and equipment. It is sometimes known as "temporary hardness" since it can be removed by boiling the water. It may be removed from pieces of equipment with hydrochloric acid, also known as muriatic acid.

**CARCINOGEN** - Any substance which tends to produce cancer in an organism.

**CATHODE** - The negative pole or electrode of an electrolytic cell or system. The cathode attracts positively charged particles or ions (cations).

**CATHODIC PROTECTION** - An electrical system for prevention of rust, corrosion, and pitting of metal surfaces which are in contact with water or soil. A low-voltage current is made to flow through a liquid (water) or a soil in contact with the metal in such a manner that the external electromotive force renders the metal structure cathodic. This concentrates corrosion on auxiliary anodic parts which are deliberately allowed to corrode instead of letting the structure corrode.

**CAUSTIC SODA** - A chemical which is sometimes used to replace soda ash and some of the lime in the lime softening process. Also known as NaOH, or sodium hydroxide.

**CAVITATION** - The formation and collapse of a gas pocket or bubble on the blade of an impeller or the gate of a valve. The collapse of this gas pocket or bubble drives water into the impeller or gate with a terrific force that can cause pitting on the impeller or gate surface. Cavitation is accompanied by loud noises that sound like someone is pounding on the impeller or gate with a hammer.

**CENTRIFUGAL PUMP** - A pump consisting of an impeller fixed on a rotating shaft that is enclosed in a casing, and having an inlet and discharge connection. As the rotating impeller whirls the water around, centrifugal force builds up enough pressure to force the water through the discharge outlet.

**CERTIFIED OPERATOR** – An individual holding a valid West Virginia PWS certification in accordance with Section 6 of 64CSR4.

**CHAIN OF COMMAND** - A clear and definitive structure of authority.

**CHAIN OF CUSTODY** - A written record that shows who handled a sample over what periods of time from the beginning to the end of the sampling and testing process.

**CHECK VALVE** - A special valve with a hinged disc or flap that opens in the direction of normal flow and is forced shut when flows attempt to go in the reverse or opposite direction of normal flow.

**CHIEF OPERATOR** - The certified operator whom the owner designates who is responsible for managing the daily operational activities of an entire PWS or a water treatment facility, or a distribution system in a manner that ensures meeting state and federal safe drinking water rules and regulations.

**CHLORAMINES** - Compounds formed by the reaction of hypochlorous acid (or aqueous chlorine) with ammonia.

**CHLORINATION** - The application of chlorine to water, generally for the purpose of disinfection, but frequently for accomplishing other biological or chemical results (aiding coagulation and controlling tastes and odors).

**CHLORINATOR** - A metering device which is used to add chlorine to water.

**CHLORINE DEMAND** - The difference between the amount of chlorine added to water and the amount of residual chlorine remaining after a given contact time. Chlorine demand may change with dosage, time, temperature, pH, and nature and amount of the impurities in the water.

**CHLORINE DOSE** - The total amount of chlorine fed into a volume of water by the chlorine feed equipment is referred to as dosage and is calculated in milligram per liter (mg/L).

**CHRONIC** - Effects of an exposure which causes symptoms to continue for a long time.

**CHRONIC HEALTH EFFECT** - The possible result of exposure over many years to a drinking water contaminant at levels above its Maximum Contaminant Level.

**CIRCUIT BREAKER** - A safety device in an electrical circuit that automatically shuts off the circuit when it becomes overloaded. The device can be manually reset.

**CHRONIC** - Effects of an exposure which causes symptoms to continue for a long time.

**CIRCLE OF INFLUENCE** - The circular outer edge of a depression produced in the water table by the pumping of water from a well. Also see CONE OF INFLUENCE AND CONE OF DEPRESSION.

**CIRCUIT** - A path through which an electrical current can flow when the path is complete.

**CLARIFICATION** - The removal of small amounts (usually less than 0.2%) of fine particulate solids from liquids (such as drinking water) by methods such as gravity sedimentation, centrifugal sedimentation, filtration, and magnetic separation.

**CLARIFIER** - A square or circular sedimentation basin with horizontal flow in which water is held for a period of time, during which the heavier suspended solids settle to the bottom. A specific kind of clarifier, known as a solids-contact clarifier, upflow solids-contact clarifier, or upflow sludge-blanket clarifier combines coagulation, flocculation, and sedimentation within a single basin. Solids-contact clarifiers are often found in packaged plants and in cold climates where sedimentation must occur indoors.

**CLEAR WELL** - A reservoir for the storage of filtered water of sufficient capacity to prevent

the need to vary the filtration rate with variations in demand. Also used to provide chlorine contact time for disinfection. The clear well should also have adequate volume to provide backwash water for the filters.

**COAGULANT AID** - Coagulant aids are chemicals added to water to promote coagulation. They add density to slow-settling flocs and add toughness so that the floc will not break up while settling out of the water. Polymers are one type of coagulant aid.

**COAGULANTS** - Chemicals that cause very fine particles to clump together into larger particles. This makes it easier to separate the solids from the water by settling, skimming, draining or filtering.

**COAGULATION** - The clumping together of very fine particles into larger particles caused by the use of chemicals (coagulants). The chemicals neutralize the electrical charges of the fine particles and cause destabilization of the particles. This clumping together makes it easier to separate the solids from the water by settling, skimming, draining, or filtering.

**COHESION** - Molecular attraction which holds two particles together.

**COLIFORM** - A group of bacteria found in the intestines of warm-blooded animals (including humans) and also in plants, soil, air and water. Fecal coliforms are a specific class of bacteria which only inhabit the intestines of warm-blooded animals. The presence of coliform bacteria is an indication that the water is polluted and may contain pathogenic organisms.

**COLLOIDS** - Very small, finely divided solids (particles that do not dissolve) that remain dispersed in a liquid for a long time due to their small size and electrical charge. When most of the particles in water have a negative electrical charge, they tend to repel each other. This repulsion prevents the particles from clumping together, becoming heavier, and settling out. Examples include bacteria, fine clays, and silts. Colloidal solids often cause colored water, such as the "tea color" of swamp water. Also known as nonsettleable solids.

**COLORIMETRIC MEASUREMENT** - A means of measuring unknown chemical concentrations in water by measuring a sample's color intensity. The specific color of the sample, developed by addition of chemical reagents, is measured with a photoelectric colorimeter or is compared with "color standards" using, or corresponding with, known concentrations of the chemical.

**COMBINED AVAILABLE RESIDUAL CHLORINE** - That portion of the total residual chlorine remaining in water, sewage or industrial waste at the end of a specified contact period, which will react chemically and biologically as chloramines or organic chloramines.

**COMBINED DISTRIBUTION SYSTEM** - The interconnected distribution system consisting of the distribution systems of wholesale systems and of the consecutive systems that receive finished water from those wholesale system(s).

**COMMUNITY WATER SYSTEM (CWS)** - A PWS which serves at least 15 service connections used by year round residents or regularly serves at least 25 persons year-round residents. Also see non-community water system, transient water system and non-transient non-community water system.

**COMPLETE TREATMENT** - A method of treating water which consists of the addition of coagulant chemicals, flash mixing, coagulation-flocculation, sedimentation and filtration. Also called CONVENTIONAL FILTRATION.

**COMPLIANCE** - The act of meeting all state and federal drinking water regulations.

**COMPLIANCE SAMPLES** – Required sample your system takes to comply with regulations. Compliance samples are identified in your monitoring plan. All compliance samples identified in your monitoring plan must be included in your compliance calculations, even if you take more than the minimum number of samples.

**COMPOSITE** - A composite sample is a collection of individual samples obtained at regular intervals, usually every one of two hours during a 24-hour time span. Each individual sample is combined with the others in proportion to the rate of flow when the sample was collected. The resulting mixture (composite sample) forms a representative sample and is analyzed to determine the average conditions during the sampling period.

**COMPOUND** - A substance composed of two or more elements whose composition is constant. For example, table salt (sodium chloride -NaCl) is a compound.

**COMPOUND METERS** - These meters are used where there is a need to measure both high and low flows, like in a hotel, school, or a commercial account where both domestic use and production use need to be measured by one meter. They are typically available in sizes from 2” through 6”.

**CONDENSATION** - The process of water vapor in the air turning into liquid water.

**CONDUCTANCE** - A measure of the conducting power of a solution equal to the reciprocal of the resistance. The resistance is expressed in ohms.

**CONDUCTIVITY** - The ability of a material to carry current or heat.

**CONE OF DEPRESSION** - The depression, roughly conical in shape, produced in the water table by pumping of water from a well. Also see CIRCLE OF INFLUENCE and CONE OF DEPRESSION.

**CONFINED AQUIFER** - The saturated formation between low permeability layers that restrict movement of water vertically into or out of the saturated formation. Water is confined under pressure similar to water in a pipeline. In some areas confined aquifers produce water without pumps (flowing artesian well).

**CONFINED SPACE** - A space defined by the concurrent existence of the following conditions:

1. Existing ventilation is insufficient to remove dangerous air contamination and/or oxygen deficiency which may exist or develop, and
2. Ready access or egress (getting out) for the removal of a suddenly disabled employee (operator) is difficult due to the location and/or size of the opening(s).

**CONFIRMED** - A stage in the threat evaluation process in which there is definitive evidence and information to establish that an incident or major event has occurred.

**CONSECUTIVE SYSTEM** - Includes all systems that buy or otherwise receive some or all of their finished water from another PWS on a regular basis.

**CONSUMER CONFIDENCE REPORT (CCR)** - All community water systems are required to deliver to their customers an annual report. This report must contain information on the quality of the water delivered by the system and characterize the risks, if any, from exposure to contaminants detected in the drinking water in an accurate and understandable manner. Systems shall deliver their reports no later than July 1 annually. Each report must contain data collected during, or prior to, the previous calendar year. A community water system that sells water to another community water system shall deliver the applicable information noted above to the buyer system no later than April 1 annually.

**CONTACT TIME** - The amount of time which the chlorine has to react with the microorganisms in the water, which will equal the time between the moment when chlorine is added to the water and the moment when that water is used by the customer. The longer the contact time, the more efficient the disinfection process is. When using chlorine for disinfection a minimum contact time of 30 minutes is required for adequate disinfection.

**CONTAMINANT** - Anything found in water (including microorganisms, minerals, chemicals, radionuclides, etc.) which may be harmful to human health.

**CONTAMINATION** - The introduction into water of microorganisms, chemicals, toxic substances, wastes, or wastewater in concentration that makes the water unfit for its next intended use.

**CONTINUOUS SAMPLE** - A flow of water from a particular place in a plant to the location where samples are collected for testing. This continuous stream may be used to obtain grab or composite samples. Frequently, several taps (faucets) will flow continuously in the laboratory to provide test samples from various places in a water treatment plant.

**CONVENTIONAL FILTRATION** - A method of treating water which consists of the addition of coagulant chemicals, flash mixing, coagulation-flocculation, sedimentation and filtration. Also called COMPLETE TREATMENT. Also see DIRECT FILTRATION and IN-LINE FILTRATION.

**CORPORATION STOP** - A water service shutoff valve located at a street water main. This valve cannot be operated from the ground surface because it is buried and there is not valve box. Also called a CORPORATION COCK.

**CORROSION** - The gradual decomposition or destruction of a material by chemical reaction. Corrosion may be caused by (1) stray current electrolysis, (2) galvanic corrosion caused by dissimilar metals, or (3) differential-concentration cells. Corrosion starts at the surface of a material and moves inward. The various types of corrosion include internal, external, electrolysis, oxygen concentration cell, and galvanic corrosion.

**CORROSION INHIBITORS** - Substances that slow the rate of corrosion.

**CORROSIVE** - Having the capability or tendency to cause corrosion

**CORROSIVITY** - An indication of the corrosiveness of water. The corrosiveness of water is described by the water's pH, alkalinity, hardness, temperature, total dissolved solids, dissolved oxygen concentration, and the Langelier Index.

**COUPON** - A steel specimen inserted into water to measure the corrosiveness of water. The rate of corrosion is measured as the loss of weight of the coupon (in milligrams) per surface area (in square decimeters) exposed to the water per day.

**COUPON TEST** – A method for determining the rate of corrosion. It involves inserting sample strips (coupons) of the pipe material into the distribution system.

**CREDIBLE** - A stage in the threat evaluation process in which there is information to corroborate a threat.

**CROSS-CONNECTION** - A connection between a drinking (potable) water system and an unapproved water supply. For example, if you have a pump moving nonpotable water and hooking into the drinking water system to supply water for pump seal, a cross-connection or mixing between the two water systems can occur. This mixing may lead to contamination of the drinking water.

**CROSS-CONNECTION CONTROL DEVICE** - Any device or assembly, approved by the Commissioner for construction on or installation in water supply piping, which is capable of preventing contaminants from entering the public water supply distribution system.

**CROSS-CONNECTION HAZARD** - Any customer facility which, because of the nature and extent of activities on the premises, or the materials used in connection with the activities or stored on the premises, would present an immediate or potential danger or health hazard to customers of the public water supply should backflow occur.

**CRYPTOSPORIDIUM** - A microorganism commonly found in lakes and rivers which is highly resistant to disinfection. *Cryptosporidium* has caused several large outbreaks of gastrointestinal illness, with symptoms that include diarrhea, nausea, and/or stomach cramps. People with severely weakened immune systems are likely to have more severe and more persistent symptoms than healthy individuals.

**CT or CTcalc** - The product of “residual disinfectant concentration” (C) in mg/l determined before or at the first customer, and the corresponding “disinfectant contact time” (T) in minutes, i.e., “C” x “T”. If a PWS applies disinfectants at more than one point prior to the first customer, it must determine the CT of each disinfectant sequence before or at the first customer to determine the total percent inactivation or “total inactivation ratio”. In determining the total inactivation ratio, the PWS must determine the residual disinfectant concentration of each disinfection sequence and corresponding contact time before any subsequent disinfection application point(s). “CT99.9” is the CT value required for 99.9 Percent (3-log) inactivation of *Giardia* cysts. CT99.9 a variety of disinfectants and conditions appear in Tables 1.1- 1.6, 2.1, and 3.1 of section 141.74(b)(3) in the code of Federal Regulations. CT99.9 is the inactivation ratio. The sum of the inactivation ratios, or total inactivation ratio shown as  $E = (CT \text{ calc}) / (CT99.9)$  is calculated by adding together the inactivation ratio for each disinfection sequence. A

total inactivation ratio equal to or greater than 1.0 is assumed to provide a 3-log inactivation of *Giardia lamblia* cysts.

**CURRENT** - A movement of electrons through a conductor. Measured in amperes.

**CUSTOMER SERVICE LINE** - The pipeline from the public water supply to the: (1) First tap, fixture, receptacle, or other point of customer water use; or (2) Secondary source of supply or pipeline branch in a building.

**DAY TANK** - A tank used to store a chemical solution of known concentration for feed to a chemical feeder. A day tank usually stores sufficient chemical solution to properly treat the water being treated for at least one day. Also called an AGE TANK.

**DECOMPOSITION** - The conversion of chemically unstable materials to more stable forms by chemical or biological action. If organic matter decays when there is no oxygen present (anaerobic conditions or putrefaction), undesirable tastes and odors are produced. Decay of organic matter when oxygen is present (aerobic conditions) tends to produce much less objectionable tastes and odors.

**DEGASIFICATION** - A water treatment process which removes dissolved gases from the water. The gases may be removed by either mechanical or chemical treatment methods or a combination of both.

**DENSITY** - A measure of how heavy a substance (solid, liquid, or gas) is for its size. Density is expressed in terms of weights per unit volume, that is, grams per cubic centimeter or pounds per cubic foot. The density of water (at 4°C or 39°F) is 1.0 gram per cubic centimeter or about 62.4 pounds per cubic foot.

**DENTAL FLUOROSIS** - The whitish to brownish spots seen to appear on teeth caused by high levels of fluoride in the drinking water. Also known as “mottled enamel”

**DEPRECIATION** – An estimate of the reduction in the value of an asset due to wear and tear, obsolescence, or impairment. Also, the allocation of the cost of an asset over time for accounting and tax purposes—an annual depreciation charge in accounts represents the amount of capital assets used in the accounting period.

**DESTRATIFICATION** - The development of vertical mixing within a lake or reservoir to eliminate (either totally or partially) separate layers of the temperature, plant, or animal life. This vertical mixing can be caused by mechanical means (pumps) or through the use of forced air diffusers which release air into the lower layers of the reservoir.

**DETENTION TIME** - The time allowed for water to collect in a settling tank. Theoretically detention time is equal to the volume of the tank divided by the flow rate.

**DEWATER** - To remove or separate a portion of the water present in a sludge or slurry. To dry sludge so it can be handled and disposed of. To remove or drain the water from a tank or trench.

**DIATOMACEOUS EARTH** - A fine, siliceous (made of silica) “earth” composed mainly of the skeletal remains of diatoms.

**DIATOMACEOUS EARTH FILTRATION or (DE filtration)** - A filtration method resulting in substantial particulate removal, that uses a process in which: 1) a “precoat” cake of diatomaceous earth filter media is deposited on a support membrane (septum), and 2) while the water is filtered by passing through the cake on the septum, additional filter media, known as “body feed,” is continuously added to the feed water to maintain the permeability of the filter cake.

**DIATOMS** - Unicellular (single cell), microscopic algae with a rigid (box-like) internal structure consisting mainly of silica.

**DIMITTIS** - Lakes and reservoirs which freeze over and normally go through two stratification and two mixing cycles within a year.

**DIRECT CURRENT** - Electrical current flowing in one direction only and essentially free from pulsation.

**DIRECT FILTRATION** - A method of treating water which consists of the addition of coagulation chemicals, flash mixing, coagulation, minimal flocculation, and filtration. The flocculation facilities may be omitted, but the physical-chemical reactions will occur to some extent. The sedimentation process is omitted. Also see CONVENTIONAL FILTRATION and IN-LINE FILTRATION.

**DIRECT RUNOFF** - Water that flows over the ground surface or through the ground directly into streams, rivers, or lakes.

**DISCHARGE HEAD** - The pressure (in pounds per square inch or psi) measured at the centerline of a pump discharge and very close to the discharge flange, converted into feet.

**DISINFECTION** - The process designed to kill most microorganisms in water, including essentially all pathogenic (disease-causing bacteria). There are several ways to disinfect, with chlorine being most frequently used in water treatment. Compare with STERILIZATION.

**DISINFECTION BYPRODUCTS** - A contaminant formed by the reaction of disinfection chemicals (such as chlorine) with other substances such as plant matter and other naturally occurring materials in the water. These byproducts may pose health risks in drinking water.

**DISINFECTANTS/DISINFECTION BY-PRODUCTS RULE (DBPR)** - The purpose of this rule is to reduce public exposure to three chemical disinfectants (chlorine, chloramines, and chlorine dioxide) and many disinfection by-products (total trihalomethanes, haloacetic acids, chlorite, and bromate).

**DISINFECTANT RESIDUAL** - Lingering disinfectant in the water distribution system to kill any other bacteria that might enter the distribution system later.

**DISPLACEMENT METERS** - These are used for measurement of low and intermediate flows, like domestic use applications. They are typically available in sizes from 5/8” through 2”.

**DISSOLVED ORGANIC CARBON (DOC)** – The fraction of TOC that is dissolved in the water sample.

**DISSOLVED SOLIDS** - The total amount of dissolved material, organic and inorganic, contained in water. Excessive dissolved solids make water unpalatable for drinking and unsuitable for industrial use. Measurements are expressed as ppm or mg/L.

**DISTRIBUTION FACILITIES** - Pipes, treatment, storage and other facilities used to distribute drinking water to end users.

**DISTRIBUTION SYSTEM** - A network of pipes leading from a treatment plant to customers plumbing systems.

**DOUBLE CHECK VALVE ASSEMBLY** - A type of backflow prevention device. This device or assembly is composed of two tightly closing shut-off valves surrounding two independently acting check valves, with four test cocks, one upstream of the four valves, and one between each of the four check and shut-off valves.

**DPD** - A method of measuring the chlorine residual in water. The residual may be determined by either titrating or comparing a developed color with color standards. DPD stands for N,N-diethyl-p-phenylene-diamine.

**DRAWDOWN** - The drop in the water table or level of water in the ground when water is being pumped from a well. The amount of water used from a tank or reservoir. The drop in the water level of a tank or reservoir.

**DRINKING WATER PRIMACY AGENCY** - The agency that has primary enforcement responsibility for national drinking water regulations, namely those promulgated under the Safe Drinking Water Act as amended. Drinking water primacy for a particular State may reside in one of a variety of agencies such as the State Health Agency, the State Environmental Agency, or the USEPA regional office. In West Virginia, this is WVDHHR/BPH/OEHS.

**DROUGHT** - A sustained period of inadequate or subnormal precipitation that can lead to water supply shortages, as well as increased water usage.

***ESCHERICHIA COLI (E. COLI)*** - Microorganisms commonly found in the lower intestine of warm-blooded animals. An ideal indicator organism to test environmental samples for fecal contamination from human and animal waste. Can cause gastrointestinal illness (e.g., diarrhea, vomiting, cramps).

**EFFECTIVE RANGE** - That portion of the design range (usually upper 90 percent) in which an instrument has acceptable accuracy. Also see RANGE and SPAN.

**EFFECTIVE SIZE (E.S.)** - The diameter of the particles in a granular sample (filter media) for which 10 percent of the total grains are smaller and 90 percent larger on a weight basis. Effective size is obtained by passing granular material through sieves with varying dimensions of mesh and weighing the material retained by each sieve. The effective size is also approximately the average size of the grains.

**EFFLUENT** - Water or other liquid - raw, partially or completely treated - flowing FROM a reservoir, basin, treatment process or treatment plant.

**EFFLUENT LAUNDER** - A trough which collects the water flowing out of the sedimentation basin and directs it to the effluent piping.

**EJECTOR** - A device used to disperse a chemical solution into water being treated.

**ELEMENT** - A substance which cannot be separated into its constituent parts and still retain chemical identity. For example, sodium (Na) is an element.

**EMERGENCY RESPONSE PLAN** - A document that describes the actions that a drinking water utility would take in response to various emergencies, disasters, and other unexpected incidents.

**EMPTY BED CONTACT TIME** - A calculation used to ensure that water in a contactor has adequate contact time with the filter media. Calculated as the volume of the contactor divided by the flow rate. The calculation is called "empty bed contact time" (or EBCT) because the volume taken up by the media in the contactor is not taken into account. Empty bed contact time should be about ten minutes.

**END POINT** - Samples are titrated to the end point. This means that a chemical is added, drop by drop, to a sample until a certain color change (blue to clear, for example) occurs. This is called the END POINT of the titration. In addition to a color change, an end point may be reached by the formation of a precipitate or the reaching of a specified pH. An end point may be detected by the use of an electronic device such as a pH meter.

**ENHANCED COAGULATION** – Refers to the process of achieving improved disinfection byproduct precursor removal by using conventional treatment.

**ENHANCED SOFTENING** – Refers to the process of achieving improved disinfection byproduct precursor removal by using precipitative softening.

**EPA** - U. S. Environmental Protection Agency.

**ENTERIC** - Of intestinal origin, especially applied to wastes or bacteria.

**ENTRAIN** - To trap bubbles in water either mechanically through turbulence or chemically through a reaction.

**EPIDEMIC** - A disease that occurs in a large number people in a locality at the same time and spreads from person to person.

**EPIDEMIOLOGY** - A branch of medicine which studies epidemics (diseases which affect significant numbers of people during the same time period in the same locality). The objective of epidemiology is to determine the factors that cause epidemic diseases and how to prevent them.

**EPILIMNION** - The upper layer of water in a thermally stratified lake or reservoir. This layer consists of the warmest water and has a fairly uniform (constant) temperature. The layer is readily mixed by wind action.

**EUTROPHIC** - Reservoirs and lakes which are rich in nutrients and very productive in terms of aquatic animal and plant life.

**EUTROPHICATION** - The increase in the nutrient levels of a lake or other body of water; this usually causes an increase in the growth of aquatic animal and plant life.

**EVAPORATION** - The process by which water or other liquid becomes a gas (water vapor or ammonia vapor)

**EVAPOTRANSPIRATION** - The process by which water vapor passes into the atmosphere from living plants. Also called TRANSPIRATION.

**EXEMPTION** - State or EPA permission for a water system not to meet a certain drinking water standard. An exemption allows a system additional time to obtain financial assistance or make improvements in order to come into compliance with the standard. The system must prove that: (1) there are compelling reasons (including economic factors) why it cannot meet EPA health standards (Maximum Contaminant Levels or Treatment Techniques); (2) it was in operation on the effective date of the requirement; and (3) the exemption will not create an unreasonable risk to public health. The state must set a schedule under which the water system will comply with the standard for which it received an exemption.

**FECAL COLIFORM** - Fecal coliform microorganisms come from human and animal fecal waste. Can cause gastrointestinal illness (e.g. diarrhea, vomiting, cramps).

**FILTER BACKWASH RECYCLE RULE (FBRR)** - The purpose of this rule is to require system to review their recycle practices and, where appropriate, work with the State to make any necessary changes to recycle practices that may compromise microbial control. This FBRR applies to all PWSs that (1) use surface or groundwater under the direct influence of surface water; (2) utilize direct or conventional filtration processes; and (3) recycle spent filter backwash water, sludge thickener supernatant, or liquids from dewatering processes.

**FILTER MEDIA** - The layers of materials in a filter which remove particles from the water. Typical filter media include sand, anthracite, and garnet.

**FILTER PROFILE** - Graphical representation of an individual filter performance.

**FILTER RUN** - The length of time between each backwashing of a filter.

**FILTER TYPES** - Rapid sand filters, pressure filters, and slow sand filters are types of filters which are used in different situations.

**FILTRATION** - A process for removing particulate matter from water by passage through porous media.

**FILTERING MECHANISMS** - Four mechanisms remove particles from water during filtration - biological action, adsorption, absorption, and straining.

**FINISHED WATER** - Water that has passed through a water treatment plant, and when all the treatment processes are completed or “finished”. This water is ready to be delivered to consumers. Also call PRODUCT WATER.

**FISH EYES** - Common term for large sticky balls of polymer that result from mixing dry polymer with water during the coagulation process. The result from inadequate flash mixing.

**FLASH MIXER** - A flash mixer is a chamber that contains mechanical stirrers, which is designed to assure fast, thorough, mixing of lime and alum for the purpose of creating floc.

**FLOC** - Clumps of bacteria and particulate impurities that have come together and formed a cluster. Found in flocculation tanks and settling or sedimentation basins.

**FLOCCULATION** - The gathering together of the fine particles after coagulation to form larger particles by a process of gentle mixing.

**FLOCCULATION BASIN** - Water flows from the flash mix chamber into the flocculation basin, where it is gently agitated to promote the formation of floc.

**FLUIDIZED** - A mass of solid particles that is made to flow like a liquid by injection of water or gas is said to have been fluidized. In water treatment, a bed of filter media is fluidized by backwashing water through the filter.

**FLUORIDATION** - The addition of a chemical to increase the concentration of fluoride ions in drinking water to a predetermined optimum limit to reduce the incidence (number) of dental caries (tooth decay) in children. Defluoridation is the removal of excess fluoride in drinking water to prevent the mottling (brown stains) of teeth. The two factors that determine the optimal fluoride level for your water system are the annual average temperature and amount consumed.

**FLUOROSIS** - Mottled brown stains on teeth resulting from excess fluoride consumption. Fluorosis results from fluoride concentrations of 2 to 13 ppm in drinking water. Although fluorosis is only an aesthetic problem, treatment plants strive to prevent fluorosis by setting the recommended fluoride level at about 1 ppm.

**FLUSHING** - A method used to clean water distribution lines. Hydrants are opened and water with a high velocity flows through the pipes, removes deposits from the pipes, and flows out the hydrants.

**FLUX** – the throughput of a pressure-driven membrane filtration system expressed as flow per unit of membrane area (e.g., gallons per square foot per day (gfd) or liters per hour per square meter (Lmh))

**FOOT VALVE** - A special type of check valve located at the bottom end of the suction pipe on a pump. This valve opens when the pump operates to allow water to enter the suction pipe but closes when the pump shuts off to prevent water from flowing out of the suction pipe.

**FREE AVAILABLE RESIDUAL CHLORINE** - That portion of the total available residual chlorine composed of dissolved chlorine gas (Cl<sub>2</sub>), hypochlorous acid (HOCl), and/or hypochlorite ion (OCl<sup>-</sup>) remaining in water after chlorination. This does not include chlorine that has combined with ammonia, nitrogen, or other compounds.

**FREEBOARD** - The vertical distance from the normal water surface to the top of the confining wall. Also, the vertical distance from the sand surface to the underside of a trough in a sand filter. This distance is also called AVAILABLE EXPANSION.

**FRICITION LOSSES** - The head, pressure or energy (they are the same) lost by water flowing in a pipe or channel as a result of turbulence caused by the velocity of the flowing water and the roughness of the pipe, channel walls, and restrictions caused by fittings. Water flowing in a pipe loses pressure or energy as a result of friction losses. Also see HEAD LOSS.

**GAC10** - Granular activated carbon filter beds with an empty-bed contact time of 10 minutes based on average daily flow and a carbon reactivation frequency of every 180 days.

**GALVANIC CORROSION** - A type of corrosion caused by two dissimilar metals coming in contact with each other.

**GALVANIC SERIES** - A list which arranges metals according to their tendency to corrode. From most active to least active, some of the common metals are: magnesium, zinc, aluminum (2S), cadmium, aluminum (175T), steel or iron, cast iron, lead, nickel, brass, copper, bronze, stainless steel (304), monel metal, stainless steel (316), silver, graphite, and gold

**GARNET** - A group of hard, reddish, glassy, mineral sands made up of silicates of base metals (calcium, magnesium, iron and manganese). Garnet has a higher density than sand.

**GASTROENTERITIS** - An inflammation of the stomach and intestine resulting in diarrhea, with vomiting and cramps when irritation is excessive. When caused by an infectious agent, it is often associated with fever.

***Giardia lamblia*** - Commonly referred to as *Giardia*. Flagellate protozoan which is shed during its cyst stage into the feces of man and animals. A microorganism frequently found in rivers and lakes, which, if not treated properly, may cause diarrhea, fatigue, and cramps after ingestion. When water containing these cysts is ingested, the protozoan causes a severe gastrointestinal disease called giardiasis. People with severely weakened immune systems are likely to have more severe and more persistent symptoms than healthy individuals.

**GIARDIASIS** - Intestinal disease caused by an infestation of *Giardia* flagellates.

**GRAB SAMPLE** - A single sample collected at a particular time and place which represents the composition of the water only at that time and place.

**GRADE** - (1) The elevation of the invert (lowest point) of the bottom of a pipeline, canal, culvert, or similar conduit. (2) The inclination or slope of a pipeline, conduit, stream channel, or natural ground surface; usually expressed in terms of the ratio or percentage of number of units of vertical rise or fall per unit of horizontal distance. A 0.5 percent grade would be a drop of one-half per hundred feet of pipe.

**GRANULATED ACTIVATED CARBON (GAC)** - Also known as GAC. A type of activated carbon with a larger particle size than PAC. GAC is used as a filter medium to remove tastes, odors, and trihalomethane precursors.

**GRAVIMETRIC FEEDERS** - Gravimetric feeders feed dry chemicals by weight.

**GREENSAND** - A sand which looks like ordinary filter sand except that it is green in color. This sand is a natural ion exchange mineral which is capable of softening water.

**GROUNDWATER RULE (GWR)** - U.S. Environmental Protection Agency rule to protect public health from waterborne microorganisms present in groundwater sources (i.e., sources unaffected by surface water). The GWR specifies the appropriate use of disinfection in groundwater and establishes a strategy to identify groundwater systems at high risk for contamination.

**GROUNDWATER UNDER THE DIRECT INFLUENCE (GWUDI) OF SURFACE WATER** - Any water beneath the surface of the ground with: 1) significant occurrence of Insects or other macroorganisms algae, or large-diameter pathogens such as *Giardia* or, 2) significant and relatively rapid shifts in water characteristics such as turbidity, temperature, conductivity, or pH which closely correlate to climatological or surface water conditions. Direct influence must be determined for individual sources in accordance with criteria established by the State. The State determination of direct influence may be based on site-specific measurements of water quality and/or documentation of well construction characteristics and geology with field evaluation.

**HALOACETIC ACID (HAA)** - One of the family of organic compounds named as a derivative of acetic acid, wherein one to three hydrogen atoms in the methyl group in acetic acid are each substituted by a halogen atom (namely, chlorine and bromine) in the molecular structure.

**HALOACETIC ACIDS (FIVE) (HAA5)** - A group of disinfection by-products. The sum of the concentrations in milligrams per liter of the haloacetic acid compounds (monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid), rounded to two significant figures after addition.

**HARD WATER** - Water having a high concentration of calcium and magnesium ions. A water may be considered hard if it has hardness greater than the typical hardness of water from the region. Some textbooks define hard water with a hardness of more than 100 mg/L as calcium carbonate.

**HARDNESS, WATER** - A characteristic of water caused mainly by the salts of calcium and magnesium, such as bicarbonate, carbonate, sulfate, chlorine, and nitrate. Excessive hardness in water is undesirable because it causes the formation of soap curds, increased use of soap, deposition of scale in boilers, damage in some industrial processes, and sometimes causes objectionable tastes in drinking water.

**HEAD** - The vertical distance (in feet) equal to the pressure (in psi) at a specific point. The pressure head is equal to the pressure in psi times 2.31 ft/psi.

**HEAD LOSS** - Head loss is the difference in the amount of pressure needed to force water through a filter when it is clean compared to when it is dirty. A large head loss means that a filter needs to be cleaned. Head loss can also be used more generally to mean the pressure lost by water as it flows through a pipe or channel as a result of turbulence caused by the velocity of the flowing water and the roughness of the pipe, channel walls or restrictions caused by fittings. Water flowing in a pipe loses head, pressure or energy as a result of friction losses. Also see FRICTION LOSSES.

**HEALTH ADVISORY** - An EPA document that provides guidance and information on contaminants that can affect human health and that may occur in drinking water.

**HOSE BIB** - Faucet. A location in a water line where a hose is connected.

**HUMUS** - Organic portion of the soil remaining after prolonged microbial decomposition, hydrogeologic cycle. The natural process recycling water from the atmosphere down to (and through) the earth and back to the atmosphere again.

**HYDRAULIC GRADE LINE (HGL)** - The surface or profile of water flowing in an open channel or pipe flowing partially full. If a pipe is under pressure, the hydraulic grade line is at the level water would rise to in a small vertical tube connected to the pipe. Also see ENERGY GRADE LINE.

**HYDROGEN SULFIDE** - Hydrogen sulfide (H<sub>2</sub>S) is a gas which can dissolve in water and turn into hydrosulfuric acid. Although hydrosulfuric acid is weak, it is highly corrosive, eating up electrical contacts, causing a rotten egg odor, and resulting in "black water" complaints. Hydrogen sulfide in water is treated with aeration, oxidation with chlorine, or by treatment with ozone.

**HYDROLOGIC CYCLE** - The process of evaporation of water into the air and its return to Earth by precipitation (rain or snow). This process also includes transpiration from plants, groundwater movement, and runoff into rivers, streams and the ocean. Also called the WATER CYCLE.

**HYDROSTATIC PRESSURE** - The pressure at a specific elevation exerted by a body of water at rest, or in the case of groundwater, the pressure at a specific elevation due to the weight of water at higher levels in the same zone of saturation.

**HYPOCHLORINATION** - The application of hypochlorite compounds to water for the purpose of disinfection.

**HYPOCHLOROUS ACID** - Hypochlorous acid, HOCl, is formed from the reaction of chlorine gas with water. It is the most effective form of free chlorine residual.

**HYPOLIMNION** - The lower layer in a thermally stratified lake or reservoir. This layer consists of colder, more dense water, has a constant temperature and no mixing occurs.

**IMPELLER** - A rotating set of vanes in a pump designed to pump or lift water.

**IMPERMEABLE** - Not easily penetrated. The property of a material or soil that does not allow or allows only with great difficulty, the movement or passage of water.

**INDICATOR** - A substance that gives a visible change, usually of color, at a desired point in a chemical reaction, generally at a specified end point.

**INFLUENT** - Water or other liquid - raw or partially treated - flowing INTO a reservoir, basin, or treatment process of treatment plant.

**INITIAL DISTRIBUTION SYSTEM EVALUATION (IDSE)** - Initial distribution system evaluation. Sampling process used to determine DBP sampling sites under stage 2 DPB Rule.

**IN-LINE FILTRATION** - The addition of chemical coagulants directly to the filter inlet pipe. The chemicals are mixed by the flowing water. Flocculation and sedimentation facilities are eliminated. This pretreatment method is commonly used in pressure filter installation. Also see CONVENTIONAL FILTRATION and DIRECT FILTRATION.

**INORGANIC** - Material such as sand, salt, iron, calcium salts and other mineral materials. Inorganic substances are of mineral origin, whereas organic substances are usually of animal or plant origin. Also see ORGANIC.

**INSECTICIDE** - Any substance or chemical formulated to kill or control insects.

**INVERT** - The lowest point of the channel inside a pipe, conduit, or canal.

**JAR TEST** - A laboratory procedure that stimulates a water treatment plant's coagulation/flocculation units with differing chemical doses and also energy of rapid mix, energy of slow mix, and settling time. The purpose of this procedure is to ESTIMATE the minimum or ideal coagulant dose required to achieve certain water quality goals. Samples of water to be treated are commonly placed in six jars. Various amounts of chemicals that provides satisfactory settling removal of turbidity and/or color is the dose used to treat the water being taken into the plant at that time. When evaluating the results of a jar test, the operator should also consider the floc quality in the flocculation area and the floc loading on the filter.

**LAMELLA PLATES** - Lamella plates are used to increase settling efficiency and speed in sedimentation basins, especially where space is limited. As water flows up between the slanted plates, floc settles out and drifts back down into the lower portions of the sedimentation basin.

**LANGELIER INDEX** - An index reflecting the equilibrium pH of water with respect to calcium and alkalinity. This index is used in stabilizing water to control both corrosion and the deposition of scale.

**LEGIONELLA** - A genus of bacteria, some species of which have caused a type of pneumonia called Legionnaires Disease.

**LOCAL EMERGENCY PLANNING COMMITTEE (LEPC)** - Established by the Emergency Planning and Community Right-to-Know Act, LEPCs have the job of increasing community hazardous materials safety through public education, emergency planning, responder training, conducting exercises, and reviewing actual responses to releases.

**LONG TERM 1 ENHANCED SURFACE WATER TREATMENT RULE (LT1ESWTR) -**

The purpose of this rule is to improve small systems' control of microbial pathogens in drinking water, particularly for the protozoan *Cryptosporidium*. In addition, the rule includes provisions to assure continued levels of microbial protection while utilities take the necessary steps to comply with new disinfection by-product standards.

**LONG TERM 2 ENHANCED SURFACE WATER TREATMENT RULE (LT2ESWTR) -**

The purpose of this rule is to (1) improve control of microbial pathogens, particularly *Cryptosporidium*, and (2) address risk trade-offs with disinfection by-products.

**MACROSCOPIC** - Organisms big enough to be seen by the eye without the aid of a microscope.

**MANIFOLD** - A pipe joining chlorine cylinders together so that chlorine gas is drawn from several cylinders at once.

**MASTER METERING** - Large meter at a point of distribution to multiple uses or users that could be further sub metered.

**MATERIAL SAFETY DATA SHEET** - A document which provides pertinent information and a profile of a particular hazardous substance or mixture. An MSDS is required to be made available to employers and operators whenever there is the likelihood of the hazardous substance or mixture being introduced into a workplace.

**MAXIMUM CONTAMINANT LEVEL (MCL)** - The largest allowable amount. The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to the MCLG as feasible using the best available treatment technology and taking cost into consideration. MCLs are enforceable standards. MCLs for various water quality indicators are specified in the National Interim Primary Drinking Water Regulations (NIPDWR).

**MAXIMUM CONTAMINANT LEVEL GOAL (MCLG)** - The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety. MCLGs are non-enforceable health goals.

**MAXIMUM-DAY DEMAND** - Total production for the water system on its highest day of production during a year.

**MAXIMUM RESIDENCE TIME (MRT)** – location where samples are collected for routine monitoring for TTHM and HAA5. The point of MRT for each plant is an active point (that is, the location is currently providing water to customers) in the distribution system where the water has been in the system the longest. This active point may not necessarily be the same as the most distant point from the treatment plant. Many factors can affect the location or locations determined to represent MRT, including the number of plants operating at the time of monitoring and seasonal variations in population.

**MAXIMUM RESIDUAL DISINFECTION LEVEL (MRDL)** - The highest level of a disinfectant allowed in drinking water. There is convincing evidence that the addition of a disinfectant is necessary for control of microbial contaminants.

**MAXIMUM RESIDUAL DISINFECTANT LEVEL GOAL (MRDLG)** - The level of a drinking water disinfectant below which there is no known or expected risk to health. Maximum Residual Disinfectant Level Goals do not reflect the benefits of the use of disinfectants to control microbial contaminants.

**MEMBRANE FILTRATION** – a pressure or vacuum-driven separation process in which particulate matter larger than 1 mm is rejected by an engineered barrier, primarily through a size-exclusion mechanism and which has a measurable removal efficiency of a target organism that can be verified through the application of a direct integrity test (includes common membrane classifications microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO), as well as any “membrane cartridge filtration” (MCF) device that satisfies this definition)

**MENISCUS** - The curved top of a column of liquid (water, oil, mercury) in a small tube. When the liquid wets the sides of the container (as with water), the curve forms a valley. When the confining sides are not wetted (as with mercury), the curve forms a hill or upward bulge.

**METALIMNION** - The middle layer in a thermally stratified lake or reservoir. In this layer there is a rapid decrease in temperature with depth. Also called the THERMOCLINE.

**METER** - An instrument for measuring and recording water volume.

**METER MAINTENANCE PROGRAM** - Scheduled program whereby meters are tested and repaired before there is a noticeable drop in consumption.

**MICROBIAL GROWTH** - The activity and growth of microorganisms such as bacteria, algae, diatoms, plankton and fungi.

**MICROFILTRATION (MF)** – a pressure-driven membrane filtration process that typically employs hollow-fiber membranes with a pore size range of approximately 0.1 – 0.2  $\mu\text{m}$  nominally 0.1  $\mu\text{m}$ )

**MICROORGANISMS** - Living organisms that can be seen individually only with the aid of a microscope.

**MILLIGRAMS PER LITER (mg/L)** - A measure of the concentration by weight of a substance per unit volume. For practical purposes, one mg/L of a substance in fresh water is equal to one part per million parts (ppm).

**MONITORING** - Testing PWSs must perform to detect and measure contaminants. A water system that does not follow EPA's monitoring methodology or schedule is in violation, and may be subject to legal action.

**MONOMICTIC** - Lakes and reservoirs which are relatively deep, do not freeze over during the winter months, and undergo a single stratification and mixing cycle during the year. These lakes and reservoirs usually become destratified during the mixing cycle, usually in the fall of the year.

**MUDBALLS** - Material that is approximately round in shape and varies from pea-sized up to two or more inches in diameter. Mudballs form on the surface of filters when adhesive materials

cause particles out of the water and media grains to stick together. If the filter is not properly backwashed and surface washed, mudballs will continue accumulating material and will grow larger, eventually sinking down into the filter media. Mudballs in the media result in shortened filter runs and in loss of filter capacity, since water will not pass through the mudballs and must flow around them.

**NANOFILTRATION (NF)** – a pressure-driven membrane separation process that employs the principles of reverse osmosis to remove dissolved contaminants from water; typically applied for membrane softening or the removal of dissolved organic contaminants

**NATIONAL PRIMARY DRINKING WATER REGULATIONS (NPDWR)** - Legally enforceable standards that apply to PWSs. These standards protect drinking water quality by limiting the levels of specific contaminants that can adversely affect public health and which are known or anticipated to occur in public water supplies. Also known as Primary Standards.

**NATIONAL SECONDARY DRINKING WATER REGULATIONS (NSDWR)** - Non-enforceable federal guidelines regarding cosmetic effects (such as tooth or skin discoloration) or aesthetic effects (such as taste, odor, or color) of drinking water. Also known as Secondary Standards.

**NEPHELOMETRIC** - A means of measuring turbidity in a sample by using an instrument called a nephelometer. A nephelometer passes light through a sample and the amount of light deflected or scattered (usually at a 90-degree angle) is then measured.

**NEPHELOMETRIC TURBIDITY UNIT (NTU)** - The unit of measure for turbidity.

**NIOSH** - The *National Institute of Occupational Safety and Health* is an organization that tests and approves safety equipment for particular applications. NIOSH is the primary Federal agency engaged in research in the national effort to eliminate on-the-job hazards to the health and safety of working place. The NIOSH Publications Catalog contains a listing of NIOSH publications mainly on industrial hygiene and occupational health. To obtain a copy of the catalog, write to NIOSH Publications, 4676 Columbia Parkway, Cincinnati, Ohio 45226.

**NON-ACCOUNT WATER** - Metered source water less metered water sales.

**NONCARBONATE HARDNESS** - Hardness caused when metals combine with anything other than alkalinity. Noncarbonate hardness is responsible for soap scum. This type of hardness is sometimes called "permanent hardness" because it is not destroyed by boiling.

**NON-COMMUNITY WATER SYSTEM (NCWS)** - A PWS that is not a community water system. There are two types of NCWSs: transient and non-transient.

**NONPOINT SOURCE** - A runoff or discharge from a field or similar source. A point source refers to a discharge that comes out the end of a pipe.

**NONPOTABLE** - Water that may contain objectionable pollution, contamination, minerals, or infective agents and is considered unsafe and/or unpalatable for drinking.

**NON-RESIDENTIAL CUSTOMER** - A commercial or industrial utility customer.

**NONSETTLEABLE SOLIDS** - Smaller sized particles, such as bacteria and fine clays and silts, that do not readily settle and treatment is required for removal.

**NON-TRANSIENT NON-COMMUNITY WATER SYSTEM (NTNCWS)** - A PWS that regularly serves at least 25 of the same nonresident persons per day for more than six months per year.

**NPDES PERMIT** - National Pollutant Discharge Elimination System permit is the regulatory agency document designed to control all discharges of pollutant from point sources in US waterways. NPDES permits regulate discharges into navigable waters from all point sources of pollution, including industries, municipal treatment plants, large agricultural feed lots and return irrigation flows.

**NUTRIENT** - Any substance that is assimilated (taken in) by organisms and promotes growth. Nitrogen and phosphorous are nutrients which promote the growth of algae. There are other essential and trace elements which are also considered nutrients.

**ODOR THRESHOLD** - The minimum odor of a water sample that can just be detected after successive dilutions with odorless water. Also called THRESHOLD ODOR.

**OHMS** - A unit of electrical resistance equal to that of a conductor in which a current of one ampere is produced by a potential of one volt across its terminals.

**OLFACTORY FATIGUE** - A condition in which a person's nose, after exposure to certain odors, so no longer able to detect the odor.

**OLIGOTROPHIC** - Reservoirs and lakes which are nutrient poor and contain little aquatic plant or animal life.

**OPERATION AND MAINTENANCE COSTS** - The ongoing, repetitive costs of operating a water system; for example, employee wages and costs for treatment chemicals and periodic equipment repairs.

**OPPORTUNISTIC PATHOGEN** - A microbe that can cause disease in immunocompromised individuals (e.g., the elderly, the very young, or ill persons), but usually not in healthy individuals.

**ORGANIC** - Substances that come from animal or plant sources. Organic substances always contain carbon. (Inorganic materials are chemical of mineral origin.) Also see INORGANIC.

**ORGANICS** - A term used to refer to chemical compounds made from carbon molecules. These compounds may be natural materials (such as animal and plant source) or man-made materials (such as synthetic organics). Also see ORGANIC.

**ORGANISM** - Any form of animal or plant life. See also BACTERIA.

**OVERFLOW RATE** - One of the guidelines for the design of settling tanks and clarifiers in treatment plants. Used by operators to determine if tanks and clarifiers are hydraulically (flow)

over- or underloaded. Overflow Rate (GPD/sq ft) = Flow (GPD)/Surface Area (sq ft) particle count. The results of a microscopic examination of treated water with a special “particle counter” which classifies suspended particles by number and size.

**OXIDANT** – Oxidants are most often used for the oxidation of reduced iron and manganese, destruction of taste and odor causing organic contaminants. Many oxidants act as coagulant aids and are used as part of an overall program for the control of potentially harmful disinfection byproducts.

**OXYGEN DEFICIENCY** - An atmosphere containing oxygen at a concentration of less than 19.5 percent by volume.

**PADDLE MIXERS** - Paddle mixers are large propellers or blades, which are slowly driven by electromechanical energy. The large paddles are rotated with the least amount of energy so as not to shear the floc, and allow the components enough mixing for the floc to form. The rpm of the motor is around 1 whereas the rpm of the flash mixer is around 100 rpm

**PALATABLE** - Water at a desirable temperature that is free from objectionable tastes, odors, colors, and turbidity. Pleasing to the senses.

**PARSHALL FLUME** - A device used to measure the flow in an open channel. The flume narrows to a throat of fixed dimensions and then expands again. The rate of flow can be calculated by measuring the difference in head (pressure) before and at the throat of the flume.

**PARTICLE COUNT** - The results of a microscopic examination of treated water with a special “particle counter” which classifies suspended particles by number and size.

**PARTICLE COUNTERS** - Particle counters can be used to count the number of particles in the filter effluent which are within the size range of *Giardia* and *Cryptosporidium* to determine how efficiently the filter has removed these microorganisms.

**PARTICULATE** - A very small solid suspended in water which can vary widely in size, shape, density, and electrical charge. Colloidal and dispersed particulates are artificially gathered together by the processes of coagulation and flocculation.

**PARTS PER MILLION (PPM)** - Parts per million parts, measurement of concentration on a weight or volume basis. This term is equivalent to milligrams per liter (mg/L) which is the preferred term.

**PASSIVATION** - Covering the surface of pipes with a protective coating

**PATHOGENIC ORGANISMS** - Organisms, including bacteria, viruses or cysts, capable of causing diseases (typhoid, cholera, dysentery) in a host (such as a person). There are many type of organisms which do NOT cause disease. These organisms are called non-pathogenic.

**PATHOGENS** - Pathogenic or disease-causing organisms.

**PEAK DEMAND** - The maximum momentary load placed on a water treatment plant, pumping station or distribution system. This demand is usually the maximum average load in one hour or

less, but may be specified as the instantaneous or with some other short time period.

**PER-CAPITA USE** - Total use divided by the total population served.

**PERISTALTIC METERING PUMP** - A positive displacement pump that uses the alternating waves of contraction and dilation of a plastic tubing to move liquid through the tubing into the water line.

**PERMEABILITY** - An aquifer characteristic measure of how fast water can travel through material. A measure of interconnectivity of pore spaces.

**PERSONAL PROTECTIVE EQUIPMENT (PPE)** - Equipment and supplies designed to protect employees from serious injuries or illnesses resulting from contact with chemical, radiological, biological, or other hazards. PPE includes face shields, safety glasses, goggles, laboratory coats, gloves, and respirators.

**pH** - pH is an expression of the intensity of the basic or acid condition of a liquid. Mathematically, pH is the logarithm (base 10) of the reciprocal of the hydrogen ion activity.

**PHENOLPHTHALEIN ALKALINITY** - The alkalinity in a water sample measured by the amount of standard acid required to lower the pH to a level of 8.3, as indicated by the change in color of phenolphthalein from pink to clear. Phenolphthalein alkalinity is expressed as milligrams per liter equivalent calcium carbonate.

**PINPOINT FLOC** - Pinpoint floc is a condition in which low turbidity in water causes the formation of very small floc. Pinpoint floc does not settle out of the water in the sedimentation basin but is removed in the filters.

**PITLESS ADAPTER** - A fitting which allows the well casing to be extended above the ground while having a discharge connection located below the frost line. Advantages of using a pitless adapter include the elimination of the need for a pit or pump house and it is a water-tight design, which helps maintain a sanitary water supply.

**PITOT GAUGE** - Measures pressure of flowing water.

**PLUG FLOW** - A type of flow that occurs in tanks, basins or reactors when a slug of water moves through a tank without ever dispersing or mixing with the rest of the water flowing through the tank.

**POINT SOURCE** - A discharge that comes out of the end of a pipe. A nonpoint source refers to runoff or a discharge from a field or similar source.

**POLYMER** - A chemical formed by the union of many monomers (a molecule of low molecular weight). Polymers are used with other chemical coagulants to aid in binding small suspended particles to larger chemical flocs for their removal from water. All polyelectrolytes are polymer, but not all polymers are polyelectrolytes.

**POSITIVE DISPLACEMENT PUMP** - A type of piston, diaphragm, gear or screw pump that delivers a constant volume with each stroke. Positive displacement pumps are used as chemical

solution feeders which measure a volume of a liquid chemical during a specific time period. They have several advantages over other types of pumps, being accurate and capable of feeding a solution against pressure into a pipe or tank of water as well as into open tanks of water.

**PORE** - A very small open space in a rock or granular material.

**POROSITY** - A measure of the spaces or voids in a material or aquifer. The ratio of the volume of spaces in a rock or soil to the total volume. This ratio is usually expressed as a percentage.

**POSSIBLE** - A stage in the threat evaluation process in which available information indicates there is an opportunity for an incident (i.e., the threat is possible).

**POSTCHLORINATION** - The addition of chlorine to the plant effluent, FOLLOWING plant treatment, for disinfection purposes.

**POTABLE WATER** - Water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered satisfactory for drinking.

**POTASSIUM PERMANGANATE (KMnO<sub>4</sub>)** - A strong chemical oxidizer which can be used to destroy many organic compounds, both natural and manufactured, present in water supplies. Permanganate is also used to oxidize iron, manganese, and sulfide compounds and is often used in conjunction with aeration for the control of these and other taste- and odor-producing substances.

**POWDER ACTIVATED CARBON** - Also known as PAC. A form of activated carbon with a very small particle size. Treatment involves adding PAC to water, allowing the PAC to interact with contaminants in the water, then removing the PAC by sedimentation or filtration.

**PRECHLORINATION** - The addition of chlorine at the headworks of the plant PRIOR TO other treatment process mainly for disinfection and control of tastes, odors and aquatic growths. Also applied to aid in coagulation and settling.

**PRECISION** - The ability of an instrument to measure a process variable and to repeatedly obtain the same result. The ability of an instrument to reproduce the same results.

**PRECURSOR** - Natural organic compounds found in all surface and groundwaters. These compounds MAY react with halogens (such as chlorine) to form trihalomethanes; they MUST be present in order for THMs to form.

**PRESEDIMENTATION** - If the intake is very high in turbidity then a presedimentation basin is used to settle out most of the turbidity before primary water treatment begins. This makes later chemical treatment of the water more efficient. Also known as plain sedimentation because the process depends merely on gravity and includes no coagulation and flocculation.

**PRESSURE CONTROL** - A switch which operates on changes in pressure. Usually this is a diaphragm pressing against a spring. When the force on the diaphragm overcomes the spring pressure, the switch is actuated (activated).

**PRESSURE HEAD** - The vertical distance (in feet) equal to the pressure (in psi) at a specific point. The pressure head is equal to the pressure in psi times 2.31 ft/psi.

**PRESSURE REGULATOR** - A post-meter device used to limit water pressure.

**PRESSURE VACUUM BREAKER (PVB)** - A type of backflow prevention device. A device or assembly containing an independently operating internal loaded check valve and an independently operating loaded air inlet valve located on the downstream side of the check valve for relieving a vacuum or partial vacuum in a pipeline.

**PRETREATMENT** - Pretreatment, or preliminary treatment, is any physical, chemical or mechanical process used on water before it undergoes the main treatment process. This may include screening, presedimentation, chemical addition, flow measurement, and aeration.

**PRIMACY** - Primary enforcement authority for the drinking water program. Under the Safe Drinking Water Act, states, U.S. territories, and Indian tribes that meet certain requirements, including setting regulations that are at least as stringent as EPA's, may apply for, and receive, primary enforcement authority, or primacy.

**PRIMACY AGENCY** – The state agency that has been granted primary enforcement responsibility for administration and enforcement of primary drinking water regulations and related requirements applicable to PWSs within a state (40 CFR 142.2)

**PRIME** - The action of filling a pump casing with water to remove the air. Most pumps must be primed before startup or they will not pump any water.

**PRODUCTION METER** - Meters on wells for water leaving the plant or pumping station.

**PROTOZOAN** - Any of a large group of single-celled, usually microscopic, eukaryotic organisms, such as amoebas, ciliates, flagellates, and sporozoans.

**PUBLIC NOTIFICATION** - An advisory EPA or the state requires a water system to distribute to affected consumers when the system has violated Maximum Contaminant Levels or other regulations. The notice advises consumers what precautions, if any, they should take to protect their health.

**PUBLIC WATER SYSTEM (PWS)** - A system for the provision to the public of piped water for human consumption, If such system has at least fifteen service connections or regularly least 60 days out of the year. Such term includes: 1) any collection, treatment, storage, and distribution facilities under control of the operator of such system and used primarily in connection with such system, and 2) any collection or pretreatment storage facilities not under such control which are used primarily in connection with such system. A PWS is either a “community water system” or a “non-community water system.”

**PUMPING WATER LEVEL** - The vertical distance in feet from the centerline of the pump discharge to the level of the free pool while water is being drawn from the pool.

**QUALITY ASSURANCE** - An integrated system of management activities involving planning, implementation, documentation, assessment, reporting, and quality improvement, to ensure that a process, item, or service is of the type and quality needed and expected by the client.

**QUALITY CONTROL** - The overall system of technical activities that measures the attributes and performance of a process, item, or service against defined standards to verify that they meet the stated requirements established by the client; operational techniques and activities that are used to fulfill requirements for quality.

**QUICKLIME** - A material that is mostly calcium oxide (Ca) or calcium oxide in natural association with a lesser amount of magnesium oxide. Quicklime is capable of combining with water, that is, becoming slaked. Also see HYDRATED LIME.

**RADIONUCLIDE** - An unstable form of a chemical element that radioactively decays, resulting in the emission of nuclear radiation. Prolonged exposure to radionuclides increases the risk of cancer. All of the radionuclides known to occur in drinking water are currently regulated, except for radon and naturally-occurring uranium, both of which were proposed for regulation in October 1999.

**RADON RULE** - Developed to reduce public radon exposure and applies to all community water systems that use groundwater or mixed ground and surface water. The regulation does not apply to non-transient non-community public water supplies or to transient public water supplies.

**RANNEY COLLECTOR** - This water collector is constructed as a dug well from 12 to 16 feet (3.5 to 5 m) in diameter that has been sunk as a caisson near the bank of a river or lake. Screens are driven radially and approximately horizontally from this well into the sand and the gravel deposits underlying the river.

**RATE** - Monies collected for water provided. Every water utility must receive sufficient total revenue to ensure proper operations and maintenance, development and perpetuation of the system, and the preservation of the utility's financial integrity.

**RATER STRUCTURE** - Means of establishing charges for water usage.

**RAW WATER** - Water in its natural state, prior to any treatment. Usually the water entering the first treatment process of a water treatment plant.

**REAGENT** - A pure chemical substance that is used to make new products or is used in chemical tests to measure, detect, or examine other substances.

**RECHARGE** - Replenishment of groundwater.

**REDUCED PRESSURE ZONE ASSEMBLY (RPZ)** - A device composed of two tightly closing shut-off valves surrounding two independently acting pressure reducing check valves that, in turn, surround an automatic pressure differential relief valve, and four test cocks, one upstream of the five valves and one between each of the four check and shut-off valves. The check valves effectively divide the structure into three chambers; pressure is reduced in each downstream chamber allowing the pressure differential relief valve to vent the center chamber to atmosphere should either or both check valves malfunction.

**REGROWTH** – Growth of microorganisms in the distribution system.

**RESIDUAL CHLORINE** - The amount of free and/or available chlorine remaining after a given contact time under specified conditions.

**REPRESENTATIVE SAMPLE** - A sample portion of material or water that is as nearly identical in content and consistency as possible to that in the larger body of material or water being sampled.

**RESERVIOR** - Any natural or artificial holding area used to store; regulate, or control water.

**RETAIL WATER METER** - Meters to monitor large customer water usage.

**REVENUE-PRODUCING WATER** - Water metered and sold.

**REVERSE OSMOSIS (RO)** - The application of pressure to a concentrated solution which causes the passage of a liquid from the concentrated solution to a weaker solution across a semipermeable membrane. The membrane allows the passage of the solvent (water) but not the dissolved solids (solutes). The liquid produced is a demineralized water.

**ROTAMETER** - A device used to measure the flow rate of gases and liquids. The gas or liquid being measured flows vertically up a tapered, calibrated tube. Inside the tube is a small ball or bullet-shaped float (it may rotate) that rises or falls depending on the flow rate. The flow rate may be read on a scale behind or on the tube by looking at the middle of the ball or at the widest part or top of the float.

**SACRIFICIAL ANODE** - A piece of very active metal (usually zinc or magnesium) which is more galvanically active than any other metal in the system. The sacrificial anode will be the only metal corroded, and even previously active anodes on the pipe wall will become cathodes and will thus be protected.

**SAFE DRINKING WATER ACT** - Commonly referred to as SDWA. An Act passed by the US Congress in 1974. The Act establishes a cooperative program among local, state, and federal agencies to insure safe drinking water for consumers.

**SAFE YIELD** - The annual quantity of water that can be taken from a source of supply over a period of years without depleting the source permanently (beyond its ability to be replenished naturally in “wet years”).

**SAMPLE** - The water that is analyzed for the presence of EPA-regulated drinking water contaminants. Depending on the regulation, EPA requires PWSs and states to take samples from source water, from water leaving the treatment facility, or from the taps of selected consumers.

**SAND FILTERS** - Devices that remove some suspended solids from sewage. Air and bacteria decompose additional wastes filtering through the sand so that cleaner water drains from the bed.

**SANITARY SURVEY** - A detailed evaluation and/or inspection of a source of water supply and all conveyances, storage, treatment and distribution facilities to insure its protection from all pollution sources.

**SATURATED ZONE** - Area beneath the unsaturated zone where all interconnected openings contain water, and is officially considered groundwater.

**SATURATOR** - A device which produces fluoride solution for the fluoridation process. The device is usually a cylindrical container with granular sodium fluoride on the bottom. Water flows either upward or downward through the sodium fluoride to produce the fluoride solution.

**SEDIMENTATION** - A water treatment process in which solid particles settle out of the water being treated in a large clarifier or sedimentation basin.

**SEDIMENTATION BASIN** - A sedimentation basin is a basin or tank in which water is retained to allow settleable matter, such as floc, to settle by gravity.

**SEDIMENTATION BASIN ZONES** - Each sedimentation basin has four zones - inlet, settling, outlet, and sludge.

**SEPTIC** - A condition produced by bacteria when all oxygen supplies are depleted. If severe, bottom deposits and water turn black, give foul odors, and the water has greatly increased chlorine demand.

**SEQUESTRATION** - A chemical complexing (forming or joining together) of metallic cations (such as iron) with certain inorganic compounds, such as phosphate. Sequestration prevents the precipitation of the metal (iron). Also see CHELATION.

**SHORING EQUIPMENT** - Equipment installed in trenches to prevent the collapse of the trench.

**SHORT-CIRCUITING** - A condition that occurs in tanks or basins when some of the water travels faster than the rest of the flowing water. This is usually undesirable since it may result in shorter contact, reaction, or settling times in comparison with the theoretical (calculated) or presumed detention times.

**SLUDGE** - The floc which settles to the bottom of the sedimentation basin and must be removed as waste.

**SLURRY** – A mixture of PAC and water.

**SLOW SAND FILTRATION** - A process involving passage of raw water through a bed of sand at low velocity (generally less than 0.4 m/h) resulting in substantial particulate removal by physical and biological mechanisms.

**SOFT WATER** - Water having a low concentration of calcium and magnesium ions. According to US Geological Survey guidelines, soft water is water having a hardness of 60 milligrams per liter or less.

**SOLE SOURCE AQUIFER** - An aquifer that supplies 50 percent or more of the drinking water of an area.

**SOLUTION** - A liquid mixture of dissolved substances. In a solution it is impossible to see all

the separate parts.

**SOURCE-OF-SUPPLY** - Facilities used to extract and/or store raw water prior to transmission and distribution.

**SOURCE METER** - A meter used to record water withdrawn from a surface water or groundwater source, or purchased from a wholesale supplier.

**SOURCE WATER** - Water in its natural state, prior to any treatment for drinking. See finished water.

**SOURCE WATER ASSESSMENT** - Provides information about the potential contaminant threats to public drinking water sources.

**SPECIFIC CAPACITY** - Expresses the productivity of a well. Specific capacity is obtained by dividing the well discharge rate by the well drawdown while pumping. It is calculated by dividing the production of the well in gallons per minute by the feet of drawdown between the static water level and the pumping water level. Water levels need to stabilize before measurements are made. The gallons per minute should be the normal production rate of the well and pumping equipment.

**SPECIFIC YIELD** - The quantity of water that a unit volume of saturated permeable rock or soil will yield when drained by gravity. Specific yield may be expressed as a ratio or as a percentage by volume.

**STABILIZATION** - Stabilization is the process of stabilizing water so that it is neither corrosive nor scale-forming.

**STAGE 1 DISINFECTANTS/DISINFECTION BY-PRODUCT RULE (S1DBPR)** - The purpose of this rule is to reduce public exposure to three chemical disinfectants (chlorine, chloramines, and chlorine dioxide) and many disinfection by-products (total trihalomethanes, haloacetic acids, chlorite, and bromate).

**STAGE 2 DISINFECTANTS/DISINFECTION BY-PRODUCT RULE (S2DBPR)** - The rule builds upon the Stage 1 DBPR to further reduce public exposure to disinfection by-products. Because disinfection byproduct concentrations can increase with increase time (i.e. increasing water age), the U.S. EPA is emphasizing compliance monitoring locations that reflect parts of the distribution system with older water. Compliance monitoring for the Stage 2 DBPR will be preceded by an initial distribution system evaluation to select site specific optimal sample points for capturing peaks. The requirements for Stage 2 DBPR will apply to all community water systems and non-transient non-community water systems that add a disinfectant other than UV or deliver water that has been disinfected.

**STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER** - A joint publication of the *American Public Health Association*, *American Water Works Association*, and the *Water Pollution Control Federation* which outlines the procedures used to analyze the impurities in water and wastewater.

**STANDARD OPERATING PROCEDURES** - Standard Operating Procedures, or SOP's, are written lists of the steps that should be followed in various circumstances to solve problems in water treatment plants.

**STATE REVOLVING FUND (SRF)** - State loan funds for water utilities established under the Safe Drinking Water Act.

**STATIC HEAD** - When water is not moving, the vertical distance (in feet) from a specific point to the water surface. The static pressure in psi is the static head in feet times 0.433 psi/ft. Also see DYNAMIC PRESSURE and STATIC PRESSURE.

**STATIC PRESSURE** - When water is not moving, the vertical distance (in feet) from a specific point to the water surface. The static pressure in psi is the static head in feet times 0.433 psi/ft. Also see DYNAMIC PRESSURE and STATIC PRESSURE.

**STATIC WATER LEVEL** - The elevation or level of the water table in a well when the pump is not operating. The level or elevation to which water would rise in a tube connected to an artesian aquifer, or basin, or conduit under pressure.

**STERILIZATION** - The removal or destruction of all microorganisms, including pathogenic and other bacteria, vegetative forms and spores. Compare with DISINFECTION.

**STREAMING CURRENT MONITOR** - A streaming current monitor (SCM) is used to determine the appropriate dosage of coagulants to use. The SCM uses an electric sensor to determine when charge neutralization has been reached in a suspension.

**STRATIFICATION** - The formation of separate layers (of temperature, plant, or animal life) in a lake or reservoir. Each layer has similar characteristics such as all water in the layer has the same temperature. Also see THERMAL STRATIFICATION.

**SUBMERGENCE** - The distance between the water surface and the media surface in a filter.

**SUBPART H SYSTEM** - A PWS serving surface water or groundwater under the influence of surface water. These systems are subject to the filtration and disinfection requirements of 40 CFR Subpart H.

**SUCTION LIFT** - The NEGATIVE pressure [in feet (meters) of water or inches (centimeters) of mercury vacuum] on the suction side of the pump. The pressure can be measured from the centerline of the pump DOWN TO (life) the elevation of the hydraulic grade line on the suction side of the pump.

**SUPERNATANT** - Liquid removed from settled sludge. Supernatant commonly refers to the liquid between the sludge on the bottom and the water surface of a basin or container.

**SURFACE LOADING** - One of the guidelines for the design of settling tanks and clarifiers in treatment plants. Used by operators to determine if tanks and clarifiers are hydraulically (flow) over or underloaded. Also called OVERFLOW RATE.

**SURFACE WASH** - Surface wash uses spray to release particles trapped at the surface of the sand during backwash of a filter.

**SURFACE WATER** - All water naturally open to the atmosphere (rivers, lakes, reservoirs, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors which are directly influenced by surface water.

**SUSPENDED SOLIDS** - (1) Solids that either float on the surface or are suspended in water or other liquids, and which are largely removable by laboratory filtering. (2) The quantity of material removed from water in a laboratory test, as prescribed in *STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER* and referred to as nonfilterable residue. Examples of suspended solids include sand and heavy silts.

**TELEMETRY** - The electrical link between the transmitter and the receiver. Telephone lines are commonly used to serve as the electrical line.

**THERMAL STRATIFICATION** - The formation of layers of different temperatures in a lake or reservoir. Also see STRATIFICATION.

**THERMOCLINE** - The middle layer in a thermally stratified lake or reservoir. In this layer there is a rapid decrease in temperature with depth. Also call the METALIMNION.

**THREAT** - An indication that a harmful *incident*, such as contamination of the drinking water supply, may have occurred. The threat may be direct, such as a verbal or written threat, or circumstantial, such as a security breach or unusual water quality.

**THREAT EVALUATION** - Part of the threat management process in which all available and relevant information about the threat is evaluated to determine if the threat is 'possible' or 'credible', or if an incident has been 'confirmed.' This is an iterative process in which the threat evaluation is revised as additional information becomes available. The conclusions from the threat evaluation are considered when making response decisions.

**THREAT MANAGEMENT** - The process of evaluating a contamination threat and making decisions about appropriate response actions. The threat management process includes the parallel activities of the *threat evaluation* and making *response decisions*. The threat management process is considered in three stages: 'possible', 'credible', and 'confirmatory.' The severity of the threat and the magnitude of the response decisions escalate as a threat progresses through these stages.

**THREAT WARNING** - An occurrence or discovery that indicates a threat of a malevolent act and triggers an evaluation of the threat.

**THRUST BLOCK** - A mass of concrete or similar material appropriately placed around a pipe to prevent movement when the pipe is carrying water. Usually placed at bends and valve structures.

**TITRATE** - To TITRATE a sample, a chemical solution of known strength is added on a drop-by-drop basis until a certain color change, precipitate, or pH change in the sample is observed (end point). Titration is the process of adding the chemical reagent in increments until

completion of the reaction, as signaled by the end point.

**TOTAL COLIFORM** - Coliforms (including fecal coliform and *E. coli*) are naturally present in the environment. Fecal Coliforms and *E. coli* come from human and animal fecal waste. Total Coliform are used as in indicator that other potential harmful bacteria may be present.

**TOTAL ORGANIC CARBON (TOC)** - total organic carbon in mg/L measured using heat, oxygen, ultraviolet irradiation, chemical oxidants, or combinations of these oxidants that convert organic carbon to carbon dioxide, rounded to two significant figures.

**TOTAL DISSOLVED SOLIDS (TDS)** - All of the dissolved solids in a water. TDS is measured on a sample of water that has passed through a very fine mesh filter to remove suspended solids. The water passing though the filter is evaporated and the residue represents the dissolved solids. Also see SPECIFIC CONDUCTANCE.

**TOTAL DYNAMIC HEAD (TDH)** - When a pump is lifting or pumping water, the vertical distance (in feet) from the elevation of the energy grade line on the suction side of the pump to the elevation of the energy grade line on the discharge side of the pump.

**TOTAL RESIDUAL CHLORINE** - The amount of available chlorine remaining after a given contact time. The sum of the combined available residual chlorine and the free available residual chlorine. Also see RESIDUAL CHLORINE.

**TOTAL TRIHALOMETHANE (TTHM)** - The sum of the concentration in milligrams per liter of the trihalomethane compounds (trichloromethane [chloroform], dibromochloromethane, bromodichloromethane, and tribromomethane [bromoform]), rounded to two significant figures. Note that some publications may use the term "THM4" instead of "TTHM".

**TOXIC** - A substance which is poisonous to an organism.

**TRANSIENT WATER SYSTEM** - A non-community water system that does not serve 25 of the same nonresident persons per day for more than six months per year. Also called a transient non-community water system (TNCWS).

**TRANSMISSION FACILITIES** - Pipes used to transport raw or treated water to distribution facilities.

**TRANSPIRATION** - The evaporation of water from plants.

**TREATED WATER** - Water treated to meet drinking water standards.

**TREATMENT TECHNIQUE** - A required process intended to reduce the level of a contaminant in drinking water.

**TRIHALOMETHANES (THM)** - Trihalomethanes are compounds formed when natural organic substances from decaying vegetation and soil, such as humic and fulvic acids, react with chlorine. A byproduct of drinking water disinfection. Can cause liver, kidney, or central nervous system problems, as well as increase the risk of cancer.

**TUBERCULATION** - Development or formation of small mounds of corrosion products on the inside of iron pipe. These tubercules roughen the inside of the pipe, increasing its resistance to water flow.

**TUBERCULE** - A protective crust of corrosion products (rust) which builds up over a pit caused by the loss of metal due to corrosion.

**TUBE SETTLER** - A device that uses bundles of small bore (2 to 3 inches or 50 to 75 mm) tubes installed on an incline as an aid to sedimentation. The tubes may come in a variety of shapes including circular and rectangular. As water rises within the tubes, settling solids fall to the tube surface. As the sludge (from the settled solids) in the tube gains weight, it moves down the tubes and settles to the bottom of the basin for removal by conventional sludge collection means. Tube settlers are sometimes installed in sedimentation basins and clarifiers to improve particle removal.

**TURBID** - Having cloudy or muddy appearance.

**TURBIDITY** - The cloudy appearance of water caused by the presence of suspended and colloidal matter. In the waterworks field, a turbidity measurement is used to indicate the clarity of the water. Technically, turbidity is an optical property of the water based on the amount of light reflected by suspended solids. Turbidity cannot be directly equated to suspended solids because white particles reflect more light than dark-colored particles and many small particles will reflect more light than an equivalent large particle.

**TURBIDIMETER** - An instrument for measuring and comparing the turbidity of liquids by passing light through them and determining how much light is reflected by the particles in the liquid.

**ULTRAFITLARATION (UF)** – a pressure-driven membrane filtration process that typically employs hollow- fiber membranes with a pore size range of approximately 0.01 – 0.05  $\mu\text{m}$  (nominally 0.01  $\mu\text{m}$ )

**UNACCOUNTED-FOR WATER** - The amount of non-account water less known or estimated losses and leaks.

**UNCONFINED AQUIFER** - The saturated formation in which the upper surface fluctuates with addition or subtraction of water. The upper surface of an unconfined aquifer is called the water table. Water, contained in an unconfined aquifer, is free to move laterally in response to differences in the water table elevations. Also known as a water table aquifer.

**UNSATURATED ZONE** - Area immediately beneath the earth surface that contains both water and area, and is not considered groundwater.

**UN-METERED WATER** - Water delivered but not measured for accounting and billing purposes.

**UV DISINFECTION** - A disinfection process exposing the water supply to ultraviolet light (irradiation) to provide pathogen inactivation.

**VARIANCE** - State or EPA permission not to meet a certain drinking water standard. The water system must prove that: (1) it cannot meet a Maximum Contaminant Level, even while using the best available treatment method, because of the characteristics of the raw water, and (2) the variance will not create an unreasonable risk to public health. The state or EPA must review, and allow public comment on, a variance every three years. States can also grant variances to PWSs that serve small populations and which prove that they are unable to afford the required treatment, an alternative water source, or otherwise comply with the standard.

**VELOCITY** - A measure of how fast water flows, usually expressed in feet/second or (distance/time).

**VENTURI METER** - A flow measuring device placed in a pipe. The device of a tube whose diameter gradually decreases to a throat and then gradually expands to the diameter of the pipe. The flow is determined on the bases of the differences in pressure (caused by different velocity heads) between the entrance and throat of the Venturi meter.

**VIOLATION** - A failure to meet any state or federal drinking water regulation.

**VIRUS** - The smallest form of microorganisms capable of causing disease. Especially, a virus of fecal origin that is infectious to humans by waterborne transmission.

**VOLATILE** - A substance that is capable of being evaporated or easily changed to a vapor at relatively low temperatures. For example, gasoline is a highly volatile liquid.

**VOLTAGE** - The electrical pressure available to cause a flow of current (amperage) when an electrical circuit is closed. Also called ELECTROMOTIVE FORCE (E.M.F.)

**VOLUME** - Volume is calculated using three dimensions; length, width, and height. Volume units are given in cubes such as cubic feet or cubic meters. One cubic foot is equal to 7.48 gallons.

**VOLUMETRIC FEEDERS** - Equipment which feed a measured volume of dry chemical into water within a given time interval.

**VULNERABILITY ASSESSMENT** - An evaluation of drinking water source quality and its vulnerability to contamination by pathogens and toxic chemicals. A systematic process for evaluating the susceptibility of critical facilities to potential threats and identifying corrective actions that can reduce or mitigate the risk of serious consequences associated with these threats.

**WATER AUDIT** - A thorough examination of the accuracy of water agency records or accounts (volumes of water) and system control equipment. Water managers can use audits to determine their water distribution system efficiency. The overall goal is to identify and verify water and revenue losses in a water system.

**WATERBORNE DISEASE OUTBREAK** - The significant occurrence of acute infectious illness, epidemiologically associated with the ingestion of water from a PWS that is deficient in treatment, as determined by the appropriate local or state agency.

**WATER CONTAMINATION INCIDENT** - A situation in which a contaminant has been successfully introduced into the system. A water contamination incident may or may not be preceded by a water contamination threat

**WATER CONTAMINATION THREAT** - A situation in which the introduction of a contaminant into the water system is threatened, claimed, or suggested by evidence. Compare *water contamination threat* with *water contamination incident*. Note that threatening a water system may be a crime under the Safe Drinking Water Act as amended by the Bioterrorism Act.

**WATER CYCLE** - Also known as the hydrologic cycle, describes the continuous movement of water on, above, and below the surface of the Earth. Processes include precipitation, condensation, interception, runoff, infiltration/percolation, transpiration and evaporation.

**WATER HAMMER** - The sound like someone hammering on a pipe that occurs when a valve is opened or closed very rapidly. When a valve position is changed quickly, the water pressure in a pipe will increase and decrease back and forth very quickly. This rise and fall in pressure can do serious damage to the system.

**WATER RIGHT** - A property right or legal claim to withdraw a specified amount of water in a specified time frame for a beneficial use.

**WATERSHED** - A regional land area, defined by topography, soil, and drainage characteristics, within which raw waters collect and replenish supplies.

**WATER TABLE** - The upper surface of the zone of saturation of groundwater in an unconfined aquifer. All water beneath is considered groundwater.

**WEIR** - (1) A wall or plate placed in an open channel and used to measure the flow of water. The depth of the flow over the weir can be used to calculate the flow rate, or a chart or conversion table may be used. (2) A wall of obstruction used to control flow (from settling tanks and clarifiers) to assure uniform flow rate and to avoid short-circuiting.

**WEIR DIAMETER** - Many circular clarifiers have a circular weir with the outside edge of the clarifier. All the water leaving the clarifier flows over this weir. The diameter of the weir is the length of a line from one edge of a weir to the opposite edge and passing through the center of the circle formed by the weir.

**WEIR LOADING** - A guideline used to determine the length of weir needed on settling tanks and clarifiers in treatment plants. Used by operators to determine if weirs are hydraulically (flow) overloaded.

**WELL LOG** - A record of the thickness and characteristics of the soil, rock and water-bearing formations encountered during the drilling (sinking) of a well.

**WELLHEAD PROTECTION AREA** - The area surrounding a drinking water well or well field which is protected to prevent contamination of the well(s).

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**WET CHEMISTRY** - Laboratory procedures used to analyze a sample of water using liquid chemical solutions (wet) instead of, or in addition to, laboratory instruments.

**WHOLESALE WATER** - Water purchased or sold for resale purposes.

**WHOLESALE SYSTEM** - A PWS that treats source water as necessary and then delivers finished water to another PWS. Delivery may be through a direct connection or through the distribution system of another consecutive system.

**YIELD** - The quantity of water (expressed as a rate of flow - GPM, GPH, GPD, or total quantity per year) that can be collected for a given use from surface or groundwater sources. The yield may vary with the use proposed, with the plan of development, and also with economic consideration. Also see SAFE YIELD.

**ZETA POTENTIAL** Zeta potential is a measurement of the magnitude of electrical charge surrounding colloidal particles. You can think of the zeta potential as the amount of repulsive force which keeps the particles in the water. The more negative the zeta potential, the stronger the particle charge and the repelling force between particles and the more coagulants will be needed to produce floc. The zeta potential is usually measured in millivolts.

**ZONE OF SATURATION** - The soil or rock located below the top of the groundwater table. By definition, the zone of saturation is saturated with water. Also see WATER TABLE.

## LIST OF ACRONYMS

AA	Atomic Absorption
AC	Alternating Current
AOP	Advance Oxidation Process
ART	Average residence time
ASTM	American Society for Testing and Materials
ANSI	American National Standards Institute
AVB	Atmospheric Vacuum Breaker
AWWA	American Water Works Association
BAT	Best Available Technology
BMP	Best Management Practice
BPH	Bureau for Public Health of WVDHHR
C&E	Compliance & Enforcement Section of OEHS
C&T	Certification & Training Section of OEHS
CCL	Contaminant Candidate List
CCR	Consumer Confidence Report
CDC	Center for Disease Control
CDS	Combined Distribution System
CEH	Continuing Education Hour
CEU	Continuing Education Unit
CFE	Combined Filter Effluent
CFR	Code of Federal Regulations
COC	Chain of Custody
CPE	Comprehensive Performance Evaluation
CT	Contact Time
CWS	Community Water System
DAF	Dissolved Air Flotation
DC	Direct Current
DCVA	Double Check Valve Assembly
D/DBP	Disinfectants/Disinfection Byproducts
DBP	Disinfection Byproduct
DBPFP	Disinfection Byproduct Formation Potential
DBPR	Disinfection Byproduct Rule
DE	Diatomaceous Earth
DI	Deionized
DOC	Dissolved Organic Carbon
DPD	<i>N,N</i> -diethyl- <i>p</i> -phenylenediamine
DWSRF	Drinking Water State Revolving Fund
EBCT	Empty Bed Contact Time
EC	Enhanced Coagulation
EDTA	Ethylenediamine Tetraacetic Acid
EED	Environmental Engineering Division of OEHS
EMF	Electromotive force
EPA	Environmental Protection Agency
ERL	Emergency Response Lead
ERP	Emergency Response Plan
FOIA	Freedom of Information Act
GAC	Granulated Activated Carbon

GC	Gas Chromatograph
GIS	Geographic Information System
GCPD	Gallons Per Capita Per Day
GWR	GroundWater Rule
GWUDI	Groundwater under the direct influence of surface water
HAA5	Haloacetic Acids, group of 5: mono-, di-, and trichloroacetic acids; and mono- and dibromoacetic acids
HAAFP	Haloacetic Acid Formation Potential
HDPE	High Density Polyethylene
HTH	High Test Hypochlorite
HTML	Hypertext Markup Language
I&CD	Infrastructure & Capacity Development Section of OEHS
ICR	Information Collection Rule
IDHL	Immediately Dangerous to Health or Life
IDSE	Initial Distribution System Evaluation
IESWTR	Interim Enhanced Surface Water Treatment Rule
IFE	Individual Filter Effluent
IOC	Inorganics Chemicals
LEL	Lower Explosive Limit
LEPC	Local Emergency Planning Committee
LOTO	Lock Out/Tag Out
LRAA	Locational Running Annual Average
LSI	Langlier Saturation Index
LT1ESWTR	Long Term 1 Enhanced Surface Water Treatment Rule
LT2ESWTR	Long Term 2 Enhanced Surface Water Treatment Rule
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
M-DBP	Microbial-Disinfectants/Disinfection Byproducts
MRDL	Maximum Residual Disinfection Level
MRDLG	Maximum Residual Disinfectant Level Goal
MF	Microfiltration
MOR	Monthly Operational Reports
MRDL	Maximum Residual Disinfectant Level
MRDLG	Maximum Residual Disinfectant Level Goal
MRL	Minimum Reporting Level
MRT	Maximum Residence Time
MSDS	Material Safety Data Sheets
MWC	Molecular Weight Cutoff
NFPA	National Fire Protection Association
NCI	National Cancer Institute
NF	Nanofiltration
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety & Health
NOM	Natural Organic Matter
NPDWR	National Primary Drinking Water Regulation
NPSH	Net Positive Suction Head
NSDWR	National Secondary Drinking Water Regulation
NSF	National Sanitation Foundation
NTNCWS	Non-transient, Non-community Water System

NTU	Nephelometric Turbidity Unit
O&M	Operation and Maintenance
OC	Organic Chemicals
OEHS	Office of Environmental Health Services
OIT	Operators-in-Training
OSHA	Occupational Safety & Health Association
PAC	Powdered Activated Carbon
PACl	Polyaluminum Chloride
PC	Personal Computer
PDF	Portable Document Format
PE	Performance Evaluation
PLC	Programmable Logic Controller
PN	Public Notification
PODR	Point of Diminishing Return
PPE	Personal Protective Equipment
PR	Public Relations
PSC	West Virginia Public Service Commission
PVB	Pressure Vacuum Breaker
PVC	Polyvinyl Chloride
PWS	Public Water System
PWSID	Public Water System Identification
RAA	Running Annual Average
RAM	Random Access Memory
RO	Reverse Osmosis
RPZ	Reduced Pressure Zone Assembly
RTU	Remote Terminal Units
SCBA	Self-Contained Breathing Apparatus
SCADA	Supervisory Control and Data Acquisition
SDS	Simulated Distribution System
SDWA	Safe Drinking Water Act
SDWIS	Safe Drinking Water Information System
SEER	Surveillance, Epidemiology, and End Results
SMCL	Secondary Maximum Contaminant Level
SOC	Synthetic Organic Chemical
SPADNS	Sodium 2-(parasulfophenylazo)-1,8-dihydroxy-3,6-naphthalene disulfonate
SSS	System-Specific Study
SUVA	Specific Ultraviolet Absorption
SWAP	Source Water Assessment and Protection
SWTR	Surface Water Treatment Rule
TC	To Contain
TCR	Total Coliform Rule
TD	To Deliver
TDS	Total Dissolved Solids
TDT	Theoretical Detention Time
THM	Trihalomethane
TTHFP	Total Trihalomethane Formation Potential
TNCWS	Transient Non-community Water System
TOC	Total Organic Carbon

TOX	Total Organic Halides
TOXFP	Total Organic Halides Formation Potential
TT	Treatment Techniques
TTHM	Total Trihalomethanes
UEL	Upper Explosive Limit
UF	Ultrafiltration
USB	Universal Serial Bus
USGS	United States Geological Survey
UV	Ultraviolet
UV-254	Ultraviolet absorbance at a wavelength of 254 nm
VOC	Volatile Organic Chemical
VSS	Very Small System
WD	Water Distribution
WHPA	Wellhead Protection Area
WTP	Water Treatment Plant
WVDEP	West Virginia Department of Environmental Protection
WVDHHR	West Virginia Division of Health and Human Resources