SMALL WATER SYSTEM TRAINING MANUAL

As compiled by the

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Small Systems Water Training Manual

Purpose and Scope

Many books and training guides have been written on the treatment of drinking water. Specifically, the Sacramento series that consists of three training manuals for water treatment plant operators. These are Small Water System Operation and Maintenance, A Field Guide for Training Program, and the two accompanying manuals, Water Treatment Plant Operation, A Field Study Training Program, Volume I and Water Treatment Plant Operation, A Field Study Training Program, Volume II. These three training guides provide the operator with a comprehensive overview of the principles of water treatment. To round out this training and make it applicable to the operator's personal water system, knowledge of the Safe Drinking Water Act and The Florida Drinking Water Rules as enacted by the Florida Administrative Code are also materials that the operator must be familiar with. The combination of these documents is voluminous and intimidating to a new operator.

The Safe Drinking Water Act with its number of rule revisions have added further materials that require the operator's attention. These materials are particularly of importance to those that operate water treatment plants that use surface waters or groundwater under the influence of surface water as their water supply source. The Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual, Microbial and Disinfection Byproduct Rules for Simultaneous Compliance Guidance Manual and the LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual all published by EPA, are good sources of information for operators who operate surface water types of water treatment systems.

The Florida Rural Water Association has developed this training manual called the Small Water Systems Training Manual to assist the operator in focusing on the basic concepts needed to successfully master skills necessary to operate small water treatment systems. The manual incorporates information contained in the above sources. It includes many helpful and practical guides for operating and maintaining plant equipment. The manual also provides refresher training for those seeking certification as D or a C operator in the State of Florida. Many helpful tables that include major concepts and troubleshooting guides have been provided for easy reference.

The successful use of this manual requires that the operator has become familiar with the Sacramento Water Plant Operator training manuals and has reviewed the Safe Drinking Water Act and the Drinking Water Rules for the State of Florida. This manual does not replace these important and necessary reference documents and is intended to supplement the operator's knowledge with a review of water treatment concepts, examples of practical application and suggested maintenance practices for the types of equipment found in many small water treatment plants.

This training manual is not intended to be all inclusive of the field of water treatment or in identifying Federal or State drinking water regulations. In all cases where sampling, monitoring or reporting requirements are called into question, the operator is instructed to consult with the Drinking Water Rules for the State of Florida for the specific application to the water system in question.

Introduction to Water Treatment

The Use of Water for Public Water Supplies

Water is a major environmental factor in man's well being. An ample supply of potable water is needed for social, economic, and health purposes. In this age of accelerating urbanization, greater demands are being placed on available sources complicating problems of allocation, development and quality control. Man's dependency on water is all encompassing. Among its countless uses, its most important is to sustain life itself.

Primary water use is considered to be for drinking and food preparation. Since water quality cannot be separated from quantity, a sufficient amount of water with satisfactory physical, biological, chemical and radiological characteristics is required. Insufficient quantity disrupts routines, leads to unsafe practices, and encourages the use of water of questionable quality. For this reason the Safe Drinking Water Act (SDWA) was established by Congress in 1974 to ensure drinking water of a quality that protects human health. The SDWA establishes both primary and secondary standards. Primary standards are set for contaminants at certain concentrations that when present in drinking water pose a threat to human health. Secondary standards primarily relate to public acceptance of the water and at higher concentrations health considerations may exist. The SDWA will be covered in more detail in later chapters.

Water for drinking and food preparation must be free from organisms capable of causing disease and from minerals and organic substances producing adverse physiological effects. To encourage people to drink water from a safe source, it must be aesthetically acceptable. The water must be free from apparent turbidity, color, and odor and from any objectionable taste. Source water in many areas of Florida must be treated to SDWA standards. When water meets these standards it is termed "potable," meaning that it may be consumed in any desired amount without concern for adverse effects on health. The treatment of water has developed over many years and the water treatment technologies when properly operated and maintained can consistently produce a very high quality drinking water meeting SDWA standards.

Water Treatment in the United States

The first treatment system in the United States was filtration through sand followed by disinfection using chlorine compounds. The first filter system was put into use in 1872 in Poughkeepsie, New York. The first attempt to disinfect a public water supply was in Jersey City in 1908, when equipment was installed to apply a chlorine solution. In 1912 commercial equipment was developed for the application of chlorine gas. Dramatic drops in the typhoid fever death rates where filtration and chlorination was in use further dramatized the need for treatment of all public water supplies.

Using chlorine or other chemicals or techniques to remove or destroy the harmful bacteria and viruses in the water is called disinfection. Disinfection does not destroy all organisms. The process of destroying all pathogens is called sterilization. Today we know that chlorine or chlorine compounds can in themselves be harmful to human health if not properly controlled. Today's operator must balance the addition of chlorine or chlorine compounds with the removal of pathogens. This process is called simultaneous treatment.

Bacteriological Examination of Water

The bacteriological examination of water is a rather recent development. The presence of coliform is used as an indicator of the presence of pathogenic bacteria. Coliform bacteria are ubiquitous, that is they are found everywhere in our living environment. An operator must be extremely careful in preparing samples and collecting samples to prevent false positive results. The term "coliform group" implies that these organisms are a bacterial group of unknown dimensions rather than a single species. When present additional sampling and testing will be required to determine the presence of fecal coliform.

Fecal coliform are a special kind of coliform that indicate a fecal source and thus make the water unsafe to drink. Fecal contamination is indicated by the presence of a group of specific organisms designated as

Escherichia coli, or E. coli. , These organisms naturally reside in the colon or intestinal tract of warm-blooded animals.

In 1884, Escherich isolated from the stools of cholera patient organisms, which he originally thought to be the cause of that disease. Further investigations, however, showed that similar organisms also were present in the intestinal tracts of healthy individuals. Because coliform organisms originate from the intestinal tracts of warm blooded animals, their existence has come to be recognized as an inherent characteristic of water which can predict its biological safety. Today's SDWA requirements require the absence of coliform organisms in the drinking water and require the removal of Girardia and Cryptosporidium. These pathogens also reside in the digestive tract of warm-blooded animals and these two organisms have been responsible for serious illness in human populations. Since identification of these two organisms is difficult, the efficient operation of water treatment processes have been found to be the best measure of their removal in drinking water.

Water Treatment Plant Operator Requirements

To ensure the safe and efficient operations of water treatment systems, the state of Florida has established standards for water treatment operator certification. The State requires a certified operator for any water treatment system that provides primary treatment (sedimentation, aeration, stabilization or disinfection.)

The duty of an operator is to provide the water user with a continuous supply of safe water at a usable pressure.

The operator is in whole or in part responsible for the operation of a water system. At times, he/she is a manager, maintenance man, meter reader, public relations man, electrician, plumber, sanitarian, engineer, salesman, and inspector. Becoming a competent operator requires the development of many skills. To become a competent operator one must have an interest in his/her work, be dependable, be willing to learn, and be willing to assume responsibility and work without supervision. Each water system represents a large financial investment in facilities and equipment and improper operation and maintenance can quickly damage both. A competent operator provides a large degree of protection for both the tremendous financial investment and the health of the community.

Setting Operational Priorities for a Water Treatment System

Because of the many water plant responsibilities assigned to a water plant operator, each operator must establish priorities that will determine which task is most important and which task must be begun first. Table 1, provides a guide to an operator in setting priorities based on potential health impacts.

Table 1

Setting Operator Priorities
For a Water Treatment Plant

Priority	Action	
1	Water Service Problems	Possible Cause(s)
	Any problem causing unsafe water to be delivered to customers	Bad sample or laboratory procedure Malfunction of treatment processes or facilities A cross-connection(s)

Priority	Action	Possible Cause(s)
	Low or no water pressure in system	Broken water line Source of water interrupted Malfunction of booster pump or pressure tank
	Large unplanned discharge of water	Broken water or service lines Damages or open fire hydrants Altitude valve failure at storage tank Malfunction of pump controls or other plant facilities
2	Preventing Plant Problems	Actions or Tasks
	Ensuring Plant Facility and Equipment Reliability and Service Life	Making timely repairs on pumps and other plant equipment. Making maintenance checks and performing lubrication. Performing plant process, facility and valve maintenance. Performing structural and grounds maintenance. Ensuring proper inventory of parts and supplies.
	Developing skills and expertise in water system operations	Certification Studying operations manuals plans and schematics. Attending workshops and reading instructional material.

3	Ensuring Financial Stability	Possible Problem/Tasks/Responsibilities
	Ensuring proper water measurement	Malfunction of meters from wear. Sand or other foreign material lodged in meters.
	Enforcing water use regulations	Customer not paying for water. Illegal taps Unauthorized multiple users on meters.
	Installing new water services	Setting new meters Construction or short extensions for new users. Re-installation of meters that have been taken out.
	Ensuring good public relations	Performing efficiently and effectively. Be courteous, professional and informative to customers.

The list is not inclusive and a cursory check will indicate the many tasks that a responsible operator must perform. Any problem that affects water safety must receive first priority. On this list the first items are handled before the latter ones, but one must be cautious about forgetting about the latter ones. For example, if one is kept so busy that he/she doesn't get around to maintaining proper lubrication of a pump, the pump will fail prematurely and then become a top priority.

Required Duties of a Water Treatment Plant Operator – State of Florida

An operator is responsible by State law for performing treatment plant operation and maintenance duties in a responsible and professional manner. These duties are shown in Table 2:

Table 2

Duties of Water Treatment Plant Operators
Excerpts from FAC Chapter 62-602.650

1	Perform responsible and effective on-site management and supervision over personnel and plant functions.
2	Submit all required reports in accordance with Florida Administrative Code (FAC).
3	Report to FDEP or the supplier of water and local regulatory agency within 24 hours any condition likely to cause unsafe treatment or discharge not in accordance with FAC or the facility's operating permit or any interruption in service.

4	Maintain operation and maintenance logs for each plant in a location accessible for 24-hour inspection. The logs shall contain a minimum of the previous three months of data at all times.
5.	Logs must contain the identification of the plant, the signature and license number of the operator making entry, the date and time, specific operation and maintenance activities and repairs performed.
6.	Records of any tests performed or samples taken unless documented in a laboratory.
7.	Any preventative maintenance and repairs or requests for the repairs of equipment.

Need for a Work Management System in a Water Treatment Plant

A work management system greatly aids in an operator in meeting state requirements while providing additional benefits. Work management is a systematic written process that an operator uses for setting preventative maintenance schedules. The system is generally set up in accordance with the equipment manufacture's recommendations combined with visual and measured observation of plant equipment and processes by the operator. The operator records all maintenance activities and checks performed on equipment. By using this information proactively to set work priorities and maintenance schedules for all plant equipment and facilities, the operator continuously improves the reliability of equipment while reducing the levels of unplanned (breakdown) maintenance. With a little experience, each operator can set more effective maintenance monitoring priorities. These will in the long term, free up more time to handle the multiple demands on the operators' time.

Professional Responsibilities of an Operator

In addition to meeting State operator requirements, an operator as a representative of the municipal utility must maintain a cooperative and professional demeanor with the public and with the utility administrative office.

Table 3 illustrates some of the responsibilities of for a water plant operator.

Table 3

Professional Responsibilities of an Operator

	Desirable Activities	Undesirable Activities
1	Accept full responsibility for the day-to-day operations of the water system.	Do not indulge in petty criticism of the administration or divulge confidential facility information.
2	Advise the Board of Directors or City Administration professionally in all matters and recommend policy affecting.	Do not interfere with the policy-forming function of the Board of Directors or City Administration or join a clique to control Administration action.
3	Implement and execute all policy when adopted.	Never refuse to support Administration policy because of personal reasons.
4	Keep the Administration fully and accurately informed about facility matters	Do not make promises and commitments prior to full discussion in Board or City Administration meetings.
5	Attempt to accurately interpret the needs of the facility.	Do not assume authority that has not been given to you by the Administration.
6	Be alert to advancements and improvements that may be benefit the facility and participate in facility activities	Do not use our position for personal gain.
7	Adhere to administrative policies on nepotism, hiring and purchasing requirements	Do not show favoritism to relatives, friends, or members of the administration or accept gifts from suppliers, contractors, etc. or otherwise gain personal advantage because of your position.
8.	Perform all needed and expected work.	Resign if unwilling or unable to do the expected work

Water Sources for Drinking Water Supplies

The Hydrological Cycle

Water sources can exhibit a wide variety of adequacy both in terms of quality and quantity. All water is governed by the hydrologic cycle. As the name implies there is a continuous circulation of moisture and water. Radiation from the sun evaporates water from surface waters and returns it as a vapor into the atmosphere. As the water vapor rises, it cools, creating clouds. From these clouds the moisture condenses on small particulate matter and falls back to the earth's surface in the form of precipitation. Precipitation is essentially the source of all our fresh water. Part of this precipitation, after saturating the surface, runs off to streams. Figure 1 shows the various relationships of the hydrological cycle.

The Hydrological Cycle

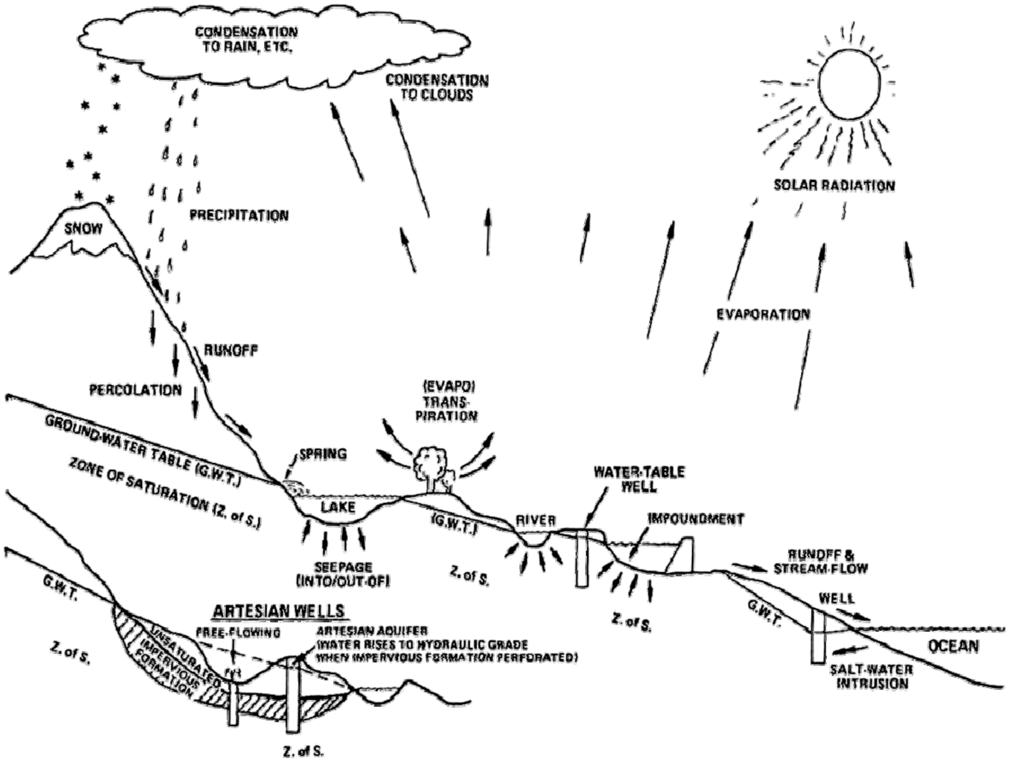


Figure 1
The Hydrological Cycle

Hydrogeologic Considerations in the Use of Source Water

The study of the movement of water underground is called hydrogeology. The water that enters the soil initially is detained in the plant root zone called the zone of aeration. Water not utilized by the plants continues on through the subsurface formations under the influence of gravity. Eventually water reaches a zone where all the formation pores are filled with water, the zone of saturation. The upper edge of this zone is what is referred to as a water table. Depending on topography, geology and the hydrostatic pressure, the water moves through the saturated formation and may reappear where the surface intersects the water table. The formations of strata that are saturated with water and from which ground water may be obtained are called aquifers. To qualify as an aquifer, a geologic formation must contain pores or open spaces that are filled with water and large enough to permit the water to move at a perceptible rate.

Aquifers may be either confined or unconfined. Unconfined aquifers have a free water surface. Confined or artesian aquifers have the water surface restricted both vertically and horizontally by formations that restrict water movement by high impermeability. The water pressure within these aquifers is such that when the upper confining layer is broken, either by a well or fault line, the water will rise above the top of the aquifer. In some cases, the water rises above the land surface and an artesian spring or well is created.

The operator must realize that from the moment of condensation, water is being contaminated by natural and manmade sources. The raindrops are formed around dust particles. Falling through the air, the water picks up small concentrations of pollutants from gases, plant seeds, and chemicals such as sulfur, nitrogen, and carbon dioxide. Upon reaching the surface, water can be significantly contaminated by pathogens or chemical compounds such as nitrogen from domestic or agricultural wastes. As water passes through subsurface formations the water can dissolve minerals (salts) that affect the quality of the water. The operator should study the figure above and understand the various relationships that affect the flow and quality of the source water.

Ground Water

Ground water is the principal source of water for almost all water supply systems in Florida. Ground water generally has a more consistent desirable bacterial quality than surface water, having undergone considerable natural purification through straining and prolonged storage. However, a number of areas have suffered contamination of their ground water due to improper disposal of wastes and sometimes due to intermixing of water from different strata.

When groundwater is under the direct influence of surface water, the source water is regulated as surface water. Generally groundwater requires only disinfection prior to use, whereas surface waters requires more sophisticated treatment. Furthermore, ground waters are readily available in most areas of the state in sufficient quantities to meet the needs of most water systems.

Surface Water

Precipitation that does not enter the ground through infiltration or is not returned to the atmosphere by evaporation flows over the ground surface and is classified as direct runoff. Direct runoff is water that moves over saturated or impermeable surfaces, and in stream channels or other natural or artificial storage sites. Runoff can transport a significant amount of contaminants to lakes, rivers and streams. When precipitation is absent for long durations, the dry weather (base) flow of streams is derived from ground water. This large variation in flow rates and water quality makes many moving bodies of water a poor choice for a water supply source.

Runoff from ground surfaces may be collected in either natural or artificial reservoirs. A portion of the water stored in surface reservoirs is lost by evaporation and from infiltration to the ground water table. Evapotranspiration from vegetation in and adjacent to a reservoir constitutes another means of water loss.

Surface water is generally classified as water contained in lakes, rivers, streams and other bodies of water on the surface of the earth. Because both man and nature expose surface waters to potentially severe contamination and because the quality of the water varies considerably, a relatively high degree of treatment is required for surface water to ensure its constant safety. The treatment is generally more sophisticated than with ground waters and requires more diligent operation and maintenance and more costs.

However, there are occasions when surface water is a source for a small water supply system because of the poor quality or lack of local ground water. Other factors being equal, impoundments such as natural lakes or ponds, or reservoirs, are preferred over streams since the quantity and quality of the water is usually less variable. However, changing temperatures in stationary bodies can result in algae and anaerobic conditions that can be problematic.

Quality of Water

Precipitation contains very few impurities. Trace amounts of mineral matter, gases, and other substances may be entrained as the precipitation forms and falls through the earth's atmosphere; but it has virtually no bacterial content.

Once precipitation reaches the earth's surface, many opportunities are presented for the introduction of foreign substances into the water. These actions may lower the water quality to the point that it constitutes a health hazard or impairs its usefulness.

Proximity of the water source to nearby sewers, waste disposal, construction projects, animal pasturing, chemically treated agricultural land, and chemical storage areas (such as salt or petroleum) increases the likelihood of contamination. Other sources of contamination are completely natural, such as high flood runoff, chemical composition of soil above the rock (e.g., the presence of iron), or decomposition of organic matter. Table 4 illustrates some common causes of source water contamination

Table 4

Causes of Source Water Contamination

1. nearby septic tanks and leach fields
2. waste disposal operations
3. animal pasturing
4. chemically treated agricultural land
5. chemical storage areas
6. subsurface liquid waste disposal systems - highways
7. Effect of high-flood runoff
8. Chemical and physical characteristics of soil above rock
9. Decomposition of organic matter

Substances that alter the quality of water as it moves over or below the surface of the earth may be classified as physical, chemical, biological or radiological. The effects of these contaminants are shown in Table 5 below:

Table 5

Contaminant Classification in Source Water

Source Contamination	Examples
Physical	The presence of color, turbidity, temperature, taste or odor
Chemical	Mineral content such as chlorides, sulfates or hardness or chemical contaminants such as iron manganese, nitrates and arsenic
Biological	The presence of viruses, bacteria and algae
Radiological	The presence of radioactivity such as radon from subsurface formations

Impurities in natural waters depend largely on the circumstances of the source water and its history. Water destined for an aquifer picks up impurities as it seeps through soil and rock, including possible pollution. Pollution sources may include domestic and wild animals, sewers, septic systems, waste disposal sites, accidental discharges and contamination from livestock. The presence of nitrates in source water is typically an indicator of contamination from these types of sources and surface water is frequently the carrier to the groundwater below.

Microbial Contaminants in Water

Microbial contaminants are bacteria and viruses that are present in drinking water. Presence of microbial contaminants indicates that the water has been impacted by an outside source and may be unfit for consumption. Table 6 is EPA's classification system for microbial contaminants.

Table 6

Classification of Microbial Contamination
Public Drinking Water Supplies USEPA

Microbial Contaminant	Description
Turbidity (indicates that microbes may be present)	A measure of the cloudiness of the water. Used as an indicator of water quality and effectiveness of the treatment processes to remove pathogens from source water.
Total Coliform Bacteria	The presence of total coliform is used as an indicator that other potentially harmful organisms may be in the water.
Fecal Coliform and E. coli	Bacteria naturally present in the intestines of warm-blooded animals. The presence of fecal coliform or E coli is a danger that the water system is likely contaminated with fresh human or animal waste
Viruses	Enteroviruses (of fecal origin) can cause infections in people. Enteroviruses can cause diarrhea, nausea, and/or stomach cramps
Protozoa (Giardia lamblia and Cryptosporidium)	Disease-causing organisms originating in the intestines of warm-blooded animals that may be present in water containing fecal pollution
Bacterial Pathogens (Legionella)	Can cause Legionnaire's Disease a specific and fatal pneumonia.

Minerals in Groundwater Sources of Water

Uptake of minerals is common in groundwater. The natural straining action does remove some of the particulate matter and, combined with a relatively long retention period in the ground, will often aid in removing microorganisms. This long retention time can, however, create problems in that ground water. Water once contaminated can be very difficult and costly to restore to acceptable potable quality. Ground waters have a fairly stable quality usually not highly affected by seasonal changes. Wells affected by seasonal changes tend to be very shallow and subject to easy contamination, such as those in the Biscayne Aquifer in South Florida and the Sand and Gravel Aquifer in Northwest Florida. However, natural and physical interconnects such as improperly cased wells, between shallow and deep aquifers are common and there is always the potential for contamination even in deeper aquifer zones used as the water source.

Treatment of Source Waters

It is always more cost effective to obtain the highest quality of source water rather than to rely on water treatment. Table 7 illustrates typical water treatment application technologies employed for removing source water contaminants. Applying any contamination removal technology adds to the expense and complexity of producing safe, high quality drinking water.

Table 7
Effective Removal of Source Water Contaminants

Groundwater Sources	
Water Quality Problem	**Typical Removal Technology**
Microbial Contamination	Disinfection (generally with chlorine)
Sulfide Odors (rotten egg)	Aeration Oxidation
Excessive Hardness (Calcium and Magnesium)	Lime (and Soda Ash) Softening Ion Exchange
Iron and Manganese	Oxidation by aeration or chemical addition
	Sequestering with polyphosphates
	Filtration with Greensand
Dissolved Minerals (high dissolved solids (TDS))	Ion Exchange
	Reverse Osmosis
Corrosivity	pH adjustment
	Chemical addition
	Aeration
Surface Water Sources	
Water Quality Problem	**Typical Removal Technology**
Microbial Contamination	Disinfection (with chlorine, ozone or chlorine dioxide)
	Coagulation, Flocculation, Sedimentation and Filtration
Turbidity and/or Color	Coagulation, Flocculation, Sedimentation and Filtration
Water Quality Problem	**Typical Removal Technology**

Odors	Clarification (Coagulation, Flocculation, Sedimentation and Filtration)
	Oxidation with Permanganate or other chemical
	Absorption with Granular Activated Carbon (GAC)
Excessive Hardness (Calcium and Magnesium)	Lime (and Soda Ash) Softening Ion Exchange
Iron and Manganese	Oxidation by aeration or chemical addition
	Sequestering with polyphosphates
	Filtration with Greensand
Dissolved Minerals (high dissolved solids (TDS))	Ion Exchange
	Reverse Osmosis
Corrosivity	pH adjustment
	Chemical addition
	Aeration

Effect of Organic Materials in Source Waters on the Disinfection Process

For plants treating surface waters or those groundwater plants under the influence of surface waters, additional requirements for removing organic constituents may be necessary to limit potential for the production of trihalomethanes (THM) and Haloacetic Acids (HAA5). These substances are produced when free chlorine reacts with organic substances (Total Organic Carbon or TOC) that are prevalent in surface waters. These considerations are discussed in later sections of this Manual.

Organic material can be significantly reduced by the proper operation of conventional water treatment processes. Conventional water treatment consists of processes that include coagulation, flocculation, sedimentation, and filtration.

Surface water will generally have higher levels of insects or other microorganisms, algae or large diameter pathogens such as Giardia lamblia and Cryptosporidium. Surface waters also exhibit rapid shifts in water characteristics such turbidity (which includes suspended microorganisms), temperature, conductivity and pH. When any combination of these characteristic occur in a groundwater source, these sources will be classified as groundwater under the direct influence (GWUDI or UDI) of surface water. In some Safe Drinking Water Regulations surface water source systems and groundwater source systems are referred to as Subpart H Systems. Subpart H is that part of the Federal Register that contains the special federal or EPA requirements for these types of water sources used for public drinking water supplies.

Safe Drinking Water Act Requirements for Water Systems

Introduction to the Safe Drinking Water Act

The late 60's and early 70's were a period of revelation to the general public concerning drinking water supplies. Reports were identifying problem areas; technologies were measuring contaminants in the parts per billion range. Some of these contaminants were suspected or known carcinogens. As public concern grew, a movement for a Federal policy to provide a comprehensive means of addressing water supply problems gained impetus. This movement resulted in the passage of the Safe Drinking Water Act (PL 93-523) in December 1974. The 1974 SDWA called for the EPA to regulate drinking water.

Congress intended that the Safe Drinking Water Act (SDWA) to be a partnership between the States, EPA, and local water utilities. Today, EPA provides the overall national guidance by determining health effects and establishing standards for contaminants, researching treatment technologies for contaminants, and monitoring State programs. Florida has, by accepting "primary enforcement responsibility" (primacy) from EPA, the responsibility for implementing and enforcing the safe Drinking Water laws within its borders. The water utilities must meet the requirements of the law, thereby providing day-to-day compliance. Table 8 illustrates the various responsibilities of the Safe Drinking Water Act.

Table 8

Responsibilities for Implementing the Safe Drinking Water Act

EPA Responsibilities	State Responsibilities	Utility Responsibilities
Set Primary and Secondary MCLs	Assume primary responsibility for enforcement of regulations	Meet the primary standards set by EPA, and the more stringent Florida standards.
Certify State Primacy Requirements	Adopt state primacy drinking water standards	
Annually Evaluate State Programs	Maintain an inventory of public water supply systems	
Conduct Research, technical assistance, training and funding to the states	Have a systematic program for conducting sanitary surveys	Have authority to require suppliers to keep accurate records and make appropriate reports to the State

Responsibilities for Implementing the Safe Drinking Water Act (Table 8 continued)

EPA Responsibilities	State Responsibilities	Utility Responsibilities
Enforce state failure to properly implement SDWA regulations	Establish a program for certification of water testing laboratories (unless testing is done by approved State laboratories).	Treatment and monitoring of bacteriological, chemical, and radiological contaminants
	Assure that new or modified public water systems are capable of compliance with State drinking water regulations	Record keeping and reporting of results to DEP and DDOH; and notification of any noncompliance to consumers and the public.
	Establish procedures for enforcement	Notification to the public for matters of health concern
	Have authority to sue in court for violations	
	Have right to entry of treatment systems	
	Establish and maintain record keeping and reporting of its activities	
	Permit variances or exemptions only under the same conditions as granted under the Federal regulations	
	Adopt and implement an adequate plan for providing safe drinking water under emergency conditions	

Primary Drinking Water Regulations and Secondary Drinking Water Regulations.

Primary drinking water standards are those standards that regulate contaminants that have known adverse health affects. Secondary standards regulate the appearance or aesthetics and quality of the water. Florida enforces both the primary the secondary SDWA standards. Other requirements in the SDWA program include the requirements and responsibilities for water providers for effective implementation.

To protect against health impacts, the SDWA provides for a multi-barrier approach. Each of the barriers allows for a level of protection from contamination of drinking water. The levels of protection are additive. The requirements for each of the barriers are prioritized by the health affects that might be result because of non-compliance. These barriers and tiered health protection levels are shown in Table 9.

Table 9

Multiple-Barrier Approach to Protecting Public Health
USEPA

Source Water	Selecting and protecting the best source.
Treatment	Installing treatment methods implemented by certified operators.
Storage and Distribution	Constructing, operating and maintaining well engineered storage and distribution systems.
Monitoring and Public Information	Providing the consumers with information on water quality and health effects.

Applicability of Safe Drinking Water Act

The SDWA applies to all public water systems. Public water system means a system providing to the public piped water for human consumption. A Public Water System has at least 15 service connections or regularly serves an average of at least 25 individuals daily at least 60 days out of the year. This includes 1) any collection, treatment, storage, and distribution facilities under the control of such a system and used primarily in connection with such a system, and 2) any collection or pretreatment storage facilities not under such control which are used primarily in connection with such a system.

Division of Public Water Systems Under the Safe Drinking Water Act

Public Water Systems (PWS) are divided into Community Water Systems (CWS) and Non-Community Water Systems (NCWS). The Non-Community Water System is further divided into Non-Transient (NTCWS) and Transient Community Water Systems (TCWS). These divisions are used to set drinking water requirements and for monitoring and reporting of water contaminants. Figure 2 shows these divisions.

Public Water Systems (PWS) are either

Community Water Systems (CWS) or Non-Community Water Systems and these

are either

Transient (TNCWS) or Non-Transient (NTNCWS)

Figure 2
The Three Divisions of Public Water Systems
Under the Safe Drinking Water Act

Community Water System Definition

A public water system that serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents. Table 10 includes examples of Community Water Systems:

Table 10

Community Water Systems (CWS)

Municipal systems and public water utilities
Mobile home parks
Condominiums
Residential institutions and schools, including hospitals, nursing homes, homes for the aged, colleges
Housing developments, public and private
Multifamily housing complexes (all varieties)

Non-Community Water System (NCWS) Definition

A Non-Community Water System is a public water system that serves at least 15 service connections or serves at least 25 people at least 60 days out of the year that does not serve the same people. The main difference between community and non-community water systems is that the former serves residential populations and the latter serves transients or non-residents who otherwise do not permanently inhabit the building served by the system.

There are two types of Non-Community Water Systems, Non-Transient and Transient, Non-Community Water Systems.

Non-Transient Non-Community Water System (NTNCWS) Definition

A Non-Transient Non-Community water system serves at least 25 of the same persons six months out of the year (e.g., school, office building, factory, etc.)

There is a requirement for public notification in specific instances. The public should be told of the shortcomings of its water supply. How the general public and the everyday customer would be notified is outlined in the SDWA. This requirement assures that the public is not only aware of the hazards of the particular shortcoming but also provides support for corrective actions. A final requirement is for record maintenance, specifying what records are to be kept and for how long.

Transient Non-Community Water System (NTNCWS) Definition

A Transient Non-Community water system serves at least 25 persons six months out of the year that are not the same people (e.g. a highway rest stop, airport, shopping center)

Some examples of Non-community and Non-transient Non-Community Systems are shown in Table 11.

Table 11

Examples of Non-Community Water Systems with own Water Supply Systems

(Includes Transient and Non-Transient)

Motels-hotels-resort areas	Migrant labor and construction
Schools (nonresident)	Office and commercial buildings camps
Highway rest areas	Public buildings and public facilities
Restaurants and other food service places	Children's and adult camps
Marinas	Gasoline service stations
Airports	Assembly facilities
Campgrounds	Social and recreation clubs
Medical care facilities	Swimming pools and beaches
Recreation areas	Industries
Shopping centers	Churches

Drinking Water Standard Applicability to Community and Non-Community Water Systems

There are differences in the standards applied to the community and non-community systems. This is based on the fact that permanent residents are exposed to potential contaminants for extended periods. Community systems generally supply drinking water to residential and institutional users who might be exposed to dangerous levels of contaminants for extended periods of time. Consequently, a wider range of contaminants is controlled by the regulations. Non-community systems generally supply drinking water to transients or non-residents, who might be exposed to dangerous levels of contaminants for lesser periods of time. Table 12 identifies the general applicability to SWDA rules to the various public water systems. The operator should consult the Florida Drinking Water Rules for specific application of any State or Federal Rule.

Table 12

Safe Drinking Water Rules And Application to Public Water Systems

SDWA Rule	Risk Type	Coverage	Overview	Monitoring
Total Coliform Rule	Microbial, Chemical, and Radiological	All PWS	Monitoring for coliform as indicators of potential wastewater contamination.	Sampling Based on population; requires fecal for positive coliform.

Safe Drinking Water Rules And Application to Public Water Systems (continued)

SDWA Rule	Risk Type	Coverage	Overview	Monitoring
Surface Water Treatment Rule	Microbial	All PWS the use SW or GWUDI*	Establishes Criteria when Filtration is required. Systems must filter and disinfect or apply for reduced monitoring.	No Filtration 1. Fecal coliform densities. 2. finished water inactivation ratios, Residual Disinfect. Concentration. (RDC) 3. With Filtration Turbidity and RDC.
Phase I Rule (Nitrate and Nitrite only)	Chemical and Radiological	CWS and NTNCWS All PWS	Establishes MCLs or treatment for 66 chemicals (IOC, VOC and SOC)	Nine Year Compliance Cycle with 3 year Compliance Period; some reduced monitoring to one yr.
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.
Disinfection Byproducts Rule (Chlorine Dioxide only)	Chemical and Radiological	CWS and NTNCWS All CWS	Reduce levels of disinfectants and DBPs. Sets MCLs HAA5s, Chlorite, Bromate and TTHMs and MRDL and MRDLG**	Monitoring for DBP. For surface water and GWUDI Total Organic Carbon (TOC) and Alkalinity.
Filter Backwashing Rule	Microbial	PWS or GWUDI that use conventional filtration	FBRR requires systems to return backwash (BW) for filtration.	By 12/8/03 submit plant schematic, by 6/8/04 retain information on BW, by 6/8/06 complete upgrades.
Consumer Confidence Report		All CWS	Consumer Confidence Report 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 24 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 timelier manner.
SDWA Rule	Risk Type	Coverage	Overview	Monitoring
Arsenic and New source Contaminants	Chemical and Radiological	CWS and NTNCWS	Sets MCL and monitoring requirements for Arsenic at .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 std. framework. Also beta if affected.
Enhanced Surface Water Treatment Rule	Microbial	PWS and GWUDI that serve less than 10,000 persons	Sets requirements for microbial contamination including Cryptosporidium and prevents risk associated with DBP requirements	Continuous turbidity monitoring on ea. Filter every 15 minutes.
Groundwater Rule	Microbial	PWS that use GW	Proposed rule will set requirements for viruses and bacteria	For systems that do not achieve deactivation levels, must sample for E.Coli, enterococci or coliphage.
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 II Disinfection Byproduct (DBP) Rule	Microbial	CWS and NTNCWS that do not use UV	Works in combination with Long Term Enhanced Surface Water Rule	Initial Distribution System Evaluation to determine monitoring sites
Long Term - Stage 2 Enhanced Surface Water Rule	Microbial	PWS that use surface water and GWUDI	Regulates treatment for source water	For systems serving under 10,000; Cryptosporidium monitoring at E. coli annual mean level

Florida Drinking Water Rules

The State of Florida was required to adopt standards that were equal or more stringent than Federal standards to maintain a program that met the conditions for receiving primacy. This includes conditions that Florida must have a systematic program for conducting a sanitary survey of all public water systems to decrease the likelihood of problems associated with inadequate protection, treatment process effectiveness and equipment reliability. The water supplier must monitor for contaminants, keep records and report results, notify the public and/or consumers when required, and obtain prior approval of plans and specifications.

The following sections contain some important excerpts from State Rules and are not meant to be all-inclusive. The operator is advised to read the actual Rule(s) and determine the specific applicability to the system being operated.

The State of Florida has adopted regulations that cover drinking water in Florida including the Safe Drinking Water Act requirements. These Florida Drinking Water Rules are found in the Florida Administrative Code and are outlined in Table 8 below: The operator should familiarize himself/herself with the Rules and Requirements found in these documents. A complete set of State Drinking Water Rules can be obtained from FDEP. Every operator should have a copy of these rules and be familiar with them.

Table 13

Drinking Water Rules
State of Florida

	Florida Administrative Code and adoption of CFR 40 Federal Regulations	Rule Coverage and Requirements
1	62-550 FAC	Drinking Water Standards, Monitoring and Reporting
	40 CFR 141, Subpart H, 7/1/03,	Filtration and Disinfection
2	40 CFR 141, Subpart I, 7/1/02,	Control of Lead and Copper in Drinking Water
3	40 CFR 141, Subpart L,1/16/01	Disinfection Residuals, Byproducts and Precursors
4	40 CFR 141, Subpart O, 12/09/02	Consumer Confidence Reports
	40 CFR 141, Subpart P, 7/1/03,	Enhanced Filtration and Disinfection serving 10,000 people or more
	40 CFR 141, Subpart T, 7/1/03,	Enhanced Filtration and Disinfection serving less than 10,000 people
5	62-555 FAC	Permitting, Construction, Operation and Maintenance of Public Water Systems
6	62-560 FAC	Requirements of Public Water systems that are out of Compliance
7	62-699 FAC	Treatment Plant Classification and Staffing
8	62-602 FAC	Drinking Water and Domestic Wastewater Treatment Plant Operators
9	62-532 FAC	Well Permitting and Construction Requirements

Applicability of Florida Drinking Water Rules to Public Water Systems

The Florida's Drinking Water Rules apply to all public water supply systems. There are some added distinctions between community and non-community systems not found in the Safe Drinking Water Act. Florida's rules are essentially the same as the Federal Regulations, with few notable exceptions. The most notable is that Florida enforces MCLs for secondary standards. Some of the more important Florida Drinking Water Rules are detailed in the following sections.

Florida Drinking Water Standards for Monitoring and Reporting Considerations

The Florida SDWA regulations include maximum contaminant levels and other requirements for Public Water Systems are detailed in 11 separate tables. The Table below, identifies Florida Rule requirements for Public Water Systems:

Table 14

Florida Rule Requirements for Public Water Systems

Florida Rule Designation	Coverage Area
Table 1	MCLs for Inorganic Compounds
Table 2	Maximum Residual Disinfection Residuals
Table 3	MCLs for Disinfection Byproducts
Table 4	MCLs for Volatile Organic Contaminants
Table 5	MCLs for Synthetic Organic Contaminants
Table 6	Secondary Drinking Water Standards
Table 7	Monitoring Frequencies
Table 8	Initial or Routine Monitoring Frequencies
Table 9	Small System Compliance Technologies for Arsenic
Table 10	Small System Compliance for Radionuclides and Limitations to Use
Table 11	Compliance Technologies by System for Radionuclides

Selected Compounds Regulated under the Florida Drinking Water Rules

For a complete listing contaminants in the Florida Drinking Water Rules the operator should familiarize himself/herself with the complete list of contaminant listed in the Tables listed above. The regulated compounds that follow are referenced in other parts of this Manual. These contaminants are included here for quick reference. Excerpts from Table 1 through Table 6, Florida Drinking Water Rules have been included:

Table 15

Excepts from Florida Drinking Water Rules Published in FAC - Tables 1 through Table 6

Some Common Inorganic Contaminants and their Maximum Contaminant Levels (MCLs)

Contaminant	MCL (mg/l)
Arsenic	0.010
Asbestos	7 MFL
Fluoride	4.0
Mercury	0.002
Nitrate	10
Nitrite	1
Total Nitrate and Nitrite	10
Sodium	160

Some Common Organic Contaminants and their Maximum Contaminant Levels (MCLs)

Contaminant	MCL (mg/l)
Alachlor	0.002
Atrazine	0.003
Chlorodane	0.002
Diquat	0.020
Lindane	0.0002

Maximum Residual Disinfection Levels (MRDLs)

Contaminant	MRDL (mg/l)
Chlorine	4.0 (as Cl2)
Chloramines	4.0 (as Cl2)
Chlorine Dioxide	0.80 (as Cl2)

Secondary Drinking Water Standards

Contaminant	MCL (mg/l) (except as noted)
Aluminum	0.2
Chloride	250
Copper	1
Fluoride	2.0
Iron	0.30
Manganese	0.05
Silver	0.1
Sulfate	250
Zinc	5
Color	15 Color Units (MCL advisory only)
Odor	3 Threshold Odor Number (MCL advisory only)
pH	6.5 to 8.5 (MCL advisory only)
TDS	500
Foaming Agents	0.5

Action Levels for Lead and Copper (ALs)

Contaminant	MCL (mg/l)
Lead	0.015
Copper	1.3

The Action Levels are exceeded if 10% of the tap water samples collected in a monitoring period exceed these levels

Many of the contaminants listed above can be found in a natural, urban or agricultural environment. Some of the contaminants such as disinfectants and fluoride compounds are added in the water treatment process by the operator. Many water treatment systems require the adjustment of pH. Some water systems have connections that contain lead solder or have used asbestos pipe in their water system affected by pH adjustment. The operator must be knowledgeable about the sources of contaminants, how contaminants can be affected, reduced or removed with the chemical process adjustments used.

Florida Monitoring Requirements for Public Water Systems

Some excerpts from Florida Drinking Water Rules that describe the majority of Public Water Systems have been included here. The operator is referred to the State Drinking Water Rules for a complete listing.

Public Water Systems (PWS) are on a nine-year compliance cycle. Each compliance cycle is broken down into three three-year compliance periods. The first compliance periods that make up the first compliance cycle begin January 1, 1993, January 1, 1996, and January 1, 1999.

Systems that monitor for a contaminate annually can do so at any time during the year, except that samples taken in consecutive years shall be taken at least 90 days apart. Systems that monitor for a contaminate quarterly may do so at any time during the quarter, except that samples taken in consecutive quarters shall be taken at least 30 days apart.

Systems that monitor for a contaminant every three years must adhere to the following schedule:

1. Community water systems, which serve more than 3,300 persons, shall monitor during the first year of each compliance period.
2. Community water systems, which serve 3,300 or fewer persons, shall monitor during the second year of each compliance period.
3. Non-transient non-community water systems shall monitor during the third year of each compliance period.
4. Systems that monitor for a contaminant every nine years shall monitor as directed by the Department.
5. Systems that monitor for a contaminant every nine years shall monitor during the first three-year compliance period of each nine-year compliance cycle.

Initial or Routine Monitoring Requirements for Public Water Systems are found in Table 8 of the Florida Drinking Water Rules.

Florida Disinfection Requirements

All suppliers of water shall provide continuous disinfection of the drinking water they distribute.
All suppliers of water are required to maintain a minimum free chlorine residual of 0.20 mg/l or a minimum combined chlorine residual of 0.60 mg/l or an equivalent chlorine dioxide residual throughout their water distribution system at all times.

Florida Requirement for Confirmation Samples that Exceed MCLs for Nitrogen Compounds

A system shall take confirmation samples whenever a sample exceeds the maximum contaminate level for nitrate or nitrite(10 mg/l for nitrate and 1 mg/l for nitrite) or whenever an unregulated contaminate is detected. However a system may take confirmation samples for other contaminates. If confirmation samples are taken, the results shall be averaged with the first sample results and the average used for the compliance determination. Confirmation samples shall be collected at the same sampling point as soon as possible after the initial sample was taken, but not to exceed two weeks.

Florida Microbiological Monitoring Requirements

All public water systems are required to analyze for coliform bacteria . Public water systems are required to collect total coliform samples at sites that are representative of water throughout the distribution system and in accordance with a written sampling plan that addresses location, timing, frequency and rotation period. These plans shall be available for review and possible revision on the occasion of a sanitary survey. Descriptions of sampling locations shall be specific, i.e. numbered street addresses or lot numbers. Pressure tank and plant samples are not acceptable for determining compliance.

Coliform monitoring is done on a confirmation basis. When coliform bacteria are detected samples must be retaken and analyzed for the presence of fecal coliform. Samples must continue to be taken until the problem is corrected.

Total coliform samples shall be taken at regular intervals and in numbers proportionate to the population served by the system. The following are excerpts from the Florida Drinking Water Rules. The operator is advised to consult the actual Rules to determining the specifics for each water system.

Community water systems, non-transient non-community water systems, transient non-community water systems that are Subpart H systems (those with a surface water source or under the direct influence of surface water) and transient non-community water systems that serve more than 1,000 persons per day during any one month shall take monthly distribution system samples. Those transient non-community that serve less than 100 shall sample two times per calendar quarter. In addition systems that are using groundwater not under the direct influence of surface water shall take a minimum of one monthly raw water sample that is representative of each groundwater source (i.e. well) not under the direct influence of surface water.

If a routine distribution sample is total coliform positive, the public water system shall disinfect and bacteriologically survey the relevant well(s) in accordance with FDEP instructions.

If a coliform sample is positive, the water provider is required to perform repeat monitoring as described below:

(a) if a routine sample is total coliform-positive, the public water system shall collect a set of repeat samples within 24 hours of being notified of the positive result. The system shall collect all repeat samples on the same day. A system that collects monthly routine samples shall collect no fewer than three repeat samples for each total coliform-positive sample found. A transient non-community water system shall collect no fewer than four repeat samples for each total coliform-positive sample found.

(b) The system shall collect at least one repeat sample from the sampling tap where the original total coliform-positive sample was taken, at least one repeat sample at a tap within five service connections upstream of the original sampling site, and at least one repeat sample at a tap five service connections downstream of the original sampling site. If a total coliform-positive sample is at the end of the distribution system, the system need not collect the repeat sample upstream or downstream of the original sampling site.

(c) If any routine or repeat sample is total coliform-positive, the system shall analyze that culture to determine if fecal coliform are present or if E. coli is present. If fecal coliform or E. coli are present in the routine or repeat sample, the system shall notify the Department by the end of the day when the system is notified of the test result, unless the system is notified of the result after the Department office is closed, in which case the system shall notify the Department before the end of the next business day and shall notify the public in accordance with the public notification requirements

Florida Reporting Requirements for Public Water Systems that Exceed MCLs

A system that exceeds a MCL shall notify the Department within 48 hours of receiving the results (except for microbiological and nitrate, which is 24 hours), begin monitoring quarterly in the next quarter after the violation occurred, and notify the water supplier must notify the customers affected.

Suppliers of water shall report to the appropriate District office of the Department or Approved County Public Health Unit the results of the test measurement or analysis within the first ten days following the end of the required monitoring period as designated by the Department, or the first ten days following the month in which the sample results were received, whichever time is shortest. The supplier of water shall use the approved DEP computer format for reporting all water analysis results, available from the Department's Drinking Water Section, 2600 Blair Stone Road, Tallahassee, Florida 32399-2400. The supplier of water shall completely fill out the analysis forms in non-erasable ink. Table 16 summarizes the reporting requirements.

Table 16

Reporting Requirements for Public Water Systems

1	Facility Name and PWSID Number	Number assigned by FDEP and must be clearly written
2	Legal address and County where facility is located	
3	Collector's name, job title and business phone	
4	Date and time of collection (month, day and year and sampling time)	If the time exceeds appropriate holding time it will be rejected by FDEP
5	Type of water system	community, non-community, non-transient non-community, or other public water system.
6	Raw or Treated Water	If samples from both water types are included on the form, they shall be clearly labeled
7	Sample type	The sample form shall clearly show if the sample was taken for compliance, recheck, main clearance, well survey, inter-agency agreement, or other purposes. If "other" is marked, the purpose for taking the sample shall be stated (e.g., complaint, quality control, special, etc.).
8	Sample location	Samples shall be taken at valid sampling locations as described in Rule 17-550.510(6), F.A.C. Legal addresses, or the best descriptions possible, shall be given for each sampling point

Florida Monitoring Reports Required for Water Treatment Systems

The operator is responsible for completing the monitoring reports and for the submittal within the established time frames to the Florida Department of Environmental Protection. These requirements should be well understood by the operator.

Table 17 lists the major categories for the various timeline requirements for reporting to the Department of Environmental Protection for public water providers. This table identifies major reporting requirements and the operator is advised to consult the Florida Drinking Water Rules for actual application to a specific water system.

Table 17

Timelines for Reporting to the Department for Public Water Systems

1	Monthly Operation Reports for a public water system	Supplier of water or certified lead operator must submit to the appropriate Department District Office or the appropriate approved County Public Health Unit within 15 days after the month of operation.
2	Failure to comply with any drinking water rule	Supplier of water shall report to the appropriate District Office of the Department within 48 hours and when compliance is achieved, the measures taken shall be reported to that office.
3	Report analytical results to the Department in cases where a Department of Health and Rehabilitative Services laboratory performs the analysis and reports the results to the Department.	Not required to report
4	Analytical Results rejected by the Department	The Department District Office or Approved County Public Health Unit shall reject invalid analytical results and return the forms to the supplier of water within 7 days. The supplier of water shall then resubmit the analysis form with the corrected information within 5 days
5	Copies of any written reports, summaries, or communications relating to sanitary surveys of the system conducted by the system itself, by a private consultant, or by any local or Federal agency	Suppliers of water shall submit to the appropriate Department District Office or the appropriate Approved County Public Health Unit within 15 days of receipt by the supplier of water of the information.
6	Public Notification Requirement(s)	Suppliers of water shall within ten days of completion of public notifications submit to the Department a representative copy of each type of notice distributed, published, posted, and made available to the persons served by the system and the media.
7	Copies of any records required to be maintained under Rule 62-550.720, F.A.C. or copies of any document, which the Department is entitled to inspect.	Upon request, the supplier of water shall submit to the Department within the time stated in the request,

Consumer Confidence Reports

Each community water system must supply to its customers annually a Consumer Confidence Report. The report must provide information on the source of the water delivered, identify the type of water, e.g., surface water or ground water and the location of the water used.

The report must also contain information on sources of contamination if the information is available and the system's susceptibility to potential sources of contamination. It must be made available to all customers of the water system.

Table 18 is the minimum water quality information from the community water system that must be included per EPA requirements in the report. The Florida Drinking Water Rules include different and more stringent MCL's for secondary standards, some regulated organic contaminants, different monitoring locations requirements, additional language for health affects of some contaminants and reporting of Drinking Water violations.

Table 18

Information to be included in a Consumer Confidence Report

1	Definitions	Maximum Contaminant Levels (MCLs) Maximum Contaminant Levels Goals (MCLGs)
2	Additional Definitions if Applicable to the Community Water System	Action Level Maximum Residual Disinfection Level (MRDL) Maximum Residual Disinfection Level Goal (MRDLG)
3	Information on Detected Contaminants	Regulated Contaminants Unregulated Contaminants Disinfection Byproducts (DBP)
4	Information on Cryptosporidium, Radon and other Contaminants	Results of Sampling and the significance to Public Health
5.	Compliance with National Primary Drinking Water Regulations (NPDWR)	Report any violations that may have occurred and the significance Filtration and Disinfection (Subpart H) and Lead and Copper (Subpart I), Acrylamide and Epichlorodrin (Subpart K)
6	If there are any Variances and Exemptions	Treatment Techniques Used
7.	Additional Information which may reasonably be expected to be found in drinking water	Microbial Contaminants Inorganic Contaminants Pesticides and Herbicides Organic Chemical Contaminants Radioactive Contaminants
8	Required Additional Information	Explanation for immuno-compromized persons Information on Arsenic above 0.01 mg/l if present Information on Nitrate above 5mg/l if present

Sanitary Survey Requirements

For all public water systems using surface water or under the direct influence of surface water regardless of population, FDEP conducts a sanitary survey every 3 years for community water systems and every 5 years for non-community water systems. The purpose of a sanitary survey is to evaluate the adequacy of a water system to produce and distribute safe drinking water and remain in compliance with the SDWA. The sanitary survey includes an on-site review of the water source and the adequacy of the water treatment facilities, equipment, operation, maintenance and monitoring required ensuring compliance with the SDWA..

Turbidity and microbiological contaminants are of particular interest to the sanitary surveyor. The surveyor may be involved in evaluating the water supplier's methods for monitoring turbidity and free chlorine residual. Monitoring requirements were also established with respect to frequency of sampling, analytical procedures, and record maintenance of test results. A review of these records could provide valuable information for determining expected water quality.   The information from the survey can point out problem areas and identify trends in water quality that can be corrected.

Well Requirements for Public Water Systems

Construction of Drinking Water Wells

To reach the ground waters underlying the earth's surface, a well must be constructed to penetrate the desired water-bearing strata. These structures may be dug, driven, bored, jetted, or drilled, depending on the geological formations through which they must pass and the depth to which they must reach. Dug, driven, bored, and jetted wells are usually confined to relatively soft soils overlaying rock and to shallow depths normally less than 50 feet. Shallow wells should not be constructed or used as public water sources unless specifically approved by the Department of Environmental Protection.

Wells for public water consumption are generally drilled to several hundred feet into aquifer formation. When they are present, the wells are drilled below strata with impermeable characteristics called confining layers. These layers have high permeability, which protect the lower aquifer from surface contamination. Drilled wells may be used in both soft and hard soil and in rock

The operator needs to have a good understanding of the effect of using wells or combinations of wells to pump ground water. The terms in Table 19 describe the various aspects of wells and their use in a water supply system.

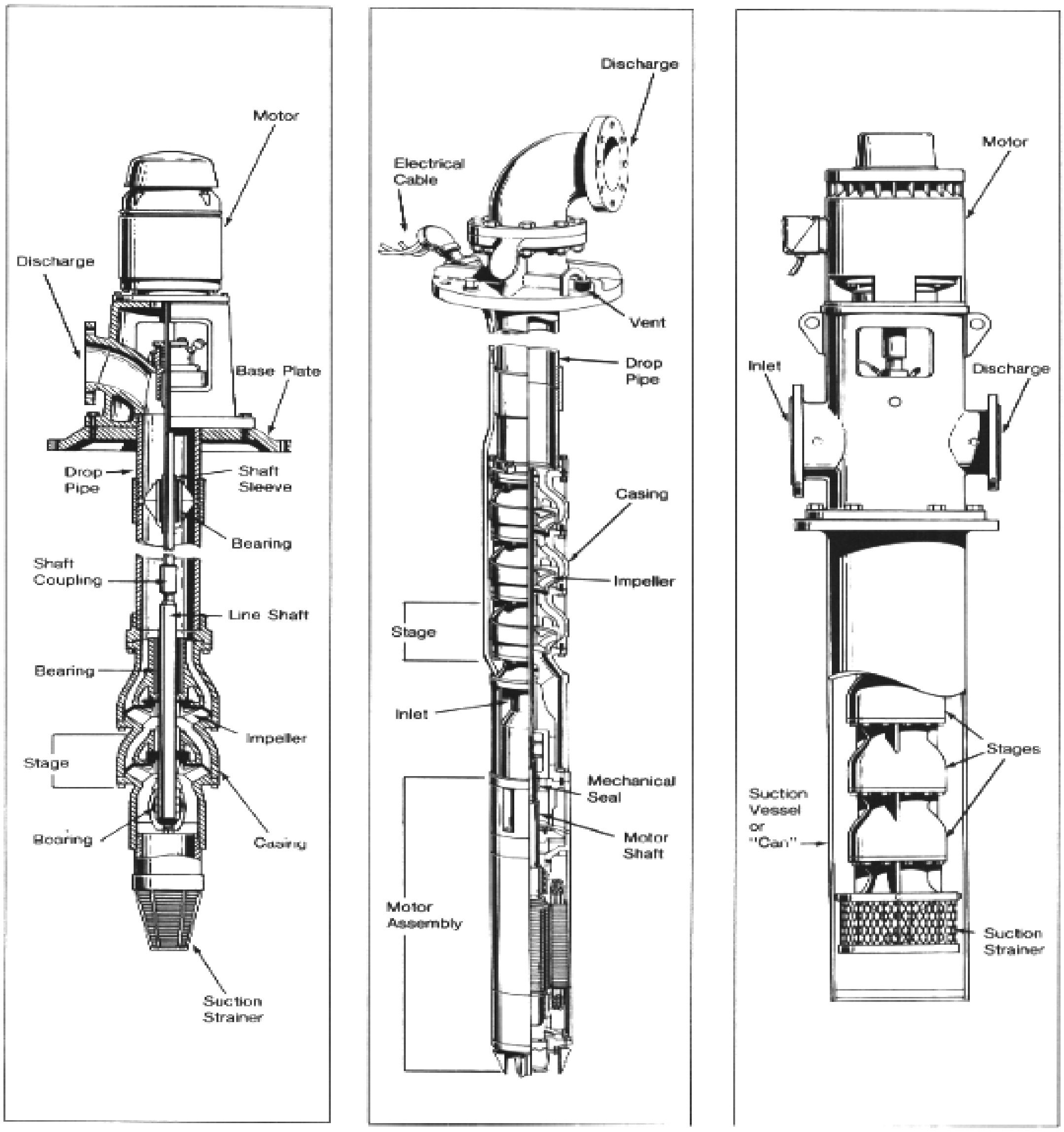
Table 19

Terms Related to Pumping Water from and Aquifer

Well or Well Pump Term	**Definition**
Static Water Level	The vertical distance in feet from the centerline of the pump discharge at the surface to the water table when no water is being pumped
Dynamic or Pumping Water Level	The vertical distance in feet from the centerline of the pump discharge at the surface to the water in the well when water is being pumped
Drawdown	The difference between the Static Water Level and the Pumping Water Level
Cone of Influence	The depression in water table roughly conical in shape caused by the pumping of water from a well
Discharge Head	The pressure in feet measured at the centerline of the pump discharge
Total Pumping Head	The head above the pump discharge and the lift below the pump discharge plus friction losses in the pipe and fittings
Total Dynamic Head	The pumping head plus the column friction losses
Capacity	The rate of flow at the pump discharge measured in gallons per minute

Drilled wells can be constructed in all instances where driven and jetted wells might otherwise be used and in many areas where dug and bored wells are constructed. The larger diameter of a drilled well, as compared with a driven or jetted well, permits use of larger pumping equipment that can develop the full capacity of the aquifer.

Well pumps are designed depending on the requirements such as depth to groundwater (pumping head) and water demand requirements. Three typical well pumps combination types used for public supplies follow.



Vertical turbine **Submersible** **Turbine Booster**

Figure 3
Well Pump Configurations

Applications of Well Pumps

The vertical turbine well pump is typically used for larger water systems. The motor is mounted on top of the unit and a long shaft provides the driving power. Pumps are stacked in stages to provide additive pumping head at a specific flow rate.

Submersible well pumps contain the motor inside a drop pipe and these wells are used for small and intermediate applications in public water systems. The turbine booster is used for small and shallow water supplies.

Parts of a Well System

Prior to the construction of a well the area must be surveyed to ensure that the well is safe from surface and underground sources of contamination. There are various components of a well, once constructed that cannot be observed by the original sanitary surveyor. To ensure long term safe operation of a well the various parts of the well must be protected. These protections are shown in Table 20 below.

Table 20

Parts of a Well and their Function

Well Casing	Well casings are installed in wells to prevent the collapse of the walls of the borehole, to exclude pollutants (either surface or subsurface) from entering the water source, and to provide a column of stored water to the well pump.
Sealing Materials	Cement grout or bentonite clay is used to fill the annular open space left around the outside of the well casing during construction to prevent undesirable water and contamination front entering the well.
Well Screen	Well screens are installed at the intake point of the well to hold back unstable aquifer material, supports the water bearing formation and permit free flow of water into the well.
Well Head Covers or Seals	Well seals are used at the top of the casing or pipe sleeve connections to prevent contaminated water or other material from entering the well
Well Column	The Well Column connects to the bottom of the pump discharge to the top of the pump bowl and delivers the water under pressure to the surface; also keeps the line shaft enclosed and aligned
Spacing from Potential Contaminants	Public drinking water supply wells serving systems with over 2,000 gallons of flow a day must be no closer than:
Separation Requirements for Wells	200 feet from septic tanks
	100 feet from septic tanks for less than 2000 gpd
	500 feet from land application areas for reclaimed water
	300 feet from wastewater storage and treatment areas

Well Maintenance Problems

Well maintenance problems are generally one of three types: 1. over pumping and lowering of the water table decreasing water production, 2. clogging or collapse of a well screen or perforated section, 3. corrosion or incrustation. Over pumping a well can damage the well by reducing the storage and consolidating the aquifer leading to reduced capacity of the well. When a well pumps air water cascades down the around the casing and can cause collapse of the borehole or permanent damage to the aquifer.

The deposits that develop on well screens can be identified and can be treated using acid or chlorine treatment depending on the type of problem encountered. Hard cement like deposits are typically carbonate and sulfates of calcium and magnesium and must be treated with hydrochloric (muriatic) or sulfuric acid. The sludge like forms is generally caused by iron and manganese hydroxide and the gelatinous slimes are caused by iron bacteria. These can be effectively treated with chlorine.

Sand in wells is another problem prevalent in unconsolidated formations. Some sand is transported and can be removed with a sand separator. Generally sand production between 0.1 to 0.3 cubic feet per million gallons of pumped water is considered acceptable. Since sand eventually will end up in water mains, a distribution system flushing program is recommended.

Bacteriological Contamination of the well can be caused by a number of reasons. The well may be contaminated from surface water entering and moving through the aquifer or from flooding from the surface. Other causes can be the failure of the casing pipe. In all cases check the well for obvious signs of component failure. This might entail taking the well out of service and inspecting the well casing with a video camera that is sent down the borehole.

Well Disinfection

To disinfect a well, a strong solution of calcium hypochlorite (HTH) containing 100 mg/l of concentrated solution to 70% available chlorine should be used. You may also use sodium hypochlorite (chlorine bleach), which is a 5.25% solution. The solution should be added gradually and only non-metallic containers used.

After a minimum of 24 hours, flush the chlorine solution from the well until no chlorine is detected at the untreated water sample tap. Use your test kit to be sure, do not go by smell. Additional bacteriological samples (minimum of 2 consecutive days) should be taken as instructed by FDEP.

Well Siting Requirements for Water Sources

The location of a water system is of primary importance in ensuring safe water. The Florida Drinking Water Rules encourage the avoidance of hazardous locations when constructing new or expanding public water systems.

Florida Drinking Water Rules requires that the source of water be obtained from the most desirable source that is available, and an effort shall be made to prevent or control contamination of the source. Additionally, the plant site area must not be subject to a significant risk from earthquakes, floods, fires, or other disasters, which could cause a breakdown of the public water.

Well Abandonment Requirments

An unsealed, abandoned well is a potential hazard to the ground water. It is therefore a necessary precaution to seal the well.

To properly abandon a well, the owner must obtain a permit from the appropriate Water Management District. All wells not being used should be properly abandoned in order to protect our groundwater. Simply capping the top of the casing is prohibited by law. The proper way to abandon a well is to plug it from bottom to top with approved cement grout.

Well Head and Well Head Protection Considerations

The 1986 amendments to the SDWA set minimum requirements for protection of wellhead (well field) areas used for public water supply. Wellhead protection program follows a series of systematic steps that require public participation to protect the community's water source. The general requirements for such a program are shown in Table 21.

Table 21

General Requirements for a Well Head Protection Program

Step	Activity
1	Obtain Community Involvement and support for protecting the well head area
2	Collect existing data including the community geology, hydrology, water supplies and at risk water supplies. At risk water supplies include locations of underground storage tanks, septic tanks, private and public wells that may provide contamination conduits and regulations that are in place that provide water source protection
3	Collect additional data and conduct surveys of the well head area
4	Determine what land uses present a threat to groundwater quality
5	Analyze the data and hydrogeology
6	Test for contaminants
7	Set well head protection zones from certain activities
8	Obtain public support and implement new well head protection regulations

Water Storage Systems

Types of Water Storage Tanks

Water storage tanks are either elevated or at ground level. Ground level storage reservoirs require pumps to re-pressurize the water to the distribution system. Smaller hydropneumatic tanks may use air to pressurize the water that is delivered to the system. Elevated or gravity tanks store pumping energy and are typically designed to deliver system pressure.

Gravity Water Storage Tanks

Operation of Gravity Water Storage Tanks

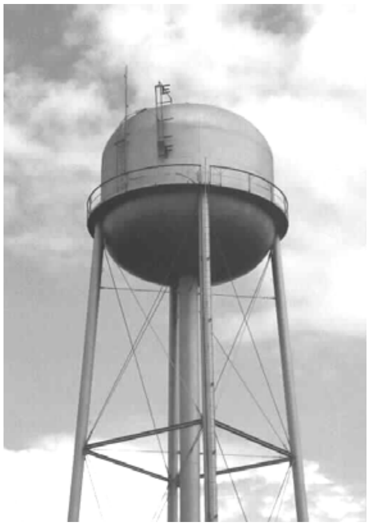


Figure 4
Gravity Storage Tank

Well supplies are often pumped directly to a gravity storage tank where water flows on demand to the water distribution system. The wells may also be pumped directly into the distribution system with the tank floating, or "riding" on the system. Either arrangement is acceptable. The pumps may be controlled by water level float controls or pressure switches. The storage tank is sufficiently elevated to ensure adequate operating pressures. Elevated storage tanks are generally used for larger water systems since water must be turned over or used to prevent loss of chlorine residual caused by long detention times. Hydropneumatic tanks serve the same storage purpose and are used for smaller installations because of water demand and cost concerns.

An elevated or gravity storage system offers several advantages over other (e.g., hydropneumatic) systems and should be considered where topographic conditions are favorable. The larger the water system, the greater the advantages in using an elevated or gravity storage tank.

Smaller water systems can benefit in using a gravity water storage tank. Because a gravity tank can store a significant amount of water compared to a A hydropneumatic tank, it offers some significant advantages.

Table 22

Advantages Provided by Gravity Storage Tanks

1. Less variation in pressure
2. Storage for fire fighting use
3. Greater storage to meet water requirement
4. Greater flexibility to meet peak demands
5. Use of lower capacity wells (pumping not necessary to meet peak system demand)
6. Sizing of pumps to take better advantage of electric load factors
7. Reduced on and off cycling of pumps
8. Tie-in of several wells, each pumping at its optimal rate

Meeting Peak Demands with Gravity Storage Tanks

Since the gravity reservoir provides the storage necessary to meet the peak system demands, the wells need not be developed to meet the peak system capacities, as is generally necessary with pressure tank systems. The wells should be capable of meeting the maximum day demand within the period of time when water use is significant. For example, day schools usually exert a significant water demand only over a 10- to 12-

hour day. The wells must, therefore, be pumped at a rate sufficient to meet the maximum day demand in a 10- to 12-hour period. Diurnal demands (daily peaks and low periods) also vary greatly. Generally water systems experience peak diurnal demands around lunch time in commercial areas and in the evening and early morning hours in residential areas. These conditions are exacerbated during irrigation seasons. To meet these varied conditions, the tank should have an effective capacity equivalent that approximates the average daily demand.

To reduce irrigation demands many water systems have incorporated water conservation measures in their municipal ordinances. The ordinance typically encourages customer irrigation reductions through ever increasing rates for higher water consumption and limiting irrigation to periods that reduce evaporation.

Pressure Considerations for Elevated Water Storage Tanks

Gravity distribution reservoirs may be elevated tanks mounted on structural supports above ground, may be located partly below ground, or may be tanks placed on pads or cradles on the ground surface. Elevated tanks are necessary when high ground is not available within the service area. The operating water levels of the tank should be sufficiently above the distribution system to produce minimum operating pressures of 35 psi (about 81 feet of head) but preferably 50-75 psi (116 to 173 feet). Pressures should not exceed 100 psi (231 feet).

Prefabricated standpipes (a cylindrical water tank) and elevated tanks are readily available with a wide range of capacities. However, shallow reservoirs with large diameters are preferred over deep ones with smaller diameters. Tanks with larger diameters have more water per foot of drawdown and are thus less prone to pressure fluctuations. They are also less costly to build. Prestressed concrete tanks are quite popular, since they require less maintenance.

Sanitary Risks at Storage Tanks

Gravity storage and ground storage tanks require considerations for sanitary site conditions to keep the water in them free from contamination. Table 23 identifies some of these considerations.

Table 23

Sanitary Considerations at Storage Tank Sites

1. Keep surface runoff and underground drainage drain away from the storage structures

2. Keep the site protected against flooding. Storage reservoirs should be located above probable ground water levels. Surface runoff and underground drainage should be away from the structure. Provisions should be included to guard against the sanitary hazards related to location; groundwater levels, movements, and quality; character of soil; possibility of wastewater pollution; and overtopping by floods. Sites in ravines or low areas subject to periodic flooding should be avoided.

   All storage reservoirs should be protected against floodwaters or high water levels in any stream, lake, or other body of water. These reservoirs should be placed above the high water level, and the structure and its related parts should be watertight. The ground surface above the reservoir should be graded to drain surface water away from the reservoir and to prevent pooling of surface water within the vicinity. Walls or fencing should surround open reservoirs, and public access should be prohibited.

3. Ensure that the storage tank is structurally sound**.** The operator should base the answer to this question on visual observation. Look for washouts and signs of foundation failure.

4. Keep overflow lines, air vents, drainage lines, or clean out pipes turned downward or covered, screened, and terminated a minimum of 3 diameters above the ground or storage tank surface. Any overflow, blow off, or clean out pipe from a storage reservoir should discharge freely into an open basin from a point not less than three diameters of the discharge pipe above the top or spill line of the open basin. All overflow, blow off, or cleanout pipes should be turned downward to prevent entrance of rain and should have removable #24-mesh screens to prevent the entrance of birds, insects, rodents, and contaminating materials. If the discharge pipes are likely to be submerged by surface or floodwater, a watertight blind flange should be provided to attach to the pipe opening to prevent contaminated water backflow into the reservoir. If the reservoir must be emptied when the normal outlet is submerged by surface or floodwaters, pumps with outlets above the floodwater should be used for emptying.

5. Ensure that surface coatings in contact with water are approved materials**.** Coatings that are in contact with water should be approved by the National Sanitation Foundation (NSF). Unauthorized coatings can create problems due to organic and inorganic contamination of the stored waters.

6. Ensure that the tank is protected against corrosion**.** Cathodic protection may be provided for metal storage tanks.

7. Tanks should be able to be taken out of the system for repair without shutting down entire system.

8. Periodically clean water storage tanks. Over a period of time, reservoirs may accumulate organic and inorganic debris, which settles to the bottom as a sludge. This sludge can contribute taste, odors, production of unwanted disinfection byproducts and turbidity to the systems if it accumulates to a depth approaching the outlet pipe. Periodic draining of the tank and cleaning is necessary. The tank should then be disinfected before reuse.

Requirements for Placing Storage Tanks in Service

New storage tanks or tanks taken out of service for maintenance must meet bacteriological requirements prior to being placed in service. To achieve bacteriological requirements the tank should be thoroughly cleaned and dosed with a 50 PPM chlorine solution for 24 hours.

The chlorine residual in the tank must then be reduced to below 4 PPM and two samples, each taken on a separate day and at least 6 hours apart must be analyzed for total residual chlorine and coliform. These tests must show at least 0.20 mg/l free chlorine or 0.60 mg/l of chloramines and zero coliform prior to placing the tank in service.

Hydropneumatic Tanks

Operation of Hydropneumatic Water Storage Tanks

Hydropneumatic systems are very common for use in storing and distributing small water supplies. They combine the energy from a pump with the principle of air pressure to force water into the distribution system. Understanding how the hydropneumatic system is susceptible to sanitary risks requires understanding basic system operation and the role of system components.

Principals of Operation for a Hydropneumatic Tank

The pump starts up at a certain pressure (cut-in pressure), and the energy from the pump moves through the water to the pocket of air at the top of the pressure 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. 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. Frequent starting and stopping of a pump will shorten its life.

Table 33 identifies the major components of a hydropneumatic tank.

Table 24

Typical Hydropneumatic System

Description	Purpose
Tank	Store water
Air volume control	Control air volume
Relief valve	Prevent excessively high pressure
Inlet piping	Allow flow of water into system
Pressure gauges	Monitor pressure
Motor controls	Control cut-in and cut-out points
High/low water level controls	Regulate water level
Low pressure or flow controls	Maintain balance between water and air pressure
Discharge piping/air	Discharge water from tank; force additional air in to increase
Compressor	pressure (pre-pressurizing)

Most hydropneumatic systems differ only in the kind of pressure storage tank used. The pressure tank is a significant part of the system in that the methods of separating water and air and the tank size and placement vary. All these factors may contribute to the degree of vulnerability to sanitary risks. The three kinds of pneumatic tanks are and their configurations are provided in Table 25.

Table 25

Types and Configurations of Hydropneumatic Tanks

Conventional

Air cushion in direct contact with water; air volume controls necessary
Capacity ranges from a few to several thousand gallons
Vertical or horizontal placement
Outlet located near bottom of tank; combined inlet-outlet or separated on opposite sides of tank
Air volume control located in upper portion of tank; provisions available for pre-pressurizing

Floating Wafer

Floating wafer (rigid floats or flexible rubber or plastic) separates water and air, but separation not complete; some loss of air expected, requiring occasional recharging
Vertical placement limits tank capacity
Inlet and outlet combined at bottom of tank
Internal air check valve to prevent premature loss of air due to electric outage or excess water demand

Flexible Separators

Separator fastened around inside of tank for complete separation of air and water, either flexible diaphragm or bag type
Vertical placement limits tank capacity
Supercharged at factory to pressures just below pump starting pressure

Pressure Considerations for a Hydropneumatic Tank

Maintenance of adequate pressure is especially important in a hydropneumatic tank. Too little pressure can cause a reversal in the flow of the water, allowing water from a polluted source to enter a potable, stored water source. Too high pressure can strain system components, cause high leakage rates, and can force air out with water. Low pressure can indicate improper connections, or cross-connections, made from storage to serviced facilities. Adequate pressure is needed to keep the water flowing from storage to serviced areas.

Backpressure backflow occurs when potable water pressure is less than non-potable pressure; backsiphonage backflow is a reversal stemming from a vacuum at the potable supply. Backflow and backsiphonage are especially hazardous sanitary risks. Operators must be aware of proximity of polluted sources and must protect stored water against cross-connections.

To ensure against backflow and backsiphonage, minimum pressure must be maintained at all times. Table 26 illustrates recommended water system pressures that should be maintained by the operator

Table 26
Recommended Water System Operating Pressures.

System Pressure Definitions	Recommended Pressure
Optimum Working Pressure	40-60 psi
Minimum Working Pressure	35 psi
Minimum Pressure at Service Connections	20 psi
Maximum Pressure at Service Connections	100 psi

Operators should check system pressures to assess potential hazards in the water of facilities served by the system. Pressures must be adequate at the meter side of the service connections. The operator may find that a small pressure gauge can be very helpful for spot checks of pressure at the tank and throughout the distribution system.

Proper operation and maintenance of the storage system is also essential. Failure to adjust gauges and controls properly can lead to inadequate pressure and/or inadequate supplies of water. Also, contamination of the storage tank can occur from airborne or waterborne foreign matter. Careful installation and maintenance of pollution prevention devices can prevent their entry into the hydropneumatic system.

To ensure proper operation and maintenance of the system, the following components must be routinely checked and adjusted for changes in the peak demand.

Figure 5
Hydropneumatic Tank

Table 27

Adjustments Necessary for
Proper Operation of Hydropneumatic Tank

1. Air volume control
2. Relief valve
3. Motor controls
4. High/low water level controls
5. Low pressure flow controls
6. Air compressor and controls

Frequently controls are not adjusted after delivery of the system from the factory. Operating records might reveal original calibration and whether peak demand has changed.

Inspection of Hydropneumatic Tank Structural Condition

The interior and exterior of a hydropneumatic tank should be in good physical condition. The operator may not be able to inspect the interior surfaces but should emphasize the importance of regular inspections. The operator may determine if they are being performed by reviewing maintenance records, if they exist. The operator should also ensure that the tank supports and foundation slab of the tank are sound.

Sizing Hydropneumatic Tanks

There are several formulas for determining the required size of a hydropneumatic tank capacity to meet water system storage demands. .

In selecting and evaluating the tank, storage capacity must be matched to the peak demand (period of highest water use) of the system. Otherwise, the tank will supply neither sufficient daily water needs nor emergency needs, such as for firefighting.

To ensure against inadequate storage capacity (and straining facilities at peak demand), operators must know pumping capacity and peak demand rates, which can be used in the formula below to compute appropriate tank size. Engineering records should list pump capacity, cut-in, and cutout pressures. Operating records show current peak demand and whether peak demand has changed since the tank was installed, which could require a change in tank size. The following formula is used to size hydropneumatic tanks for water systems.

Formula for Estimating Appropriate Tank Size

$$Q = \frac{Qm}{l-(P1/P2)}$$

Q = Tank volume in gallons
Qm = Peak demand rate, gpm x desired minutes of storage
$P1$ = Cut-in pressure + atmospheric pressure (14.7 psi)
$P2$ = Cut-out pressure + atmospheric pressure (14.7 psi)

The pressure pump should not cycle frequently (6 to 8 cycles/hour is generally considered acceptable). Frequent or constant operation of the pressure pump can indicate a “waterlogged” tank or improper settings

When a pressure tank is “water logged” the pump will build up to cut-off pressure, stop, and a very short time later start up again. This cycle will continue over and over, eventually causing damage to the pump. If a pressure gauge is installed on the system, the gauge will show a steady drop in pressure, even though no water is leaving the water plant.

To remedy this problem it is necessary to drain and refill the pressure tank. Table 28 provides the proper procedures for draining and refilling a hydropneumatic tank.

Table 28

Steps for Draining and Refilling a Pressure Tank

1. Notify the customers that the water will be shut-off.
2. Close the pump discharge valve.
3. Turn off the pump.
4. Open the tank drain valve and drain the water from the tank.
5. When the tank is empty, close the drain valve.
6. If the pressure tank is a bladder tank, use a tire gauge to take a pressure reading from the air fill/bleed valve. The reading should be around 15 psi.
7. Turn the pump on, open the discharge valve, and fill the tank.
8. If the pressure can not be maintained, shut down the tank and determine the cause.

Always check the tanks for leaks and make any necessary repairs. A pressurized vessel with a leak is extremely dangerous.

If using a bladder tank, it may be necessary to replace the tank if the bladder has been ruptured.

If customers complain about milky water or air bubbles in the water lines, and the water system consists only of a well, pump, hypochlorinator, and pressure tank, you should check to see that the air-volume control valve on the pressure tank is working properly. It should be replaced if necessary and the pressure tank checked frequently.

Air Charging Hydropneumatic Tanks

Two methods are used to add air to a hydropneumatic tank: 1. using the air in the well column as the pump comes on, and 2. automatically adding the air with the hydraulic type or use of an air compressor. Since many systems use air compressors, some considerations for their use follow.

Air Compressors

Air compressors are commonly used in water treatment plants to control pump systems, valve operators and water pressure tanks.

Each air compressor is different and the operator should follow the guidelines given by that particular manufacturer for its care and maintenance.

Some common maintenance procedures are indicated in Table 29.

Table 29

Suggested Maintenance Procedures for an Air Compressor

1. The compressor should be serviced at least twice each year.
2. The condensate must be drained from the air receiver daily to insure satisfactory operation of the compressor. There is usually a small valve located at the bottom of the air receiver for this purpose. If the unit has an automatic drain valve, it should be inspected each day to be sure it is working properly.
3. Filters. Inspect the suction filter of the compressor at least every month. The frequency of cleaning of this filter depends upon the use of the compressor and the atmosphere around it. Under normal operation, it should be cleaned or replaced every three to six months.
4. Paper filters must be replaced when dirty. The cloth type filters can be washed with soap and water, dried, and reused; it is recommended that a spare filter be kept on hand so that one can be used while the other is being cleaned. Wire mesh and Oil bath filters can be cleaned with a standard solvent, re-oiled or oil bath filled and used again.
5. Never operate a compressor without the filter in place, this can allow dirt or foreign objects to build up on the mechanical parts and cause damage and unnecessary wear.
6. Lubrication. Most compressors require the bearings to be oiled. Often special oils or greases are required, consult manufacturers instructions prior to servicing. All oil reservoirs or greased fittings should be checked daily and reservoirs kept full to insure the proper lubrication of the equipment.
7. The oil should be changed every three months unless the manufacturer instructions state differently. Any oil filters should also be changed.
8. The cylinder and casing fins should be cleaned or vacuumed off weekly to allow proper cooling of the compressor.
9. Unloader. An unloader allows the compressor to start in a no load condition, allowing less strain on the equipment. If it is not working properly, the compressor will stall when starting, not start, or if belt driven, burn off the belts.
10. Check the operating controls. Be sure it is starting and stopping at the correct pressures and adjust as necessary.
11. Test safety valves every week. These are usually located on the air receiver or storage tank, and prevent the air pressure from building up beyond a specified point by venting to the atmosphere. Some compressors also have high pressure cut off switches, low oil pressure switches or high temperature cut off switches. The safety switch settings should be recorded and kept in the equipment file.
12. Inspect the belt tension. As a rule you should be able to press down about three-quarters of an inch at a point mid-way between the pulleys. Make Sure the Compressor is locked out before inspection. Do not over tighten belts.
13. Dirt and excess oil should be removed from the area and the compressor should be cleaned at least monthly.

Chlorination and Disinfection

Use of Chlorine in Water Treatment Systems

Chlorination refers to the application of chlorine to drinking water, Chlorine is a widely available chemical and has been used successfully for many years in water treatment systems. Table 30 identifies the major uses of chlorine in a water treatment plant.

Table 30

Uses of Chlorine in a Water Treatment Plant

1. Use as a Primary and Secondary Disinfectant
2. Removing Taste and Odors
3. Removing Slime Growths
4. Controlling Algae in Plant and in the Distribution System
5. Use as a Coagulant Aid

Purpose of Disinfection

Disinfection is the process of destroying a large portion of the microorganisms in water with the probability that all pathogenic bacteria are killed in the process. In water treatment, disinfection is almost always accomplished by adding chlorine or chlorine compounds. Other processes that may be encountered are ultraviolet disinfection and the use of ozone or chlorine dioxide.

The measure used to determine effectiveness of disinfection is the coliform group. The coliform group is used as an indicator of pathogenic organisms. The use of this indicator group has several advantages over testing for specific pathogenic organisms. Principally these advantages are:

1. Ease of isolation: Using relatively unsophisticated analytical procedures and equipment, the presence of coliform can be detected. The procedures can give results in 24 hours, making it a comparatively rapid bacteriological test.

2. Coliform are present in large numbers in feces of all animals: Any fecal pollution results in the presence of coliform organisms in sufficient quantities to determine the degree of pollution with fair accuracy.

3. Coliform are resistant to the forces of natural purification to a greater degree than commonly encountered pathogens. Consequently, the coliform will normally still be present after the disease-producing pathogens may have died off and will continue to indicate the possible danger to the water.

Chlorine added to the water reacts with compounds such as ammonia (NH_3) to form chloramines and organic material (measured by total organic carbon or TOC) to form chlororganics. Many chlororganics such as Trihalomethanes (THMs)and Haloacetic Acids (HAA5s), are health concerns and EPA has set Maximum Contaminant Levels (MCLs) concentrations to ensure public protection. Total THMs and HAA5s present after chlorination are called disinfection byproducts or DBPs.

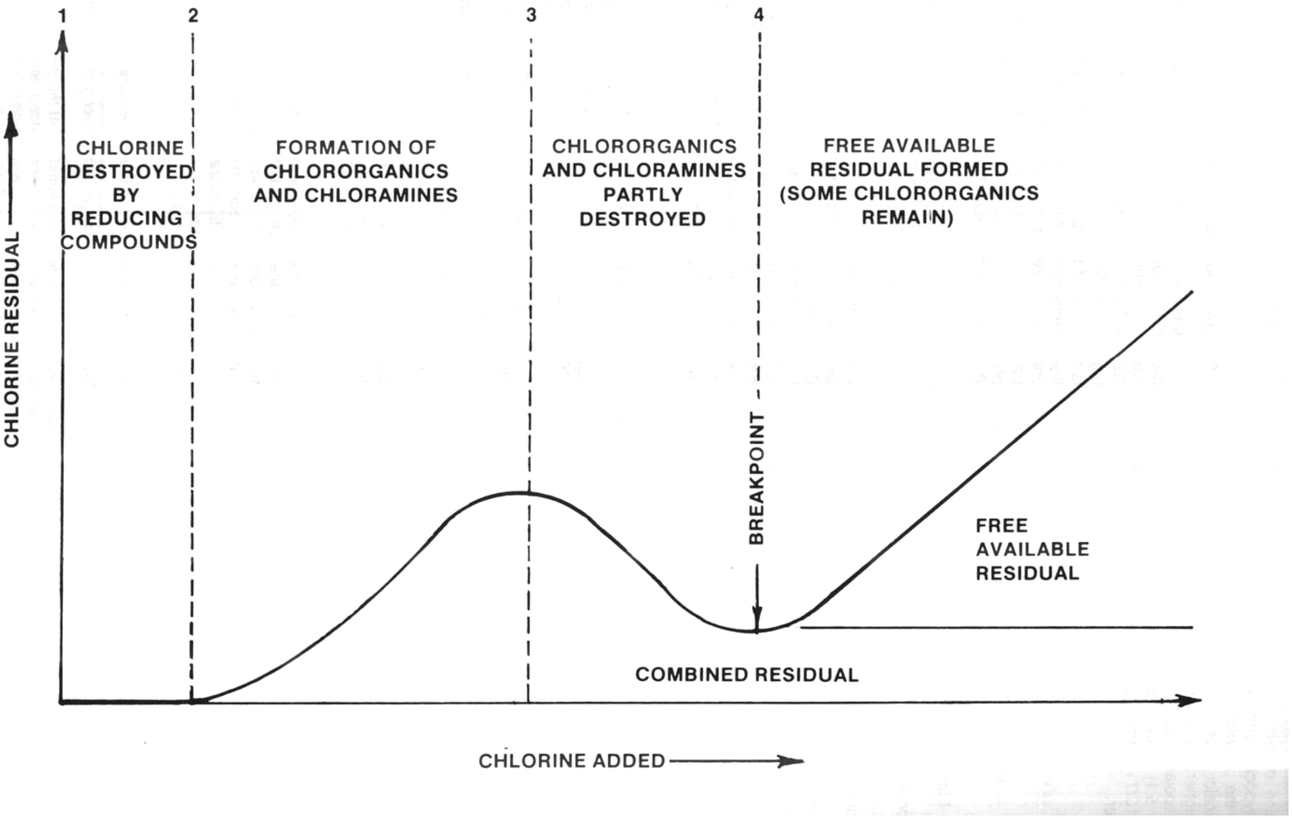


Figure 6
Breakpoint Chlorination Curve

Principles of Chlorination

Chlorination of water is accomplished by the addition of chlorine either as a gas or as chlorine in a liquid compound. Whether a gas or a liquid form, the reaction in water is basically the same.

The standard term for the chlorine concentration is either milligrams per liter (mg/l) or parts per million (ppm).

Figure 6 is a standard breakpoint chlorination curve. It describes the reactions that take place when chlorine is added to the water. To understand the disinfection process using chlorine, the operator must have an understanding of the concepts that follow.

Breakpoint Chlorination

Breakpoint chlorination is the name of the process of adding chlorine to water until the chlorine demand has been satisfied. Further additions of chlorine will result in free chlorine residual. Presence of free chlorine in the distribution system of 0.20 mg/l or 0.60 combined residual is required by the State drinking water rules.

Water being chlorinated, generally contains small amounts of manganese, iron, organic matter, and ammonia. When chlorine is added to the water, it reacts with (oxidizes) the manganese and iron first. There must be adequate chlorine to meet this "demand" or there will be no residual. As additional chlorine is added it reacts with the organics and ammonia present in the water and Chlororganics and Chloramines will form. The chloramines produce combined chlorine residual, a chlorine residual combined with other substances so it has lost some of its disinfecting strength. Combined residuals have a lower disinfecting power than free chlorine residual. However combined chlorine residuals are sometimes used for disinfection to prevent the formation chlororganics such as regulated disinfection byproducts (DBPs.) Some DBP and may cause tastes and odors and must be considered when using chloramines for disinfection.

By adding just a little more chlorine the chloramines are destroyed. Now any more chlorine that is added is free chlorine; free in the sense that it has not reacted with anything and is available to react with contaminants in the water .

Chemistry of Chlorine Addition to Water

When chlorine is added to the water several chemical reactions take place. Some involve the reactions with the water molecules themselves. It is important to have an understanding of these reactions and their significance in disinfection.

When chlorine is added to water, free chlorine combines with the water to form hypochlorous and hydrochloric acid. The hypochlorous acid (HOCL)is a weak acid and easily disassociates into the hydrogen (H+) ion and the hypochlorite ion (OCl-). Depending on the pH of the water both hypochlorous acid (HOCl) and the hypochlorite ion (OCl-) will be present. HOCl has much higher disinfection ability than OCl- .

In the chlorination process only hypochlorous acid (HOCl) and the hypochlorite ion (OCl-) have disinfecting ability.

At a pH of 7.3, the HOCl and the OCl- will be present in the same in the same amount. At lower pHs the HOCL will predominate and at higher pHs the OCl- will predominate. At pH 2, hypochlorous acid will be 100% and no hypochlorite ions will be present. This is why chlorine is more effective at lower pH.

Chlorine is a very effective reducing (oxidant) agent and will react with the hydrogen sulfide (H_2S), and the ions of Ferrous (FE++), Manganese (Mn++), and Nitrite (NO_2-).

Chemistry of Chlorine Addition to Water Containing Sulfur Compounds

Sulfur compounds are frequently found especially in groundwater used as a water source. Hydrogen Sulfide (rotten egg gas) and the mineral form hydrogen sulfate are both highly reactive with chlorine. It takes 2.08 times as much chlorine by weight (mg/l of chlorine for each mg/l of hydrogen sulfide) to oxidize hydrogen sulfide and 8.32 times more chlorine by weight to oxidize hydrogen sulfate. Even small amounts of these sulfur compounds in source water can exert significant demands on the added chlorine.

When chlorine reacts with hydrogen sulfide, elemental sulfur will precipitate and water and the chloride ions (Cl-) will form. Elemental sulfur (S) can be problematic since it can cause odors and precipitates as finely divided colloidal particles. The chloride ion Cl- that is formed has no disinfectant ability. Remember that only hypochlorous acid (HOCl) and the hypochlorite ion (OCl-) exert disinfectant ability.

When chlorine reacts with hydrogen sulfate, sulfuric and hydrochloric acid (HCL) is formed. The chloride ion (Cl^-) that forms has no disinfection ability.

Chemistry of Chlorine Addition to Water Containing Ammonia Compounds

When chlorine is added to water containing ammonia (NH_3), it reacts rapidly with the ammonia and forms chloramines. Chloramines are a weaker disinfectant than hypochlorous or hypochlorite ions. However, some utilities add ammonia to the chlorine to produce chloramines for disinfection. The optimal ratio of chlorine to ammonia by weight (mg/l Chlorine to mg/l Ammonia) is 3 parts chlorine to 1 part ammonia to produce monochloromines. Higher additions produce dichloromines, which produce taste and odor problems.

Chloramines provide a disinfectant while preventing chlorine from reacting with other organic materials (TOCs) and forming THMs. However it is always more effective to remove organics (precursors) that react with chlorine prior to disinfection and when not feasible to control the amount of prechlorination (for sulfide, iron or manganese removal) to eliminate any free available chlorine.

Care must be taken when using a DPD method for measuring free chlorine when chloramines are present because they impart a color that can be mistaken for free chlorine.

Chloramines residuals in the distribution system must be monitored in the distribution system because of the tendency for nitrification in warmer months. Controls include tight monitoring for evidence of changes in ammonia levels, combined chlorine levels, pH or nitrites in the distribution system. Some utilities develop strategies for increasing the chlorine to ammonia levels in warmer months and providing higher flush through times for water storage reservoirs and the distribution system or changing to free chlorine residual during the problematic times of year.

Chlorine Demand

Chlorine is a very active chemical oxidizing agent. When injected into water, it combines readily with certain inorganic substances which are oxidizable (hydrogen sulfide, nitrites, ferrous iron, etc.) and with organic impurities including microorganisms and their decay products. These reactions consume or use up some of the chlorine before it can fully destroy microorganisms. This amount used up is chlorine demand.

Chlorine Demand = Chlorine Dose - Chlorine Residual

Free Chlorine and Combined Chlorine Residual

Free Chlorine Residual is the amount of chlorine (by test) present in the water after the chlorine demand is satisfied. The presence of a “free” residual of at least 0.2 – 0.4 ppm in relatively unpolluted, low turbidity water) after the chlorine demand is satisfied, usually provides a high degree of assurance that the disinfection of the water is complete.

Chlorine can be either in the form of Combined Chlorine Residual (chloramines) or Free Chlorine Residual (accomplished by Breakpoint Chlorination.)

A free residual is much more reactive and provides some protection against any chance contamination which may inadvertently enter the system. Combined chlorine residual may be desirable when there are high levels of organic materials present that many form DBP when free chlorine is available. Combined chlorine residual will not remove slime growths, algae or color and is not as effective a disinfectant as Free Chlorine Residual.

The chlorine residual test sample is usually collected before the first point in the distribution system where water is consumed. However, it is also advisable to take the test at the furthest point in the system to insure that a residual exists throughout the whole system. The residual test is the basis for increasing or decreasing the chlorinator feed rate to achieve the desired value. Too much chlorine residual will be offensive to some consumers.

Chlorine Residual = Chlorine Dose - Chlorine Demand

Chlorine Contact Time

The Chlorine Contact time is the time interval (usually minutes) that elapses between the time when chlorine is added to the water and the time when that same slug of water passes by the sampling point. A certain minimum period of time is required for the disinfecting action to become completed. The minimum required time for disinfection depends on several factors as shown in Table 31.

Table 31

Factors Affecting Chlorine Contact Time Disinfection Efficiency

1. The chemical form of the available chlorine residual. “Free available chlorine” is faster acting than “combined chlorine.”
2. The magnitude of the residual – The higher the residual, the more active and faster the disinfection.
3. The pH of the water – The higher the pH, the longer the time required.
4. Water temperature – The lower the temperature, the longer the contact time required.

Types of Chlorination Equipment

There are two types of chlorination used to mix chlorine with the water. Hypochlorination equipment feeds a liquid chlorine solution that is mixed from dry chemical or comes in a premixed form (bleach) to the water to be treated. Chlorination equipment converts liquid chlorine from a tank to a gas, mixes the chlorine with feed water, and injects the chlorine solution into the water to be treated. The Hypochlorination method is used for smaller systems.

Hypochlorination

Chlorine compounds come in a variety of forms. They are readily available throughout the country because of their common household and swimming pool use. All forms of hypochlorite will raise the pH of the water. The following are the typical concentrations of commercially available hypochlorite.

Liquid chlorine solution of sodium hypochlorite (NaOCl), are available as 5.25% chlorine (common household chlorine bleach) and 15% solutions available in 5-gallon carboys and larger quantities.

1 gallon of 5.25% hypochlorite solution contains 0.42 lbs. Of available chlorine
1 gallon of 15% hypochlorite solution contains 1.25 lbs. Of available chlorine

The Chlorine solution mixes easily with water to make such water solutions of the desired strength.

Solid granular form as high-test calcium hypochlorite containing 65-70% available chlorine, commonly marketed as HTH, PitChlor, Perchloron, etc.

The dry forms of chlorine require mixing with water to make a stock solution of the desired strength. Mixing is somewhat tedious and precipitates of calcium salts in the stock solution and Chemical feeder requires regular maintenance. The dry forms can be stored for considerable periods in the original container, in cool dry places.

Chlorine Injection into Water

The water solutions of either the liquid or granular dry forms are prepared in predetermined stock strengths and are injected into the water supply using special chemical metering pumps called hypochlorinators.

Positive displacement hypochlorinators are highly accurate and reliable Positive displacement type hypochlorinators are readily available from water conditioner suppliers at relatively modest costs. These small chemical feed pumps are designed to pump (inject under pressure) an aqueous solution of chlorine into the water system. They are designed to operate against pressures as high as 100 psi but may also be used to inject chlorine solutions at atmosphere or negative head (suction side of water pump) conditions. In the latter cases, anti-siphon devices are necessary (usually built into the unit). Hypochlorinators come in various capacities ranging from 1.0 to 60 or more gallons per 24 hours. Most manufacturers make an intermediate range unit adjustable from 1 to about 24 gallons per 24 hours. This size is usually adequate for small systems.

Chlorine Injection Considerations

The pumping rate is usually manually adjusted by varying the stroke of the piston or diaphragm. Once the stroke is set, the hypochlorinator feeds accurately at that rate, maintaining a constant dose. This works effectively if the water supply rate is fairly constant, as with the output of a pump. If the water supply rate varies considerably, a metering device may be used to vary the hypochlorinator feed rate synchronized with the water rate. Where a well pump is used, the hypochlorinator is connected electrically with the on-off controls of the pump. If two or more wells are designed to operate independently, a hypochlorinator may be required for each pump output.

Where hypochlorinators are used, spare repair kits and a standby hypochlorinator should be available at all times. For systems larger serving 350 or more people or 150 connections this is a State requirement.

Hypochlorination Operation

Hypochlorination refers to chlorination of a water supply by use of a solution-metering pump (called a hypochlorinator), which applies a pre-mixed chlorine solution to the water being treated. The chlorine solution is prepared by mixing granular (calcium hypochlorite) or sodium hypochlorite with water in a container called a solution barrel.

Hypochlorination is practiced most commonly by small water supplies processing less than 100 gallon per minute flows from the source of supply when considering overall equipment and facility requirements and operator safety.

Hypochlorination Metering Pump Considerations

The typical solution-metering pump used in Hypochlorination of drinking water supplies has certain characteristics of which the operator should be aware.

Solution metering pumps – diaphragm type – can discharge or pump against a pressure up to only 100 psi. The manufacturer's specifications should always be reviewed when considering Hypochlorination installations. Utilizing a diaphragm pump when discharge pressures exceed 100 psi will result in inaccurate application and the hypochlorinator motor being "burned up."

Solution metering pumps (piston type) are capable of pumping against pressures exceeding 100 psi. Again, check your particular proposed application and the manufacturer's specifications for metering pumps.

It is a common mistake for the operator to assume that liquid flows continuously from the solution metering pump whenever it is "plugged in" and operating. The assumption is incorrect.

Solution metering pump functioning is comprised of two separate operations. These separate operations are the suction stroke and the discharge stroke, which occur independently and <u>not simultaneously</u>.

Discharge of liquid solution from the pump head does not occur during the suction stroke as liquid solution must first be drawn into the pump head before it can be discharged. Once solution is drawn into the pump head, the reverse action of the pump will only then discharge solution. Generally speaking, the solution metering pump works 50% of the time it is operating when considering discharge of liquid solution from the pump head.

An exception to this process con occur when pump discharge solution tubing is connected to a free flowing delivery point lower in elevation than the level of liquid in the solution barrel or connected to a water main at which point a siphonage action can occur and draw mixed solution through the pump head continuously.

To prevent any possibility of this occurrence, a solution-metering pump should be equipped with an anti-siphon device to prevent uncontrolled discharge of chlorine solution by siphonage.

Hypochlorination of Small Well Supplies

Initiating chlorination of small well water supplies is considered by many to be a simple process. However, there are several items to consider when initiating chlorination of a small water supply, which can create problems if any details are overlooked. A basic hypochlorination treatment system consists essentially of a hypochlorinator (solution metering pump), plastic solution barrel (NSF approved for potable water), hydropneumatic tank, well pump, and related accessories.

Hypochlorination Using Hydropneumatic Tanks

Many installations use a hydropneumatic tank in combination with a hypochlorinator. The hydropneumatic tank is commonly referred to as a pressure tank and provides pressurized water storage for the water. Water stored in the pressure tank permits a limited amount of water to be withdrawn from the system without activating the well pump.

The pressure tank is interconnected with the well pump electrical supply by a pressure switch mechanism, which automatically controls operation of the well pump. As water is withdrawn from the pressure tank, water pressure within the system drops. The pressure switch is pre-set such that when water pressure drops to a certain point, the well pump is automatically activated to again build pressure by pumping water into the system and pressure tank. When a pre-set pressure is reached, the well pump is automatically shut off by the pressure switch mechanism. These two controlling pressures are called cut-in and cutout pressure respectively.

Pressure tanks can be provided with separate incoming and outgoing piping and are commonly referred to as separate inlet-outlet pressure tanks.

Separate inlet-outlet pressure tanks can provide both mixing of chlorine with well water and chlorine contact time (depending on tank size and well pump capacity) when the chlorine injection point is located between the well pump and pressure tank.

A common inlet-outlet pressure tank is provided with only a single or common line through which water enters and exits the pressure tank. When water is withdrawn from the pressure tanks and the well pump is activated due to pressure drop (water emptying from the pressure tank), water can be pumped directly from the well to the distribution system. This occurrence can prohibit uniform mixing of chlorine solution with well water as the hypochlorinator injects chlorine solution only on the discharge stroke as noted previously. Thus a portion of water being pumped directly from the well contains no chlorine and another portion of water contains excessive chlorine.

Also, chlorine contact time is eliminated as water can travel directly to the free flowing outlet with continued withdrawal of water from the distribution system. This situation is remedied by providing a mixing tank with separate inlet-outlet piping prior to the common inlet outlet pressure tank. Chlorine solution is injected into the water line connecting the well pump and mixing tank.

Hypochlorinators and Well Considerations

The hypochlorinator must be “electrically wired” with the well pump such that when the well pump is activated, chlorine solution is injected into the water being pumped form the well to the pressure tank or mixing tank as appropriate.

When the well pump ceases operation, the hypochlorinator must cease operation to prevent excessive chlorine solution from being added to the water supply.

This is accomplished by electrically wiring the hypochlorinator with the well pump electrical system. It is extremely important that the installer note that the hypochlorinator electrical supply is normally 110V while the well pump motor electrical supply is usually 220V. Improper electrical connection or hookup can result in the hypochlorinator motor being “burned up” electrically.

Hypochlorinator Maintenance Considerations

Because hypochlorinators are subject to corrosive and scale forming conditions, they require significant maintenance to ensure reliability and proper dosing of chemical. Table 32 is a troubleshooting guide for hypochlorinators.

Table 32

Troubleshooting Guide for Hypochlorinator Problems

Problem	Possible Solution
Loss of pump prime	If the solution barrel is slowed to become empty or the suction line is removed from the solution barrel, “priming” is generally necessary.
	Refill the solution barrel and remove the discharge hose at the hypochlorinator pump head. Place the hypochlorinator into operation and expel all air from the pump head until continuing spurts of chlorine solution are observed, which is free of air bubbles. Reconnect the discharge hose and resume operation
	Sometimes, in extreme cases, it is necessary to remove the discharge valve in the pump head and pour water into the pump head. Priming is initiated by placing the thumb lightly over the valve opening until liquid is again drawn into the pump head and discharges. Reinstall the discharge valve and allow it to operate until all air bubbles are gone. Reinstall discharge hose and initiate operation.
Build-up of calcium carbonate on valves and valve seats	Periodic removal and cleaning of the suction and discharge valve seats, and O-rings is needed for proper hypochlorinator operation. Cleaning of these parts is best performed by soaking parts in muriatic acid followed by cleaning with a soft bristle brush, pipe cleaner, etc. Do not use sharp objects to remove deposits as plastic parts are easily damaged.

Problem	Possible Solution
Deposits on both suction and discharge tubing	Periodic cleaning and removal of deposits from both suction and discharge tubing must be performed to prevent blockage. Additionally, there is usually a separate discharge valve at the point of interconnection of the discharge tubing and a water line under pressure. This must be periodically disassembled and cleaned also.
	Deposits can be partially eliminated by mixing granular calcium hypochlorite in a separate container from the solution barrel. Many operators mix the referenced chlorine compound in a separate container, allow it to settle over several hours, and then decant or draw the chlorine solution into the solution barrel, leaving un-dissolved solids in the bottom of the mixing container for disposal.
Undersized solution pump	solution metering pump must provide the proper dose of chemical for the flow rate The operator should check to insure the properly sized solution metering pump is installed by determining both maximum and minimum range of chemical feed rates, solubility of the chemical added to the water, and the rate of water flow to be treated from the source. If there is any doubt, check with a knowledgeable source to verify the size solution-metering pump needed. Solution metering pumps come in a great range of sizes regarding capacity – from 5-7 gpd (gallons per day) to several thousand gallons per day. Flexibility in application rate (solution metering pump daily output) must be such to allow application of chemicals to meet any expected conditions for your particular water supply.

Repairs to Hypochlorinators

Prior to beginning any repairs to a hypochlorinator, disconnect from the power source.

The best solvent to use for removing scale is a dilute solution of hydrochloric acid, sold commercially as muriatic acid.

Check for leaks by using a rag soaked in ammonia, and holding it near places where leaks may occur. If there is a leak, a white cloud will appear.

When the chlorinator is shut down, it is important to check and be sure the chlorine residual is maintained.

Regular cleaning can prevent flow restrictions. Waters with high levels of iron, calcium hardness, or magnesium hardness can be problematic unless a regular cleaning routine is established. It is important to flush all vital parts daily. In some cases a strainer installed at the end of tubing that is submerged in the hypochlorite solution will prevent clogging problems. The tubing should be equipped with a float to position the tubing in the vat so that the end of the tubing does not touch the bottom.

Rinsing with muriatic acid and brushing can remove mineral deposits. Worn and damaged parts should be replaced to ensure proper dosing..

Always adjust the chlorinator while it is in operation. Adjusting the chlorinator when the pump is off can result in damage.

Safe Handling of Hypochlorite Solution

Hypochlorite solution can cause serious burn injuries and can cause permanent damage to the eyes. When working with Hypochlorite solution a great degree of caution should be exercised and protective eye goggles and clothing should be worn at all times. Hands should be protected from contact.

The following steps should be taken when handling hypochlorite solution.

Table 33

Consideration for the Safe Handling of Hypochlorite Solutions

1. Protect skin, eyes, and respiratory tract from hypochlorite dust.
2. All containers should be covered to prevent evaporation and the release of fumes.
3. Content of hypochlorite drum must be kept dry, covered and stored in a cool dry area away from direct sunlight.
4. Protective gloves should be worn. Hypochlorite in contact with moisture will burn and damage skin.
5. When mixing a hypochlorite solution, the water should be put in the container before the hypochlorite powder is added.
6. All spills should be flushed away with large amounts of water.
7. The chlorine room should be well ventilated.
8. Calcium hypochlorite should not be stored where it can come in contact with organic matter. The reaction between the two can result in a fire.

Upkeep of Hypochlorinators

Daily cleaning of the exterior of the hypochlorinator should be performed. Daily cleaning will also help keep the rate adjustment indicator controls free of obstruction from deposits.
Regardless of good maintenance in hypochlorinators, parts do wear out and need to be replaced.

Common replacement parts to keep on hand are diaphragms, suction and discharge valves, seats, O-rings, etc. dependent upon your particular solution metering pump.

A listing of spare parts and repair kits and provision of these parts should be readily available from your supplier/manufacturer.

Calibration Solution Metering-Pump

The operator must know the capacity of the solution-metering pump. Capacity of solution metering pumps is normally expressed in gallons per day. Most smaller solution metering pumps have the rated capacity in gallons per day labeled on the pump motor housing adjacent to a rate of flow adjustment indicator (adjusting knob).

Many solution metering pump manufacturers provide tables or charts listing pumping capacity, which can be dependent upon both discharge pressure and multiple drive belt pulley settings connecting the drive motor and pump.

An operator must be able to calibrate the solution-metering pump. Table 34 illustrates calibration considerations for a metering pump.

Table 34

Proper Calibration of a Solution-Metering Pump

1. Fill a container or graduated cylinder with water and prime the solution-metering pump. That is, fill the pump with solution (water) by operating the pump with the suction hose being submerged in water in the container or graduated cylinder.

2. The discharge tubing should be disconnected from the pump head until such time visual inspection reveals that all air has been forced form the pump head and no bubbles are observed in the pump discharge. The discharge tubing is then connected to the pump head and to the delivery point (if connected to a water main, etc.). Pumping should then continue for several minutes to force air from the discharge tubing prior to determining discharge rate.

3. Once this has been done, use a stopwatch or watch with a second hand and time the operation for a few minutes and determine the average amount of solution withdrawn from the container or graduated cylinder in milliliters (ml) per one (1) minute time interval.

4. The large graduated cylinder is best utilized for this calibration. This process should be repeated for a total of three (3) times and the results averaged to determine the flow in milliliters (ml) per one (1) minute interval.

Solution metering pump discharge rate is readily determined by the following formula:

ml pumped per one minute x 0.38 = GPD (gallons per day).

or the milliliters of solution pumped in a one-minute time period times 0.38 will indicate the total output of the metering pump in gallons for a 24-hour continuous time period.

It is important to calibrate the solution-metering pump at several different "settings" of the rate control adjustment for accuracy in calibration. Other methods such as collecting and measuring the pump output over a given time period using a "household" measuring cup with proper conversion to gallons per day can successfully be made. However, the most accurate method to determine solution metering pump output should always be made by determining the amount of solution (water, etc.) withdrawn through the suction tubing and not the amount of liquid discharged by the pump. Discharge from a solution-metering pump can be affected by pressure at the point of application.

Preparing a Chlorine Solutions for Hypochlorinators

Determining the amount for granular or liquid chlorine used in preparing a chlorine solution for the purpose of chlorination is a basic water treatment plant function that every operator should be capable of performing.

Determination of chlorine solution strength and application rate is dependent upon the following.

1. The flow rate of water to be treated (from the source of supply).
2. The amount of solution that a solution metering pump (hypochlorinator) will discharge at a given rate adjustment setting.
3. The type chlorine compound used (calcium or sodium hypochlorite) and actual listed chlorine content. For example, most calcium hypochlorite contains 65% available chlorine. In other words, one (1) pound of calcium hypochlorite contains 0.65 pounds (10.4 ounces) of chlorine. Standard "household bleach" is <u>usually</u> 5-1/4% chlorine content.
4. Calculating the amount of chlorine mathematically or the utilization of a nomograph to determine how much chlorine compound (calcium or sodium hypochlorite) to add to a given amount of water in a solution barrel.

A nomograph is simply several lines marked in increments and arranged such that when a straightedge is used to connect known values on two lines, an unknown value can be determined on another line at the point of intersection of straightedge and intersected.

The operator must be aware that only a certain amount of granular calcium hypochlorite can be dissolved in one gallon of water (called maximum solubility) and is usually considered to be 6-8 ounces per gallon of water in the solution barrel.

Chlorine demand must be considered when initiating chlorination.

Chlorine Feed Rates

Chlorine Feed or Dose is the total amount of chlorine fed into the water system by the chlorinator in pounds per day.

With gas chlorinator, the dose is often expressed as pounds of chlorine per day as measured with weight scales which show the daily loss in weight of the chlorine cylinder.

When chlorine compounds are injected as a water solution by means of a hypochlorinator, the number of gallons of stock solution fed per day is recorded. The solution strength is usually expressed as a percentage of chlorine or simply the number of gallons of chlorine bleach (%) per gallon of water to make up the stock solution.

Chlorine Concentration

The chlorine concentration is the concentration of the chlorine desired in the water to which the chlorine is applied. It is expressed in mg/l. It is calculated from the formula:

Chlorine Dose = Flow X Chlorine Concentration

Developing an Emergency Preparedness Plan for Hypochlorine Emergencies

The operator should develop an Emergency Preparedness Plan for emergency situations for each water system. Written emergency procedures ensure that proper actions have been proactively identified and can be quickly implemented to minimize the affect of problems related to the release of chlorine, power outages, cross connections or broken water mains when they occur.

Emergency telephone numbers should be posted near a telephone unlikely to be affected by the hazard. At a minimum the following numbers should be listed:

Table 35

Contacts for Hypochlorine Emergencies

1. Police
2. Fire
3. Hospital or physician
4. Local and State Emergency Disaster Office
5. CHEMTREC - (800) 424-9300 The CHEMTREC toll free number may be called any time for information on how to handle an emergency created by hazardous materials such as chlorine.

Gas Chlorination

Chlorine gas is frequently used by small systems. The difference between chlorine gas (using chlorinators) and hypochlorination is the side products of the reaction. Hypochlorination raises the pH and Chlorination lowers the pH of the water.

Chlorine gas is shipped as a liquid in 100 lb., 150 lb. and 2,000 lb. cylinders. Water plants smaller than .5 MGD generally uses the smaller cylinders. Chlorine cylinders are never shipped full because the liquid can expand and rupture a tank. Liquid chlorine expands 450 times its volume when converted to a gas form. Chlorine gas is a greenish-yellow and is 2.5 times heavier than air. Chlorine detectors must always be installed a low point below the chlorine tanks. Chlorine gas is non-flammable but will react violently and support combustion with other chemicals and must be stored separately.

Chlorine cylinders are supplied with fusible plugs that melt between 158 to 165 degrees F. These prevent build up of pressure and possible rupture in case of a fire. The ton cylinders will have 6 of these plugs, 3 on each end. The ton cylinder has two taps, one for removal of liquid chlorine and one for removal of gas chlorine. This provides an added safety feature because the tank can be rolled in case of a leak forcing the escape of gas instead of a liquid. Cylinders are made of welded steel and must be tested every 5 years at 800 psi. Gas is withdrawn in the vertical (cylinder top facing up) from a 150 lb unit and horizontal position (cylinder on its side) from the ton unit.

For smaller systems that use the 150 lb. cylinders, chlorine is removed from the top of the tank as a gas and applied to the water system. For larger systems the liquid chorine is withdrawn from the tank and evaporated. A maximum of 40 lbs. of chlorine per day can be withdrawn from a 100 or 150 lb. cylinder or 400 lbs. from a ton cylinder without the discharge point freezing up. Chlorine gas is only slightly soluble in water and at 49.2 degrees F forms a crystalline substance called chlorine ice. The gas vapor pressure in a cylinder depends on the temperature not the amount of liquid in the cylinder. Table 36 is identifies the major parts of a chlorination system for a system that uses gas chlorine with a direct connection to the water system.

Table 36

Chlorinator Set Up for a Small Water System
Major Parts and Their Function

Interconnection Manifold	Sometimes used where more than once cylinder is used at the same time
Vacuum Regulator	Allows the chlorine gas to enter under vacuum to the Rotameter. If vacuum is lost the valve will close
Rate Valve	Controls the rate of flow that chlorine enters. T
Rotameter	A Rotameter is a device that measures chlorine flow. The dose is measured by the loss of weight in the chlorine cylinder.
Check Valve Assembly	Prevents water from back flowing into the chlorination system
Ejector	Consists of a venturi nozzle that creates a vacuum to transport chlorine gas to the water supply.

Gas chlorination for a system that uses one-ton cylinders, the operation is basically the same except that the chlorine is removed from the cylinder as a liquid and converted to gas with a device called an evaporator.

Chlorine Safety for Chlorinators

Chlorine is extremely toxic to human health. Breathing even small concentrations can be fatal. Table UUU shows the effect of chlorine on humans at various concentrations. Chlorine will deaden the sense of smell and must be measured with a chlorine concentration devise.

Table 37

Effects on Humans for Chlorine Concentrations in the Air

Chorine in Air (PPM)	Human Physiological Response
.5	Maximum Permissible Exposure Level (8 hours)
1	Slight symptoms after several hours' exposure
3	Detectable Odor at this level
4	1 hour exposure inhalation without serious affects
5	Immediate Noxious Effects
15	Throat Irritation
30	Coughing (Immediately Dangerous to Life or Health, IDLH Level)*
40	Dangerous affects from ½ to 1 hour
1000	Death after a few deep breathes

* Immediately Dangerous to Life or Health or IDLH is the level that one could escape in 30 minutes without irreversible health effects

The following minimal safety precautions are required for gas chlorine use at all times.

Table 38

Minimum Safety Precautions for The Use of Gas Chlorine

1	Follow Manufactures instructions on all chlorine equipment at all times
2	All exposed metal parts should be painted or protected with petroleum jelly to prevent corrosion.
3	All chlorine equipment should be kept in a separate room.
4	Temperature should not be allowed to go below 50 degrees or above 140 degrees F.
5	Continuous ventilation should be provided wherever chlorine is stored
6	Connections should be checked frequently with a rag soaked in ammonia being careful not to get liquid on exposed parts
7	Connections and joints should be loosened or tightened with great care. Excessive force will damage fittings.

Chlorine Safety Program for Gas Systems

Because of the inherent danger with chlorination systems, gas systems require a high level of safety training and training procedures to ensure operator and public safety. Table 39 provides suggestions for the content of such a safety program.

Table 39

Contents of a Safety Program
For Gas Chlorination

	Chlorine Safety Program Requirements	Description of Safety Components
1	Written Safety Program	Documented Safety program with clear responsibilities and supported by management
2	Written Rules and Safety Procedures	Documented procedures that identify safety concerns in the plant
3	Periodic hand-on training	The training should include both classroom and on the job. At minimum the operator needs to be trained in the use of leak-detection equipment, self-contained breathing apparatus, and atmospheric monitoring devises.
4	Establishment of Emergency Procedures	There needs to be written procedures for emergencies, for chlorine leaks and for first aid
5	Establishment of Maintenance and Calibration Program	Operators should follow manufacture's maintenance recommendations and keep equipment operating and calibrated at all times
6	Fire, Police, Emergency Agency Coordination and (Chemtrec 800-424-9300.)	Procedures and training needs to be conducted with public safety departments to ensure coordination in the event of an emergency

Alternative Disinfectants Used in Water Treatment

Other disinfection systems for water treatment consist of the use of chlorine dioxide, ozone and Ultraviolet Disinfection. These systems are used when taste and odor problems are difficult to control with chlorine and/or in consideration for the production of Disinfection Byproducts (DBP), i.e. Trihalomethanes (THM) and halogenatedacetic acids (HAA5).

Chlorine Dioxide Disinfection Systems

Chlorine Dioxide is a widely used chemical in the disinfection of drinking water. It has long been used to control taste and odor and for iron and manganese control.

The chemistry of chlorine dioxide treatment is different than that of chlorine addition because chlorine dioxide is a moderately stable compound that does not undergo further reaction with water after it dissolves. In general the reactions with other compounds will not produce THMs and HAA5s will less than the amounts produced by chlorine addition. However chlorine dioxide can result in chlorite and chlorate residuals in drinking water. Chlorate has an established MCL.

Chlorine dioxide is more effective in killing bacteria than chlorine between the pH ranges of 8 and 10.

Since chlorine dioxide is unstable sodium chlorite is supplied as a salt that must be mixed with water on-site to produce chlorine dioxide. Sodium chlorite is extremely combustible and must be stored away from organic materials. It is hazardous to humans and will burn tissue and any organic substance on contact.

Chlorine Dioxide is extremely corrosive and piping systems must be constructed of PVC or polyethylene pipe.

Ultraviolet (UV) Disinfection Systems

UV works by damaging the genetic material in the cells of microorganisms preventing reproduction and ultimately killing them. Because of the concern with the production of DBP with the addition of chlorine, UV is expected to become more prevalent for water treatment in the future.

Because UV must work on cell tissue, turbidity control is extremely important. Lamps must be cleaned at frequent intervals to prevent the build up of scale. Algae control is also necessary.

Ozone Disinfection Systems

Ozone is extremely unstable and must be generated on-site. Ozone is produced by passing and electrical charge through dioxygen (O2). Ozone is responsible for the familiar smell after lightening strikes. Ozone is a powerful oxidant, which engages in oxygen atom transfers. In addition, the direct action of Ozone (O3) on living tissue can cleave water molecules producing a hydroxyl radical, which can act as a disinfectant.

Ozone has a particular reaction with the bromide ion that produces bromate that is important in the DBP formation and must be monitored. PH and ammonia addition are treatment methods for reducing the production of bromate in the when using ozone. Ozone is far more effective in inactivating Cryptosporidium oocycsts than hypochlorine or chlorine.

Ozone reactions with other compounds in the water to produce carboxylic acids, aldehydes and keytones, which are nutritious compounds to other microorganisms. These compounds may be high enough to require biostability treatment (biological filtration) in the treatment plant.

Chlorine Residual Required in Water Distribution Systems

A free chlorine residual of 0.20 mg/l or a combined chlorine residual of 0.60 mg/l or an equivalent chlorine dioxide residual, must be maintained in the water distribution system at all times.

Filtration

Filtration

Filtration is the process of passing water through material such as a bed of sand, coal, or other granular substance to remove floc and particulate impurities. Impurities generally consist of suspended fine silts, clays, colloids, bacteria, algae, floc and materials carried over from other plant processes.

There are a number of related mechanisms that occur in a filtration process. A media type filter captures most particles by the process of sedimentation. Table 40 identifies these filter mechanisms.

Table 40

Filtration Removal Mechanisms

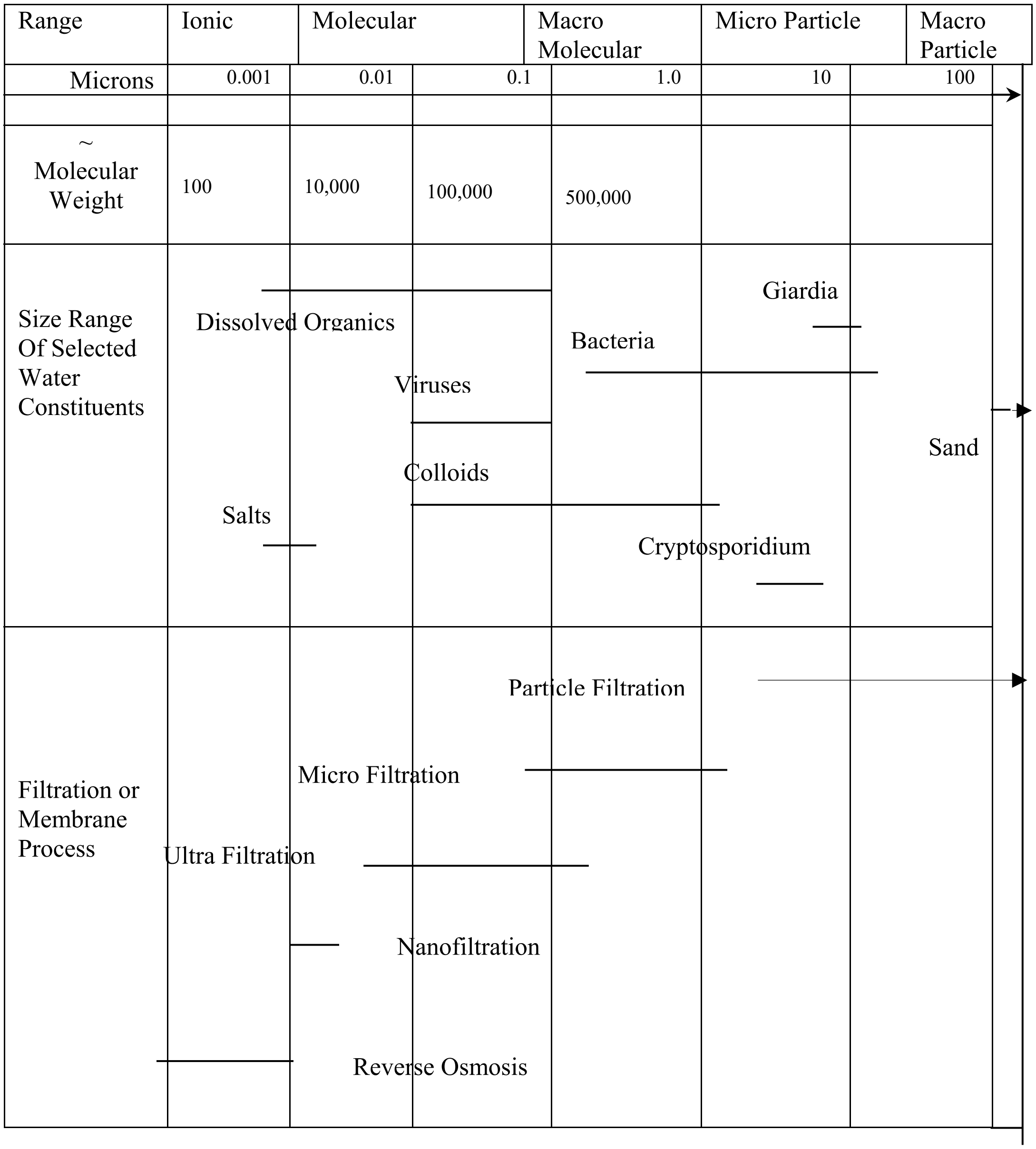
	Removal Mechanism	Particle Capture Process
1	Sedimentation	Sedimentation on media
2	Adsorption	Gathering of particles on the surface of the media or interfaces
3	Biological Action	Break down of organic materials by bacteria that cause a mat to develop that stains particles (Scmutzdecke)
4	Absorption	Soaking particles into the body of the media by chemical action
5	Straining	Capturing particles in media pore spaces

Filters are extremely important in the removal of particulate material including pathogens. Table 47 illustrates the removal abilities for filtration systems used in water treatment. Note that protozoa such as Giardia lamblia and Cryptosporidium are removed in conventional filtration processes. Virus and most bacteria must be inactivated by disinfection.

Conventional filters will not remove minerals or salts from the water. Special membrane filters must be used for these processes.

Table 41

Size Range of Selected Water Constituents
And Effective Water Treatment Removal Processes



Types of Filters

There are four filter types, gravity (rapid sand), pressure, slow sand filters, and diatomaceous earth. The type used most often in water treatment is the gravity type. Table 48 compares the various filter characteristics for a small water plant. These comparisons are helpful in understanding the different applications of filters for the water being treated. Note the much higher loading rates possible with the rapid sand filter.

Table 42

Comparison of Filter Types for a Small Water Treatment Plant (1 MGD)

Characteristic	Rapid Sand	Slow Sand	Diatomaceous Earth or Pressure Filter
Filtration Rate	2 gpm/sft.	.06 gpm/sft.	1 gpm/sf
Filtration Area	350 sft.	11,000 sft.	700 sft.
Depth of Media	18" gravel 30" sand Permanent	12" gravel 42" sand to 12" after ultimate use	1/16 to 1/8" surface Recoating Required
Size of Sand (Uniformity Coef .)	.35 to .80 mm U.C<1.7.	.20 to .40 mm U.C.<2.5	.01 to .20 mm
Media Distribution	Stratified	Unstratified	Unstratified
Loss of Head	< 1 ft. initial 9 ft. final	0.2 ft. initial 4 ft. final	2 psi (5 ft.) initial 30 psi (70 ft.) final
Cycle Time	To 200 hrs.	60 days	To 40 hrs
Penetration of Matter	Deep Vertical	Shallow	Surface
Cleaning Method	Backwash/expansion	Surface Scraping of Schmutzdecke	Air Bump/Backwash
Wash Water Used	> 1%	< 0.6 %	< 1%
Pretreatment	Coagulation Flocculation Sedimentation	None Sometimes Aeration And/or Presettling	None, sometimes Aeration, Presettling or micro screening
Chlorination	Always	Always	Always
Raw Water Quality	High Turbidity High Color Moderate Algae	Moderate Turbidity Low Color Moderate Algae	Low Turbidity Low Color Low Algae
Hydraulic Type	Gravity Flow	Gravity Flow	Vacuum or Pressure

Gravity Filters

Gravity filters can be classified as single media (sand also sometimes called rapid sand filters), dual media (sand and anthracite), mixed/multi media (sand, anthracite and garnet) In a gravity filter the water flows into the top of the filter and then flows downward by gravity.

Single media filters use a layer of sand over a supporting gravel bed. Dual media filters use anthracite coal over sand. This allows for longer filter runs than a single media filter. The mixed media filter uses three or more materials with the coarsest media on the top and the finest on the bottom. Mixed media filters sometimes require a secondary coagulant applied immediately ahead of the filters.

Pressure Filters

The pressure filter uses a smaller grain sand than the rapid sand filters. Pressure is used instead of gravity to achieve higher rates of flow than gravity filters. These types of filters are found in smaller water systems.

Diamaceous Earth Filters

There are four basic operations involved in the diatomite filter process, precoat, body feed, filtration and backwash.

Precoat

When diatomaceaous earth filter units are place into operation slurry of diatomaceous earth is introduced at the tank influent line and is hydraulically deposited on the filtered water on each septum. It is desirable to recirculate until all the diatomaceous earth is deposited. This will insure and even deposition of the filter septums. The minimum amount of diatomaceous earth used under recirculation conditions is 0.1 pound per square foot of filtering areas. Without recirculation .15 pounds are needed. Applying diatomaceous earth without recirculation can result in uneven deposition on the septums.

Body Feed

This is the process of feeding mixed amounts of diatomaceous earth from a feed tank to the filter system. In this process continuous body feed results in more even coverage of the septums and a more effective filter operation.

Filtration in Diatomaceous Earth Filtration Systems

The process of maintaining a flow of water through the filter tank after the filtering process is initiated and before the recirculation line is closed. The filter is operated into the desired head loss is achieved. This is about 30 psi in pressure systems and 15 inches of mercury in vacuum systems.

Backwashing of Diatomaceous Earth Filtration Systems

When the desired head loss is achieved the filter is backwashed. Backwashing consists of an air bump of 50 to 60 psi air that removes spent diatomaceous earth from the septums. Vacuum units are cleaned by manual hosing.

Common Problems in Filter Systems

There are many factors that can affect filter performance. The most troublesome and dangerous is caused by the release of dissolved oxygen due to temperature changes in the water. This problem is called air binding and has the potential to damage the filter beds by air releasing too quickly and dislodging the sand and gravel medial.

Problems can also occur during the backwash cycle. These can include media loss, media boils, and overall failure of the filter to come completely clean during the backwashing process.

Improper coagulation or sedimentation can cause the formation of mud balls. Mud balls are problematic because they cause cracks and cause clogging in filter media. They must be physically removed.

Importance of Turbidity in Filter Operation

The most important water quality measure in filtration to ensure good filtration is the monitoring of influent and effluent turbidity. These factors are also used to measure filtration efficiency. The goal of the operator should be to establish an effluent turbidity goal and remain below that level. Continuous measurement of effluent turbidity is a state requirement.

Head Loss in Filter Operation

Filter runs are set by effluent turbidity or the amount of head loss occurring in the filter. Loss of head is the measure of the drop in pressure through the filter. Gauges are used to measure head loss. The loss of head is greater in a dirty filter than a clean one. Loss of head will be greater in a fined sand filter. Low water temperature will produce a greater head loss than water with high temperatures. Table 43 is a typical filter backwash procedure.

Table 43

Typical Filter backwash Procedure

Step	Activity
1	Record length of filter runs (time since last backwash.)
2	Close Filter influent valve
3	Open Filter effluent valve
4	Open drain valve
5	Start surface wash (scour)
6	Slowly start backwash system
7	Observe filter during backwash process
8	Continue washing until wash water leaving filter clears. Close surface wash system.
9	Slowly turn off backwash system
10	Close drain valve
	Record length of backwash and number of gallons used.

Removal of Taste and Odors

If taste and odors are a problem, granular activated carbon (GAC) can be added to the filter media.

Removal of Iron and Manganese by Filtration

In areas where high levels of iron are present in the water greensand is added to the filter media. Greensand is a natural ion resin, which will remove iron and manganese during the filtration process. As with all ion resins greesand needs to be regenerated periodically. This is done with potassium permanganate. To ensure removal there must be permanganate residual in the filter effluent.

There are two methods to regenerate greensand. Method on is to dose the filter with a 5% solution of potassium permanganate to the filter and let it stand for 24 hours. In the other method permanganate is added until pink water flows out of the greensand media. The dosage is decreased so that water going to the filter has a slight pink color. However there should be no pink color in the filter effluent.

Troubleshooting Filter Operations

Table 44 identifies typical maintenance problems associated with filter operation and their probable cause and solutions.

Table 44

Troubleshooting Guide for Filter Operation

Problem	Check	Solution
Filter effluent increases in color, chlorine demand or turbidity	Verify performance of the coagulation, flocculation and sedimentation process	Adjust coagulant dosage. Change coagulant. Change sludge removal frequency. Adjust rapid mix or flocculation speed.
Media boils, media loss, or failure of the filter to come clean during backwash	Improper backwash flow rates, surface scour rates or duration	Adjust backwash flow rates. Adjust surface scour rates. Change duration of backwash cycle.
Mud ball formation in the filter bed	Poor coagulation. Poor Sedimentation. Improper backwashing.	Correct coagulation and sedimentation problems. Adjust backwash cycle.

Demineralization

Types of Demineralization Water Treatment Processes

Methods for removing minerals from waters can be divided into two classes: 1. those using a phase change such as freezing or distillation, and 2. those sing non-phase change such as reverse osmosis, electrodialysis and ion exchange.

Demineralization systems are primarily used to treated waters with high dissolved inorganic materials (TDS) from source water. Table 45 illustrates the applications of various demineralization systems for source waters.

Table 45

Ranges for TDS Removal for Demineralization Treatment Processes

Treatment Process	TDS Low Range Removal Limit (PPM)	TDS High Range Removal Limit (PPM)
Ion Exchange	10	1200
Electrodialysis	100	1300
Reverse Osmosis	100	20000
Freezing	5000	100000
Distillation	5000	100000

Spent Chemical (Reject Water) Disposal with Demineralization Processes

Mineral salts produced by demineralization processes can be of sufficient volume and concentration to present problems to the receiving environment. Disposal alternatives have included deep well injection, natural and physical evaporation, surface discharge (through proper permitting authorities), discharge to sanitary sewers (with proper permit) and discharge to the ocean.

Reverse Osmosis

Osmosis is defined as the passage of a liquid from a weak solution to a more concentrated solution across a semi permeable membrane. The membrane allows the passage of water but not dissolved solids. In reverse osmosis pressure is applied to the concentrated solution, which causes the liquid to pass through the membrane resulting in a more concentrated solution on one side and a less concentrated solution on the other side of the membrane.

There are two types of membranes used in RO systems, cellulose acetate and thin film composite membranes. The composite membranes can handle higher flux rates (flows) at lower pressures but are sensitive to oxidants and have higher tendencies to foul.

Factors Affecting Performance of Reverse Osmosis Systems

There are several factors, which influences the performance of RO system. These are pH, temperature, suspended solids and turbidity, and presence of biological organisms. The PH of the water is adjusted to 5.5

by adding sulfuric acid to achieve optimal removal efficiency. The acid added to the feed water to lower the pH prevents minerals from coming out of solution and clogging (scaling) the membrane.

If the ph and temperature are allowed to increase a process known as hydrolysis will begin to separates Hydrolysis is the breakdown of the membrane allowing an increase in mineral flux. When this occurs replacement of membrane elements is necessary.

Suspended solids and turbidity can also foul the membrane and must be removed. For colloidal material filtration may be required . Cartridge type filters may then be used as a screening device. Turbidity should be less than 1 NTU to a cartridge filter.

To prevent biological fouling of the membranes, a dose of 1 to 2 mg/l of chlorine is typically added to the feed water. When oxidant intolerant membranes are used dechlorination with sodium bisulfate may be necessary.

Increasing Flux

To increase rate of recovery, the pressure of the feed water may be increased. This will increase the flux of is the product water with a corresponding increase in salt rejection. Miner flux increases will not increase the quality of the product called permeate, since concentration of the permeate it is not dependent on the pressure. The flow of the salt through the RO membrane is constant. Any slight increases of salt in the permeate will be considerably diluted by the increase in the flow of the product water.

Control factors include the rate of recovery, which is the amount of product water vs. feed flow. These are influenced totally by the desired quality of the product water. If the desired water quality is high then the percent of recovery will be low and the percent of salt removal will be high. Table 46 illustrates typical flux rates for various concentrations of feed water.

Table 46

Acceptable Flux Rates for
Various Feed Water Sources

Feed water Source	Flux Rate (G/D/sq. ft.)
Industrial/Municipal Waste	8 to 12
Surface Water (River, Lake, Seawater)	8 to 14
Groundwater	14 to 20

Polarization

Polarization is another serious problem in RO operation. It is caused by the buildup of deposits along the edges of the membrane. Increasing he flow velocity, which will cause the minerals to break off from the edges of the membrane, minimizes this affect.

Reverse Osmosis Pretreatment Considerations

Reverse Osmosis systems are very vulnerable to fouling and scaling caused by a wide variety of constituents. The constituents and the typical removal technology are shown in Table 47.

Table 47

Reverse Osmosis
Pretreatment Considerations

Constituent	Problem	Treatment
Fine Suspended Solids	Fouling Elements	Coagulation/Clarification
Gross Suspended Solids	Blockage of Lead Element	Media Filtration with cartridge type filters o protects pumps
Oil and Grease	Fouling of Membrane Surface	Ultrafiltration
Microbiological Matter	Fouling of feed/concentrate mesh spacer	Use of Oxidizing Agent
Oxidizing Agents	Membrane Degradation	GAC Removal
Carbonates	Scaling on Membrane Surface	Softening
Sulfates	Scaling on Membrane Surface	Scale Inhibiter/Softening
Silica	Forms insoluble Gel on Membrane Surface	Lime softening
Iron	Scaling and Fouling	Greensand Filtration
Hydrogen Sulfide	Forms Sulfur Scale	Degasification

Nanofiltration

Nanofiltration is a selective reverse osmosis process that is designed to remove hardness, DBP potential formation potential of source water and for removing TDS.

Ion Exchange

Ion exchange is a chemical process that replaces undesirable ions with more desirable one. Typically calcium and magnesium ions are exchanged with sodium. There are four stages in the ion exchange process.

Table 48

Stages in the Ion Exchange Process

Stage	Definition	Process Description
1	Service Stage	Normal operating stage where actual softening takes place
2	Backwash Stage	The stage used to expand and clean the resin particles.
3	Brine or Regeneration Stage	The stage used to regenerate the resin using either a cationic or anionic solution, which is circulated through the resin.
4	Rinse Stage	The stage where clean water is washed through the system to rinse the resin and washout excess brine solution

Electrodialysis

Electrodialysis is the removal of inorganic salts by introducing an electrical charge to cause the ions to pass through a semi-permeable membrane.

Electrodialysis uses a membrane that is specific to cations and anions so that 3 compartments are formed. The process allows water to flow between alternating cation permeable and anion permeable membranes. D.D. power is used to cause ions in the feed water to migrate through the membranes leaving fresh product water and concentrated brine solution.

Pretreatment Requirements for Electrodialysis Treatment Systems

Electrodialysis systems require suspended or dissolved solids to be removed prior to treatment. These materials can block passageways of water flow and lead to treatment failure,

Iron in excess of 0.30 mg/l and manganese in excess of 0.10 mg/l are also problematic for these systems and must be removed.

Chlorine and hydrogen sulfide in any concentration must also be removed because it will attack the membranes.

Hexametaphosphates in excess of 10 mg/l are problematic.

Coagulation and Flocculation

Coagulation and Flocculation

The purpose of coagulation and flocculation is to remove particulate impurities, especially non-settleable solids, and color from the water being treated. Settleable solids can be removed by gravity settling. These consist of sand and heavy silt.

Non-settleable solids consist of bacteria, fine clays and silts. This material is also called colloidal matter. These particles have a negative charge and tend to repel one another keeping them in suspension. These small particles in the water must be removed by the use of coagulating chemicals. This chemical cause the particles destabilize to clump together forming floc. When pieces of floc clump together they form larger heavier floc, which will settle out.

Coagulation is most effective at a pH between 5 and 7. The chemicals used in the coagulation process will alter the pH and the alkalinity of the water must be tightly controlled or coagulation will not occur.

Flash mixing is the process of mixing coagulant chemical and dispersing it evenly in the water.

Flocculation is a gentle mixing process that encourages particles to clump together.

Coagulant Chemicals

Coagulant chemicals are divided into two types, metallic salts and synthetic organic polymers. The operator should be familiar with these chemicals and the types of polymers used in water treatment. Table 49 lists some of the more common coagulant chemicals used for the treatment of water

Table 49

Common Coagulant Chemicals
Used in Water Treatment

Metallic Salts	Uses and Optimal pH Ranges
Aluminum Sulfate (Alum) $Al_2(SO_4)_3 \cdot 18\ H_2O$	PH range of 5.5 – 6.8 optimum. Effective on highly colored waters below pH 5.5. Effective with waters of high mineral content to pH 7.5 Sometimes used with lime up to pH 10.5
Ferric Sulfate $Fe_2(SO_4)_3$	Optimum range is pH 3.5 to 5.5. Forms heavier floc than Alum
Ferrous Sulfate $FeSO_4 \cdot 7\ H_2O$	Optimum range is pH 3.5 to 5.5 and above 9. Sometimes used with lime softened waters Used with chlorine to form trivalent ion to increase effectiveness.
Ferric Chloride $FeCl_3 \cdot 6\ H_2O$	PH range of 5.5 – 11. Very corrosive
Sodium Aluminate $NaAlO_2$	Alkaline rather than acidic Used for very turbid or highly colored waters Reduces carbonate and non-carbonate hardness

Primary Coagulants

The coagulants can be used as primary coagulants or coagulant aids. Primary coagulants are generally the metallic salts listed above. Lime and sodium hydroxide are also used as primary coagulants. Primary coagulants are added to the water to exceed the solubility limit of the metal hydroxide resulting in the formation of a precipitate that absorbs particles (turbidity) in the water. Some chemicals such as Alum are can be used both as primary coagulant and coagulant aids.

Polymers

Polymers are long chains of small subunits or monomers that have a linear or branched structure that contain ionizable groups. These groups attach to negative (turbidity) or positively charged particles in the water forming larger clumps that then settle. The following types of polymers are used in water treatment.

Table 50

Synthetic Polymers Used in Water Treatment

Polymer and Ionic Charge
Cationic +
Anionic -
Nonionic

Care must be used in adding polymers because adding too little will fail to produce a settleable floc and adding too much results in dispersion rather than coagulation of particles.

Coagulation Process

Coagulation is a physical and chemical process and includes pH of the water, the mineral content, the water temperature and the coagulant mixing reaction occurring between the alkalinity of the water and the coagulant added to the water, which results in the formation of insoluble floc.

Good settling floc should be firm, compact and about the size of a pin head. The water should be clear between floc particles. Floc particles should settle in slow motion. Good floc formation is affected by poor mixing, inadequate or excess application of chemical, inferior preconditioning of the water or short detention times.

Factors Affect Coagulation

The best pH for coagulation usually falls in the range from 5 to 7. Alkalinity must be present for the process to occur. The factors that affected Coagulation is include in Table 51. The effectiveness of the coagulation process is typically determined by the Jar Test**.**

Table 51

Factors affecting the Coagulation Process

1	PH
2	Alkalinity of water
3	Concentration of Salts
4	Turbidity
5	Type(s) of chemicals used
6.	Temperature
7	Adequacy of mixing

Jar Test

A jar test is a laboratory procedure where varying dosages of coagulant are tested in a series of glass or plastic jars under identical conditions. The jars are injected with coagulant dosages and gently paddled or flocculated to match field conditions as closely as possible. After a set of time to simulate field conditions the jars are observed to determine which dosage produces the largest, strongest floc or which dosage produces the floc that settles the fastest.

Other laboratory tests sometimes include a jar test to determine the optimal pH or determine the turbidity of the settled water and its filterability.

The jar test is an integral part of maintaining the effectiveness of the treatment process and should be performed daily by the operator.

Flocculation

Flocculation is a gentle stirring process that causes small-coagulated particles to clump together in larger flocs the will then settle out of suspension.

The formation of floc is controlled by the rate at which collisions occur between particles and by the effectiveness of these collisions. If the speed of the stirring process I s too great, then the floc particles will be sheared or broken apart. This will cause an increase in turbidity. IF the speed of the flocculation is too slow the short-circuiting may occur. The slow forming floc will not settle and will move through the contact basin. Turbidity in the finished water, solids carryover, and the development of pin-floc are all problems related to flocculation and/or coagulation.

A flocculation basin should have a detention time of 20 to 60 minutes.

Floc Description

The best settling floc are smooth, circular and slightly dense. This type of particle will tend to settle quicker. Irregular shaped particles with ragged edges tend to settle slower. Larger clumps settle fast but are indicative of chemical overdosing.

Temperature Effects on Floc Formation

Temperature has an affect on the formation and settling of floc. Colder temperatures slow floc formation and cause them to settle slower in he water because of its increased density.

Sedimentation

Sedimentation Process

Sedimentation is the process of allowing water to flow at a slowed speed to allow particles to settle. The time in a settling basin that it takes a theoretical drop of water to pass through is called the detention time. A perfect flow is called a slug flow. However in reality slug flow rarely occurs and actual detention times must be measured using a dye test.. Theoretical and actual detention times for a sedimentation basin can differ substantially under high flow conditions where short-circuiting can occur.

Types of Sedimentation

Sedimentation is used in three areas in water treatment plants. Table 52 gives their description and application.

Table 52

Types of Sedimentation Tanks
And Their Application

Sedimentation Description	Application
Plain Sedimentation (also called presedimentation)	Used to remove sand and course silt Aids the coagulation process. Lowers the turbidity of the water
Coagulation Sedimentation	Follow the coagulation process. Often used without presedimentation if water is of low uniform turbidity
Sludge Thickening (Up flow Clarifier)	Combines coagulation and sedimentation process. Reduces overall detention time needed for particulate removal Used in water softening plants

Short Circuiting in Sedimentation Tanks

The theoretical detention time in a sedimentation tanks is determined by dividing the volume of flow through the basin by the flow rate. This is known as plug flow. In practice sedimentation processes rarely exhibit plug flow conditions and actual detention time can be significantly less than the theoretical value especially under high flow conditions. When the actual detention time is less than the theoretical detention time the condition is called short-circuiting. Short-circuiting occurs when the path of the flow passes directly through potions of the sedimentation tank at high velocities. Short-circuiting causes particulate mater to be held in suspension and be transported through the tank. Baffling to break up the flow paths can control short-circuiting.

Table 53 provides a troubleshooting guide for maintaining and improving sedimentation tank performance.

Table 53

Troubleshooting Guide for Sedimentation Tank Performance

Problem in Sedimentation Tank	Probable Cause	Possible Solution
Time Provided for Settling	Two to four hours should be sufficient.	Determined by flow through the basin. Theoretical flow velocity is 1 to 3 feet per second.
Characteristics of the Suspended Matter	Dense compact floc will settle quicker.	Determined by coagulants and speed of flocculation
Degree of Short Circuiting in the Tank	Dependant on the shape of the tank and flow conditions	Can be modified with baffling
Tank Inlet and Outlet Arrangement	Dependant on the shape of the inlet and outlet conditions	Weir troughs can be adjusted to provide for even flow across basin
Tank Overflow Rate	Determined by dividing the flow b the surface area	Should be in he range of 400 to 600 GPD/ sq. ft.
Currents in the Tank	Caused by flow, inertia (velocity head), wind action and temperature difference	Cover or screen tank from the wind. Remove accumulated sludge to eliminate washouts.

Aeration

Use of Aeration in the Water Treatment Process

Aeration is the treatment process recommended for the removal of the majority of the substances responsible for taste and odor problems. It is the process of introducing air into water. Aeration is most often used to remove impurities from the water by the addition of air that causes oxidation. The impurities most commonly affected by aeration are Carbon Dioxide, Hydrogen Sulfide, Methane, Iron, Manganese, and Dissolved Oxygen. Volatile compounds, which are those that cause taste and odor problems in drinking water, are also removed by aeration.

Algal Problems in Aeration Systems

Algae present in the water system will also cause taste and odor problems. Disinfection can be used to remove the algae.
Phenols present in the raw water will produce a “medicinal” odor and methods to remove the phenols must be implemented.

If the water has a “swimming pool” odor, it means the chlorine has combined with organic matter in the water, and an increase in the chlorine residual will usually eliminate this problem.

Removal of Hydrogen Sulfide

Hydrogen sulfide is a gas which, when dissolved in water, gives it a “rotten egg” odor. Chlorination will remove this gas from the water but the effectiveness of the chlorine for disinfection is lessened.

When Hydrogen sulfide reacts with chlorine, it produces Sulfuric acid and elemental Sulfur: It is therefore recommended that aeration be applied prior to the addition of chlorine for the most effective disinfection. Aeration works in two different ways to remove the undesirable compounds from the water:

1. A sweeping or “scrubbing” action, which is caused by the turbulence of the water and air mixing together. Undesirable dissolved gases such as Hydrogen Sulfide or Carbon Dioxide are physically removed by the turbulence and allowed to escape into the air. Good contact between the water and the air (oxygen) is necessary to make the aeration effective. The smaller the air bubbles, the more efficient the aeration.

2. Oxidation of certain dissolved gases and minerals such as iron or manganese. Oxidation is the chemical combination of oxygen from the air with the undesirable metals. Once oxidized, these substances can come out of solution and settle in the holding tank or be filtered out.

Categories of Aerators

There are two main categories of aerators:

1. Water into Air. This method produces small drops of water that fall through the air.
2. Air into Water This method creates small bubbles of air that rise through the water being aerated. (less common in small systems).

Table 54 lists the various categories of aerators used in water treatment. In each category there are a wide variety of aerator styles.

Table 54

Type of Aerators Used in Water Treatment

Water into Air	Air into Water
Cascade	Diffuser
Cone	Draft Tube
Draft	
Spray	

The two most commonly used types for small systems are Cascade and Spray aeration. Cascade aerators are a series of small water falls down a series of steps. The falling action of the water down the steps creates turbulence in the water, which allows the dissolved gasses to escape. Spray aerators spray the water through the air. To be effective the water must be dispersed in fine droplets. Evaporation is the major drawback to this type of aeration.

In all cases the aerators must be screened to prevent the water from being contaminated by insects or other creatures. Aerators should be cleaned regularly to prevent the build up of algae or mold. Aerators should be located in a well-ventilated area and out of direct sunlight (to prevent the growth of algae).

Removal of Sulfide

State drinking water requirements state that direct chlorination can not be used to remove sulfide when the concentration in the source water exceeds 0.30 mg/l unless the elemental sulfur formed in the process is removed. Sulfur formed in the process will result in undesirable turbidity and must be removed by filtration. Table 55 provides guidelines on the selection of the aeration systems for efficient sulfide removal. The achievable ranges assume pH adjustment. Corrosivity caused from the high dissolved oxygen content of the finished water may require additional pH adjustment, alkalinity recovery or the use of corrosion inhibitors.

Table 55

Guidelines for Removal of Sulfide
In Source Waters Using Aeration

Sulfide Concentration (mg/l)	Recommended Treatment Process	Achievable Range Of Removal
< 0.3	Direct Chlorination	100%
0.3 to 0.6	Conventional Aeration	50%
0.6 to 3.0	Forced Draft Aeration	90%
> 3.0	Packed Tower Aeration	> 90%

Stabilization

Stabilization of Water

Potable water should be stable, neither corrosive nor scale forming. The term pH is an expression of the intensity of the basic or acid condition of a liquid. The pH range is 0 - 14. Stable water has a pH of 7.0. Water with a pH value higher than 7.0 is considered to be basic. Water with a pH value lower than 7.0 is considered to be acidic. Acidic or corrosive water can leach lead, manganese, copper and other metals from the piping causing the water to be contaminated. Corrosive water can also result in complaints of “red” or “black” water.

Water is considered stable when it is saturated with calcium carbonate. In some cases water can cause corrosion problems or cause deposits of scale to form on pipes and plumbing fixtures. This water is said to be unstable. Stabilization is the process by which these problems are reduced or eliminated. There are three basic methods of stabilization:

Table 56

Basic Methods to Stabilize Drinking Water

1. pH adjustment
2. Providing protective coatings
3. Chemical Binding through Sequestering or Chelation

Stabilization by pH Adjustment

Adjusting the pH of the water requires adding certain chemical to the water to make it more stable. Raising the pH will decrease Corrosivity, lowering the pH will decrease scale formation. Some of the compounds used to adjust the pH are:

1. Increase pH - lime. soda ash (calcium carbonate), sodium bicarbonate, or caustic soda.
2. Lower pH - carbon dioxide (recarbonation), or sulfuric acid.

Stabilization by Providing a Protective Coating

Softening of the water by lime addition is an example of providing a protective coating. The Langlier Index is used to identify a water saturation that provides a slight coating on the inside of pipes and fixtures. Some examples of other chemicals used to provide protective coatings are: Sodium silicate, Sodium hexametaphosphate, Sodium polyphosphate, Sodium Zinc phosphate, and Zinc Orthophosphate.

Stabilization by Chemical Binding

Corrosion inhibitors coat the pipes. Sequestering agents chemically tie up the scale forming ions so they cannot react to form scale. Some examples or these are: Sodium hexametaphosphate and tetra Sodium pyrophosphate. These orthophosphates can also be used to treat for iron, they tie up the iron molecule so that it cannot be oxidized. An orthophosphate can be used to treat iron up to one part, anything over this requires filtration.

Which treatment is required or most effective for a particular water system depends on a variety of factors such as: water quality, other treatment, and condition of the distribution system. It is necessary in most cases to contact a qualified person, experienced in corrosion control to evaluate the water system and determine the appropriate treatment.

Many of these compounds can be hazardous if they contact the skin or respiratory tract. The operator should consult the information from the chemical manufacturer for safety hazards associated with that particular substance.

Effective treatment methods for controlling scale and corrosion are shown in Table 57.

Table 57

Scale and Corrosion Control Methods
Used in Water Treatment

Method	For Control of:	
	Scale	Corrosion
Controlled $CaCO_3$ Scaling		▪
Other Protective chemical coatings		▪
Softening	▪	
pH/Alkalinity adjustment	▪	▪
Chelation	▪	
Sequestering	▪	▪

Chemistry of pH/Alkalinity Adjustment with Lime

Low pH water can be treated with lime to raise the pH. For each milligram per liter of lime added, approximately 0.56 mg/L of carbon dioxide is removed. Carbon dioxide is in the form of carbonic acid (H_2CO_3) when dissolved in water. The following equation indicates the chemical reaction that takes place:

$$H_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 + 2H_2O$$

As carbon dioxide (carbonic acid) is removed, pH increases.

For each milligram per liter of lime added, the alkalinity of the treated water will increase by about 1.28 mg/L. The reaction is:

$$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 + 2H_2O$$

If the lime dose is too high, excessive scale will form. If it is too low, the water will be corrosive.

Langlier Index

Langelier's Calcium Carbonate Saturation Index is one technique used to determine the tendency of water to scale or corrode piping and tanks. This method is based on the assumption that every water has a particular pH value where the water will neither deposit scale nor cause corrosion. This stable condition is termed saturation. The pH value, called saturation pH and abbreviated pHs, varies depending on calcium hardness, alkalinity, and temperature. Once the pHs is calculated , the Langlier Index (also called the Saturation Index, S.I.) is found as follows:

$$\text{Langlier Index} = pH - PH_s$$

If the actual pH of the water is less than the calculated pHs then the water has a negative Langlier Index and is corrosive. If the actual pH is grater than the calculated pHs then the Langlier Index is positive and the water is likely to from scale. In either case the water is unstable. The greater the difference or concern for corrosion. Thus, water with a Langlier Index +0.4 will have a stronger scaling tendency of one with a Langlier Index of +0.1. Similarly, water with a Langlier Index of –0.4 has a stronger corrosion tendency than one with an index of –0.2. If the pH and pHs are equal, then the Langlier Index is zero and water is stable. Neither scale formation nor corrosion should occur.

Theses value of pHs can be calculated mathematically or derived graphically. To find pHs, calcium hardness in milligrams per liter as $CaCO_3$, alkalinity in milligrams per liter as $CaCO_3$, pH, TDS milligrams per liter and water temperature are required. Table XXX gives the various conversion values to compute the pHs for the formula, pHs = A + B – log (Calcium Hardness) – log (Alkalinity)

Table 58

Values for Computing pHs
Used in Determination of Langlier Index

Temperature C	A Value	TDS mg/l	B Value	Ca or Alk As $CaCO_3$ mg/l	log
5	2.27	0	9.63	0	1.00
10	2.20	50	9.72	20	1.30
15	2.12	100	9.75	40	1.60
20	2.05	200	9.80	80	1.90
25	1.98	400	9.86	100	2.00
30	1.91	800	9.94	200	2.30

The Langlier Index can be computed from the formula, Langlier Index = pH – pHs

Marble Test

A quick method for computing the calcium carbonate saturations of water is the use of the marble test. To conduct this test the pH, alkalinity, temperature and hardness of the water is required. Two samples of water are collected in flasks and stoppered being careful to avoid splashing in the flask. One gram of powdered calcium carbonate is added and mixed in with the water in the water in one of the flasks. The flasks are stoppered and allowed to sit for one hour. The values for pH, alkalinity, hardness and temperature are measured for both flasks. The following observations indicate the tendency of the water to be corrosive or scale forming.

Table 60

Scale or Corrosivity of Water Observed by the Marble Test

Sample Compares	Water Stability	Water Condition
pH and Alkalinity Increases	Water is Corrosive	Water was Under saturated with Calcium Carbonate
PH and Alkalinity Decrease	Water is Scale Forming	Water was Supersaturated with Calcium Carbonate
PH and Alkalinity about the same	Water is Stable	Water Saturated with Calcium Carbonate

Chelation

Chelation is a chemical treatment process used to control scale formation. The chemical added is known as a chelating agent. It is a water-soluble compound that captures scale-causing ions in solution, preventing precipitation and scale formation. There are several natural organic materials in water that have chelating ability, including humic acid and lignin. When added to water, the chelating agent reacts with calcium ions to keep them in solution and prevent the formation of calcium carbonate scale. In Equation 51, the 'y' represents the chelating agent.

$$2Ca^{+2} + Na_4Y - Ca_2Y + 4Na^+$$

Sequestration.

Sequestration is a chemical addition treatment process that controls scale. The chemical added to the water sequesters, or holds in solution _, scale-causing ions such as calcium, iron and manganese: thus preventing them from precipitation and forming scale. Any one of several polyphosphates may be used in this process. The most commonly used is sodium hexametaphosphate, $(NaPO_3)_6$. A common dosage for scale prevention is approximately 0.5 mg/L.

Controlled $CaCO_3$ Scaling

One commonly practiced form of corrosion management is controlled $CaCO_3$ scaling. As stated at the beginning of this section, there are three conditions water can have relative to scale formation and corrosion. Water may be corrosive, stable, or scale forming. By carefully controlling the pH/alkalinity adjustment, the condition of water can be altered so that it is slightly scale forming. Eventually the scale will build up beyond the desired thickness. Adjusting pH and alkalinity to a point that is slightly corrosive will then dissolve the excess scale.

Controlled scaling requires careful and continuous laboratory monitoring, since the slightest change in the quality of water may require a change in the amount of lime needed. It is also necessary to monitor the thickness of the $CaCO_3$ coating developed in the distribution system pipeline. The coating should be thick enough to prevent corrosion without obstructing the flow of water.

Other Chemical Protective Coatings

There are two other chemicals used to create protective coatings in pipelines: (1) polyphosphates and (2) sodium silicate. Polyphosphates include sodium hexametaphosphate ($(NaPO_3)_6$), sold under the name "Calgon"; sodium pyrophosphate (NaP_2O_7), sold under the trade name "Nalco", and a group known as "bimetallic glassy phosphates." After being fed into the water, polyphosphates form a phosphate film on interior surfaces protecting them from corrosion. Polyphosphates are also effective as sequestering agents for preventing calcium carbonate scale and for stabilizing dissolved iron and manganese. Dosages of 5-10 mg/L are recommended when treatment is initiated. After one to two months protective film is established. The dosages are then reduced and maintained at approximately 1 mg/L.

Sodium silicate ($Na_2Si_4O_9$), or water glass, can also be used to control corrosion in water systems. Sodium silicate combines with calcium to form a hard, dense calcium silicate film ($CaSiO_3$). Dosages vary widely depending on water quality.

Stabilization Chemistry

Water ionizes to a slight degree producing both hydrogen and hydroxyl ions:

$$H_2O \leftrightarrow H^+ + (OH)^-$$

It may be said that water is both an acid and a base because it produces both hydrogen and hydroxyl ions.

Since these are present in identical concentrations, however, water is considered neutral. It is known that water ionizes to the extent that the concentration of each of the ions, H+ and (OH)-, is 1 molecular weight/ 10,000,000 per liter.

A short mathematical way of writing this concentration is 1/10^7 Molar, the reciprocal of the hydrogen ion concentration + 1 x 10^7 and the logarithm of the reciprocal of the hydrogen ion concentration (pH) = 7.0. Since, as we noted previously, in pure water the hydrogen ion concentration equals the hydroxyl ion concentration p(OH) also equals 7.0. From a chemical law, called "The Law of Mass Action", we k now that whenever water is present H + X (OH)- a constant value = 1 x 10^14, or, in other words pH+p(OH)=14.

It is not necessary, therefore, for us to determine both pH and p (OH); all we need to do if p(OH) is desired is measure pH (with an instrument designed for the purpose) and subtract the value from 14. There are several water treatment processes, notably chlorination and coagulation, which are affected by pH of the water.

Table 61

The pH Scale.
Hydrogen ion Concentrations in Terms of Molecular Weight vs. pH

A Gram molecular weight of H^+ ions per liter (M)	B Reciprocal of A	C Log B (pH)		
1.0	1.0	0		
0.1	10	1	↑	
0.01	100	2		Acid
0.001	1,000	3		
0.0001	10,000	4		
0.00001	100,000	5		
0.000001	1,000,000	6		
0.0000001	10,000,000	7	(neutrality)	
0.00000001	100,000,000	8		
0.000000001	1,000,000,000	9		
0.0000000001	10,000,000,000	10	↓	Alkaline
0.00000000001	100,000,000,000	11		
0.000000000001	1,000,000,000,000	12		
0.0000000000001	10,000,000,000,000	13		
0.00000000000001	100,000,000,000,000	14		

Careful examination of this table discloses several important facts

1. When the hydrogen ion concentration is highest, pH is lowest
2. When the hydrogen ion concentration is lowest, pH is highest.
3. Neutrality at pH 7 is midpoint in the scale; pH values lower than 7 represent higher hydrogen ion concentration (more acid) than neutrality and pH values higher than 7 represent lower hydrogen ion concentrations (more alkaline) than neutrality.
4. pH values between the values listed in column C represent hydrogen concentrations between those listed in column A and column B. For example, pH 5.5 represents a H+ ion concentration of 0.00000316-gram molecular weight/liter (3.16 X 10^-6 gram molecular weight/liter). The value 0.00000316 would appear in column A and the corresponding value in column B is 316,000.

pH Altering Ability of Water Treatment Chemicals

Table 62 is a listing of common chemical used in water treatment to raise or lower pH.

Table 62

Some Common Chemicals Used in Water Treatment and Their Effect on pH

Lower pH	Raise pH
Gas Chlorine	Sodium Hydroxide (Lye)
Sulfuric Acid (Muriatic)	Calcium Hydroxide (Lime)
Carbon dioxide	Sodium bicarbonate (Soda)
Alum	Sodium Carbonate (Soda Ash)
Ferric Chloride	Calcium Hypochlorite
Hydrofluosilicic Acid	

Equivalents of Acids and Bases

An equivalent weight of an acid is the weight of an acid, which will supply one-gram molecular weight of H+ ions (1.0 gram) in a liter of solution of the acid in water. For acids, which ionize to produce one H+ ion per molecule of the acid, an equivalent weight of the acid is the same as its molecular weight. This concept is very important in determining the acid or base reactions that will take place in water when acids or bases are added.

Softening

Water Hardness and Softening

Water hardness is a measure of the soap consuming ability of water. In addition to this, hardness causes deposits to shorten the life of fabrics by deposits lodging in fabrics. The major problem with hardness from a treatment standpoint is that water hardness causes scale formation. Hard waters form carbonate deposits or scales in pipelines and boilers. The cations (positive ions) of Calcium, Magnesium, Iron and Manganese technically cause water hardness, but Calcium and Magnesium hardness are generally present in significant concentrations and therefore hardness is an expression of these two concentrations. Water hardness must either be removed or chemically bound to prevent scaling from damaging treatment plant equipment, pipelines and plumbing fixtures.

For domestic consumption, water is considered soft when the hardness is below 90 mg/l expressed as a calcium carbonate equivalent. Hardness between 90 and 130 mg/l are generally acceptable by a consumer. Hardness above 250 is considered too hard for domestic use.

Water Softening Terminology

The processes for alkalinity adjustment used in water softening are used in many water treatment processes. Familiar with the terms used in water softening and their meaning is important. Some are shown in the table below.

Table 64

Water Softening Terms

Term	Definition
Hardness	A characteristic of water caused mainly by the salts of Calcium and Magnesium. For softening purposes the hardness caused by other cations is generally small and ignored in the softening process.
Calcium Hardness	Hardness causes by the cation Ca++
Magnesium Hardness	Hardness caused by the cation Mg++.
Carbonate Hardness	Carbonate hardness is the combination of the hardness caused by carbonate and bicarbonates of Calcium and Magnesium. It does not include the hardness caused by sulfates.
Non-carbonate Hardness	Non-carbonate hardness is the hardness caused by sulfates. When dealing with hardness removal by lime addition, the non-carbonate hardness is not removed and remains as hardness.
Calcium Carbonate Equivalent	An expression of the concentrations of the various hardness constituents in water equivalent to their value as Calcium Carbonate. The conversion allows for a quick method for calculating chemical dosing for multi-constituent hardness removal.
Alkalinity	The capacity of the water to neutralize acids expressed by how much acid must be added to a water to reduce its pH to 4.5. Alkalinity is the measure of carbonate, bicarbonate and hydroxide present in the water.
Bicarbonate Alkalinity	The potion of the alkalinity of the water when the pH is between 4.5 and 8.3. At a pH of 4.5 there is no alkalinity present and the carbon in the water is in the form of CO2.
Carbonate Alkalinity	The portion of the alkalinity of the water when the pH of the water is between 8.3 and 11.3.
Hydroxide Alkalinity	The portion of the alkalinity of the water when the pH is above 8.3.
Total Alkalinity	The combination of the Bicarbonate, Carbonate and Hydroxide alkalinity.
Natural Alkalinity	The combination of Bicarbonate and Carbonate alkalinity or the total alkalinity below a pH of 8.3 (since no Hydroxide alkalinity can exist.)

Alkalinity

Alkalinity is measured in the laboratory by addition of color indicators that indicate the amount of Bicarbonate, Carbonate and Hydroxide Alkalinities (Total Alkalinity) that are preset. The Methyl Orange indicator is used to determine the Total Alkalinity (T), the combination of Carbonate, Bicarbonate and Hydroxide Alkalinity. The color indicator Phenolphthalein (P) is used to determine the amount of Hydroxide and Carbonate Alkalinity by titrating the water to a pH of 8.3. From these titrations the constituents of Carbonate, Bicarbonate and Hydroxide alkalinity can be determined. Table 65 is used to determine the amounts of the Carbonate, Bicarbonate and Hydroxide alkalinities present after titration with Phenolphthalein (P) and Methyl Orange (T) color indicators.

Table 65

Alkalinity Constituents in Drinking Water

Based on Titrations with Phenolphthalein (P)
and Methyl Orange (T) Color Indicators

Equations	Titration Result	Bicarbonate ph 4.5 to 8.3	Carbonate >PH 8.3	Hydroxide >11.3
1	P = 0	T	0	0
2	P < ½ T	T – 2P	2P	0
3	P = ½ T	0	2P	0
4	P > ½ T	0	2T-2P	2P-T
5	P = T	0	0	T

The operator should study the example below to help with the understanding of the use of the Table.

Example 1

Titration results give a Phenolphthalein (P) value of 34 mg/l as CaCOC3 and 180 mg/l as and Methyl Orange (T) alkalinity. What are the Carbonate, Bicarbonate and Hydroxide Alkalinity constituents in the water.

Given T = 180 mg/l
P = 34 mg/l

Compute Values for T and for P to use the Table

T = 180 mg/l
½ T = 90 mg/l
P = 34 mg/l

Refer to Table and observe that P < ½ T and that the Equations in Line 2 of the Table will be used

P < ½ T 34 mg/l is less than 90 mg/l determined above
Compute Values for 2P or 34 mg/l X 2 = 68 mg/l

Bicarbonate Alkalinity = T – 2P or 180 mg/l – 68 mg/l or 118 mg/l
Carbonate Alkalinity = 2P or 68 mg/l
Hydroxide Alkalinity = 0 Line 2 of the Table

In using the Table the operator must find the Line on the Table that governs the alkalinity relationships and use plug the appropriate values into the equations to determine the various alkalinity constituents.

Alkalinity Reactions

When acid is added to water that contains only a high concentration of Hydroxide, OH^- ions predominate, this water is very high in pH. When acid is added H+ ions are released by the acid and combine with the OH^- ions in the water to form H_2O. As long as the water contains OH- ions, those ions will neutralize the added acid and the water will remain basic. After enough acid has been added to combine with all the OH– ions, addition of more acid will give the water a high concentration of H^- ions—the water will become acidic.

However, if acid is added to water containing carbonate (CO_3^{-2}) ions in addition to OH – ions, then some of the H+ ions released by the acid will combine with the OH^- to form H_2O, and some will combine with the CO_3^{-2} ions to form HCO^-_3 (bicarbonate). As more acid is added, the H^+ ions released will combine with the HCO^-_3 ions to form H_2CO^3 (carbonic acid). A concentration of H^+ ions will begin to accumulate (the water will become acidic) only after enough acid has been added to convert all the OH^- to H_2O and to concert all the CO^{-2}_3 to HCO^-_3 and then to H_2CO_3.

The CO^{-2}_3 and HCO^-_3 ions in the water increase the capacity of the water to neutralize (or Buffer) an acid. Alkalinity is measured of water's capacity to neutralize an acid, whether the neutralization is the result of OH-, CO^{-2}_3, HCO^-_3, or other negative ions.

In water treatment, OH^-, CO^{-2}_3, and HCO^-_3 are ions causing most of the alkalinity. Alkalinity caused by OH^- is called Hydroxyl alkalinity; if caused by CO^{-2}_3 it is called Carbonate alkalinity; and if caused by HCO^-_3 it is called Bicarbonate Alkalinity. The combined effect of all three types is reported by a lab as the Total Alkalinity.

Recarbonation

Lime softened water is supersaturated and if not recarbonated will deposit calcium and magnesium carbonates on the filters and distribution piping. Recarbonation is the process to reduce the high pH of the treated water in the softening process and make the water stable. Without recarbonation, lime softened water can have a detrimental affect on sand filters. The sand grains can be cemented together forming hard lumps. To prevent excess buildup of calcium and magnesium carbonate on the filters the pH of the water is reduced to reach stability. The stability of water is computed by the Langlier Index.

Compliance with Stage 1 Disinfectants and Disinfectant Byproducts Rule

Stage 1 Disinfectants and Disinfectant Byproducts Rule Application

The Stage 1 Disinfectants and Disinfectant Byproducts Rule that took effect on January 1, 2004, applies to all community water systems and non-transient community water systems that add chemical disinfectants as well as transient community water systems that use chlorine dioxide. However, systems need to monitor at different frequencies depending on the source water. Surface water sources and ground waters under the direct influence of surface water must monitor more frequently. Requirements for additional monitoring and corrective actions are triggered by initial monitoring results. The trigger is a sample that exceeds either 0.80 mg/l for TTHM or 0.60 mg/l for HAA5. Table 69 describes the general requirements for monitoring by system size for ease of presentation, a Subpart H System is on that uses surface water as a source or that uses ground water under the direct influence of surface water. .

Table 66

General Monitoring Requirements for Stage 1 Disinfectants and Disinfectant Byproducts Rule

Monitored Parameters	Subpart H 500-9,999 people	Subpart H > 500 people	Ground Water <10,000 people
TTHM	1 sample per plant per quarter year	1 sample per plant per year at month of warmest temperature	1 sample per plant per year at month of warmest temperature; may reduce if TOC in source water < 4.0 mg/l and annual average TTHM is .>.04 mg/l***
HAA5	1 sample per plant per quarter year	1 sample per plant per year at month of warmest temperature	1 sample per plant per year at month of warmest temperature; may reduce if TOC in source water < 4.0 mg/l and if annual average is > .30 mg/l***
Chloramines	Only if chlorine is used as a residual disinfectant; same time as coliform samples are taken	Only if chlorine is used as a residual disinfectant; same time as coliform samples are taken	Only if chlorine is used as a residual disinfectant; same time as coliform samples are taken
Chlorine Dioxide	Only if chlorine dioxide is used	Only if chlorine dioxide is used	Only if chlorine dioxide is used
Bromate	Only if ozone is used	Only if ozone is used	Only if ozone is used
Chlorite	Only if chlorine dioxide is used	Only if chlorine dioxide is used	Only if chlorine dioxide is used

Monitored Parameters	Subpart H 500-9,999 people	Subpart H > 500 people	Ground Water <10,000 people
DBPP Precursor removal*	Only if conventional filtration treatment is used	Only if conventional filtration treatment is used	No

* Precursor removal consists of enhanced coagulation/enhanced softening
** Convention filtration treatment consists of coagulation, flocculation, sedimentation and filtration
*** Also can reduce TTHM and HAA5 monitoring frequency if two consecutive years annual average values are < 0.20 TTHM and 0.15 HAA5.

Disinfection Byproduct Formation

When free chlorine is added to source waters containing natural organic material (NOM) chemical reactions will occur, which produce Disinfection Byproducts (DBP). NOM is the precursors of Disinfection Byproduct (DBP) formation. NOM in source 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. The three methods of reducing precursors are shown in Table 67.

Table 67

**Precursor Reduction Strategies for
Reducing Disinfection By Product Formation**

Precursor Reduction Strategy	Precursor Reduction Effect
1. Source water selection and control	This might include selection of higher quality water or managing incoming organic matter
2. Removal of Precursors by treatment	Conventional or enhanced treatment can remove 15% to 50% of organic substances
3. Disinfection Strategy Selection	Disinfection application points and/or selection of different primary or secondary disinfectants can significantly reduce DBP formation potential

Identification of Natural Organic Material (NOM)

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 test (TOC) gives a good approximation of the DBP precursors present. Dissolved Organic Concentration (DOC) requires the TOC to be filtered though a 0.45 um filter.

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 non-humic materials and values above 4 to 5 indicate waters with primarily humic materials present.

Disinfection Byproducts (DBP) is 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 t o 5 mg/l, a temperature of 25 degrees centigrade 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 ± 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

DBP 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.

DBP 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. The bromine replacement in the methane compound is a particular reaction caused by free chlorine. When bromide compounds are present, chlorine oxidizes bromide ions resulting in the formation of free bromide that reacts with the organic material to produce bromoform, bromodichloromethane, dibromochloromethane, monobromoacetic acid and dibromoacetic acid. Three of these compounds are THMs and 2 of them are Haloacetic Acids and part of the HAA5 group regulated by the Safe Drinking Water Act.

The Safe Drinking Water Rule 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) or HAA5s. The groups of compounds that make up TTHMs and HAA5s regulated under the Safe Drinking Water Act listed in Table 68.

Table 68

List of Components for
Total Trihalomethanes (TTHM) and Haloacetic Acids (HAA5)
Produced by the Addition of Chlorine to Natural Waters

Total Trihalomethanes	Haloacetic Acids
Chloroform	Monochloroacetic Acid
Bromoform	Dichloroacetic Acid
Bromodichloromethane	Trichloroacetic Acid*
Dibromochloromethane*	Monobromoacetic Acid
	Dibromoacetic Acid

* These compounds are also regulated under the SDWA

The factors governing TTHM and HAA5 Disinfection By Product formation are shown in Table 69.

Table 69

Factors Governing TTHM and HAA5 Formation

DBP Production Factor	Effect on TTHM and HAA5 Formation
Temperature	The higher the temperature the faster the production of TTHMs and HAA5s.
Contact Time	The greater the contact time the higher the production of TTHMs and HAA5s.
PH	The higher the pH the higher the production rate for TTHMs Higher pHs effects vary for HAA5s. Higher pH increase Dichloroacetic Acid, show little effect on Dibromo and Monochloro and actually lower Trichloroacetic formation
Organic Material Present	The greater the concentration the higher the production of TTHMs and HAA5s.

Treatment Methods to Remove DBPs

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 DBP Rule sets process performance standards for TOC removal for surface and GWUDI water treatment plants.

Disinfection Byproducts (DBP) and Chlorination Considerations

Disinfection is typically practiced in water treatment plants by pre-disinfection, primary disinfection and secondary disinfection. These are identified in Table 70**.**

Table 70

Disinfection Practices in a Water Treatment Plant and their Purpose

	Type of Disinfection	Purpose in Water Treatment
1	Pre-disinfection	Added prior to the treatment process. Provides inactivation of pathogens. Controls algae and microbial growth. Aids coagulation. Controls tastes and Odors.
2	Primary Disinfection	Used in treatment process with the primary goal of achieving microbial inactivation.
3	Secondary Disinfection	Used primarily to maintain residual disinfectant throughout the water distribution system.

DBP are formed when free chlorine comes in contact with precursors (organic material) in the water. When precursors can not effectively be removed, it is sometimes necessary to change to another method of disinfection Since DBP's are produced by the reaction of free chlorine with organic material, changing to the use of combined chlorine in the treatment process is often used. Combined chlorine is produced by the introduction of ammonia.

The use of combined chlorine residual can result in other problems. First combined chlorine residual is not as an effective disinfectant as free chlorine residual, it will not control biological growth in the plant or the distribution system and this can lead to a process called nitrification that results in the production of nitrite that exerts an extremely high chlorine demand. Nitrification is problematic in warm water conditions, at an optimal pH of 8.4 and where ammonia and oxygen are present in the water. Of particular concern are water storage tanks and dead ends of distribution mains.

Some water treatment plants have switched to other disinfectants such as ozone and chlorine dioxide. However both of these disinfectants can also be problematic.

Ozone is particularly reactive with bromide products found in natural waters. Natural waters impacted by seawater and most surface waters have concentrations of bromide compounds in sufficient concentration to be of concern. When water contains bromide products, ozone addition will produce bromate a regulated compound.

Sulfur Dioxide does not produce DBP but can produce Chlorite a regulated compound as a residual. Sulfur Dioxide addition must be tightly controlled.

DBP and Disinfection Residual Health Impacts

DBP are dangerous to human health. They can be carcinogenic (cancer causing), can cause reproduction problems, and can damage to blood or kidneys. Similarly disinfection residual products can be carcinogenic. Consequently both type of compounds are regulated by the Safe Drinking Water Act. Control of DBPs and Disinfection Residuals at the same time is called Simultaneous Compliance.

MCLs for Disinfection By Products and Disinfection Residuals

Table 71 identifies the MCLs for DBP and Disinfection Residuals.

Table 71

Regulated Disinfection By Products and
Disinfection Residuals by the
Safe Drinking Water Act

Disinfection By Product	MCL		Disinfection Residual	MRCL***
TTHM	.080 mg/l		Chlorine	4 mg/l
Bromodichloromethane (MCLG)****	0 mg/l			
Bromoform (MCLG)****	0 mg/l		Chloramine	4 mg/l
Dibromochloromethane (MCLG)****	.06 mg/l			
HAA5	.060 mg/l		Chlorine Dioxide	0.8 mg/l
Dichloroacetic Acid (MCLG)****	0 mg/l			
Trichloroacetic Acid (MCLG)****	.3 mg/l			
Chlorite (MCLG)****	1.0 mg/l 0.80 mg/l*			
Bromate (MCLG)****	0.010 mg/l ** 0 mg/l			

* associated with the use of Chlorine Dioxide
** associated with the use of Ozone
*** Maximum Residual Concentration Level (MRCL)
**** Maximum Concentration Level Goal (non-enforceable at this time)

Enhanced Coagulation and Enhanced Softening

Enhanced coagulation is the term used to define the process of obtaining improved DBP precursor removal using conventional treatment. Enhanced softening refers to the process of obtaining improved DBP precursor removal using precipitative softening. Because TOC is easily measured and monitored the treatment technique uses a TOC removal requirement.

USEPA has established a standard protocol for Jar Testing that sets acceptable TOC removal based on changes in removal efficiencies for TOC over a range of coagulation additions at certain alkalinities and pH. The operator is referred to USEPA's Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual for more specific information on conducting these jar tests and their applicability to specific water treatment systems.

All public water systems are required to meet the MCLs and MRCLs shown in the table above. However, USEPA does allow variances from meeting these regulations if Best Available Technology is being employed. The variances are shown in Table 72 below.

Table 72

Variances for Disinfection By Products (DBP) and Disinfectants for Water Treatment Systems Using Best Available Technology (BAT)

Variance Request	Chemical	Best Available Technology
Disinfection	TTHM and HAA5	Enhanced Coagulation or GAC, with chlorine as the primary disinfectant
By	Chlorite	Control of Treatment Processes to reduce disinfectant demand and levels
Product	Bromate	Control of treatment process to reduce Bromate
Disinfectant	Chlorine, Chloramine And Chlorine Dioxide	Control of Treatment Processes to reduce disinfectant demand and levels

Timetable for meeting DBP Rule

The Disinfection Byproducts rule applies to all community water systems and all non-transient community water systems that add chemical disinfectant. Subpart H systems (surface water source or GWUDI) that serve greater than 10,000 people were required to be in compliance by January 1, 2002. Subpart H systems that serve less than 10,000 people were required to be in compliance by January 1, 2004. Systems that made a clear and irrevocable financial commitment before the applicable compliance date to install technologies to limit TTHM to 0.04 mg/l and HAA5 to 0.03 mg/l must have the technologies installed and operating.

Additionally, Subpart H systems that use conventional treatment must implement enhanced coagulation or enhanced softening to meet TOC removal levels specified in the following table.

Table 73

Required Removal of Total Organic Carbon (TOC) For Water Treatment Plants Using Conventional Treatment

Source Water TOC	Source Water Alkalinity mg/l	Source Water Alkalinity mg/l	Source Water Alkalinity mg/l
	0 to 60	> 60 to 120	> 120
> 2.0 mg/l – 4.0 mg/l	35.0%	25.0%	15.0%
> 4.0 mg/l – 8.0 mg/l	45.0%	35.0%	25.0%
> 8.0 mg/l	50.0%	40.0%	30.0%

Conventional Water Plants do not have to meet the above requirements if they can meet one of the following six criteria:

Table 74

Variance Criteria for TOC Requirements for Treatment Plants Using Conventional Treatment

1	Source Water TOC < 2.0 mg/l
2	Treated Water TOC < 2.0 mg/l
3	Source Water SUVA ≤ 2.0 mg/l
4	Treated Water SUVA ≤ 2.0 mg/l
5	Source Water TOC < 4.0 mg/l, Source Water Alkalinity > 60 mg/l as ($CaCO_3$), TTHM < 40 ug/l, HAA5 < 30 ug/l
6	TTHM < 40 ug/l, HAA5 < 30 ug/l with only chlorine for primary disinfection and maintenance of a residual

Or for Plants Using Softening;

	(Softening Plants must meet one of the above and one of the below)
1	Softening that results in lowering the treated Alkalinity < 60 mg/l, measured monthly and calculated quarterly as a running average
2	Softening that results in removing at least 10 mg/l magnesium hardness as measured monthly and calculated quarterly as a running average

Pathogen Requirements

The Total Coliform Rule (TCR) that was implemented by USEPA in 1989, set a Maximum Concentration Level Goal (MCLG) of zero. The rule applies to all public water systems.

USEPA also set a MCL for coliform. Coliform can be easily detected in water and they indicate the water system's vulnerability to pathogens in the water. If 5% of the samples collected in the required monthly water distribution system samples, contain coliform, the water system operator must report this violation to the state and to the public.

EPA also implemented the Surface Water Treatment Rule (SWTR) in 1989. The SWTR applies to all public water systems that use surface or ground water under the direct influence of surface water (all Subpart H Systems).

Table 75

Maximum Contaminant Levels Goals (MCLG)
for Pathogens and Coliform
Under Safe Drinking Water Act

Pathogen	MCLG	Applicability
Giardia lamblia	0	Surface/GWUDI
Viruses	0	Surface/GWUDI
Legionella	0	Surface/GWUDI
Cryptosporidium	0	Surface/GWUDI
Coliform	0	All Public Water Systems

Water Treatment Performance Standards for Pathogen Removal

To meet the Safe Drinking Water Act Goals the Surface Water Treatment Rules (SWTR) requires that Subpart H systems have sufficient treatment to reduce the source water concentration in the source water of Giardia lamblia and Viruses by 99.9% (3 log) and 99.99% (4 log) respectively. A detectable disinfection residual must be maintained throughout the distribution system. For systems that filter, the adequacy of the filtration process is determined by measuring effluent turbidity.

The Interim Enhanced Surface Water Treatment Rule IESWTR set a Maximum Contaminant Goal of 99% (2 log) removal for Cryptosporidium and set turbidity standards for Subpart H systems that filter. The following Tables summarize the requirements.

Table 76

Subpart H Requirements for
To Ensure Pathogen Protection

Pathogen or Process	Reduction/Treatment Required
Giardia lamblia	99.9% 3 log reduction
Viruses	99.99% 4 log reduction
Cryptosporidium	99% 2 log reduction*
Turbidity (applies to conventional or direct filtration; those that do not filter must submit watershed control plan)	95% of distribution samples taken each month must be $\leq$ 0.3 NTUs and at no time can turbidity > 1 NTU

Plants meeting the turbidity requirement are assumed to meet the Cryptosporidium requirements.

Requirements for Subpart H Surface Water Systems in Florida

The State of Florida has implemented rules related to the disinfection and filtration of surface waters and ground water under the direct influence of surface water, and for the recycle of filter backwash. All of these systems must employ disinfection and filtration.

The State requires that that the water treatment processes be properly installed and operated to meet the 3-log and 4-log inactivation requirements for Giardia and Viruses. The State provides the following inactivation credits for properly operated filtration processes.

Table 77

Filtration Credits for
Giardia and Virus Removal

Filtration Type	Log Credit Removal for Giardia lamblia	Log Credit Removal for Viruses
Conventional	2.5	2.0
Direct	2.0	1.0
Slow Sand	2.0	2.0
Diatomaceous Earth	2.0	1.0

Since these credits do not provide in themselves the necessary 3-log and 4 log microbial inactivation, the remainder of the inactivation must be determined using microbial inactivation potentials provided by disinfection and described in the sections below.

For systems that serve fewer than 10,000 people, these systems must take necessary steps to address any deficiency identified in a sanitary survey and respond within 45 days of the survey indicating how and the schedule for correction.

Systems that fail to achieve compliance, FDEP will require a composite correction program (CCP) that includes a comprehensive performance evaluation (CPE) and a comprehensive technical assistance program (CTA).

Microbial Inactivation Potential

Pathogens such as Giardia lamblia, Cryptosporidium and Viruses are very difficult and expensive to measure. Removal rates were established by USEPA using best practices at many water treatment facilities. These performance standards have been substituted and can reasonably be expected to achieve the desired pathogen water quality requirements.

Disinfection Profiling and Benchmarking

All Subpart H systems that serve more than 10,000 people must perform disinfection profiling and benchmarking.

Simultaneous compliance requires the water treatment plant to be in compliance with both DBP and with microbial requirements. Surface water or GWUDI systems having average annual TTHM > 0.064 mg/l annual average or HAA5 0.048 mg/l as a result of data or specific monitoring must develop a disinfection profile.

The disinfection profile is a compilation of daily inactivation of Giardia (and in some cases viruses) based on daily disinfectant residual, pH, temperature and peak flow that affect the efficacy of the disinfection process (the Microbial Inactivation Potential) over one year.

The disinfection benchmark is the lowest monthly average microbial inactivation potential for the year. The benchmark is used to evaluate the inactivation effects of process modifications to reduce DBPs.

The disinfection profile and benchmarking is performed to ensure that there is no loss in microbial protection as a result of changes in disinfection practices to meet the DBP MCLs.

Disinfection profiles must include disinfectant residual concentration, pH and temperature, daily at each disinfection sampling point. The measurements must be taken at peak hourly flow. The measurements must be retained by the public water system for review at the 3-year sanitary survey interval.

Determining Microbial Deactivation Potential

Free chlorine has been found to be extremely effective as a disinfectant. However, in many instances it will be necessary to tightly control chlorine addition to meet DBP removal requirements. The effectiveness of a disinfectant relies on the added concentration and the contact time with the microbe. To achieve DBP reduction it may be necessary to reduce free chlorine and/or reduce contact time (CT). Both of these steps reduce disinfection ability while reducing DBP formation potential.

Some treatment systems have chosen to change the disinfectant, change the application point or use a combination of disinfectant and application points. The effectiveness of changing disinfectants is unique to each water treatment plant. Disinfectants that reduce DBP formation potential are the use of Chloramines, Ozone or Chlorine Dioxide. These can be used separately or in combination to reduce DBP formation.

When achieving higher levels of DBP removal, the benchmark establishes the point at which degradation in the microbial deactivation potential will occur. The benchmark is used to calculate the effect of a disinfection or plant process change on the average log Giardia and virus deactivation potential.

Whatever disinfectant(s) is used in the treatment plant, deactivation potential will be dependant on the concentration of the disinfectant times the amount of time it is in contact with the pathogens.

Determining Contact Times for Disinfection Profiles

The contact time for a perfect plug flow is calculated by dividing the volume of the vessel by the flow rate. This contact time is called "plug flow" and in reality only occurs in pipelines. All basin flows are considered to have some short-circuiting and must be individually evaluated.

Actual contact time in a basin is dependent on its shape, inlet, and outlet and baffling. Tracer tests can be used to identify the actual detention time in a basin but these are difficult to conduct and must be conducted over a wide range of conditions for long periods of time. For this reason average values based on basin configurations have been developed to estimate actual contact times.

Actual contact time (T_{10}) is the time which 90% of all the water passing though the basin is retained. Contact time can be improved by adding baffling that intercepts and redirect basin currents.

Table 78 identifies baffling classifications that can be used to estimate T_{10}. T_{10}/T is also called the Baffling Factor (BF) and is used to compute actual contact times in the following equation.

Actual Contact Time (T) = Calculated Theoretical Contact Time under Plug Flow conditions X BF

Table 78

Baffling Classifications for Basins Estimating T_{10} and Baffling Factor (BF)

Baffling Condition	BF or T_{10}/T	Description
Unbaffled	0.1	No baffles, agitated basin, very low length to width ratio, high inlet outlet velocities
Poor	0.3	Single or multiple unbaffled inlets and outlets, no intra-basin baffles.
Average	0.5	Baffled inlets or outlets, with some intra-basin baffles.
Superior	0.7	Perforated inlet baffle, serpentine or perforated intra-basin baffles, outlet weir or perforated launders.
Perfect (plug flow)	1.0	Very high length to width ratio (pipeline flow). Perforated inlet, outlet and intra-basin baffles.

Inactivation Tables for Giardia and Viruses

C_T Values for 3-Log inactivation of Giardia Cysts and 4-Log inactivation of Viruses have been developed for Free Chlorine and are found in the LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual. C_T Values are provided over a wide range of temperature and pH conditions. The manual can be obtained from USEPA or from FDEP.

Determining the Plant Disinfection Profile and Benchmark

The determination of s plant disinfection profile and benchmark is a step process of computing the disinfection residual and C_T value to determine the Giardia and Virus deactivation for each segment and adding the segments to determine the plant log-inactivation profile. These steps are shown in Table 79.

Table 79

Steps in Developing Disinfection Profile And Benchmark for a Water Treatment Plant

1. Identify Disinfection Segments
2. Collect Data
3. Calculate C_T Value
4. Calculate inactivation
5. Develop the Disinfection Profile
6. Report and Evaluate the Profile

Use of the Plant Disinfection Profile and Benchmark

The water treatment plant must consistently provide the necessary log inactivation through disinfection to achieve adequate Giardia and Virus log reductions as required by the Surface Water Treatment Rule.

If a benchmark is less than the required log inactivation than the treatment plant will have to modify disinfection practices. If the benchmark is greater than the required log inactivation than the treatment plant may want to decrease disinfectant. The system must consult with FDEP before making any changes.

Typical Plant Modifications for Simultaneous Compliance

The water treatment plant must consistently provide the necessary log inactivation through disinfection to achieve adequate Giardia and Virus log reductions as required by the Surface Water Treatment Rule and meet the DBP MCLs under the SDWA. These are shown in the following Table. Prior to making any modifications the operator should consult with FDEP.

Table 80

Typical Water Treatment Plant Modifications to Achieve Simultaneous Compliance

1. Moving the point of disinfection after clarification
2. Using enhanced coagulation before disinfection
3. Developing a system to provide adequate contact time to achieve sufficient disinfection
4. Developing seasonal modifications in disinfection to reduce summer high DBP levels
5. Changing the primary or secondary disinfectant
6. Changing the contact basin geometry and/or baffling
7. Increasing the pH during disinfection > 1 unit

Maintenance Considerations for Centrifugal Pumps

Pump Construction

Centrifugal pumps have a wide application in water supply, treatment and distribution Knowledge of pump construction is basic in properly operating and maintaining centrifugal pumps. Table 81 identifies the parts of a centrifugal pump and provides considerations for protection of the pump and its component parts.

Table 81

Parts of a Centrifugal Pump

Pump Impeller

That paddle-wheel device inside a pump is called the "impeller"

Note that the blades curve out from its hub. As the impeller spins, liquid between the blades is impelled outward by centrifugal force. The impeller is open at the center and the point of entry for the water is called the "eye". As liquid in the impeller moves outward, it will suck more liquid in behind it through this eye. Pumps that take water from the outside environment such as a well pump or a suction pump in a reservoir, are provided with screens to intercept foreign materials. Sand that enters a pump will wear the impeller and caused reduced pumping over time.

Pump Shaft

The shaft is the part of the pump that turns the impeller. It must maintain the impeller in precisely the right place. The shaft must be protected from the corrosive or abrasive effects of the liquid pumped… so we must protect it with sleeves slid on from either end. The metal that is used for sleeves is generally softer material than the shaft. This is to ensure that any wear is on the sleeves and not on the stationary pumping unit.

Pump Bearings

The shaft is mounted on sleeve, ball or roller bearings depending on the application. Clearances between moving parts of a pump are *quite small*. These clearances are called tolerances.

Pump Lubrication

If bearings supporting the turning shaft and impeller are allowed to wear excessively and lower the turning units within a pump's closely fitted mechanism, the life and efficiency of that pump will be seriously threatened.

It is extremely important to keep the right amount of the right lubricant in bearings at all times. Following the pump manufacturer's lubrication instructions to the letter is best insurance for long-term protection and operation.

The main points to keep in mind with bearing lubrication are:

1. Although too much oil won't harm sleeve bearings, too much grease in antifriction type bearings (ball or roller) will promote friction and heat. The main job of grease in anti-friction bearings is to protect steel elements against corrosion, not friction.
2. Operating conditions very so widely that no one rule as to frequency of changing lubricant will fit all pumps. It is best to change lubricant before it's too worn or becomes too dirty.
3. Some utilities analyze oil and identify the amount of metal wear to optimize lubrication and

lubrication scheduling. Some lubrication vendors will provide this service with the use of their product.

:

Pump Coupling

The part that connects with the motor with a pump is called a coupling flange. Some pumps are built with pump and motor on one shaft, of course, and offer no alignment problems. Most require an attached flange to one end of the shaft through which bolts will connect with the motor flange.

The pump and motor flanges must be parallel vertically and axially. If shafts are eccentric or meet at an angle, every revolution throws tremendous extra load on bearings of both pump and motor. Flexible couplings will *not* correct this condition if there is excessive misalignment. Checking alignment should be regular procedure in pump maintenance. Foundations can settle unevenly, piping can change pump position, bolts can loosen. Misalignment is a *major* cause of pump and coupling wear. Sometimes a flexible coupling is used to connect pumps to motors. Flexible couplings will not compensate for misalignment.

Laser alignment and vibration analysis are two predictive maintenance practices that have found to be helpful in reducing alignment and resulting vibration problems. Successful use of these techniques require training and experience.

Pump Piping Considerations

The size and configuration of piping that is connected to a pump is very important. The suction piping must be:: 1) horizontal piping sloping upward toward the pump, 2) any reducer which connects between the pipe and pump intake nozzle should be horizontal at the top i.e. eccentric, not concentric. This up sloping prevents air pocketing in the top of the pipe…which air might be drawn into the pump and cause loss of suction. Loss of suction greatly endangers a pump reducing its useable life

The piping that connects to the pump must be properly sized to insure proper operation of the pump. Discharge piping should be sized so that the velocity of the water leaving the pump is 7 feet per second. Suction piping should always be larger than the discharge piping. It should be sized so that the water entering the pump is moving about 4 feet per second. The suction nozzle of a centrifugal pump should be installed in a pipe larger in size than the nozzle.

Pump Casing

The casing is the part of the pump where the suction piping bolts. And the manner in which it is attached is of great importance. It is important that the piping puts absolutely no strain on the pump casing.

Pump Support

When the original installation is made, all piping should be in place and self-supporting before connection. Openings should meet with no force. Otherwise the casing is apt to be cracked… or sprung enough to allow closely fitted pump parts to rub. It's good practice to check the piping supports regularly to see that loosening, or settling of the building, hasn't put strains on the casing.

Wear Rings

As water is sucked into the spinning impeller, centrifugal force causes it to flow outward… building up high pressure at the outside of the pump (which will force water out) and creating low pressure at the center of the pump (which will suck water in.) Since water tends to be sucked back from pressure to suction through the space between impeller and casing. Wearing rings are used to plug internal liquid leakage. Wear rings are removable and replaceable. When wear enlarges the tiny gap between them and the impeller. (Sometimes rings are attached to impeller rather than casing – or rings are attached to both so they face each other), the pump will lose pumping efficiency.

Never allow a pump to run dry (either through lack of proper priming when starting or through loss of suction when operating). Water is a lubricant between rings and the impeller. Wearing rings should be examined at regular intervals. When seriously worn, their replacement will greatly improve pump efficiency.

Stuffing Box

Stuffing boxes are used to keep air leakage out of a pump, which is apt to cause a pump to lose suction.
Each stuffing box consists of a casing, rings of packing and a gland at the outside end.

Pump Packing

Packing should be replaced periodically – depending on conditions – using the packing recommended by your pump manufacturer. Forcing in a ring or two of new packing instead of replacing worn packing is *bad practice*. It's apt to displace the seal cage. Put each ring of packing in separately, seating it firmly before adding the next. Stagger adjacent rings so the points where their ends meet do not coincide. Never tighten a gland more than necessary as excessive pressure will wear shaft sleeves unduly. Maintenance If shaft sleeves are badly scored, replace them immediately or packing life will be entirely too short.

To make packing more airtight, both water seal piping are used. In the center of each stuffing box is a "seal cage". By connecting it with piping to a point near the impeller rim, we bring liquid under pressure to the stuffing box. This liquid acts both to block out air intake and to lubricate the packing. It makes both packing and shaft sleeves wear longer, providing it's clean liquid.

Pump Sizing

The amount of water a particular centrifugal pump will put out depends on the pressure the pump must work against. These pumps are always rated at a specific gpm discharge against so many feet of head pressure (or psi). These relationships are called discharge curves and are supplied by the pump manufacturer for proper pump application. Centrifugal pumps operate over a wide range of discharge heads and flow amounts. If the discharge head (the total head that the pump must pump against) becomes greater than the design rating of the pump, the amount of water that is being pumped will be less than the designed rate. When the head pressure is less than the designed rating, more water will be pumped. For each flow and head condition the pump will operate at a different efficiency. There is a point where the head pressure rises and the pump will not be moving any water. This point is known as the "shut off head" of the pump. The designed rating of the pump is the condition under which it operates most efficiently.

The amount of water a pump is capable of moving depends on three factors; the design of the impeller, the speed which the impeller turns and the size of the impeller. When a pump is installed it is important that it is designed to pump the proper amount of water at the correct head pressure. Pumps that are not properly sized will fail to give satisfactory performance. It is good practice to purchase a pump with an impeller diameter less than the maximum impeller size, or its volume and head cannot be increased at a later date. It is also a good idea to have extra motor power should it become necessary to increase the volume and head. The pump will not use any more power than required by the conditions it must operate against regardless of motor size. Motor efficiencies will not vary greatly between ¾ load and full load.

The steps in properly sizing a centrifugal pump are shown below. Following these will result in properly sizing a pump for a given application.

Table 82

Steps in Properly Sizing a Centrifugal Pump

1. Determine the GPM:

The pump should be able to meet the peak daily demand that will be encountered.

2. Determine the discharge head:

The discharge head is the vertical distance from the centerline of the pump to the overflow of a storage tank.

3. Determine the suction head:

The suction head is the vertical distance from the surface of the water supply to the centerline of the pump. If the water supply is below the centerline of the pump, the distance is negative suction head. If the water supply is above the centerline of the pump it is known as positive suction head. Negative suction heads should never be greater than 22 feet at sea level.

4. Determine the total head:

The total head can be determined by adding the suction head to the discharge head when the water is below the pump, or by subtracting a positive suction head from the discharge head when the water is above the pump.

5. Determine the total dynamic head:

The total dynamic head (TDH) is the head at which the pump should be rated. The pump must overcome friction loss caused by water running through the piping including valves and fittings. Once the friction loss has been determined, it is added to the total head to calculate the total dynamic head.

The pump can now be selected from a pump curve according to the GPM demand and the total dynamic head that it must work against.

Pump Curves

Every pump has certain characteristics under which it will operate efficiently. These conditions can be illustrated with characteristic curves. The chart in which they are printed on should show the head capacity curve (A); the brake horsepower curve (B); and the efficiency curve (C).

To use a pump curve, start at the particular head pressure that is desired, then travel across the chart to the point where it crosses the head capacity curve (A). Drop a straight line from this point, down to the bottom of the chart to determine the gpm output at the particular head pressure. The brake horsepower can be determined by starting at the point where the vertical line crosses the horsepower curve (B) and going across to the right side of the chart. The efficiency under these conditions is determined by starting at the point where the vertical line crosses the efficiency curve (c) and going over to the right side of the chart.

If the impeller or the speed of the pump changes, all of the pump's characteristics will also change.

Impeller Design

The number of veins in the impeller and the curvature of these veins will greatly affect the characteristics of a pump. Impellers having only two or three veins with just a slight curvature, generally pump larger amounts of water at lower discharge pressures. As the number of veins increases or the sweep of the veins becomes greater, less water will be pumped, but the discharge pressures will be higher.

Centrifugal pumps also are categorized as volute or turbine. A volute pump has an impeller that with no diffuser vanes or guides and is generally used for low head, applications or low to mid range head booster applications. The turbine pump uses diffuser vanes with slightly enlarging passages and is used for high-pressure conditions. Turbine pumps are used frequently in deep well applications and can be stacked called stages where pressure is added for each stage and flows stay constant at each stage.

Pump Changes

The affinity laws for centrifugal pumps govern the replacement of a pump with a different pumping unit. The affinity laws for centrifugal pumps state that if the speed at which an impeller turns changes, the diameter, or the width of the impeller must change according to a set of rules to achieve the same pumping rate. The affinity laws describe how the flow, pump speed, head pressure, and horsepower are affected by any change to the pump. Table 83 describes the affinity laws for a centrifugal pump.

Table 83

Affinity Laws for a Centrifugal Pump

1. The amount of water pumped (Q) will change proportionally to the change in pump speed (RPM) or impeller diameter (D).

$$\mathbf{Q_1/Q_2 = RPM_1/RPM_2 = D_1/D_2}$$

2. The head pressure that the pump develops will vary according to the square of the change.

$$\mathbf{H_1/H_2 = (RPM_1/RPM_2)^2 = (D_1/D_2)^2}$$

3. The horsepower that will be required to pump the water at the new GPM and head pressure will vary according to the cube of the change.

$$\mathbf{BHP_1/BHP_2 = (RPM_1/RPM_2)^3 = (D_1/D_2)^3}$$

Example of the Use of Affinity Laws in Sizing a New Pump Installation

In order to better understand the affinity law, take the following example of a pump uses a motor that delivers 5 horsepower and turns at 1750 rpm's. In an attempt to increase the production of the pump, a new motor that will run at 2100 rpm's is being considered as a replacement. First compare the old pump motor configuration with the desired replacement.

	Old	New
RPM	1750	2100
GPM	100	120
Head (ft)	100	144
Horsepower	5	8.65 (10)

Determine the ratio of the old motor's rpm's and that of the new one. This number will be the factor used to compute the performance under the new conditions. The factor of change is computed as 1.2.

$$\frac{\text{New rpm}}{\text{Old rpm}} = \frac{2100}{1750} = 1.2$$

Compute the new gpm, head pressure and horsepower requirements:

The new GPM is determined by multiplying the old GPM by factor of the change computed above.

100 x 1.2 = 120 GPM

New head pressure is determined by multiplying the old head by the square of the factor. $(1.2)^2$

100 ft. x (1.2 x 1.2) = 144 feet of head.

New horsepower requirements are determined by multiplying the old horsepower by the cube of the factor. $(1.2)^3$

5 hp x (1.2 x 1.2 x 1.2) = 8.65 hp

The new motor must be rated at least at 8.65 HP, however, a 10 HP pump will probably have to be used.

The affinity law also applies to changes in the diameter or width of the impeller. The laws apply to all centrifugal pumps. The method of calculation for diameter and width of the impeller remains the same.

Scheduled Maintenance Programs for Centrifugal Pumps

Centrifugal pumps will give many years of service with proper lubrication and attention to wear. The most important considerations are lubrication and proper sealing of the rotating shaft. These are best addressed with a sound preventative maintenance program.

Pump Lubrication

When developing a lubrication program always refer to the manufacturer's recommendations when setting up and performing scheduled maintenance. Lubricants will be different for each pump. If the particular type of lubricant recommended by the manufacturer cannot be obtained, a cross-reference equivalent should be used. Some pumps may require special maintenance procedures that may differ from those mentioned in this manual. Always follow manufacturer's recommended maintenance procedures if this is the case. Anytime a pump is being worked on, it must be locked and tagged in the "off position.

Pumps are equipped with antifriction ball or sleeve bearings, to allow smooth rotation of the pump shaft. Pump bearings are usually lubricated with oil or grease and occasionally with gas. Well pumps are often lubricated with water. Lubricants perform a number of functions. They reduce friction and wear of the moving parts and, therefore, reduce heat buildup. They also transfer heat to the outside of the bearing housing and prevent corrosion by sealing out dirt and contaminants. Most bearings must be periodically relubricated with new oil or grease. Always follow manufacturer guidelines. When greasing bearings, open the relief plug to allow old grease to drain from the housing. Excessive amounts of grease will act as an insulator, interfering with the heat transfer the lubricant is designed to accomplish. For oil-lubricated bearings, the oil level in the feed reservoir must be periodically checked. Oil should be changed at intervals as recommended by the pump manufacturer, but no less than once a year.

Many types of oil and grease lubricants are available, including synthetic and lithium- and calcium-based lubricants. Lubricants have varying chemical components and viscosity for different purposes, which may lead to confusion when the time comes to purchase them. One electric motor manufacturer, for example, lists grease and oil lubricants sold by 24 different companies, each one available under a different brand name.

Lubricants, whether oil or grease, should be the type and viscosity recommended by the manufacturer and applied as recommended. Do not mix lubricants of different chemical compositions, because they can react chemically with each other and damage the bearings. When changing the type of lubricant, first drain the bearing housing, wash with solvent, and dry with moisture-free compressed air. Remember that lubricants in contact with drinking water must meet AWWA or National Science Foundation (NSF) specification Proper lubrication is one of the easiest and most important maintenance operations that an operator must perform. Proper lubrication can aid in sustaining the equipment's life span while improper lubrication eventually results in equipment failure. The tendency to over lubricate is probably the most common error made in pump maintenance. If the bearing reservoir is kept completely full, the grease will not be able to dissipate heat properly and lubricant failure will result. Heat will also result from under lubrication because there is not enough lubricant to cover all metal surfaces. Lubricant failure is detected by a change in the grease's color. Petroleum base grease will have the appearance of glossy brittle varnish.

Always keep grease free of dirt or other contaminants. Grease is also responsible for protecting metal surfaces from corrosion, which can be damaged from dirt and grit. Always waste the grease pun's first shot of grease just in case dirt or grit has been picked up since it was last used. Remove the grease plug located on the side of the bearing reservoir opposite the grease fitting. Add new grease until all of the old grease has been forced out through the plug. While the plug is still out, start the motor and allow it to run for about a minute. This will force the excess grease out through the plug. Replace the grease plug and clean the fittings.

Drip oilers should be inspected and filled with the proper weight and type of oil on a daily basis
A regularly scheduled maintenance program is essential to sustain the normal operating life of pumps. The oiler should be adjusted so that it feeds about 3 to 8 drops per minute.

Pump Packing Maintenance Considerations

Pump packing is one of the biggest problem areas for operators in charge of pump maintenance. More pumps have been damaged due to poor maintenance of packing than any other reason. Improperly maintained packing can cause several different problems. Below are a few:

Table 85

Problems Caused by Defective Pump Packing

1. Loss of suction due to air leak.
2. Shaft or sleeve damage.
3. Water contamination of bearings.
4. Flooding of building or pumping station.

There are a number of different types of packing available for use today. It can be round, square, braided, solid, loose, or almost any shape or form. It can be manufactured from jute, asbestos, Teflon, rubber, plastic, lead or many other types of material. Prices range from cheap (several dollars per pound) to very expensive (several hundred dollars per pound). A rule of thumb is to use the most expensive packing that you can afford. It will usually pay for itself with a longer and more trouble free life.

Table 86

Proper Steps in Replacing Pump Packing

Removing Old Packing

1. Lock and tag pump in the "off" position.
2. Isolate the pump by closing suction and discharge valves.
3. Drain pump by removing plug in the bottom of the volute.
4. Remove packing gland. If it is not split for removal, it must be backed off the shaft so packing can be removed.
5. Remove packing with a packing hook. Take care not to score the shaft with the packing hook.
6. Measure the distance to the lantern ring (seal cage) and the remove it with the packing hook. It is usually split so that it can be removed from the shaft.
7. Remove remaining packing rings and clean stuffing box and shaft.
8. Disconnect and inspect seal waterline.

Steps in Repacking a Pump

1. Determine the number of rings, the size of the packing and the location of the lantern ring.
2. Great care should be taken to keep the packing clean and free of dirt. Cut packing to proper length using a very sharp knife Packing that becomes contaminated with any foreign material must be discarded.
3. Wrap packing around the shaft or old sleeve.
4. Cut packing on shaft so that parallel ends will butt together square.
5. Cut all of the rings at once.
6. Roll packing flat with a short pipe on a clean newspaper. Never flatten with a hammer.
7. Wrap each packing ring around the shaft and insert in the stuffing box. Always open the packing ring by twisting the ring rather than pulling the ends apart. Stagger the joints so that they do not line up when installed. Make sure that the lantern ring is in the proper position when inserted.
8. Install packing gland. Make sure the gland is tightened down square to prevent damage.

Adjusting the Packing Gland

The final adjustment of the packing gland is made while the pump is running. The pump can be restarted once the discharge and suction valves are completely opened and the pump is primed. More packing jobs have been ruined by improper gland adjustment than any other single reason.

1. Tighten the gland slowly one half turn a time on each side until the leakage is reduced to the desired level.
2. One way is to allow 20 to 60 drops per minute.
3. Or tighten until the water coming out is lukewarm then back each nut off about one half turn after the pump has been turned off.
4. Pumps with grease lubrication should not leak and care must be taken not to over tighten. If the gland heats up it is too tight.
5. Keep the packing gland square at all times. Uneven take-up jams the packing and the shaft.

Mechanical Seals

Seals may be the mechanical or the packing type. Pumps use seals on the shaft to prevent intrusion of air into the pump case or loss of water when pumping.. The mechanical seal is located in a stuffing box, which provides housing for the seal. Mechanical-seal wearing surfaces must be replaced if they leak excessively.

A mechanical seal has two faces, which mate to prevent water from passing through them. One half of the seal is mounted stationary in the stuffing box while the other is mounted on the shaft and rotates. The faces of the seal are held together by a spring mounted behind one of the faces.

Mechanical seals are very expensive but last several years when properly maintained. However, they will burn up in a matter of seconds if lubrication fails and the pump must be pulled to replace one. Replacement requires special tools and procedures that vary with each type of seal. Refer to the manufacturer's specific maintenance procedures when replacing mechanical seals.

Preventative Maintenance Program

The operator should check all pumps and motors every day to insure proper operation. After spending a certain amount of time with these pumps and motors an operator should be able to tell just by listening to them whether they are working properly. More sophisticated methods include the use of vibration analysis Vibration analysis is a system of vibration measurements at each bearing that establishes a signature that can be monitored over tie to predict wear and ultimate failure.

Operating conditions vary so widely that recommending one certain schedule of preventive maintenance for all pumps would be unrealistic. Therefore, the following timetable should be considered relative. The recommended inspection and service is based on the most sever applications. A maintenance schedule must be set up and followed to get the best service out of any pumping equipment. Table 87 is a suggested maintenance program for a centrifugal pump.

Table 87

Suggested Maintenance Program for a Centrifugal Pump

Daily Inspections

Check for excessive noise
Drain and clean drip oiler or grease cup.

Monthly Inspections:

Check running temperature of bearings.
Check packing and tighten when necessary.
Check shaft rotation by hand with the pump shut off and isolate.
Grease bearings
Drain and clean drip oiler or grease cup

Six Month Inspections:

Check alignment of meter and pump.
Check for loose piping supports.
Check shaft sleeves for wear.
Vibration while pump is operating.
Check oil in motor and drip oilers. If packing is water-lubricated, check water feed lines.
Check for gallons per minute (gpm) discharge.
Check for leaks around packing and all fittings

Yearly Inspection

Tear down and inspect impeller and wear rings.
Clear water seal piping.
Inspect check valves and foot valves
Replace packing.

Preventative Maintenance Checks Recommended for Pumping Units

Pumps should be periodically checked for performance, for air in the pipelines, for excessive vibration and from blockages from foreign materials.

Pump Performance Check

The operation of a pump should be inspected at regular six-month intervals to verify that the pump discharge conforms to the pump curve. Pump discharge will decrease if abrasive materials such as sand have worn the impeller, if the impeller is clogged, or if the system is air-locked. Replacing a worn impeller and wear rings may restore a pump's performance to nearly its original design efficiency.

Pump Air Lock Check

Pump systems usually include air relief valves at high points in the suction and discharge piping to prevent air lock, a condition in which sufficient air may accumulate in the pump housing or discharge piping to prevent flow of water.

The simplest air relief is a manually operated valve on a short discharge tube. The valve may be located in a tap on the pump housing or placed on a high point in the piping. Manual air reliefs should be operated at intervals determined by the operator because each piping system will accumulate air at different rates.

Automatic air release valves are often provided in the piping system to relieve air as it accumulates without need of manual operation. Inspect automatic air release valves periodically to verify correct operation.

Vibration Check

Centrifugal pumps should. operate smoothly. Excessive vibration caused by loose foundation bolts, a broken impeller, worn bearings, misaligned shafts, or similar mechanical failure can damage the pump. If a centrifugal pump vibrates, it should be shut down and checked.

Debris Check

Well pumps often pump sand. Repairs or installation of new pipe may also introduce foreign objects like sand, gravel, rocks, or trash into the suction piping of booster pumps. If the suction piping is not equipped with a basket strainer, this material may reach the pump, impede the flow, and wear the impeller. Reduced pump discharge or unusual noise may indicate foreign material in the pump.

Problems Associated with Centrifugal Pump Operation

The four major problems associated with centrifugal pumps are cavitation, air locking, loss of prime and water hammer caused by rapid stops and starts.

Cavitation

One of the most serious problems an operator will encounter is cavitation. It can be identified by a noise that sounds like marbles are being pumped. Cavitation occurs when the pump starts discharging water at a rate faster than it van be drawn into the pump. This situation is normally caused by the loss discharge head pressure or an obstruction in the suction line. When this happens a partial vacuum is created in the pump causing the flow to become very erratic. Cavities or tiny gas bubbles are formed behind the impeller blades. As the water surges into the pump the partial vacuum is destroyed and the cavities collapse allowing the water to slam into the impeller blades. These cavities are formed and collapsed several thousand times a second accompanied by tremendous pressure. The impact created by the water slamming into the impeller is so great that pieces of the impeller may be chipped away. When cavitation occurs, immediate action must be taken to prevent the impeller from being damaged to the point it will have to be replaced. Cavitation can be temporarily corrected by pinching down the discharge valve. This action is to prevent damage to the pump until the cause can be found and corrected.

A noisy pump should be checked to see if the problem is cavitation. Modifications to the system may be necessary, such as reducing suction lift to decrease net positive suction head (NPSH) at the pump, modifying suction piping, or selecting a different pump with a lower required NPSH. Such changes often require the assistance of an experienced engineer.

Air Locking

Air locking is another common problem with pumps and is caused by air or dissolved gasses being trapped in the volute of the pump. As these gasses collect they become compressed creating an artificial head pressure within the pump housing. This artificial head will continue to build as more air is sucked into the pump until the maximum discharge head pressure (shut off head) is reached completely restricting the flow of water.

Air locking is most often caused by leaks in the suction line or failure of low level cut-off switches allowing the clear well to be sucked dry. Air locking can usually be prevented or corrected by removing the trapped air through a bleeder valve located on the suction line.

Loss Of Prime

Loss of Prime happens when the vacuum or suction lift created by the pump is broken. This occurs only when "negative suction head" conditions exist. When a pump loses its prime it must be shut down, reprimed, and all the air bled out of the suction line before starting the pump again. Loss of prime is normally caused by leaks in the suction line, worn packing, or defective check valves.

Water Hammer

Water hammer results when a moving column of water is suddenly stopped such as by the closing of a valve. A pressure wave develops at the valve and travels back upstream to the water source. Pressures developed by water hammer can be very high for a brief instant before the pressure wave is reflected back upstream. Pressure dissipates in an oscillating manner as the wave travels back and forth in the closed pipe, causing a loud banging or hammering sound. Although brief, the pressures can be high enough to damage the system piping. Installation of a pump control valve and slow operation of downstream valves may prevent water hammer.

Pump Troubleshooting

Table88 identifies common pump related problems, their cause and possible solutions.

Table 88

Centrifugal Pump Troubleshooting Guide

Problem	Possible Cause	Possible Solution
No water is delivered	Lack of Prime	Fill pump and suction pipe completely with water
	Impeller plugged	Remove top of pump and clean impeller
	Air Leak in suction line	Repair or replace suction line
	Water level below suction line	Lower the section line
	Line or strainer is blocked	Clean the strainer and remove any obstructions
	Suction or discharge valve is closed	Open valves
	Check valve is stuck	Repair or replace check valve
	Check valve installed backwards	Reverse check valve
Excessive packing leakage	Worn Packing	Replace packing
	Glands too loose	Tighten glands only enough to stop excessive leakage. Replace rings if necessary
Not enough water is delivered	Air leaks in suction	Check for leaks and repair
	Air leaks in stuffing box	Check for occasional drops of water from the stuffing box. Adjust the gland if it is adjustable or replace the packing.
	Impeller partially plugged	Remove the top of the pump and clean the impeller.
	Voltage to control box or magnetic starter is low	Check input voltage, or call power company.
	Strainer or riser pipe is clogged or corroded	Pull pump and clean strainer. Check riser pipe. Replace if necessary.
Pump has excessive vibrations	Packing is too tight	Release gland pressure. and/or rings
Pump works for a while and quits	Incomplete priming	Bleed out air in the piping and pump
	Air leak in the stuffing box	Adjust the gland. Replace packing, if necessary.
	Air leaks in the suction line	Check for leaks and repair
	Air or gases in the water	Provide a separate chamber or suction line near the pump. Periodically bleed off gas or air.
Pump has hot bearings	Over or under lubrication	Follow manufacturer's recommendations for lubrication bearings
	Grit in lubrication	Clean bearings thoroughly and replace with clean lubricant.
Pump is too noisy	Foreign matter in pump	Clean out foreign matter
	Air leaks	Check for air leaks and repair
	Air is entrapped in pump	Release entrapped air
	Pump is not completely primed	Prime pump
	Inlet is clogged	Clean inlet line to the pump
	Pump not lubricated properly	Follow manufacturer's direction for lubricating the pump.
	Strain on pumps caused by unsupported piping fastened to the pump	Secure all pipes connected to the pump.
	Foundation insecure	The pump should be located on a firm, immovable surface.
Pump does not run	Control box not mounted vertical (single phase pumps)	Remount box in vertical position

	Wiring to control box wrong (single phase pumps)	Review wiring diagram
	Thermal overload tripped	Check control box or starter
	Fuse blown in disconnect switch	Replace fuse
	Fuse too small	Check fuse size
Pump does not stop running	Pressure switch is set too high	Reset switch to a lower pressure
	Pump is set too deep in well for high setting of the pressure switch	Check maximum pump setting and tank pressure. If too deep in well, lower the "high" pressure switch setting.
	Pump is air or gas bound	Open disconnect switch allowing pump to stand idle for ½ to 1 hour, then start pump
Pump starts or stops too often	Tank water logged	Tank may have an air leak
	Pressure switch differential set too close	Check and reset the start and stop pressures

A piston or reciprocal pump should never be operated with the discharge valve closed.

Pump Motors

Pump motors come in a variety of sizes. In general those that are 3 horsepower and above are usually supplied with three-phase power. Motors are come with nameplate information that includes motor class, proper voltage and allowable current. Most motors in a water plant will be off the class B rated to operate at 104 degrees F. A motor should be warm to touch and the operator should be able to place a hand on it for 10 seconds. Ensuring that the motor is operating below 104 degrees F. and at the proper voltage and current will ensure long life and trouble free operation.

Table 89

Motor Problems, Causes and Solutions

Problem	Possible Cause	Possible Solution
Motor overheating	Overloaded	Provide ventilation of natural or forced air
	Motor is dirty	Clean motor inside and outside
Motor will not start	Fuse burned out Loose or open connection	Replace fuse Correct open condition
	Thermal overload, switch open	Determine cause, correct and close switch
	Loose wiring connections	Tighten loose connections
Motor hot	incoming service problem motor could be overloaded there could be too many starts and stops	Check voltage and amperage draw. Check powered equipment for blockages. Observe and correct improper operating conditions.
Motor Noisy	Electrical load unbalanced Excessive vibration Bad bearings	Check current balance Remove load and check vibration, correct Replace bearings

Pumps for Special Applications

Pumps perform a variety of functions critical to water supply, treatment, and distribution. Pumps of one type or another accomplish a major part of the work accomplished and energy expended in a water system.

The proper operation and maintenance of pumps, therefore, is essential to the overall performance of the water system. Loss of flow and pressure will result in customer complaints, reduced fire protection and possible damage to the water system. Improper operation of a pump will shortened it's life and increase repair and replacement costs. It is important that operators have an understanding proper application of pumps for the service desired. Table 90 illustrates the proper application of pumps for a water system.

Table 90

Pump Application in a Water System

Application	Function	Pump Type
Low service	To lift water from the source to treatment processes or from storage to filter backwashing system.	Centrifugal
High service	To discharge water under pressure to distribution system	Centrifugal
Booster	To increase pressure in the distribution system or to supply elevated storage tanks	Centrifugal
Well	To lift water from shallow or deep wells and discharge it to the treatment plant, storage facility, or distribution system	Centrifugal or jet
Chemical feed	To add chemical solutions at desired dosages for treatment processes	Positive displacement
Sampling	To pump water from sampling points to the laboratory	Positive displacement
Sludge	To pump sludge from sedimentation facilities to further treatment or disposal	Positive displacement or centrifugal

Positive Displacement Pumps

Most positive displacement pumps operate by having a piston or plunger moving back and forth in an enclosed cylinder. As the piston pulls back, suction is created that fills the cylinder with water. The piston then forces the water out of the cylinder on the return stroke. Check valves, usually the ball-type, are used to restrict the flow of water back through the pump. This type of pump will operate efficiently against a wide fluctuation in the discharge head pressure, which is limited only by the structural integrity of the pump. Positive displacement pumps are expensive and bulky. They also have a much lower operating efficiency than centrifugal pumps. Never operate a positive displacement pump while the discharge valve is closed or damage to the pump or piping will result.

Cross-Connection and Backflow Prevention

Cross Connection Definition

Cross connections are defined as actual or potential connections between a potable and non-potable water supply. A cross connection presents a serious public health hazard and there are many documented instances of contamination of drinking water.

For this reason all municipalities with public water systems are required to have a cross connection control program.

Cross Connections and Backflow

A Cross-connection means any physical arrangement whereby a public water supply is connected, directly or indirectly, with any other water supply system, sewer, drain, conduit, pool, storage reservoir, plumbing fixture, or other device which contains or may contain contaminated water, sewage or other waste or liquid of unknown or unsafe quality which may be capable of imparting contamination to the public water supply as the result of backflow. By-pass arrangements, jumper connections, removable sections, swivel or changeable devices, and other temporary or permanent devices through which or because of which backflow could occur are considered to be cross-connections.

Cross connections can occur within any part of a water system both at the plant and in the distribution system. Backflow will occur through any unprotected cross-connection where higher water pressures or backsiphonage conditions exist. Therefore, cross-connections must be eliminated or protected at all customer service locations, as well as at the water facility itself.

Principles of Backsiphonage and Backflow

Cross connections are links through which it is possible for contaminated materials to enter a potable water supply. The contaminant enters the potable water system when the pressure of the polluted source exceeds the pressure of the potable source. The action may be called backsiponage or backflow. Essential it is reversal of the hydraulic gradient that can be produced by a variety of circumstances.

In order for backsiphonage or backflow to occur there must be a connections between two sources of water and the resultant force or pressure must be higher at the contaminated source.

Backsiphonage results in fluid flow in an undesirable or reverse direction. It is caused by Atmospheric pressure exerted on a contaminated liquid forcing it toward a potable water supply. That is under vacuum.

Backflow occurs a reversal of flow produced by the difference in pressure between two systems.

Typical Cross Connections

Cross connections typically result from three reasons:

Table 91

Common Causes of Cross Connection Problems

1. plumbing is frequently installed by persons unaware of the inherent dangers of cross connections
2. connections are made a matter of convenience without regard to the dangerous situation that might occur
3. connections are made with reliance on inadequate protection such as a single valve or other mechanical device that does not provide the needed protection from backflow

The best protection against cross connections is backflow education to those that install water connections.

Primary Purpose of a Cross Connection Program

The primary purpose of a cross connection program is to define, describe and illustrate typical cross-connections and to identify methods and devices that may provide needed protection to the public without interfering with the function s of the plumbing or water distribution system.

Backpressure Backflow

Backpressure backflow occurs at a cross connection when the customer's water pressure is greater than the potable water system's pressure. When this occurs potentially contaminated water from the higher pressure in the customer's pipelines will flow into the potable water system's pipelines. Increased pressure on a customer's premises may be produce by several means. A booster pump, elevation difference, storage on the premises, and even temperature increases (e.g. as in a boiler) can produce enough of a pressure differential to "push" water back into the distribution system.

Backsiphonage Backflow

Backsiphonage backflow results at a cross connection from pressure in the distribution system falling below atmospheric pressure (14.7 psi at sea level). Potentially contaminated water in the customer's pipelines is "sucked" into the potable water system because the supply pressure is less than atmospheric pressure. A reduced pressure or partial vacuum can occur when high water flow conditions exist. Fire-fighting efforts, a water line break or even peak demand on a system can cause this condition. For a backflow incident to be termed backsiphonage the potable water system pressure must fall below atmospheric pressure.

Approved Devises for the Prevention of Backflow and Back-siphonage

The Florida Drinking Water Rules define the devices as approved for the prevention of backflow and back-siphonage. For the purposes of these definitions a check valve is a valve that is drip tight at one psi in the normal direction of flow and when the outlet pressure is zero. Backflow and back-siphonage devices are identified in Table 92.

Table 92

Approved Backflow and Back-Siphonage Devices
Florida Drinking Water Rules

Approved Devise	Abrev.	Description	Device Requirements/Application
Air Gap Separation	AG	A physical separation between the free flowing discharge of a potable water pipeline and an open non-pressurized receiving vessel.	Air gap separation must be at minimum double the diameter of the supply pipe. Gap must be greater than 1".
Reduced Pressure Zone Backflow Preventer	RPZ or RP	A devise containing within its structure two independently acting check valves together with an automatically operating pressure differential relief valve located in between.	The unit must include tightly closing shutoff valves located at each end of the device. Must be fitted with a test cock. Works for backpressure of back-siphonage.
Atmospheric Vacuum Breaker	AVB	A devise operated by atmospheric pressure in combination with the force of gravity.	Works in a vertical plane only. Poppet valve must be carefully sized to slide in a guide chamber. Shuts off flow when negative pressure exists. These are small devices generally used on hose spigots. Not used in water supply applications.
Pressure Vacuum Breaker	PVB	A devise operated by atmospheric pressure in combination with the force of gravity.	Poppet valve is operated by a spring. Does not require a negative pressure to react. Can be used on the pressure side of a valve. These devises are used on internal plumbing and are not recommended for public water supply protection
Double Check Valve Assembly	DCVA	Consists of two independently operating check valves provided with a suitable connection for the testing of each check valve..	The closure element must be internally weighted or internally loaded to prevent rapid closure. These are used in residential applications.
Residential Dual Check Valve	RDC	Consists of two independently spring operated check valves	Acceptable only in areas served by water reuse systems.

Degree of Hazard

Backflow and Back-siphonage devises are specified by the degree of hazard that exists for contamination to a public water supply system. The Two degrees of hazard are considered and defined in Table 94 that lists both health and non-health contaminant situations.

Table 94

Degree of Risk for Cross Connection and Back-siphonage Devises

Health Contaminant	Any substance that could, if introduced into the potable water supply, cause death, illness, spread disease, or have a high probability of causing such effects.
Non-health Contaminant	Any substance that generally would not be a health hazard, but would constitute a nuisance, or be aesthetically objectionable, if introduced into the domestic water supply.

The degree of hazard increases as a function of both the probability that backflow will occur and the toxicity of the substance that may backflow. However, the risk associated with the substance's toxicity (or virulence) is always a greater concern than the probability of backflow. Thus, when selecting the type of assembly (the degree of protection), the health hazard governs the final choice.

Degree of Protection

A utility has the ultimate responsibility for the quality of the water in the distribution system. For that reason most utilities choose to require installation of an assembly at the property line of the customer to "contain" the potential contamination. The health department may require the owner of the property to install other assemblies to "isolate" a particular piece of equipment or building on the premises, such as a boiler, a chemical injector or even a lab, from another water user on the same property. The type of backflow protection required must be commensurate with the degree of actual or potential hazard that exists on the premises.

Application and Reliability of Backflow Devises

The most reliable type of backflow prevention device, which would be either a reduced pressure zone (RPZ or RP) assembly or an air gap (AG) installation must protect against a health hazard (contaminant). The RP is preferred, since most AG on water services are very likely to be bypassed.

Air gaps (AG) are frequently used at connections between water storage tanks and pipelines.

Reduced pressure zone backflow (RPZ) devices have a wide use for high to medium hazard industrial and commercial backflow protection. A RPZ devise is shown below. The RP provides protection against both back-siphonage and backpressure, for either non-health or health hazard conditions. It is considered to be a "fail safe" assembly, since it causes flow to be discharged to atmosphere under any partial failure conditions . Installation of this assembly requires special attention to adequate clearances and surrounding flood levels, since the relief valve is open to the atmosphere.

Double Check Valve assemblies are used in low to medium hazard conditions such as apartment buildings.

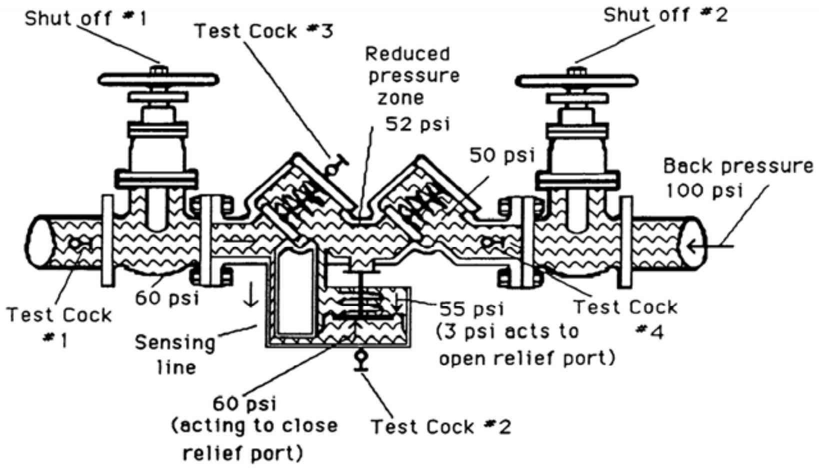


Figure 7
Reduced Pressure Zone Backflow Preventer

Cross Connection Control Program

The successful promotion for cross-connection control and backflow prevention in a municipality will be dependent upon he legal authority to conduct the program. To accomplish this the municipality must enact a ordinance that contains at minimum the following provisions:

Table 95

Legal Requirements for a
Cross-Connection Control and Backflow Program

1. Authority for establishment of the program
2. Technical provisions for eliminating backflow and cross-connections
3. Penalty provisions

The water purveyor is ultimately responsible for the quality of the water in the distribution system. Courts have recognized that the only defense that a water systems has (with regards to backflow incidents) is an effectively and diligently implemented cross-connection control and backflow prevention program.

Components of a successful Cross-Connection Control and Backflow Program

The suggested components for a successful Cross-Connection Control and Backflow Program are illustrated below. For smaller systems all of these requirements can be the responsibility of the operator.

Table 96

Components of a Successful Cross-Connection Control and Backflow Program

1. Legal authority – An enacted ordinance supported with written utility cross-connection control policies and procedures.
2. Program Administration – This will include a person knowledgeable about the program requirements and who takes incoming calls, answers questions relating to the program and is responsible for the tracking of customers, dates and schedules for inspections, completion of testing, non-compliance, etc. A filing system including all correspondence related to the program will be necessary. It is recommended that tickler files and form letters and test forms be maintained to ensure consistency in getting the same essential information to each customer.
3. Survey, inspections and retrofit of existing facilities - Someone delegated to do inspections and to become an expert in cross-connections and their control. Effectiveness is lost if these responsibilities are divided up between too many persons. Identify existing customers and their order of priority depending on the hazard. These should be documented in a written list of facilities needing inspection including a list names of businesses, addresses, telephone numbers, and, if possible, name of manager or contact.
4. Plan review of new construction - Increase lines of communication between building officials, inspectors and reviewer as well as health department.
5. Testing and Maintenance – A program for annual testing of all assemblies and devices
6. Record keeping - Inventory of number and types of assemblies and devices in place, number of annual tests conducted, number of surveys and inspections conducted.
7. Standards and specifications to delineate “Approved Assemblies.”. These should be maintained and updated periodically and include a list of approved devices along with installation instructions and diagrams
8. Training and education - Not only to the customer, which must be an on going effort, but also for the employees that work in the program. This includes the person that would answer the phone and perhaps be the first contact in a backflow incidence. Training also requires maintenance of a technical library that includes equipment catalogues, manuals, handbooks, laws, codes, and device standards.
9. If the program is to include in-house testing of devices it will require someone who understands the principles of backflow preventers and has had formal instruction on testing and be certified. The program will also require the needed testing equipment to include a duplex gauge for testing DCVA and a pressure differential gauge for testing RP and PVB (you will find many other uses for these gauges once you have them).
10. Incidence response plan - The entire procedure for what to ask, who to contact etc. should be in a manual that is readily available. The person that takes the call must get all the pertinent information if an incident is to be “controlled”.
11. Program manual - This would be used to assemble all the components of the program. It should state the goal, have a copy of the ordinance (or policy), sample letters, forms, required protection for degree of hazard and various other information that would be useful to the implementation of a successful program.

The State does not “certify” backflow testers”. A utility may or may not recognize certificates of training from a number of different institutes. .

Cross-Connection Control and Backflow Inspections at Water Treatment Plant Sites

The operator should not only be aware of municipal cross-connection programs but should ensure that the plant site is safe from cross connection contamination hazards. The operator should look for obvious cross-connections, for example, hoses hanging into tanks or on the ground, untraceable piping configurations, etc. Also, look at water lubricated bearings, chemical injectors, drain lines from equipment and so forth.

Table 97

Examples of Potential Cross-connections Hazards At Water Treatment Facilities

1. Air Conditioning Cooling Water
2. Air Conditioning Chiller Water (or make-up water)
3. Air Conditioning Condensing Water
4. Auxiliary Water
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Basic Chemistry for Water Plant Operators

Matter

Matter is anything that occupies space and has weight (mass). Matter includes subatomic particles- protons and electrons- as well as the atoms that such particles form. Matter also includes everything formed by atoms- nearly everything you encounter in the world.

Matter exists in three forms: (1) solids, (2) liquids, and (3) gases. Solids, liquids, and gases may exist in pure form, may combine chemically with other elements to form compounds, or may be mixed together without chemically combining to form mixtures.

Pure Elements

Elements are matter built up from subatomic particles, with properties determined by their nucleus (protons and neutrons) and by their electron shells. All of the atoms of an element have the same number of protons in their nuclei. Elements do not break down into simpler elements. There are over 100 elements known; 92 occur naturally, and others have been produced in the laboratory. Elements important in water chemistry are listed in Table 1.

A few elements exist I pure form. Carbon is an example--a diamond is pure carbon in a particular arrangement. Oxygen in the air is another example of an element in its pure form. However, most elements are unstable and are usually found combined with other elements in the form of compounds.

Compounds

Compounds are two or more elements that are "stuck" (bonded) together by a chemical reaction (explained in the next module). A chemical can only be broken down into its original elements by reversing the chemical reaction. The weight of the atoms of any one element in a compound is always a definite fraction (or proportion of the weight of the entire compound). For example, in any given weight of water, 2/18 of the weight is atoms of hydrogen.

Table 98

Common Elements found in Water Treatment

Element	Symbol	Element	Symbol	Element	Symbol
Aluminum	Al	Chromium	Cr	Oxygen	O
Arsenic*	As	Fluorine†	F	Phosphorus	P
Barium*	Ba	Hydrogen	H	Potassium	K
Boron	B	Iodine	I	Radium*	Ra
Bromine	Br	Iron	Fe	Selenium*	Se
Cadmium*	Cd	Lead*	Pb	Silicon	Si
Calcium	Ca	Magnesium	Mg	Silver*	Ag
Carbon	C	Manganese	Mn	Sodium	Na
Chlorine	Cl	Mercury*	Hg	Strontium*	Sr
Copper	Cu	Nitrogen	N	Sulfur	S

*This element must be monitored according to the requirements of the Safe Drinking Water Act.
†Fluoride, an anion of the element fluorine, must be monitored according to the requirements of the Safe Drinking Water Act.

When atoms of two or more elements are bonded together to from a compound, the resulting particle is called a Molecule. A molecule may be only two atoms of one or more elements bonded together; or it may be dozens of atoms bonded together, and may consist of several elements. For example, when two atoms of hydrogen and one of oxygen combine , a molecule of water is formed. When one atom of carbon and two of oxygen combine, a molecule of water formed. When two atoms of oxygen combine, a molecule of oxygen is formed.

Table 99

Examples of Compounds

1. Salt (sodium and chlorine),
2. Sulfuric acid (hydrogen, sulfur, and oxygen),
3. Ammonia (nitrogen and hydrogen),
4. Rust (iron and oxygen),
5. Lime (calcium, oxygen, and hydrogen), and
6. Sand (silicon and oxygen).

The number of compounds that can be formed by chemical reaction between elements is enormous. Chemists have identified well over two million compounds, and the number is still increasing.

Mixtures

When two or more elements, compounds, or both, are mixed together and no chemical reaction (bonding between individual particles) occurs then the result is a Mixture. No new compounds are formed , and the elements or compounds may be mixed in any proportion. Any mixture can be separated into its original elements or compounds by "physical" means, such as filtering, setting, or distillation. For example, a mixture of salt water can be separated into its compounds, salt and water, by the process of distillation-heating the mixture causes the water to evaporate, leaving the salt behind.

Table 100

Examples of Mixtures

1. Air (mostly oxygen, carbon dioxide, and nitrogen),
2. Glass (sand, various metals, and borax),
3. Steel (primarily iron and carbon), and
4. Concrete (lime, sand, and water).

Ionization

Water has a property of splitting molecules into positive and negatively charged particles called ions. This process is also known as disassociation. Not all substances that dissolve in water ionize and some ionize only to a very slight degree. Those that readily ionize are considered strong acids or strong bases. Some strong acids are sulfuric, nitric and hydrochloric. A strong base is sodium hydroxide.

Some molecules disassociate to form groups of atoms. Some examples of these are ammonia, sulfate and hydroxyl ions. These are called radicals.

Neutralization

Neutralization is the process that occurs when an acid solution containing one equivalent of hydrogen ions is mixed with a base solution containing one equivalent of hydroxyl ions. These will combine to form water.

Mathematics for Water Plant Operators

Introduction to Mathematics for Water Plant Operators

A water plant operator is expected to be able to perform a significant number of mathematical computations. These computations identify proper amounts of chemical to add to unit processes, determine loadings and detention times in tanks, identify concentrations of chemicals and flow rates in plant processes.

There have been many techniques developed to aid the operator in remembering formulas, however these lend themselves to memorization that limit true understanding of the mathematical concepts. The methods presented here, build gradually on fundamental concepts of weight, volume and measures that are applied repeatedly and directly in solving the types of mathematical problems encountered by the operator. In general, the operator will be required to recognize or determine mathematical values and plug these values into standard equations and then calculate the desired results.

Use of Water Conversion Factors

It is frequently necessary to express water by weight or flow in different units. Table 101 contains frequently used conversion factors for expressing weight or volume of water. The operator should understand how to use this conversion chart.

The chart can be entered from the left side or from the right side. For example, if it is desired to convert cubic feet to gallons, enter the chart from the left in Row 1, multiply the number cubic feet (column 2) by 7.48 (column 3) to get gallons. In reverse, if it is desired to convert gallons to cubic feet, enter the chart from the right and divide the number of gallons (Column 3) by 7.48 to get cubic feet (Column 2).

Examples in the use of the chart have been provided.

Table 101

Frequently Used Conversion Factors
For Water and Water Constituents

	Frequently Used Conversion Factors for Water and Water Constituents	
Row	Multiply ⟶	⟵ Divide
1	1 cubic foot of water	7.48 gallons
2	1 gallon of water	8.34 pounds
3	1 cubic foot of water	62.4 pounds
4	1liter of water	1,000 grams
5	1 ounce	28.35 grams
6	1 milliliter of water	1 gram
7	1 pound per million pounds	1 part per million .
8	1 part per million	1 milligram per liter
9	1 percent	10,000 parts per million
10	1 ounce per cubic foot	1 gram per liter
11	1 million gallons per day	1.55 cubic feet per second
12	1 million gallons per day	694 gallons per minute
13	1 cubic foot per second	450 gallons per minute
14	1 psi	2.31 feet of head

15	1 foot of head	0.433 psi

Example 1: Convert PSI to Feet of Water

What is the equivalent feet of head of water above a pressure gauge that reads 20 psi?

Step 1	Write Down Known Information	Given: 20 psi Need: feet of water
Step 2	Find Value In Conversion Table	Go to Row 15, enter from the left side 1 psi = 2.31 feet of head
Step 3	Multiply Given times Conversion Factor	Multiply 20 psi X Conversion Factor = feet of head
Step 4	Calculate Answer	20 psi X 2.31 = 46.2 feet of head

Example 2: Convert Percent Concentration of a Solution to PPM

How many parts per million is a 1.4% chlorine solution?

Step 1	Write Down Known Information	Given: 1.4% Solution Need: Parts per Million
Step 2	Find Value In Conversion Table	Go to Row 10, enter from the left side 1% = 10,000 parts per million (PPM)
Step 3	Multiply Given times Conversion Factor	Multiply 1.4% X Conversion Factor = PPM
Step 4	Calculate Answer	1.4 X 10,000 = 14,000 PPM

Sometimes it is necessary to use a conversion chart in reverse if the conversion units are not available on the right side of the chart.

Example 3: Convert Grams to Ounces

Water in a beaker weighed 56.7 grams, how many ounces were in the beaker?

Step 1	Write Down Known Information	Given: 56.7 grams Need: ounces of water
Step 2	Find Value In Conversion Table	Go to Row 5, from the right side 1 ounce = 28.35 grams
Step 3	Divide by Conversion Factor	Divide 56.7 grams <u>divided by</u> 28.35 = ounces
Step 4	Find Answer	56.7 / 28.35 = <u>2 ounces</u>

Calculating Areas and Volumes

The operator must be proficient in calculating areas and volumes of rectangular and round tanks and pipelines.

Rectangular Tank	
Area = Length X Width	Volume = Area X Height
Round Tank or Pipe	
Area = 3.14 X Radius Squared	Volume = Area X Height

Example 4: Compute Area and Volume of a Tank

What is the Area and Volume of a Round Tank, 100 feet in diameter and 10 feet deep?

Step 1	Write Down Known Information	Given: 100 feet in diameter Depth or Height of Water is 10 feet Need: Area and Volume
Step 2	Write Down Formulas	Area = 3.14 X Radius Squared Volume = Area X Height Recall that Radius = ½ of Diameter or 50 feet
Step 3	Plug Known Values into Equation(s)	Area = 3.14 X 50 X 50 Volume = 3.14 X 50 X 50 x 10
Step 4	Calculate Answer	Area = 7,850 square feet Volume = 78,500 cubic feet

Converting the Volume of Water to Gallons from Cubic Feet in a Tank or in a Pipeline

Example 5: Convert Cubic Feet of Water to Gallons or Pounds of Water

Sometimes it is necessary to convert a pipe or tank capacity into gallons or into pounds (weight of water). In this example use the Conversion Factors in Table 1.

Determine the volume (78,500 cubic feet) in the tank calculated above in gallons and its weight in pounds of water in the tank.

Step 1	Write Down Known Information	Given: 78,500 cubic feet Need: Gallons and Pounds
Step 2	Find Value In Conversion Table	Go to Row 1, 1 cubic foot of water = 7.48 gallons Go to Row 2, 1 gallon of water = 8.34 pounds
Step 3	Multiply Given times Conversion Factor	Multiply by Conversion Factor(s) 78,500 X 7.48 = Gallons of Water Gallons of Water X 8.34 = Pounds of Water
Step 4	Calculate Answer	587,180 gallons 4,897,081 pounds of water

Calculating Concentration of a Chemical in a Tank or Pipeline

The calculation of chemical concentration is the amount of chemical by weight in the weight of the water.

Concentration in PPM = Pounds of Chemical Added ÷ Million Pounds of Water

Example 6: Calculating Chemical Concentration and Dose

What is the concentration of chlorine in parts per million if 10 pounds of 100% chlorine was added to the above water tank?

Step 1	Write Down Known Information	Given: 4,897,081 pounds of water or 4.9 Million Pounds 10 Pounds of Chlorine Added Need Concentration in PPM
Step 2	Write Down Formula	Concentration = Pounds Chlorine : Pounds Water
Step 3	Plug in Values	Concentration = 10 : 4.9
Step 4	Calculate Answer	Concentration = 2 PPM of Chlorine

Calculating Concentration When the Chemical Added is less than 100% Available

Example 7: Determining Concentration when Chemical Availability < 100%

Chlorine such as HTH comes in less than 100% pure form. Sometimes it is necessary to calculate and actual concentration by multiplying by the percentage of chemical that is available. An example calculation is shown below.

If the chlorine added above was only 65% available chlorine, what is the actual concentration in the tank?

Step 1	Write Down Known Information	Given: Concentration of 100% Available Chlorine is 2 PPM Since there was only 65% available the concentration will be less
Step 2	Write down formula	Concentration = 2 PPM X Actual Percent Concentration
Step 3	Plug Known Values into Equation	Concentration = 2 X 65%
Step 4	Calculate Answer	Concentration = 1.3 PPM

Example 8: Determine a Chemical Dose to achieve a Desired Concentration

Sometimes the operator is required to add chemicals to achieve a desired concentration.

If the operator needs to maintain a 2 PPM concentration in the tank, and is adding HTH with 65% available chlorine, how much chlorine should be added by weight to the tank (recall from above that there are 4,897,081 pounds of water in the tank)?

Concentration in PPM = Pounds of Chemical Added ÷ Million Pounds of Water

Pounds of Chlorine Added = Concentration in PPM Desired X Million Pounds of Water

Step 1	Write Down Known Information	Given: 4,897,081 pounds of water or 4.9 Million Pounds Concentration required: is 2 PPM Need how many Pounds of HTH to add to tank
Step 2	Write Down Formula	Pounds of Chlorine = Concentration X Million Pounds Water
Step 3	Plug in Values	Pounds of Chlorine = 2 PPM X 4.9 Million Pounds Water
Step 4	Calculate Answer	Pounds of Chlorine = 9.8 Pounds
Step 5	Account for Concentration	Since only 65% chlorine is available, must add more HTH and so divide by percent available chlorine 9.8 : 65% = 15. 1 Pounds of HTH needed

Flow, Volume, and Pumping Rate Relationships

Flow is a measure of the volume of water flowing over a given time. The volume of water will be measured either in cubic feet or in gallons. Time may be measured in seconds, minutes, hours, or days.

Example 9: Determine Time to Fill a Tank with known Pumping Rate

For the Tank above (100 feet in diameter and 10 feet deep), how long will it take to fill the tank with a pump that has a capacity of 300 gallons per minute?

Go back to Example 5 and recall how we calculated the Volume of the Tank in cubic feet and then used a conversion factor to change the volume into gallons.

Volume in cubic feet = Area X Height

Volume in Gallons = Volume in cubic feet X 7.48 (from Table 1 Conversion Factors)

Volume = 587,180 Gallons

Time to Fill a Tank = Volume of the Tank ÷ Pumping Rate

Step 1	Write Down Known Information	Given: 587,180 Gallons Pump Rate = 300 Gallons per Minute Need: Time to fill tank
Step 2	Write Down Formula	Time to Fill a Tank = Volume of the Tank : Pumping Rate
Step 3	Plug in Values	Time to Fill a Tank = 587,180 : 300
Step 4	Calculate Answer	Time to Fill Tank = 1,957 minutes or about 32 hours

When calculating time to fill a tank all flow and volume numbers must be in the same units. If the tank volume is in gallons the flow must be in gallons. If units are different it is necessary to convert them using the Conversion Factor Table.

Chemical Dosing

Chemical dosing problems are determined by using the formula; (note that the conversion factor of 8.34 pounds for each gallon of water converts the flow into million pounds of water per day):

$$\textbf{Feed (lbs of chemical) = Flow (MGD) X 8.34 } \frac{\textbf{lbs}}{\textbf{gal}} \textbf{ X Dose (PPM)}$$

Example 10: Determining Chemical Dose for a Flow and Desired Concentration

How many pounds of 100% chlorine solution should be added to maintain a concentration of 2 mg/l at a flow rate of 500,000 gallons per day?

Step 1	Write Down Known Information	Given: Flow Rate 500,000 Gallons Per Day Concentration is 2 mg/l or 2 PPM Need: Feed in Pounds
Step 2	Write Down Formula	Feed (lbs of chemical) = Flow (MGD) X 8.34 X Dose (PPM)
Step 3	Plug in Values	Feed = .5 MGD X 8.34 X 2 PPM
Step 4	Calculate Answer	Feed = 8.34 pounds of chlorine per day

Example 11: Convert Dose in Pounds Liquid per Day to Volume Liquid per Day

If a hypochlorite solution of with 5.25% available chlorine is used in the example above, how many gallons would need to be added each day?

Step 1	Write Down Known Information	Given: 8.34 lbs of chlorine per day Concentration is 5.25%
Step 2	Write Down Formula	Go to Conversion chart, Row 2, enter from right so must divide By 8.34 pounds / gallon
Step 3	Plug in Values	Gallons of 100% solution = 8.34 pounds : 8.34 lbs / gal
Step 4	Calculate Answer	Gallons of 100% solution = 1 gallon per day
Step 5	Since concentration by weight is only 5.25% will need more chemical	1 Gallon : 5.25% = 19 gallons per day–

Determining Detention and Contact Times

The computations of detention and contact times are an important part of an operator's duties. The formula below is used to determine the detention time. The units of volume and flow must be in gallons.

Detention Time (days) = Volume of the Tank ÷ Flow Rate

To convert the Detention Time in Days to minutes multiply Days by 1440 or

$$24 \frac{hr}{day} \ X \ 60 \frac{min.}{hr} = 1440 \frac{min.}{day}$$

Example 12: Determine Detention and Contact Times for a Basin

A basin is 10 feet in depth, 20 feet in width and 30 feet in length, the plant flow is 1,000,000 gallons per day, what is the detention time in the tank?

Step 1	Write Down Known Information	Given: Tank Size = 10’ X 20’ X 30’ Flow = 1,000,000 GPD
Step 2	Write Down Formulas	Volume of Tank = Length X Width X Height
Step 3	Plug in Known Values	Volume = 10 X 20 X 30
Step 4	Calculate Volume	Volume = 6,000 cubic feet (convert to gallons) Volume in Gallons = 6000 X 7.48 (Row 1 of Conv. Chart) Volume = 44,880 gallons
Step 5	Write Down Formula	Detention Time = Volume of the Tank : Flow Rate
Step 6	Plug Values Into Equation	Detention Time = 44,880 gallons : 1,000,000 $\frac{\text{Gallons}}{\text{Day}}$
Step 7	Compute Detention Time	Detention Time = .045 days X 1440 $\frac{\text{min}}{\text{Day}}$ Detention Time = 65 minutes

Contact Time

The contact time is the amount of time a residual disinfectant is in contact with the water at peak hourly flow.

Example 13: Determining Contact Time at Peak Hourly Flows

Assume that the peak hourly flow in the example above was 2 MGD. Since the detention time was calculated based on an average flow of 1 MGD, the contact time at 2 MGD will be 50% of the time calculated or 32.5 minutes:

44,880 gallons ÷ 2,000,000 gallons / day X 1440 minutes / day

The contact time calculated above is a “theoretical contact time.” It is based on a condition of plug flow that does not typically occur in practice. The theoretical contact time must be converted to actual contact time by using a baffling factor. For our basin assume that the baffling factor was determined to be .5. The actual contact time is then:

Contact Time Actual = Contact Time Theoretical X Baffling Factor

Contact Time Actual = .5 X 32.5 minutes

= 16 minutes

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