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September 2010
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Water Treatment & Distribution

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§ 3.1 WATER TREATMENT & DISTRIBUTION INTRODUCTION

Clean water is necessary in almost every aspect of an industrialized society. Ironically, the greater the industrialization, the harder and more expensive it is to treat water to ensure its purity. Moreover, water is not just necessary for public consumption. Industries, such as power, chemical, pharmaceutical and healthcare all require a consistent water quality.

Water is the most essential life-sustaining substance on earth. At the same time, it is also a substance that accounts for over 5 million deaths each year (Introduction to Water Investing 2008 by Summit Global Management, Inc. 9171 Towne Centre Drive, Suite 465, San Diego, CA 92122), half of them children under the age of five, due to poor sanitation and purification techniques. Three quarters of the Earth's surface is covered in water yet only ½ of 1% of that water is considered "fresh" water and the majority of that "fresh" water is still unsuitable to drink.

The contamination of water is not just a Third World issue. The North American population is draining aquifers underlying the land at an alarming rate. Where water was once considered an infinite resource, people and governments are realizing it is in fact a renewable resource.

In the United States the supply of drinking water typically is the responsibility of the local municipality. Some of these municipalities have infrastructures over 100 years old. Others have aging treatment systems, which can no longer process the contaminants in raw feed water. Still others are experiencing failures in the distribution systems. Lastly, many municipalities are in attractive locations but don't have the water resources available to support the population growth. Those municipalities realize that they must address these problems.

The major problem in addressing the infrastructure failures is the public conditioning that water should be, if not free, very cheap. Water systems usually sell the water they produce at a loss or breakeven. There is no profit for improvements. Municipal bonds, Federal grants, loan guarantees and other sponsored financing are used to repair, improve and expand the infrastructure.

With varying degrees of success, Municipalities have also turned to private companies to take over water system operations. The private-public partnership usually results in an increase in costs to the consumer. The reasons for the cost increase is not because private companies are less efficient, but because private companies must account for the risk of infrastructure failure and they have shareholders who expect the company to generate profits.

The quality of water supplied can effect all downstream users. Disruption in the water supply can cause improper operation of specialty water treatment systems in hospitals and industry, along with public health hazards in residents and homes. Consequently, there is a continuous re-evaluation of the risks of certain contamination. For instance, three decades ago certain viruses were identified in the drinking water systems which had not previously been known as widespread hazards. These hazards resulted in changes to the basic design and construction of water treatment plants.

§ 3.1.1 Background of Water Treatment Industry

In 1878 the Barnstead Water Treatment Company was founded by Robert ***Barnstead***, a master plumber who was commissioned to create an all-metal ***water*** still for Massachusetts General Hospital. Barnstead is largely recognized as the first water treatment equipment company. Today the water industry is a very diverse group of companies providing technologies, services and products which culminate in the supply of water of a purity which meets the standards for its intended use. Such multinational companies as General Electric and Siemens are some of the largest operators in the industry. There are numerous other large companies that support the development of water projects. Each with their own specialty and focus.

The design and engineering of water treatment plants is a specialty that many engineering firms focus on as a business group. Depending on the approach the driving discipline could be chemical, mechanical or civil engineers. These groups work closely with municipalities or local governments and assist in funding proposals and other financing arrangements in addition to the actual brick and mortar design. There are numerous technologies to choose from to complete the design. The choices are driven by the source of raw water, seasonal changes, operator expertise and costs. With respect to the design of water systems, there is no “right” answer. Ten engineers, given the same set of design criteria will present the client with ten different designs. All of which will meet the operating requirements.

The structure and execution of the construction may vary from project to project. Typically a construction manager or general contractor is hired. As a general rule the larger the water through-put, the more build and assembly is done on site. The smaller the through-put, the more pre-packaged and skidded equipment are supplied for integration.

Civil contractors, if not the lead contractor, are usually very important subcontractors. Everything from the installation of concrete tanks to the pipe distribution system will fall under the contractual responsibility of the civil contractor. As with the engineers, many civil contractors make water treatment its own specialty and focus within the company.

The large scale use of mechanical equipment is integral to the water treatment process. The most traditional plant design has some type of filtration and chemical injection systems while the most modern is desalinating sea water through the use of highly specialized membrane filters. There are also skimmers, ultraviolet lights, ozone generators and numerous other specialty equipment designed for specific purposes. The mechanical design and integration of these individual mechanical components can effect the capital cost, operating costs and final water quality. As new contaminant standards are established new technologies and mechanical equipment are adapted to the water treatment industry.

Instrumentation and controls is also a key discipline in the execution of a water treatment project. The instrumentation and controls affect everything from the plant operation to the determination or verification of the plant performance. From an operational perspective, start-up and acceptance can be delayed due to improper operation of equipment. This situation occurs frequently when there are multiple equipment suppliers and a central control system to coordinate them all. Delays can also occur when the measurement devices indicate a quality issue. Sometimes the quality of the water is affected by the control logic of the facility.

Suppliers of expendable goods or consumables that are used in the operation of a water treatment plant can alter dramatically the operating costs. Caustic, acid, ammonia and chlorine are all chemical commodities whose costs can vary from month to month. The quality of the suppliers' goods can also be an issue in the operation and production of safe drinking water. Feasibility of a plant can change considerably with the change in price of consumables three years later.

These independent parties all come together for the successful execution and operation of a water treatment facility. Failure by any one of the parties can lead to failure of the plant to perform.

§ 3.1.2 Water Characteristics

Water is critical to all life as we know it. Water is a universal solvent that can carry nutrients and chemicals, it supports chemical reactions and it can suspend materials. These same properties that make it critical to life also make it susceptible to delivering diseases and harmful chemicals into the human body.

To understand what makes water work, one must examine the scientific nature of water. The water molecule is slightly bent, at 108 degrees, with a slight positive and negative charge. This unique characteristic helps make it a universal solvent. Furthermore, the purer water becomes, the more aggressive it becomes in absorbing substances from its environment.

One way to measure water's purity is to create an electrical field across an atmosphere of water and measure the amount of electricity conducted across the field. Conductivity is measured in microSiemens per cm. Theoretically pure water will have a conductivity of 0.056 microSiemens per cm. At this purity, water will attack: metals causing corrosion; plastics removing organics; concrete removing minerals; and even the electrolytes within a living organism. All these materials provide nutrients for small bacteria and viruses which can then grow and establish themselves. Water does not want to be just water.

The aggressive nature of water means that, unlike many other substances, water can be pure at one point and contaminated at another point. This feature comes from the ability of organisms to grow within the medium of water. A single organism in the water can multiply to millions, colonize on pipe walls and in hard to reach areas making sanitation very difficult. Accordingly, one of the most challenging aspect of water treatment is that a treatment process may sequentially remove bacteria or viruses only to have the water re-contaminated down the line or in the distribution system.

Since water can extract and grow its own contaminants after purification there are public water supply maintenance and monitoring requirements. Each of the local water treatment plants must test and report the results of water quality not only at the outlet of a facility but throughout the distribution system. Proscribed testing is required per the EPA and usually State and sometimes local standards. These standards establish the timing and method of testing and monitoring.

Generally chemical tests can be completed in a real-time fashion while microbial and bacterial tests require incubation with results not available for several days. Continuous of online testing for some things such as total dissolved solids (TDS), total suspended solids (TSS), turbidity and organics are available to give an indication of the degree of control and reliability of the water quality. These measurements can be used to adjust the water treatment parameters and determine if there is a trend toward instability. Actual measurement and identification of specific bacteria, viruses or organics requires grab samples. Grab samples are used for contaminants such as trihalomethanes, e-coli, cryptosporidium, other bacteria and bacteria and specific inorganics such as uranium or cyanide. The issue with grab samples are that they are a snap shot, not a movie, of the operation of a facility. They also take days and sometimes weeks to process so the recreation of conditions is difficult. Lastly, results of grab samples are not known until well beyond the time when the water has already been consumed.

§ 3.2 WATER TREATMENT STANDARDS/CERTIFICATIONS

In the United States, the leading agency for establishing and enforcing water quality standards is the Environmental Protection Agency (EPA). Two specific laws govern most of the issues in this area. First, the Clean Water Act (CWA) establishes the standards for discharges into water sources such as lakes, rivers and bays. Second is the Clean Drinking Water Act which establishes limits and standards for impurities in drinking water.

§ 3.2.1 The Clean Water Act

The Clean Water Act (CWA) is the cornerstone of surface water quality protection in the United States. The Act does not deal directly with ground water nor with water quantity issues such as riparian rights. The statute employs a variety of regulatory and non-regulatory tools to sharply reduce direct pollutant discharges into waterways, finance municipal wastewater treatment facilities, and manage polluted runoff. These tools are employed to achieve the broader goal of restoring and maintaining the chemical, physical, and biological integrity of the nation's waters so that they can support "the protection and propagation of fish, shellfish, and wildlife and recreation in and on the water." A secondary benefit is that the CWA reduces the risk of dangerous pollutants entering the drinking water system.

§ 3.2.2 The Clean Drinking Water Act

The Clean Drinking Water Act is applicable directly to municipal and city drinking water systems. This Act establishes the standards of purity for water supplied to the public. It also establishes drinking water testing, monitoring and reporting requirements. The regulations associated with the Act establish “maximum contamination levels” or MCL’s for over 80 substances found in raw water. The full list of MCL’s can be found at http://www.epa.gov/safewater/regs.html.

The States each have their own laws and regulations for the supply of water to the public. The States incorporate the EPA Standards and, in some cases, supplement them with additional requirements. The States also manage permits, permit fees, water rights management, groundwater management. The States work with local municipalities to manage the construction process, provide funding and supervise the reporting. The local municipalities have the ultimate responsibility for the financing, construction and operation of water treatment plants. They may be the owner-operators or they may contract out the operations. A large city will have multiple plants under its control each with a different design and operating conditions.

The organization NSF International certifies products and standards for food, water and consumer goods. The company is an independent not-for profit firm that reviews products, materials, coatings and other equipment for its suitability in food and drinking water production. The NSF Water Treatment and Distribution Systems Program is responsible for the Certification of drinking water treatment chemicals and drinking water system components to ensure that these products do not contribute contaminants to drinking water that could cause adverse health effects. Specifically:

- NSF/ANSI Standard 60: Drinking Water Treatment Chemicals -- Health Effects is the nationally recognized health effects standard for chemicals which are used to treat drinking water.
- NSF/ANSI Standard 61: Drinking Water System Components -- Health Effects is the nationally recognized health effects standard for all devices, components and materials which contact drinking water. For more information on these two Standards click on "Relevant Standards."

These two Standards are the main regulations for water treatment plants.

§ 3.2.3 Other Oversight Organizations

The World Health Organization has established an international version of the US Drinking Water Standards. The difference between the WHO and the EPA is that the WHO standards are published guidelines for drinking water with the primary intent of protecting the public health. The guidelines do not address wildlife or industry, WHO does not address pollution per se but only the purification of polluted water.

The American Water Works Association is a trade organization that provides training, knowledge, information and advocacy to improve the quality and supply of water in North America. The AWWA's purpose is to provide knowledge to the members and advocate certain legislation and regulations for water treatment.

The Water Quality Association is also a trade organization that focuses more on smaller water treatment suppliers and home installation services. The Association represents the members in evaluation of products, training and legislative support.

Each State and Municipality is able to establish its own monitoring and reporting requirements. In most States an Annual Quality Report is issued for each operating plant. Most States and local municipalities require the plant Operators to be Certified by continuing education sponsored by the trade organizations.

§ 3.3 NATURE OF THE PROJECT

Before the start of a project, a municipality may spend years performing a study. The studies include population projections, raw water source identification and testing, and potential site identification. Environmental impacts will also be included in the early studies. Based on these studies the municipality will work with engineers to identify and evaluate treatment technologies, and develop budgets and schedules. The municipality may also include plans to acquire riparian rights, right-of-ways and discharge permits. Based on the outcome of the preliminary work the municipality may apply for federal funding. The EPA has funding and grant opportunities to help States and local municipalities meet the Federal standards, plan bond offerings and develop other financing options.

§ 3.3.1 Process Engineering

Engineering of a water treatment facility starts with the determination of the design parameters. The most basic concept is to determine what quality and quantity of water is required then evaluate the raw water supply capabilities and design the plant's process to purify the water. While it sounds simply enough, the actual practice of establishing the parameters can take on a life of its own.

Upon preliminary engineering, a municipality may find out that they don't have enough water from the source, the source water is so inconsistent that the cost to purify the water is prohibitive or that the standards to which they wish to adhere are so stringent the costs, once again, escalate out of control. The process engineers must determine the appropriate purifications steps, their size and sequence before the rest of the team can move forward.

The basic operating assumptions establish the parameters under which the plant will operate. The EPA has established Primary and Secondary Drinking Water Standards, which define the federally mandated water qualities a system must produce while the States or local municipalities may chose to mandate additional or more stringent standards. The raw water inlet must also be tested for availability of the volume desired and the quality. As a general rule ground water sources are more consistent and the quality changes very slowly. Large bodies of water tend to change but the process is seasonal and slow, thus making it more manageable. On the other hand, smaller bodies of water may change rapidly, especially after a rainfall. Lastly, rivers can change moment to moment and can be very unpredictable.

One of the main challenges of a water treatment plant design is establishing the raw water parameters. Many municipalities and regulatory agencies rely on “grab” samples or point in time samples. These samples can give a good idea of the average maximums and minimums of certain contaminates but cannot be considered absolute predictors. In a small volume source or a flowing source, a spike exceeding any measurements may occur between samples, thus never being recognized. To establish the validity of the proposed process, especially in a small volume of flowing source, a pilot plant should be considered. This step in the design process may add time to the completion but it will ensure the final quality of water produced by the plant.

Raw water is tested for microbial parameters and non-microbial parameters. Microbial testing is done to identify many waterborne pathogens that can be present, usually in surface waters or ground waters under a surface influence. Microbial testing can take 24 to 48 hours to obtain results because the microbes must be incubated and grown to measure them. To identify each and every pathogen would be time consuming and expensive. The industry now operates under an index concept: if certain species are present then all the related species are assumed to be present because they spring from the same sources. Certain pathogens from fecal matter of infected people or animals may be easily identified thus indicating that other pathogens are present. The objective of this type of testing is to minimize fecal-oral transmission of diseases. The most common group for testing in this area is coliforms which includes e. coli, as an indicator of contamination. Identification of this group of microbial contamination is cause for immediate investigation and corrective action. Two other viral based microbes that have caused some headlines in resent years are Giardia cysts and Cryptosporidium oocysts. These species are capable of infecting a person and are associated with fecal matter from a warm blooded host. These viral cysts can survive for long periods and are resistant to traditional water treatment techniques. They must be removed through coagulation and filtration. Even with all the design pre-testing, grab samples can still miss spikes.

In addition to microbial levels water chemistry must be evaluated. Unlike microbial testing water chemistry, in most cases, is instantaneous and probes and electronics can measure spikes, if they are placed in the right locations. Rapid changes in water chemistry, though, can be an indicator of rapid changes in microbial levels.

The speed of variations or their rate of change affects the control parameters, technologies chosen and the costs of a water treatment plant. Often a request for proposal will contain a minimum, maximum and an average value for key water quality parameters. Rarely is there any rate of change information. The only way to be absolutely sure of the operating parameters is to run a pilot plant, ideally for a year or longer. Certainly through at least two seasons with an opportunity to measure rainfall events which can lead to rapid changes. Unfortunately, the schedule rarely accommodates this type of delay in initiation of the project.

§ 3.3.1.1 Sizing Criteria

After water chemistry and microbial loading, the largest determinant of the cost of a water treatment plant is the size. In order to properly size a water treatment plant the designer must consider the current population and industrial base along with the future growth the region expects. Sizing a plant such that it is too large can be almost as bad as sizing one that is too small. Water treatment equipment runs most efficiently under consistent loads and at close to capacity. A compartmental approach is better for operation and performance but is more expensive to construct.

The largest determinant of the size of a water treatment plant is the population. Depending on the customs, conservation efforts and regulations regarding water use, the per capital demand can range from over 150 gallons per day per person down to 75 gallons per day per person. Remarkably only between 10 and 15 gallons goes to direct individual use. The rest goes to agricultural (almost 70%) and Industrial (23%). In highly developed areas these ratios can be reversed. While agricultural applications can use water that does not meet drinking water standards, there is still concern with contamination of food sources.

Lastly, the process engineer must determine how the contact time requirements will be met. Since disinfection and elimination of microbial contamination is not measured in real time, the industry has developed the concept of contact time and log reduction. A 6-log reduction, for instance, is the equivalent of reducing microbial contaminants by a factor of 99.9999%. The log reduction is not measured directly but is established based on the disinfectant being used and contact time.

Chlorine is the primary disinfectant used in the United States. In order to be effective, the chlorine must be given time to react with the microorganisms. The time required (contact time) depends on the temperature and the pH of the water. Chlorine works best in water with a low pH and a high temperature. The concentration and contact time required to inactivate Giardia (a common parasite) using chlorine is approximated by the following formula.

$$CT=.2828 * (pH^{2.69}) * (Cl^{.15}) * (.933^{(T-5)}) * L$$

- CT = Product of Free Chlorine Residual and Time required
- pH = pH of water
- Cl = Free Chlorine residual, mg/l
- T = Temperature, degrees C
- L = Log Removal

Based on the results of this formula the engineer can determine at what point chlorine must be injected into the water stream to obtain the appropriate reduction of microbials. As discussed later, the numerous side reactions, or “disinfection by products” (DBPs) make the calculation a little less straight forward. The engineer may also take credit for certain log reductions offered by mechanical equipment such as ultrafilters, which will change the calculation.

§ 3.3.2 Civil & Structural Design

Once the general process is designed, there is typically a large amount of both civil and structural detailed design which must occur. Engineers that perform this design are typically considered a part of the Utility System Construction Group within the civil engineering and construction sector. These engineers will design distribution lines, water plant settling basins, pumping stations, storage tanks, reservoirs, well drilling requirements and other structural components. This design work may be performed in a design-build approach based on parameters supplied by the engineering firm. In such a case the main contractors will be the civil and structural contractors.

§ 3.3.3 Instrumentation and Monitoring

The instrumentation and monitoring of the water does not occur just at the place where the water leaves the plant - known as the effluent. Instruments and sampling ports are placed throughout the plant. Monitoring information at the inlet side of the plant is fed forward to adjust the plant's operation to ensure it meets the process and is balanced and adjusted based on variations of the raw water intake. Monitoring is also placed throughout the facility to determine the performance and efficiency of the individual operations. Lastly, the water quality is monitored as it leaves the plant to the distribution system to ensure compliance with local and federal regulations.

§ 3.3.4 Sustainable Design

In recent year "sustainable design" has crept into the vernacular. While process efficiency has always been a desire, a sustainable design which minimizes waste streams adds a level of complexity to the design process. Water plant designs have typically included instrumentation and pump controls to minimize energy consumption and optimize chemical use. Now, however, plant designs include innovative recovery of non-hazardous sludge and biodegradable chemicals in addition to other practices to lower the carbon footprint.

§ 3.3.6 Construction

Construction of a water treatment plant, like any other project, is typically driven by the schedule and the budget. As mentioned previously, this approach can sacrifice the optimization of the plant based on the results of a pilot plant study. Especially in a fast tracked project or a design-build approach where the schedule is further compressed and the engineering is being done concurrently with the basic construction and site work. The other important note concerning a budget driven project is the operational efficiency and serviceability of the plant. The least expensive construction is rarely the most efficient plant to operate. Municipalities must take ownership of certain portions of the project to ensure that when they finally take over the operations they do not assume increased costs for the water generation, that the process is efficient and there is not the need to raise rates more than necessary.

One other approach to construction and facilities is the privatization of new or existing plants, infrastructure and equipment. The initial approach to this arrangement by the municipalities was to shift the risk of failure, especially for older infrastructure, to the operating company. The cost accounting of an operating company is different than a municipality and privatization usually resulted in an increased cost to the customers. These issues lead to numerous disputes. As the parties' understanding of the issues has improved, the risk sharing has similarly improved. Many municipalities actively consider privatization with incentives for process efficiency and cost containment while guaranteeing the water quality.

§ 3.4 SOURCES OF DRINKING WATER

Drinking water can be provided by treating virtually any source of raw water. Sources can include ground water from wells, springs, rivers, lakes, seawater or any other source that provides a consistent volume. In some water starved areas the raw water source can include sanitary sewer recycled water. Technology exists to treat all of these raw water sources, it is just a matter of the cost. The raw water quality has the single greatest impact on the design of a water treatment plant and its operating costs. Costs of production can vary from $0.20 to $2.00

or more per 1,000 gallons. The key parameters include volume, temperature and pressure and energy costs.

The contaminants contained in the raw water must also be determined. An example of a typical monitoring program is:

Parameter	Minimum	Average	Maximum
Calcium (mg/l)	10	22	54
Magnesium (mg/l)	0.94	1.34	4.66
Sodium (mg/l)	18.1	29.6	38.2
Potassium (mg/l)	1.87	3.33	4.64
Sulfate (mg/l)	6	9	13
Chloride (mg/l)	14	27	48
Carbonate (mg/l as CO3)	0	0	0
Bicarbonate (mg/l as CO3)	42	44	67
Nitrate as N (mg/l)	0.01	0.15	0.40
Bromide (mg/l)	0.03	0.11	0.16
Total Dissolved Solids (mg/l)	89.34	114.77	231.08
Total Phosphate as P (mg/l)	0.19	0.48	0.82
Suspended Solids (mg/l)	4.3	22.6	113.2
Conductivity (umhos/cm)	140	237	332
Total Alkalinity (as CaCO3)	33	49	65
Hardness (as CaCO3)	38	59	93
Turbidity (NTU)	10	28	72
Fluoride (mg/l)	0.03	0.15	0.22
Color (Co-Pt units)	7.2	20.1	53.3
Total Iron (mg/l)	0.55	1.42	2.05
Manganese (mg/l)	<0.01	0.04	0.10
Total Organic Carbon (mg/l)	3.9	10.8	17.6
UV254 (absol. Units)	0.149	0.501	0.819
pH (pH scale)	6.95	7.54	8.18
Temperature	47	58	82
pHs (pH scale)	8.11	8.68	9.74
Langelier Index (pH scale)	-2.14	-1.23	-0.23
Total Coliform (MPN/100 ml)	126	4439	42267
E. Coli (MPN/100 ml)	<10	176	1196
MTBE (ppb)	0.02	0.21	0.73

EXAMPLE OF RAW WATER PARAMETERS FOR A DEFINED PERIOD

The level of raw water data available is site dependent. Some municipalities have data that extends back a decade or more. This database of information is usually available when the local government had a well developed growth strategy with sources of water identified. As a minimum a year of raw water data should be available to proceed with an evaluation of appropriate technologies. Keep in mind, water quality can change over time. Groundwater may have impurity or contamination trends that can be identified over time while surface waters usually change from season to season as leaves fall from the trees, salt is put on roads and snow melts. The problem with many of these samples is that they are grab samples and grab samples only provide a snapshot of the water. Some water sources can change rapidly form high to low. An example is the water quality of a river source during dry weather and just after a rainstorm.

§ 3.4.1 Groundwater

Springs and wells are considered groundwater. Rain water and other surface water sources percolate down through the ground and underlying rock to porous reservoirs. Depending on the nature of the geology of the aquifer there may be water trapped which require drilling and pumping in order to access the water and bring it to the surface. An artisian well, on the other hand, is an aquifer that is under pressure such that a well drilled into the formation allows the water to flow to the surface without a pump. Lastly, a pressurized aquifer may be fractured or open to the surface resulting in a naturally occurring spring.

Groundwater is generally higher in dissolved solids, silica and hardness while lower in organics. The source is generally of consistent quality over time. One factor that can affect the water quality is when the aquifer is considered under the influence of surface conditions. For instance, if the aquifer is shallow, surface contaminants such as fertilizers, animal wastes and other pollutants can change the nature of the raw water quality.

Groundwater and wells have been the traditional homestead source of water for remote homes and ranches. In the American Midwest the rate of withdrawal of water from the underlying aquifers greatly exceeds the rate the water is replenished. Removal of water from the underlying rock removes support and leads to subsidence. For example, some sections of the City of Houston have settled over three feet. Consequently, municipalities have begun to phase out the widespread use of ground water in favor of surface water sources.

§ 3.4.2 Surface Water

Surface water systems are considerably different from a groundwater source. Lakes and rivers are affected by the surrounding countryside on a continuous basis. Heavy rains, dry weather and droughts can affect not just the quantity of water available but the quality. Surface water quality can change based on the nature of the run-off from the drainage area it services. Heavy rains upstream may result in a certain type of contamination while heavy rains closer to the raw water intake may have a decidedly different character. For example, a tributary system experiences heavy rains in an area that has a high population of ranches. The run off contains high quantities of organics which drastically change the way a plant must be operated.

Surface water systems are also subject to change over time. In most cases a plant is being built because the community has determined that it is or will experience growth which will require additional water treatment capacity. That same growth can alter the water quality by allowing rainwater to wash the streets clean of oils, chemicals and other substances. A plant that was based on 5 years of testing and took 5 years to fund and construct may have drastically different raw water characteristics because instead of being in an undeveloped location it is in the middle of a suburban sprawl.

§ 3.4.3 Ocean Water

As stated in the introduction, 98% of the water on Earth is salt water and undrinkable. A number of technologies have been employed over the years to recover ocean water. The traditional method was through distillation. Distillation is an energy intensive process that boils the salt water driving off the water and leaving the salt and other material behind. The water vapor is then condensed into drinking water. Due to the energy costs distillation was used in limited applications. It wasn't until the development of membrane filtration that desalination started to become a practical, long term supply of potable water.

Membrane operation is discussed in greater detail later in the chapter. Membranes are sheet of material whose pores are so small that it can segregate or filter components dissolved in water.

The energy associated with membrane operation is the pumping pressure that must be supplied to drive the water through the membrane. While this energy is high, it is far less than the energy required to boil the same volume of water then condense it. Since the 1960's membrane quality and efficiency has steadily improved. Today the Middle East and California lead the way in desalination plants and technologies. Rooms full of rows and rows of membranes produce millions of gallons per day.

Desalinization plants have special considerations beyond that of the typical membrane filtration of a surface water source. A surface water source may use reverse osmosis membranes but typically they will use an ultrafilter. The pores in ultrafilters can separate viruses, bacteria or other large organic molecules but do not remove any small, dissolved material in the feed water. Reverse osmosis membranes can separate sodium ions dissolved in water from the water itself. Reverse osmosis membranes are more expensive and require greater monitoring for problems, failures and maintenance. The type of material used in the construction of the process equipment and piping systems must also be considered. Salt water attacks most metals, can cause stress fractures in steel and reduces the operating life of mechanical equipment. In addition to the process equipment, most desalination plants are in coastal zones which subjects the buildings and external materials to salt water spray. As a result, corrosion is a large concern in desalination plants.

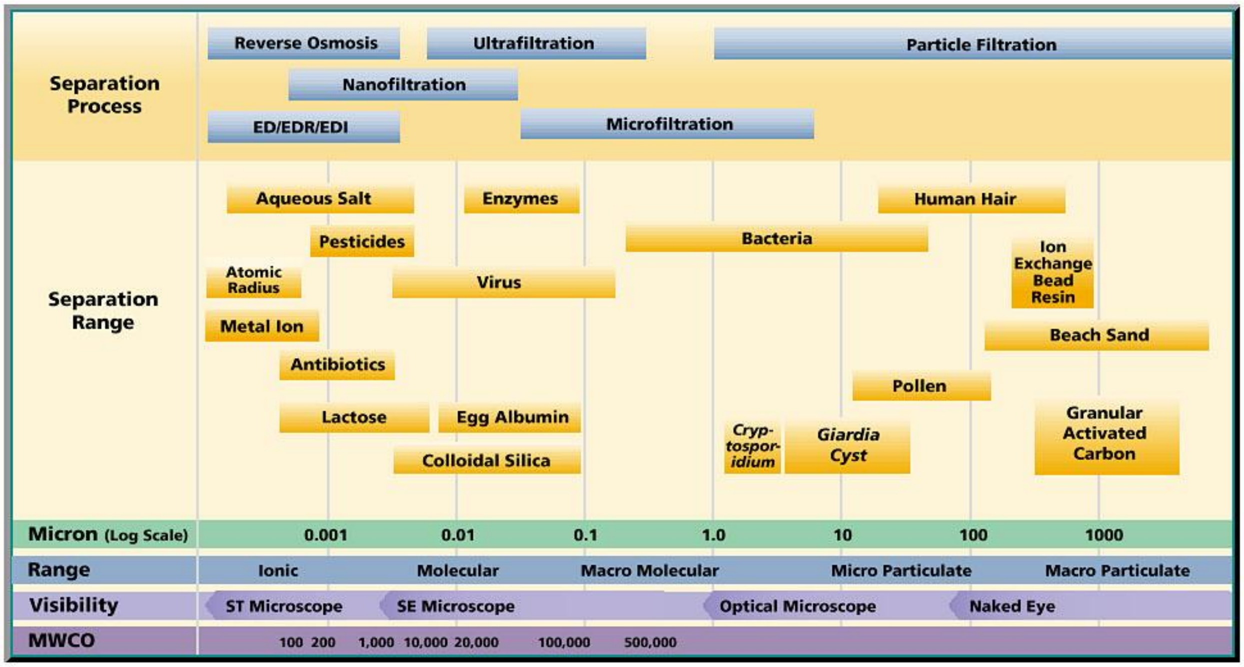
Once designed, the major consideration in desalination is the water temperature. Seasonal changes in the temperature are enough to change the operating characteristics of the membranes. Colder water requires more power to penetrate the membrane. In addition, desalination can be affected by pollution events offshore. Membranes are not made to process large volumes of oil without the proper pretreatment.

§ 3.4.4 Other Sources of Water

As industry and municipalities have become more aware of the limited nature of the availability of water, a number of water recycling plants have been built. Some of these plants return water for none potable use as a replacement to increased water consumption. In recent years, with the improvement of membranes, the recovery of wastewater from non-hazardous sources, has increased. Once the "yuck" factor is overcome the quality of water is indistinguishable from other sources.

§ 3.5 PURIFICATION PROCESSES

Purification of most materials is a sequential removal of contaminants until the desired purity is achieved. The purification process could involve chemical reactions which must be controlled and by-products that must be removed. The purification of water proceeds in a similar manner with the exception that purified water can be re-contaminated because microbial organisms can reproduce and grow. Unlike chemical processes the purification of water must account for the fact that water that is acceptable and pure at one stage can become contaminated and, thus, be unacceptable at a later stage.



Identification of Certain Contaminants and Removal Technology Ranges, courtesy of GE Infrastructure

The general flow process through a water treatment facility consists of the gathering of raw water, passing it through a series of purification steps then storing it until such time that the water is distributed to the end users. A water treatment plant uses a combination of technologies that include chemical treatment, mechanical separations and pumps to move the fluid. To understand the plant operations it is useful to start at the beginning and work through the facility.

§ 3.5.1 Influent structures

Influent structures or intakes are the places that the water treatment plant obtains the raw water that will be purified. Sources of water can be wells, springs, lakes, rivers or any other location that has a sufficient volume that can be either drawn down or replenished. The structure must have a low environmental impact and protect against sediment uptake, fish entrapment and air suction.

Due to variability of site conditions, the environmental hydraulic engineer is faced with challenges when assessing water supply availability. The major factors that can affect the selection and design of an intake are site hydrologic conditions, site access, ease of construction, and operation and maintenance. Without a careful and responsible evaluation of various design factors, an intake may be designed and constructed but may not be operable due to lack of adequate water supply or may be adversely impacted due to degraded environment.

The following factors are considered of primary importance in siting and designing an intake:

- Water Availability
- Bathymetry
- Sediment Transport
- Environmental Regulation
- Climatic Conditions
- Constructability

- Initial and Maintenance Dredging
- Operation and Maintenance

By far the most important of these factors is availability of water to meet the required demand without creating an environmentally and physically adverse effect on the water body. This is particularly important for fresh water supply. Therefore, detailed hydrologic studies including analysis of historic data must be performed. In areas where no historic data on stream flow are available, rainfall data should be analyzed to determine rainfall frequency. Hydrologic modeling can be used to estimate the runoff.

Locating and selecting the specific type of intake requires adequate knowledge of the bathymetric condition of the river, estuary or sea bottom in the vicinity of the intake. Bathymentic data is the water level in the body of water and its variation from season to season or year to year. Without this information, no specific intake concept can be selected. Making assumptions could lead to erroneous cost and schedule estimates for the project. A drop of water levels below the raw water intake would shut the entire treatment plant down. Conversely, locating the intake too deep under the surface could lead to the intake of solids, sand and other materials.

Sediment is comprised of solids carried by the flow of the water. In rivers the type of sediment can be either bed load or suspended load. Bed load is sediment that is disturbed or transported during high water velocities. Suspended load is material so small that the water suspends it. In a coastal environment, sediment is referred to as littoral drift. The existence of sediment affects the design concept and the suitability of the site for locating an intake.

Other important factors to consider are any water withdrawal limitations as well as the feasibility of dredging and disposal of dredge spoil. In some situations, water may be physically available, however, because of water rights, water required for aquatic habitats or waste assimilation may not be legally available. In addition, dredging and disposal in areas where there are endangered species or contaminated soil, could be harmful to the environment. These factors and others could affect the selection of a desired intake site and may affect the feasibility of a project.

Climatic conditions such as severe winter weather can affect the concept and details of the pump intake structure. A region with below freezing air temperature requires protection for traveling screens and trash racks against the formation of anchor and/or frazil ice. Such protection will affect the design concept and should be considered in the planning phase. If the intake is remote from the plant, electrical heating elements will be required which will increase the power demand. Alternatively the design could be made to encapsulate the intake and prevent air circulation. However, this concept can not eliminate the need for protection against frazil ice.

Construction, maintenance and access are also important factors to be considered in selecting the intake location. Availability of an access road, potential for local and riverine flooding and access to the intake equipment all year round should be considered. („Water Intakes – Siting and Design Approaches“ by Adnan M. Alsaffar and Yifan Zheng, Bechtel Corporation, 9801 Washington Blvd., Gaithersburg, MD 20878)

Experience in the design and operation of various water supply intakes indicates that no single design concept is suitable for all locations. Therefore, any intake design must be based on site specific information. This may not be possible at the planning phase of the project due to the absence of specific site data. Therefore, the hydraulic engineer must develop design parameters from the limited data that may be available, and develop programs for the field data collection and analysis for use in detailed design.

Lack of site specific information generally occurs in remote areas of the world where no historic data, studies or maps are available to help in the planning and design. The most practical approach for work under these conditions is to make a site visit and obtain aerial photographs. An important aspect of this effort is the identification of river banks and shoreline conditions and the presence of erosion and deposition. Aerial photos can best be utilized in assessing the presence of shoreline changes and of river meanders.

§ 3.5.2 Pump Stations

Pumps are used to move fluids from one place to another. They convert electrical energy to mechanical to hydraulic energy. There are different pump styles or technologies including positive displacement, progressive cavity and centrifugal, to name a few. Regardless of the design, all pumps convert low pressure fluids to high pressure fluids to overcome friction in the pipes and elevation changes.

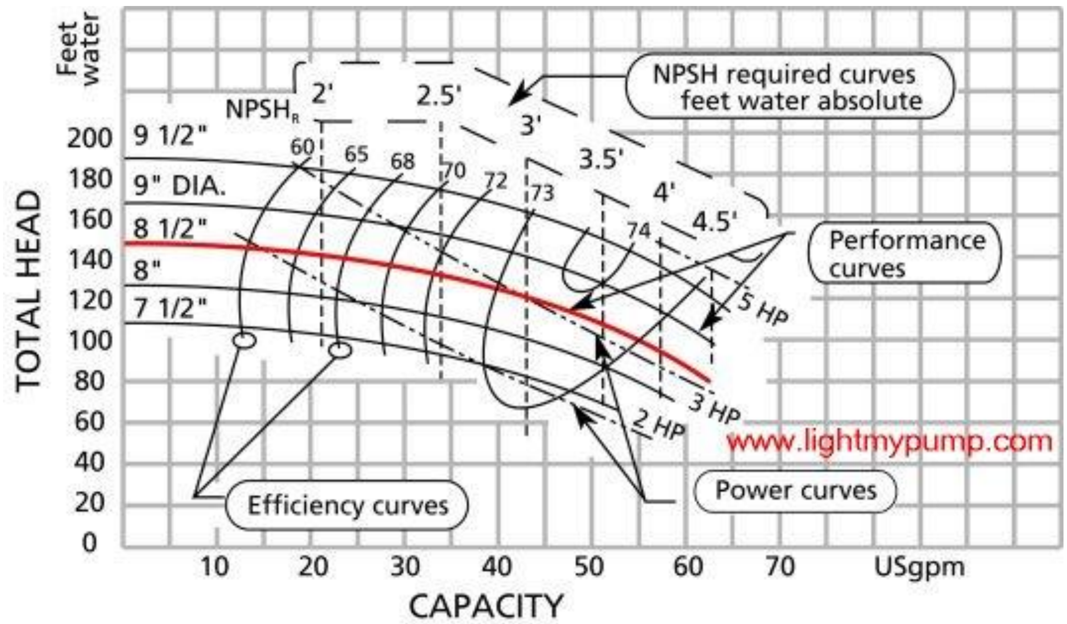
The most common pump in water plants for movement of water is centrifugal pumps. Centrifugal pumps are similar to a fan, the faster it runs and the bigger the blade the more water is pushed forward. Centrifugal pumps boost the pressure of the water. If 100 gallons per minute (gpm) enters the pump at 100 pounds per square inch gauge (psig) and the pump is rated at 50 psi boost at 100 gpm then the outlet pressure will be 150 psig. So centrifugal pumps can be additive. Many times in water treatment a “multi-stage” pump will be used. These pumps are just centrifugal pumps stacked together in a single housing and driven by the same electrical motor.

A pump’s characteristics are tied to the speed of the motor. The designer must balance pump efficiency with longevity and maintenance. Standard motors turn at 3600 revolutions per minute (rpm). At this high speed pumps can be worn down by impurities in the water or other actions which increase the maintenance requirements. However from an energy stand point these pumps are typically more efficient. Due to the size, expense and criticality of pumps in water treatment the motor speed will be reduced to 1800 or even 1200 rpm. A centrifugal pump operating at 3600 rpm will impart more pressure on a greater volume of water than the same pump at 1800 rpm.

“Variable frequency drives” or VFDs are becoming more common. These drives adjust the speed of the pump by modulating the electrical current feeding the motor. Virtually all VFDs are equipped to be controlled based on measured parameters in the water treatment plant. For example, if the plant requires a specific water pressure to operate, the plant control scheme can measure pressure at the critical point then send an electronic signal to the VFD to speed up or slow down to maintain the set pressure. VFDs and motors do have limits on the turndown or how slow they can operate. The designer must keep in mind that, for very large pumps, VFDs can be quite expensive and may result in oversized motors that only operate at capacity occasionally. Despite the increased capital costs, VFDs do reduce the energy consumption of the facility lowering operating costs.

In dealing with pumps it is important to understand a pump's “characteristics” (i.e. how the pump behaves while operating). If we think of a centrifugal pump as a fan in a window, we can imagine how they operate. First, if the window behind the fan is closed then no air can enter it. The fan will shake and overheat as it tries to get enough air to push. Similarly, if we close the window at the front of the fan then the air has no place to go. The air being pushed by the fan “slips” backwards through the fan and no air can blow.

Centrifugal pumps operate similar to the fan in the window. All pumps, including centrifugal, operate according to a “pump curve”. A pump curve is a chart of the volume of water passed through the pump versus the pressure water must overcome to reach its destination. For a centrifugal pump the curve looks like:



TYPICAL CENTRIFUGAL PUMP CURVE

From: www.pumpfundamentals.com/centrifugal-pump-tips.htm

It can be seen that the lower the backpressure on the pump the more water its going to move. Like the fan with the window closed in the front, water will slip back on the centrifugal pump and not as much will be pushed forward. In the curve above the red line represents an 8-1/2" diameter impeller (or fan blade). If the pump does not have much pressure to overcome, say 100' of head (43.3 psi) then it will move approximately 50 gallons per minute. But, as the backpressure increases to 140' of head (60.6 psi) then the flowrate decreases to approximately 25 gallons per minute. The pump efficiency is shown on the curve. The designer uses it to optimize performance and efficiency. Water also cools the pumps, so at a critical point the pump will begin to overheat. Lastly, as flow in the system increases the friction causes backpressure on the pump, decreasing flow. The pump will operate at the equilibrium point on the curve between water flow and system backpressure.

A second part of the pump curve is the "net positive suction head" (NPSH) which is the amount of pressure into the pump that is required for it to run properly. Just like the fan with the window closed behind it, a pump with low NPSH available to it cannot take in water fast enough. The NPSH is calculated based on the inlet pressure necessary to make sure that if the pump is designed to move 100 gpm at 50 psig, then 100 gpm can enter the pump. If the NPSH is low, the pump will try and move as much water as it can. The result is ultralow pressures within the pump which allow the water to vaporize or "cavitate". Cavitation occurs when small vapor bubbles form in the water because the pump is creating extremely low pressures at its inlet then when the water moves to the high pressure side of the pump the vapor bubbles collapse. Bubbles collapsing may sound innocuous, but when millions of then collapse on the surface of a pump it causes corrosion of the materials as if they were hit by microscopic hammers thousands of times a second.

While some pumps are designed to work with low or no NPSH, centrifugal pumps are not of that design. A centrifugal pump must always have some feed pressure. The amount is based on the manufacturer's recommendations which is determined by the configuration of the pump. The most common way to ensure adequate NPSH is to make sure there is water of adequate height on the inlet side of the pump. For example, if the pump is moving water from a tank to the public distribution system, then the level of water in the tank may have to be at least 5 feet above the pump intake. Or, if the pump is moving water out of a lake, the intake may need to be 8 feet under the surface. And, when we refer to the intake, the location of the blades or "impeller" of the pump is being referenced, not just a pipe stuck into the water like a straw.

Pump output pressure can be measured in a few different units. Pump outlet "feet" of head or head pressure refers to how high a pump could move a certain volume of water. Pounds per square inch (psi) or psi is a measure of the amount of force per square inch the water exerts. Psi – gauge (psig) is a measure of the pressure above atmospheric pressure and is the absolute pressure while psi usually refers to a change in pressure across a pump or piece of equipment.

As water passes through equipment or pipe it has friction losses. These friction losses are measured in psi. For example:

> 100 gpm of water enters a filter at 50 psig. At that flow rate the construction of the filter will cause a 5 psi loss of pressure or "pressure drop" on the water. Therefore, one would measure a water pressure of 45 psig at the outlet of the filter.

In sizing the pump the engineer must make sure that all of the sequential pressure drops are accounted for. These may occur in passing through equipment, filters, pipe or when changing elevations.

Pressure can also be measured in SI units such as newtons per meter squared (N/m^2), bars or atmospheres. Each of the pressure measurements has a conversion factor to translate between the units. It should be noted that not only can flow of water be designated in gallons per minute (gpm) it may also be presented in gallons per day (gpd), millions of gallons per day (MGD), cubic feet per minute (CFM) and cubic meters per second (MPS). Similar to pressure, any of these units can be converted to another one with the right conversion factor.

Pipe walls are rough and create a friction, which must be overcome. Just like sliding this book across a desk top, a certain force must be imparted on the book to make it slide. Similarly, a certain force (pressure) must be imparted to the water to get it to slide through the pipe. The longer and rougher the pipe the more friction must be overcome and the greater the pressure drop. As flowrate is increased, the friction and pressure drop also increase.

Since pipe has a limited maximum pressure rating a pump's outlet pressure is limited. High friction due to flow requirements and elevation changes can result in preeure requirements above the rating of the pipe. To overcome this problem the designers may either add booster pumps downstream or increase the diameter of the pipe used to reduce the friction. Either option requires higher capital expenditures.

Redundancy of pumps is used to allow for maintenance of the mechanical devices and to ensure plant operation in the event of a catastrophic failure. While one pump is unable to operate the others can carry the load.

§ 3.5.3 Pipelines

Pipes are used to transport water from one location to another. Common materials of construction for pipes in a water treatment plant include:

- Cast Iron
- Carbon Steel
- Steel
- PVC
- ABS

The diameter of the pipe is determined by the engineer based on friction losses described above, velocity of the water in the pipe, pressure rating of the pipe and the economics of equipment versus pipe. For a given flowrate, a smaller pipe will cost less per foot to purchase and install, but the pumps will be larger to supply the necessary pressure to overcome friction. A larger pipe is just the opposite. In addition to installation versus operating costs, the engineer must also consider material transport. If, for example, the engineer is designing a raw water pipeline, then one of the considerations is to keep the water moving quickly enough that the solids suspended in the water do not settle in the pipeline. Velocity of the water in a pipe is typically designated in feet per second or FPS.

§ 3.5.4 Treatment Processes

§ 3.5.4.1 Chemical Injection Equipment

Chemicals are used to create a chemical reaction within the water to alter the characteristics of the contaminants. For example, chlorine injected into water with dissolved iron will react with the iron to form ferrous or ferric chloride. Neither compound is soluble in water so the iron can be removed downstream in a settling basis or filter bed. Other common chemicals include ammonia, potassium permanganate, caustics and acids.

A chemical injection systems is typically composed of a storage tank or small tote of chemical, an injection pump, and injection port and the instrumentation which tells the plant operating system how much chemical to add. Chemical injection pumps are generally pumps that run at variable speeds depending on the target chemical levels in the water. The pumps may speed up or slow down based on flowrate, contaminant level or any other indicator used by the designers. As the measured parameter increases or decreases, the pump speeds up or slows down. If, for example, we wish to maintain 5 parts per million chlorine in a water stream, then a flowmeter that measures the water flow will send a signal back to the controller which will in turn increase or decrease the chemical injection pump's speed. If the operation of the plant requires pH to be maintained in a certain range then a pH probe may provide feedback to the chemical injection pump to increase or decrease chemical injection, regardless of the flowrate.

Instrumentation and probes are installed within the process to measure certain parameters. Depending on the chemical injection system the probe may be as simple as a flowmeter, to sophisticated analyzers. Instruments not only control the chemical injection systems, they also monitor and record that the chemicals have successfully been injected. The recording of critical chemical levels, such as chlorine, determine if the plant has sufficient contact time for the necessary microbial log reduction requirements.

In order to have a chemical injection system the plant is required to have some chemical storage on site. With the storage of chemicals comes the need for secondary containment, ventilation systems, safety monitors, release plans and other safety requirements to protect employees and the community. Depending on the design and size of a plant, the chemicals may be supplied in anything from small 400 gallon day tanks, to tanker trucks which top off an onsite bulk tank, to railcars. As the onsite storage volume increases, the requirements for containment and contingency plans become more complicated.

There is a tradeoff between the costs of the safety plan and the operating costs. Bulk chemicals are less expensive. To avoid any unscheduled service interruptions the plant must always have a sufficient volume of chemicals on site. The chemicals are also coming in contact with potable water so they are subject to NSF/ANSI Standard 60: Drinking Water Treatment Chemicals -- Health Effects. NFS 60, as previously noted, is the nationally recognized health effects standard for chemicals which is used to treat drinking water. It is the Standard in 45 of the 50 States along with most of Canada and numerous international countries.

§ 3.5.4.2 Chlorine

Chlorine is a highly efficient disinfectant, (HOCl or OCl) and it is added to public water supplies to kill disease-causing bacteria that the water or its transport pipes might contain. Unfortunately, chlorine also reacts with naturally occurring organics in the water to form "Disinfection Byproducts". Trihalomethanes and haloacetic acids are two broad categories of disinfection byproducts formed from the use of chlorine. These byproducts are discussed in detail later in the chapter.

Sodium Hypochlorite is another form of chlorine delivery. Another name for sodium hypochlorite is bleach. While this is a relatively inexpensive and easy to handle substitute for chlorine gas, is still has the problem with disinfection by-products.

§ 3.5.4.3 Ammonia

In order to inhibit disinfection by products caused from chlorine addition, ammonia is added just after the chlorine injection. The ammonia is added after chlorine because this causes CT (contact time) values to be lower than when ammonia is added first. Chloramines are as effective as chlorine for the deactivation of bacteria and other microorganisms, however the reaction mechanism is slower. Chloramines, like chlorine, are oxidators. Chloramines can kill bacteria by penetration of the cell wall and blockage of the metabolism. Monochloramine is the most effective disinfectant. It reacts directly with amino acids in the bacterial DNA. During deactivation of microorganisms chloramines destroy the shell which protects a virus.

When the pH value is 7 or higher, monochloramine is the most abundant chloramine. The ideal pH value for the reaction between chlorine and ammonia is 8.4, so this means the water is slightly alkaline, which may require some caustic injection. The pH value, though, does not interfere with the effectiveness of chloramines.

Little to no trihalomethanes (THM) and other disinfection byproducts are formed during chloramine disinfection. Also chloramines will remain active within the plumbing much longer, because it takes a long time for chloramines to be broken down. Lastly, chloramines do not give off any taste or smell and are relatively safe.

§ 3.5.4.4 Potassium Permanganate

Potassium Permanganate (KMnO4) is used in water treatment to control taste and odors, remove color and remove iron and manganese. Potassium permanganate is also useful in preventing the formation of disinfection byproducts (DBPs) because it oxidizes some of the naturally occurring organic precursors. The addition of potassium permanganate at the front end of the plant can reduce chlorine and ammonia requirements downstream but it is more expensive than chlorine and ammonia. Continuous dosing of potassium permanganate is also useful at controlling adult zebra mussels. Because of the reaction time, the components in the water being treated and the biological control of mussels, potassium permanganate is typically added at the raw water intake.

§ 3.5.4.5 Acid and Caustics

Acids and caustics are used to optimize the pH of the water based upon the process. Certain reactions are optimized at different pH levels. PH measurement is an indication of the acidity or alkalinity of the water. A balanced water solution will have a pH of 7. Naturally occurring waters rarely have a neutral pH. Typically the pH is slightly alkaline, over 7, but industrial pollutants in the form of run off or acid rain, can lower the pH into the acidic level.

Through the chemical injection systems the pH may be adjusted up and down several times as is passes through the plant. In order to adjust the pH, plants use either sodium hydroxide solution (NaOH), calcium carbonate, or lime suspension ($Ca(OH)_2$) to increase pH levels. Plants use diluted sulphuric acid (H_2SO_4) or diluted hydrochloric acid (HCl) to decrease pH levels. The dose of neutralizing agents depends upon the pH of the water in the process.

§ 3.5.4.6 Ozone disinfection

Ozone is a highly reactive combination of oxygen. The oxygen we breath contains two atoms of oxygen to keep it stable. Ozone contains three atoms of oxygen with a negative charge. It is more aggressive than chlorine and actively attacks virtually any carbon based material or organisms. Ozone works as a "free radical" which readily gives up the extra atom of oxygen providing a powerful oxidizing agent which is toxic to most waterborne organisms. It reduces carbon based molecules to carbon dioxide and water. Ozone produces fewer dangerous by-products than chlorination, it reacts faster than chlorine and once it reacts there is no residual odor or taste.

Ozone is made by passing oxygen through certain wavelength ultraviolet lights or via a corona discharge (similar to lightening on a very small scale). Ozone cannot be stored for any long period of time. It must be created on-site and added to the water, usually in a bubble chamber. The transfer of ozone via bubbles is very inefficient and only 20-50% of the ozone is transferred into the water.

Two main limitations of ozone are the lack of residual disinfectant and the capital cost of the generation equipment along with the materials of construction. The short life of ozone means that once disinfection is complete there is nothing to keep microbes from re-establishing themselves. Either chlorine or chloramines must be injected into the water to keep microbial contamination under control. The injection of chlorine can be done without the concern for DBPs. The second area of concern is the capital cost. Ozone will require a generator and a contact chamber. In addition, typical construction material may not be appropriate. Rubber gaskets or PVC pipe is readily attacked by ozone. Gasket materials, pipe and other materials in contact with ozone containing water must be upgraded, which is an increased capital cost.

The last thing to consider with the use of ozone is its hazardous nature. Ozone that is not dissolved in the contactor must be destroyed, typically via a catalytic converter, or else it can linger in the air. The airborne ozone, if not treated, is poisonous and will attack external surfaces. Considering the costs and the hazards, ozone has been used in drinking water plants since 1906 and the U.S. Food and Drug Administration has accepted ozone as being safe.

§ 3.5.4.7 Ultraviolet Germicidal Irradiation

Ultraviolet germicidal Irradiation (UVGI) uses ultraviolet light, which is light at very short wavelengths, to destroy microbes in water. Ultraviolet light of specific wavelengths (254.7 nanometers) breaks down a microbe's DNA function and it is considered a sterilization method. It is used in a variety of applications, such as food, air and water purification. UV light does not use chemicals or add anything to the water that could change its color, taste or odor, nor does it generate harmful disinfection by-products. The amount of UV energy, or dosage, is a function of the light's intensity and the time the water spends exposed to the light.

Dosage = Intensity * Time

The units for dosage are microwatt-seconds per square centimeter (uW-sec/cm^2). The single greatest issue with UV dosage is that light travels in a straight line and microbes can be shielded from dosage by large particles in the water. High turbidities (suspended particles, discussed later) can limit the effectiveness of UV lamps. UV lamps will generally be placed later in the process after some treatment operations to reduce or eliminate solids are complete.

UV radiation can produce a 4-log reduction at 15,0000 uW-sec/cm^2 of most common microbes. The application of UV to disinfection has been an accepted practice since the mid-20th century.

§ 3.5.4.8 Disinfection Overview

Every disinfection technique has its specific advantages and its own application area. In the table below some of the advantages and disadvantages are shown:

Technology	*Environmentally friendly*	*Byproducts*	*Effectivity*	*Investment*	*Operational costs*	*Fluids*	*Surfaces*
Ozone	+	+	++	-	+	++	++
UV	++	++	+	+/-	++	+	++
Chlorine dioxide	+/-	+/-	++	++	+	++	--
Chlorine gas	--	--	-	+	++	+/-	--
Hypochlorite	--	--	-	+	++	+/-	--

++ Very Good in addressing the issue
+ Good
+/- Average
- Not Good
- Not Recommended if the issue is a major concern

§ 3.5.4.9 Flocculation

Flocculation is a process where chemicals are added to the water and the small suspended solids coagulate and eventually become either too heavy to remain suspended in the water or they are large enough to be removed by filtration. Flocculation takes time and requires slow agitation of the water stream with enough energy to cause the particles to collide and stick together, but not too much stirring energy such that the larger particles are kept in suspension.

The larger particles are called precipitate. As the precipitate forms, turbidity is reduced and color and clarity improve. This process is called "clarification". Flocculation can form coagulants that eliminate most of the suspended solids in the water. The chemicals used for flocculation include:

1. Iron (III) hydroxide, usually added to water at a pH greater than 7;

2. Aluminum hydroxide which is a well established chemical that is also used in antacids and other applications; and
3. Synthetic polymers that have a high molecular weight and form very stable and readily removed floculants (these chemicals tend to be more expensive).

§ 3.5.4.10 Sedimentation

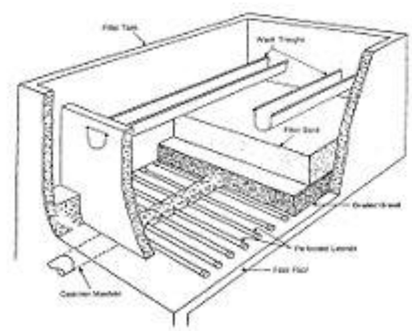
Waters exiting the flocculation basin usually enter a sedimentation basis or clarifier. These basins are very large with a low flow velocity which allows the precipitant to settle to the bottom. The basin is typically adjacent to the flocculation mixer so the flocculant does not settle in an undesired location or start to break-up. Sedimentation basins may be rectangular, where water flows from end to end, or circular where flow is from the centre outward. Sedimentation basin outflow is typically similar to a decanter where the water flows over a weir so only a thin top layer exits. The amount of precipitant that settles out of the water is dependent on the basin retention time and on basin depth. The retention time of the water must therefore be balanced against the cost of a larger basin. The minimum clarifier retention time is normally 4 hours. A deep basin will allow more precipitant to settle out than a shallow basin because large particles settle faster than smaller ones. The large particles collide with and integrate smaller particles as they settle. In effect, large particles sweep vertically through the basin and clean out smaller particles on their way to the bottom.

As particles settle to the bottom of the basin, a layer of sludge is formed on the floor of the tank. This layer of sludge must be removed and treated. The amount of sludge that is generated is significant, often 3 to 5 percent of the total volume of water that is treated. The cost of treating and disposing of the sludge can be a significant part of the operating cost of a water treatment plant. The tank may be equipped with mechanical cleaning devices that continually clean the bottom of the tank or the tank can be taken out of service when the bottom needs to be cleaned.

§ 3.5.4.11 Filtration

After separating most of the precipitant, the water is filtered as the final step to remove remaining suspended particles and unsettled solids or flocculant.

Rapid sand filters



Cutaway view of a typical rapid sand filter

The most common type of filter is a rapid sand filter. Water moves vertically through a bed that can consist of activated carbon or anthracite coal and sand. The carbon or coal removes the remaining organic compounds, which contribute to taste and odor. The sand captures large material on its surface and smaller particles throughout the depth of the bed. Initially the pores between the particles of sand are very large. As the filtered material is removed the sand actually becomes more efficient but the flow through the bed decreases because it is harder for the water to pass through the pores.

Eventually it is necessary to clean, or “backwash” the filter bed. To backwash the filter, water is passed quickly upward through the filter, opposite the normal direction to remove embedded particles. Prior to this, compressed air may be blown up through the bottom of the filter to break up the compacted filter media to aid the backwashing process; this is known as *air scouring*. This contaminated water can be disposed of, along with the sludge from the sedimentation basin, or it can be recycled by mixing with the raw water entering the plant.

Slow sand filters

Slow sand filters require more land than rapid sand filters as the water must be passed very slowly through the bed. These filters rely on biological treatment processes for their action rather than physical filtration. The filters are carefully constructed using graded layers of sand with the coarsest sand, along with some gravel, at the bottom and finest sand at the top. Drains at the base convey treated water away for disinfection.

Filtration depends on the development of a thin biological layer, called the zoogleal layer or Schmutzdecke, on the surface of the filter. An effective slow sand filter may remain in service for many weeks or even months if the pre-treatment is well designed. The filtered water is naturally low in available nutrient levels which limits the ability of any remaining microbes to reproduce. Very low nutrient levels allow water to be safely sent through distribution system with lower disinfectant levels thereby reducing consumer irritation over offensive levels of chlorine and chlorine by-products. Slow sand filters are not backwashed; they are maintained by having the top layer of sand scraped off when flow is eventually obstructed by biological growth.]

Activated Carbon Adsorption

Activated carbon can be used in two forms, powdered or granulated. Activated carbon uses a process call adsorption to capture organics and certain dissolved gasses. One primary dissolved gas removed very effectively by activated carbon is chlorine. Downstream of any activated carbon treatment chlorine levels will be reduced to zero.

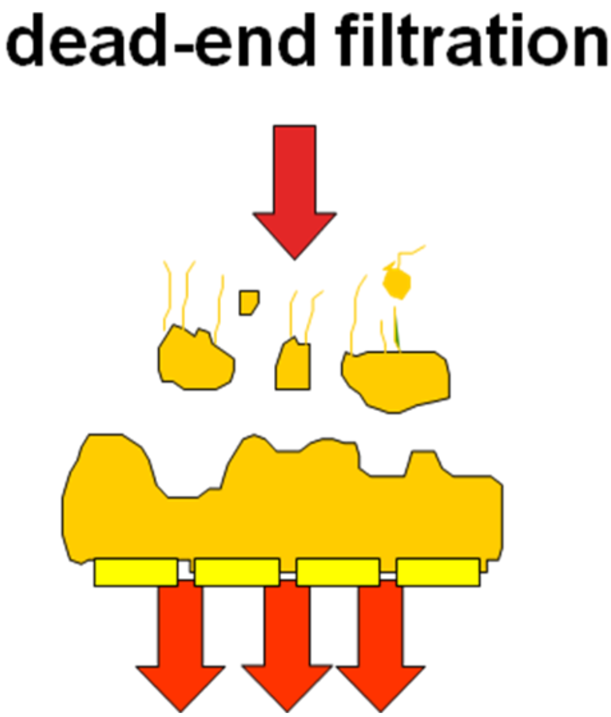
Powdered Activated Carbon (PAC) is supplied as a powder or fine granules less than 1.0 mm in size with an average diameter between .15 and .25 mm. PAC is generally added directly to other process units, such as raw water intakes, rapid mix basins, clarifiers, and gravity filters. The PAC is allowed to adsorb materials, mostly organics, as it flows through the plant. It must eventually be removed, typically by filtration. Then disposed of. Activated carbons have a limited ability to adsorb organics and can be used to remove the precursors to disinfection by-products but their ability to do so is rapidly depleted. PAC provides a high surface area to capture organics while flowing through the front end of the facility.

Granular activated carbon (GAC) has a relatively larger particle size compared to PAC. These carbons are therefore preferred for all adsorption of gases and vapors as their rate of diffusion is faster than organics. GAC can be placed in a filter bed and remove residual chlorine, deodorize the water and adsorb some materials. GAC can be either in the granular form or extruded. GAC is designated by sizes such as 8×20, 20×40, or 8×30 for liquid phase applications. A 20×40 carbon is made of particles that will pass through a U.S. Standard Mesh Size No. 20 sieve (0.84 mm) (generally specified as 85% passing) but be retained on a U.S. Standard Mesh Size No. 40 sieve (0.42 mm) (generally specified as 95% retained). AWWA (1992) B604 uses the 50-mesh sieve (0.297 mm) as the minimum GAC size. The most popular aqueous phase carbons are the 12×40 and 8×30 sizes because they have a good balance of size, surface area, and head loss characteristics.

Membrane Filtration

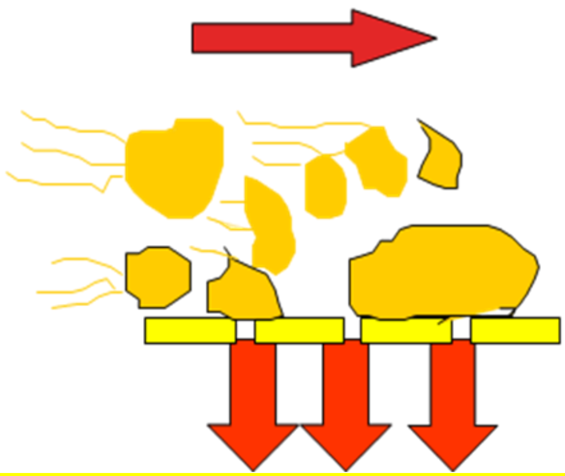
Membrane filtration refers to a series of filtration technologies based on very thin and very selective membranes. The membranes are referred to as semi-permeable because they have the ability to separate fluids, gases, particles and/or solutes from a water stream. Membranes may be a thin film or sheet or they may be long hollow tubes or fibers. Water is a small molecule and it is forced through the membranes along with any other material small enough to pass. The difference between other types of filtration and membranes is that membranes operate at molecular levels so chemical actions, such as precipitation, can occur. For this reason the pretreatment of water prior to reaching the membranes is more important, especially in reverse osmosis.

To what section do these pictures refer?



Traditional dead end filtration collects material on the surface of the filter. The filter eventually requires replacement or backwashing.

cross-flow filtration



Cross flow filtration carries material across the surface of the filter. A continuous waste stream flows from the filter but no back washing is required.

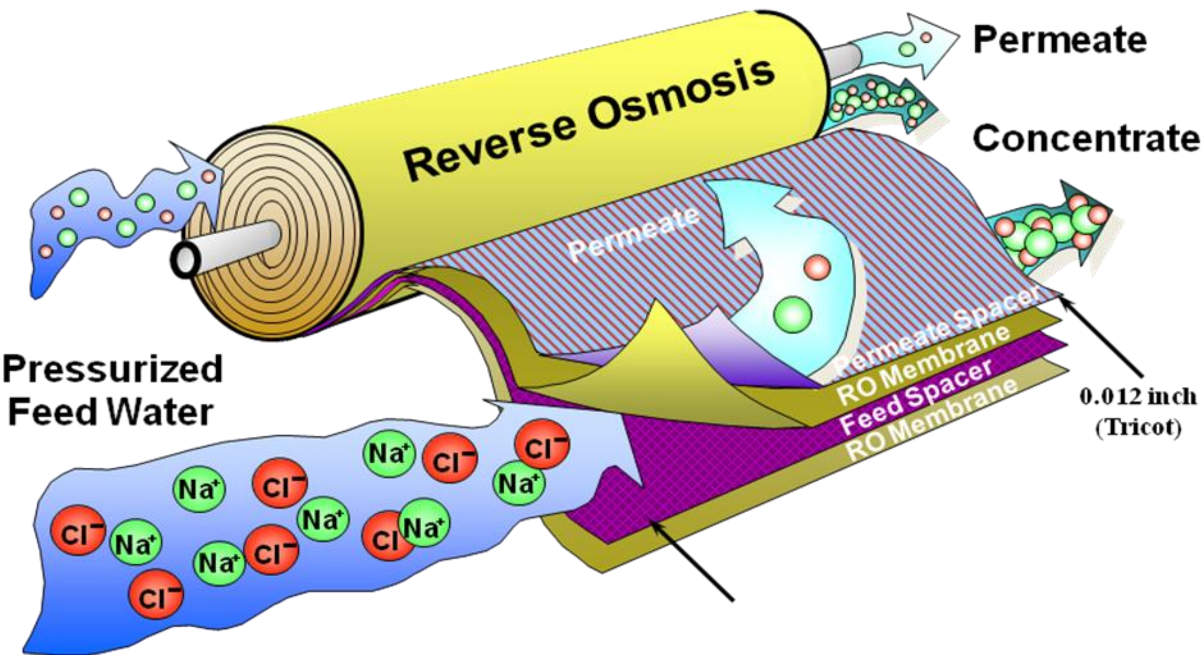
Membranes come in two predominant forms, hollow fiber and spiral wound. Hollow fiber membranes are membranes rolled into tubes that resemble spaghetti. The pores are on the surface and the water can flow down the center and out the perimeter or from the outside perimeter into the center. Because water can flow in both directions these membranes are often backwashable.

Spiral wound membranes are large sheets that are glued together at three edges then glued to a central product tube. The water is pressurized on the outside of the membrane envelope and it passes through and into the center product tube. These sheets are placed side by side radially out from the center tube then rolled in a spiral. Because of the construction of spiral wound membranes, they cannot be backwashed. There are some membranes that can tolerate chlorine and oxidizing chemicals in the water but most of the high efficiency membranes cannot tolerate continuous exposure to chlorine, permanganate or ozone.

Membranes range from “ultrafilters” to “nanofilters” to “reverse osmosis” applications. The major difference in the classification is the size of the materials excluded. Ultrafilters remove large organics, viruses and microbes. Nanofilters can remove larger ionic materials such as calcium and magnesium. Nanofilters are sometimes referred to as softening membranes. Reverse osmosis membranes remove even smaller ions such as sodium and chloride. As the membrane pore sizes decrease it takes more energy to pump the water through the system. It also leads to a greater potential for some of the ions being separated to precipitate or fall out of solution.

Water can only dissolve so much of certain materials. For instance, the ability of water to dissolve sugar and salt is very high but it is very low for other materials such as oils or calcium chloride. If enough water is allowed to pass through the membrane the remaining water cannot keep the remaining ions in solution. At this point the ions will form scale. Membrane systems, especially nanofilters and reverse osmosis membranes, must be designed such that enough water remains on the concentrating side of the membrane to keep the remaining ions in solution. This concentrate water is then rejected from the system and either returned to the environment or used for grey water applications. In membrane systems, anywhere from 5% to 60% of the feedwater is rejected as concentrate, depending upon the selectivity of the membranes.

The use of membranes requires more monitoring and maintenance but tends to use less chemicals, have lower opportunity for disinfection by product formation and can handle rapidly changing raw water quality. When they were first introduced, membranes were far more expensive than traditional water treatment plant technologies. As membrane design and production has improved costs have decreased and reliability has increased.



Cut Away of Typical Spiral Wound Membrane Module
Graphic supplied courtesy of GE Water and Infrastructure

Membrane filtration was introduced in drinking water treatment in the 1950s, mainly for desalination of seawater, brackish water and groundwater. Membrane filtration features the unique property that a membrane can be chosen that removes just the components that is needed from the actual raw water. Such components typically are:

- Inorganic or organic salts
- Metals
- Biodegradable organics
- Disinfection by-products
- Turbidity and particles
- Infectious species (bacteria, virus, parasites)

Since the late eighties membrane use for the treatment of traditional surface waters began to be seen. During this period membranes improved along with the ability to measure contaminants and microbes. At the current time, membrane filtration is very cost competitive with traditional water treatment plants and in many cases produce better, more reliable water quality at reduced operating costs. The main problem with membranes is the lack of widespread experience in their design, operation and maintenance.

Pretreatment

The pretreatment of a membrane feedwater is dependent on the membrane itself. A prefilter is an essential part in a membrane plant in order to prevent any particles larger than the size of the narrow channels between the membranes or fibers to enter the modules. Still some accumulation of matter on the membrane surface takes place and eventually reduces the flux and the capacity of the plant. This phenomenon is referred to as fouling. Avoiding and controlling fouling is the most important challenge for successful membrane filtration. Part of the maintenance program is the cleaning of fouled membranes. Most membranes are also sensitive to oxidizing materials such chlorine, potassium permanganate and ozone. In order to avoid damage to a membrane these materials must be either removed or not injected.

As the membrane selectivity becomes greater the concern that precipitate may form increases. In nanofiltration and reverse osmosis, large ionic molecules such as calcium and magnesium are separated from the product water. These two atoms are the main component of "hardness" in raw water.

Water hardness is caused by soluble ions of the alkaline earth metals, calcium, magnesium, strontium and barium. The hardness of natural waters is mainly formed by calcium and magnesium, since strontium and barium rarely occur in substantial concentrations. Water hardness is not a health risk, but it is unwanted because under certain conditions, such as reduced volume of water versus dissolved hardness or increases in temperature, the ions drop out of solution and form scale.

A common distinction is made between temporary and permanent hardness. Temporary hardness, e.g. Ca(HCO3)2, is hardness that can be removed by boiling or by the addition of lime (calcium hydroxide). Boiling, which promotes the formation of carbonate from bicarbonate, will precipitate calcium carbonate out of solution, leaving the water less hard on cooling. Hardness that cannot be removed by boiling, e.g. hardness associated with gypsum, is called permanent hardness.

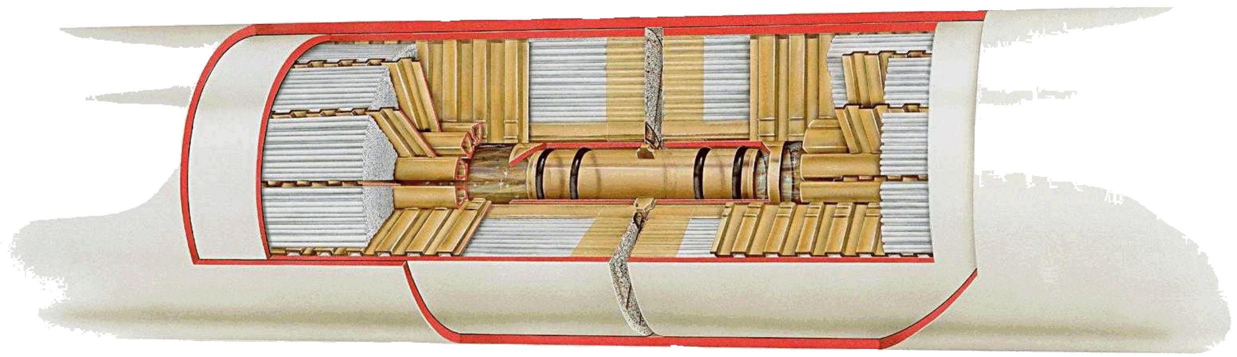
Removal or treatment of the "hardness" is called "softening" the water. Traditional methods for water softening include ion exchange, lime softening and pellet softening. In ion exchange, the water is passed through an ion exchange resin. During the passage calcium, magnesium and other bivalent or higher charged metals are exchanged with sodium or potassium ions from the resin. When the mediums capacity is exhausted, it is regenerated. Ion exchange leads to increased levels of sodium or potassium in the drinking water. This process is very expensive for large scale water treatment facilities.

Lime softening is a relatively simple process, with low to moderate capital cost for high flow rate applications, but the hardness reduction is limited to a minimum calcium concentration of about 20 mg/L. The process requires the addition of large amounts of lime and acid, and produces large quantities of sludge that requires disposal.

The use of reverse osmosis and nanofiltration membranes on groundwater and surface waters present a serious problem in the control of scale. Scaling or precipitation fouling occurs in a membrane process whenever there is not enough water to keep ions of a sparingly soluble salt in the concentrate stream dissolved. Inorganic foulants found in reverse osmosis and nanofiltration applications include carbonate, sulphate and phosphate salts of divalent ions, metal hydroxides, sulphides and silica. The most common constituents of scale are CaCO3, CaSO4 · 2 H2O and silica. Other potential scalants that are rarely found are BaSO4, SrSO4, Ca(PO4)2 as well as ferric and aluminum hydroxides. As with other types of fouling precipitation, fouling reduces the quality and the flow through the membrane system. The problem is usually aggravated in attempts to increase the water recovery. Scaling frequently leads to physical damage of the membranes due to the difficulty of scale removal and to irreversible membrane pore plugging.

Ultrafiltration (UF)

Ultrafiltration is the most popular membrane treatment technology for surface waters and groundwaters under the influence of surface water. UF may be employed using traditional spiral wound membranes but the more popular design utilizes hollow fibers.



Cut Away View of Hollow Fiber Membrane Module
Supplied courtesy of GE Water and Infrastructure

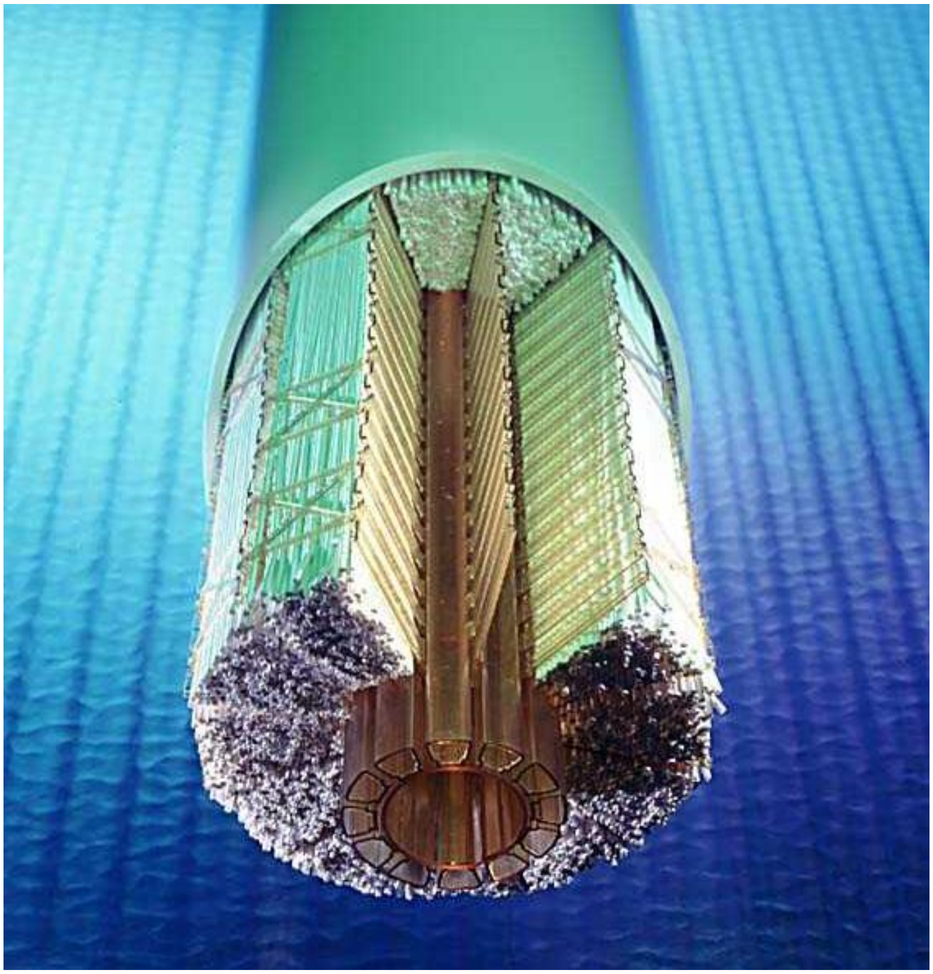
Hollow fiber membranes are popular in potable water treatment because it offers a number of benefits over other technologies:

- **Modest energy requirement –** pumping costs are low compared to other membrane filtration technologies.
- **No waste products -** Since the basic principal of hollow fiber is filtration, it does not create any waste from its operation. There is a backwash stream that is a concentrated flow of unwanted components in the feed stream.
- **Large surface per unit volume –** The surface area, and hence the number of pores in a hollow fiber is very high when compared to other membrane types. This means a smaller equipment footprint.
- **Flexible** : Hollow fiber is a flexible membrane, it can carry out the filtration by 2 ways, either is "inside-out" or "outside-in". The configuration refers to the flow of water from inside the capillary out or the opposite direction.
- **Low operation cost** : Hollow fiber needs low operation costs compare to other types of unit operation.

However, it also have some disadvantages:

- **Membrane fouling** : Membrane fouling of hollow fiber is more frequent than other membrane due to its configuration. Typically hollow fibers are used like traditional filters where all the water passes through the filter membrane and the contaminants are captured on the surface. These filters then must be backwashed. Contaminated feed water can increase the rate of membrane fouling.

- **Expensive -** Because of its fabrication method, the Hollow Fiber is more expensive to manufacture than other membranes which are available in the market.
- **Physical and Chemical constraints** : Hollow fiber, which is made of polymer, cannot be used in corrosive substances or high temperature conditions.



Cut Away View of a Hollow Fiber UF
Supplied courtesy of GE Water and Infrastructure

UF units run at pressures ranging from 90 psig to 40 psig. One of the key measurements is "transmembrane pressure". This measurement is the difference between the water on either side of the membrane. The membranes are rated for flow per module per pound of transmembrane pressure. The suppliers will also calculate backwash requirements and timing based on transmembrane pressures.

Traditional spiral wound membranes, including UF units, cannot be backwashed because the membrane sheets are manufactured for flow in a single direction. Any attempt to backwash a spiral wound membrane will result in irreversible damage to the membrane module. Therefore, spiral wound membranes use cross-flow where a small amount of water continuously carries the concentrate stream along the membrane surface and out to the waste.

UFs are popular in water treatment because they can separate the large organic molecules and colloidal silica from the rest of the product water. They eliminate disinfection by-products, reduce the opportunity for silica scaling and improve the color and taste. UFs will not remove most disinfection by-products because they are much smaller molecules than the precursors.

Therefore, when using UF technology it is not necessary, and in fact is not advisable, to use chlorine prior to the filtration unit.

Nanofiltration (NF)

Nanofiltration is the range of membrane filtration between UF and reverse osmosis. NF processes are capable of removing hardness, heavy metals, color, taste, large organics, particles and a number of other organic and inorganic substances in one single treatment step. Operating pressure is typically in the range of 75 psig or higher with rejection rates from 10% to 50%. The membranes are good for surface and ground waters with high concentrations of total dissolved solids (TDS), i.e. more than 500 mg/L, but with low NaCl concentrations. NF membranes are a way to soften water without chemicals or ion exchange. Unfortunately, NF membranes still have the same scaling issues associated with reverse osmosis membranes.

Reverse Osmosis (RO)

Osmosis is a naturally occurring process where water tends to flow through a semipermeable membrane from a solution with low concentration of salts to one of high concentrations. Water will attempt to make the concentrations of the salts on both sides of the membrane equal. In a sealed chamber one can see the water level on the concentrate side of the membrane rise as water tries to dilute it. Eventually the back pressure caused by the higher volume of water will cause the flow across the membrane to stop. The difference in the water levels represents a difference in pressures at the membranes and is called the osmotic pressure.

Reverse osmosis is the process of forcing water from a high concentration of salts and other dissolved materials through a semipermeable membrane to a lower concentration. In order to accomplish this, flow pressure greater than the osmotic pressure must be applied. Once the osmotic pressure is overcome, water will flow in the reverse direction of naturally occurring osmosis.

RO membranes are usually a layer of polymer or cellulous acetate matrix where only very small molecules can pass. Water is a very small molecule along with most gasses and some disinfection by-products. Cellulous acetate membranes are of an older design, require a higher driving pressure, more energy and can be subject to microbial attack but they can tolerate low levels of chlorine. The modern polymers are typically more efficient, run at lower pressures, can tolerate a wider pH range and have better rejection of salts but they cannot tolerate chlorine or other oxidizing agents. The polymer composites constitute an overwhelming majority of the applications.

RO membranes require a higher drive pressure than UF or NF on the high concentration side of the membrane, usually 100–250 psig for fresh and brackish water and 600–1000 psi for seawater (seawater has an osmotic pressure of approximately 350 psi). The rejection rate can range from 25% up to as high as 90% depending on the application.

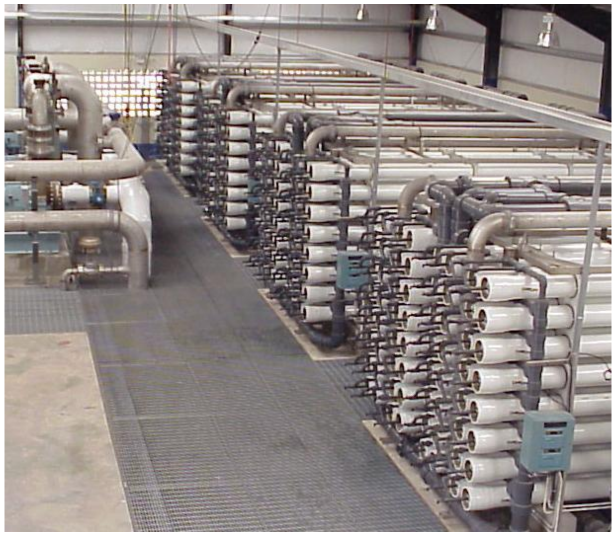


Photo of desalination membrane racks
Supplied courtesy of GE Water and Infrastructure

While RO may be used on surface waters, it is the dominant application for desalination. Prior to the development of RO the dominant technology was distillation. Distillation requires heating water to a vapor then condensing it as a product water. The phase changes, from liquid to vapor back to liquid again, are very energy intensive and the water remaining on the feed side has the same scaling and precipitation issues as RO membranes. RO is a less energy intensive way to remove salt from seawater because there is no phase change required - just pump energy. At the current time, desalination is a growing application in California and the Middle East but is also gaining in popularity as a technology choice in places like Florida, New Jersey, Africa and China. The major economic determinant on its viability is the cost of power.

Distillation

Distillation is the separation of water from its impurities by use of a phase change. Water is vaporized in one chamber then condensed in another. The process is very energy intensive as the heat to vaporize one pound of water is about 970 BTU's per pound. In comparison, the heat required just to raise the temperature of water by 1oF is only 1 BTU per pound. In other words, the energy necessary to vaporize water is almost 1,000 times greater than the energy required to raise it 1oF without the phase change.

Distillation is a proven technology for the separation of water from impurities. With the exception of volatile organics, all other contaminants are left behind. It is effective for the desalination of water as most of the contaminants tend to stay in solution while being heated.

Two main methods of distillation are multistage distillation and vapor compression distillation. Multistage stages the water distillation into 2 to 4 stages using the waste heat from the first stage to distill the second stage. This method requires the management and control of pressures and temperatures from a high temperature, high pressure stage to progressively lower pressures and lower stages. While the control of the stages reduces the energy requirements there is a limit as to the size of the steps. Multistage distillation is limited in the volume of water produced.

Vapor compression stills utilize a compressor to reduce the pressure in the distillation chamber. The heat of compression of the vapor is used to supplement the heat required to distill the water. These units are typically able to produce a greater volume of water and they were the standard in distillation prior to the introduction of membranes.

Aeration

Aeration is the treatment process whereby water is brought into intimate contact with air for the purpose of (a) increasing the oxygen content, (b) reducing the carbon dioxide content, and (c) removing hydrogen sulphide, methane and various volatile organic compounds responsible for bad taste and odor. The treatment results mentioned under (a) and (c) are always useful in the production of good drinking water. Reducing the carbon dioxide content, however, may shift the carbonate-bicarbonate equilibrium in the water so that deposits of calcium carbonate are formed which may cause problems.

Aeration is widely used for the treatment of ground-water having too high an iron and manganese content. These substances impart a bitter taste to the water, discolor it and can give brownish-black stains to clothes washed and white enamel buckets, bowls, sinks, baths and toilets. The atmospheric oxygen brought into the water through aeration will react with the dissolved ferrous and manganous compounds changing them into insoluble ferric and manganic oxide hydrates. Sedimentation or filtration can then remove these. It is important to note that the oxidation of the iron and manganese compounds in the water is not always readily achieved. Particularly when the water contains organic matter, the formation of iron and manganese precipitates through aeration is likely to be not very effective.

For the treatment of surface water, aeration would only be useful when the water has a high content of organic matter. The intimate contact between water and air, as needed for aeration, can be obtained in a number of ways. For drinking water, treatment is mostly achieved by dispersing the water through the air in thin sheets or fine droplets (waterfall aerators), or by mixing the water with dispersed air (bubble aerators). In both ways the oxygen content of the water can be raised to 60-80% of the maximum oxygen content that the water could contain when fully saturated. In waterfall aerators there is an appreciable release of gasses from the water; in bubble aerators this effect is negligible. The reduction of carbon dioxide by waterfall aerators can be considerable, but is not always sufficient when treating very corrosive water. A chemical treatment such as lime dosing or filtration over marble or burned dolomite would be required for this type of water.

Other Unit Operations

The descriptions of specific unit operations is neither exhaustive nor complete. These operations are merely some of the most common. As a process review is completed it is probable that specific technologies, not covered within this chapter, are employed to address specific characteristics of the feedwater to the plant.

Disinfection and Disinfection By-Products

In order to supply disease free water to the public, municipalities must disinfect the water. Disinfection is accomplished through any one, or a combination of, the technologies previously discussed, including chlorine addition, chloramines, ozone, membrane filtration and ultraviolet light. One of the greatest challenges to today's water treatment technologies is the control and removal of disinfection by-products (DBPs). These chemicals are undesirable side reactions that produce harmful and hazardous chemicals as a result of the addition of oxidizing chemicals to, or the irradiation of, a raw water stream.

Reduction of disease causing microbes is measured in “log reductions”. Log reduction relates to the percentage of microorganisms physically removed or inactivated by a given process.

- 1-log reduction = 90%
- 2-log reduction = 99%
- 3-log reduction = 99.9%
- 4-log reduction = 99.99%

Minimum surface water treatment requires a 3-log removal for Giardia lambliacysts and 4-log removal for viruses.

There are several groups of disinfection by-products:

Trihalomethanes (THM) are a group of four chemicals that are formed along with other disinfection byproducts when chlorine or other disinfectants used to control microbial contaminants in drinking water react with naturally occurring organic and inorganic matter in water. The trihalomethanes are chloroform, bromodichloromethane, dibromochloromethane, and bromoform. The EPA has published the Stage 1 Disinfectants/Disinfection Byproducts Rule to regulate total trihalomethanes (TTHM) at a maximum allowable annual average level of 80 parts per billion.

Haloacetic Acids (HAA5) are a group of chemicals that are formed along with other disinfection by-products when chlorine or other disinfectants used to control microbial contaminants in drinking water react with naturally occurring organic and inorganic matter in water. The regulated haloacetic acids, known as HAA5, are: monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid. The EPA has published the Stage 1 Disinfectants/Disinfection Byproducts Rule to regulate HAA5 at 60 parts per billion annual average.

Bromate is a chemical that is formed when ozone used to disinfect drinking water reacts with naturally occurring bromide found in source water. The EPA has established the Stage 1 Disinfectants/Disinfection Byproducts Rule to regulate bromate at annual average of 10 parts per billion in drinking water.

Chlorite is a byproduct formed when chlorine dioxide is used to disinfect water. The EPA has published the Stage 1 Disinfectants/Disinfection Byproducts Rule to regulate chlorite at a monthly average level of 1 part per million in drinking water.

Chemical inactivation of microbiological contamination in natural or untreated water is usually one of the final steps to reduce pathogenic microorganisms in drinking water. Combinations of water purification steps (oxidation, coagulation, settling, disinfection or filtration) cause (drinking) water to be safe after production. As an extra measure, many countries apply a second disinfection step at the end of the water purification process in order to protect the water from microbiological contamination in the water distribution system. During this disinfection process, one usually uses a different kind of disinfectant from the one used earlier in the process. The secondary disinfection makes sure that bacteria will not multiply in the water during distribution. Bacteria can remain in the water after the first disinfection step or can end up in the water during backflushing of contaminated water (which can contain groundwater bacteria as a result of cracks in the plumbing).

Disinfection commonly takes place because of cell wall corrosion in the cells of microorganisms, or changes in cell permeability, protoplasm or enzyme activity (because of a structural change in enzymes). These disturbances in cell activity cause microorganisms to no longer be able to multiply. This will cause the microorganisms to die out. Oxidizing disinfectants also demolish organic matter in the water, causing a lack of nutrients. (Read more: http://www.lenntech.com/processes/disinfection/what-is/what-is-water-disinfection.htm#ixzz0wt1R47MU)

The EPA has establish strict rules on the disinfection of water and the control and monitoring of disinfection by-products. The EPA Guidance Manual on the Surface water Treatment Rule and Disinfection Profiling can be downloaded at the following websites:

http://www.epa.gov/safewater/mdbp/lt1eswtr.html
http://www.epa.gov/ogwdw000/mdbp/pdf/profile/lt1profiling.pdf

A sample excel sheet for calculating log removal credits can be downloaded from the following site:

http://www.epa.gov/safewater/mdbp/lt1/xls/profile_benchmark_calculator_short.xls

The following table illustrates the log removal credits available from select technologies:

Process	Typical Log Removal Credits		Resulting Disinfection Log Inactivation Requirements	
	Gardia	Viruses	Gardia	Viruses
Conventional Treatment (flocculation, sedimentation and filtration)	2.5	2.0	0.5	2.0
Direct Filtration	2.0	1.0	1.0	3.0
Slow Sand Filtration	2.0	2.0	1.0	2.0
Diatomaceous Earth	2.0	1.0	1.0	3.0
Alternative (membranes, bag filters, cartridges)	Log reduction must be demonstrated by pilot study or other means showing microbial reductions			
Untreated	0.0	0.0	3.0	4.0

As previously mentioned gardia requires a 3.0 log reduction or 99.9% removal and viruses require a 4.0 log reduction or 99.99% removal.

§ 3.6 DISTRIBUTION SYSTEMS

Once water is treated it is sent to storage or holding tanks. From this point the water must be delivered to the community. Prior to distribution, additional chlorine or chloramines may be added so that a residual disinfectant is present throughout the network of pipes.

Pump Stations are installed at the outlet of the product water tanks to supply water from the plant to the users. These pumps operate under the principals discussed previously. Engineers must determine elevation changes, friction losses and flowrates to design the pumps. Operation and maintenance should also be taken into consideration.

All pumps must be periodically maintained. Some maintenance items are as simple as non-invasive inspections and observations, while other items are more rigorous and may require taking a pump out of service. In addition, Pumps are, by their nature, high speed mechanical equipment and may fail.

Pump configurations can be installed based upon maintenance considerations, failure analysis and capital costs. Some typical configurations are:

Configuration	Size per Pump	Benefits	Limitations
Single Pump	100%	Low Capital Cost low maintenance costs	Plant Failure if Pump Fails, limited turn down for VFD controls.
Dual Pumps	100%	Lower Capital Cost, Redundancy	Limited turn down for VFD controls
Triplex	50%	Better redundancy, lower pump motor for turn down with VFD	Higher capital costs in both piping, controls and pumps, higher maintenance costs
Quad	33%	Flexibility in operations, redundancy, lower maintenance costs per pump, better energy efficiency. More flexibility for future expansion.	Higher capital costs in both piping, controls and pumps, higher total maintenance costs.

As pumps are added the flexibility and ease of maintenance improves. It also improves the energy efficiency if variable frequency drives (VFDs) are used to slow the motors down during periods of low demand. The slower the motor runs the less water is transferred and the less energy is used. The motors, however, can only be slowed to a certain point so the variable flow is not infinite.

Pipelines are used to direct the water from the pumps to its final destination - in this case, the public, commercial and industrial customers. Typical household fixtures require 25 to 30 psi to operate properly. In areas with large elevation changes booster pumps may be necessary to deliver the proper pressure. It is also possible to use elevated storage tanks as part of the distribution system.

The distribution pipe is typically buried and in areas with the potential for freezing conditions, the pipe is below the frost line. The pipe material of construction can be plastic, iron or concrete where the deciding factor is a balance of durability, life expectancy and cost. Plastic, left undisturbed can have a life expectancy of fifty years or more which can make it a very economical infrastructure investment. Plastic, though, is not as robust as iron pipe or concrete if it is struck by items such as construction equipment.

Plastic tubing is the material of choice and it is widely used for its light weight, chemical resistant, non-corrosive properties, and ease of making connections. Plastic materials include polyvinyl chloride (PVC), chlorinated polyvinyl chloride (CPVC), fiber reinforced plastic (FRP)[2], reinforced polymer mortar (RPMP)[2], polypropylene (PP), polyethylene (PE), cross-linked high-density polyethylene (PEX), polybutylene (PB), and acrylonitrile butadiene styrene (ABS). In many countries, PVC pipes account for most pipe materials used in buried municipal applications for drinking water distribution and wastewater mains.[3]

Older designs and applications relied on metal such as iron. Water can corrode iron and release it into the water stream. This corrosion can cause problems with fixtures and stain ceramic surfaces. Proper balancing of the pH and alkalinity or injection of corrosion inhibitors is necessary to limit distribution systems corrosion.

Failure of distribution system pipe systems is the largest single infrastructure issue associated with water treatment. Cracks in pipes can cause mixing of dirt, sewage and other materials post water treatment. Larger leaks can cause sinkholes that develop over years prior to discovery. Catastrophic failures can ruin other infrastructure, such as streets and cause a disruption in service. It is estimated that 20-40% of water in older distribution systems is lost to leaks. Technologies are being developed to inspect pipe, in situ, and perform repairs.

In order to reliably supply water to its customers a utility maintains water storage at the treatment plant and throughout the distribution system. Storage supplies a buffer in the event of mechanical equipment or process failures. Water tank application parameters include the general design of the tank, its materials of construction, as well as the following:

- Location of the water tank (indoors, outdoors, above ground or underground).
- Volume of water the tank will need to hold
- For what the water will be used.
- Temperature in area where water will be stored (i.e. concern for freezing).
- Pressure requirements.
- How the water is to be delivered into and extracted from the water tank.
- Wind and Earthquake design considerations to allow the water tank to survive seismic and high wind events.

§ 3.7 PLANT CONTROL AND MONITORING

The instrumentation, electronics, plant monitoring systems and control systems are all designed to ensure each individual unit operation is functioning within its parameters and to ensure the water produced by the plant meets the Drinking Water Standards. In addition to the online monitoring and control, municipalities must also report key parameters, some of which must be measured in a certified lab remote to the plant.

The onsite control and monitoring system consists of inputs from instruments located throughout the facility. The characteristics of the raw water feed to the facility, the water into and out of each purification step or unit operation, and the final water quality. The information gathered can be used for adjustments to the process operation and recording of data for reporting.

The instrumentations' signals can feed into discrete programmable logic controllers (PLC) which have software programs internally that make logic decisions for the operation of a process or piece of equipment. A second option is to have a building automation system or central process automation systems which may have subprograms similar to the PLC but also have overriding central programs that make global decisions, interface with the plant operators and record critical data. The input signals can be either digital or analog. Digital signals indicate either "on/off", "start/stop", "open/closed" etc. Analog signals are inputs that supply a number such as 50^{o}F, 400 parts per million, 500 gallons per minute and other quantitative measurements. The program logic will use this information to send signals to automated equipment. These signals may also be either digital or analog. For example a digital signal may cause a valve to move from the open position to the closed position while an analog signal may increase or decrease the speed of a pump.

Large scale drinking water systems are required to report water quality, water quality excursions or failures, and certain mineral, organic and other impurity levels to state and federal agencies. The monitoring must be done either by certified and calibrated instruments or by certified labs.

The certified analytical methods may be found at
http://water.epa.gov/scitech/drinkingwater/labcert/analyticalmethods.cfm.

Certain substances and qualities are readily measured by instrumentation while others are more difficult. Total dissolved solids, organic carbon and silica are examples of direct measurements. Chlorine, iron and hardness are parameters that are typically measured via grab samples or inferred indirectly. Chlorine is very aggressive and is measured by an instrument that determines the oxidation reduction potential of the water. By measuring the ORP level we can infer the chlorine level. In a grab sample the water has indicator chemicals, usually with some color change indication, added to the water in certain rations or until a visual change occurs. Newer plants or fully automated plants may have chlorine monitors installed eliminating the need for any grab sampling or inferred measurement.

§ 3.8 KEY DESIGN, CONSTRUCTION & OPERATIONS LEGAL ISSUES

Contracts between the municipalities, engineers and construction parties allocate risk of failure. Key risk factors include:

1. Performance guarantees
2. Disinfection By Products
3. Virus and Bacterial Contamination
4. Operating Costs
5. Cost guarantees
6. Manpower
7. Chemical Consumption
8. Energy Consumption
9. Changing raw water feed
    a. Rain Fall
    b. Floods
10. Infrastructure Failure
11. Contamination
12. Risk of Underutilization
13. Schedule
14. Commissioning and Start-up
15. Acceptance
16. Criteria
17. Sustainable Designs

Municipalities have bonds and other state and federal financing vehicles which they must pay from the profits of selling the water to customers. Engineers typically have a standard of care duty for design and performance of other services. The constructors must build within the parameters established by the design drawings and specifications.

The single greatest area of project and plant failures occur during the gathering of design data and establishment of assumptions. Municipalities secure water rights, sometimes years in advance. Water quality is typically monitored via grab samples. Preliminary budgeting and schedules are developed based on these snapshots of the water quality. A problem may develop if there are singular events, which are not captured or when changes in the topography or development occurs around the water source. These changes are not so surprising in the case of lakes and reservoirs supplying raw water. Communities can grow around the lake in a very short time changing the characteristics of the water.

Municipalities also tend to be over optimistic with respect to their own population growth. Who should be responsible for the increased costs when a plant is underutilized and run inefficiently?

Engineers may try to gather all the possible design data they can. More information means greater delays prior to initiation of the design and initiation of construction. One of the most important pre-design studies that can be done is a pilot plant study. Many constructors and equipment suppliers have pilot plants that can be run to prove the technological operation prior to full scale development. Typically the membrane treatment suppliers insist on this type of study.

Finally, the constructors and the equipment suppliers have standard operating parameters which will ensure their system operations will perform according to the specifications. The engineer's job is to ensure each unit operation functions as part of the whole. If water quality falls out of specification and a workmanship or quality issue is suspected it will be necessary to confirm that the unit operations were operating within specifications.

With sufficient information and reasonable expectations a water treatment plant can be built which is economical, supplies water with meet the quality requirements and can be expanded to meet future needs. If risk is allocated to a party that cannot control the availability of information the stage is set for conflict.

§ 3.9 SUMMARY

Water is a limited, renewable resource that populations around the world are starting to appreciate and understand. Many groups, especially in developed countries, view water as a right - specifically cheap water. As industrialization continues and populations grow there is more stress placed on the available water supply. As this evolution occurs the technologies exist to meet the demand, but always at a cost.

The technologies outlined in this chapter are not an exhaustive list. Entire books are written describing the available technologies. Any ten engineers or designers given the same set of parameters will, most likely, design ten different water treatment plants. All ten will work and all ten are within the standard of care for the engineer. The reader should understand that there is no right way to design a perfect water treatment plant and there is no perfect way to operate one. There is a certain amount of art to the process.

Water projects will not be diminishing. In developed countries the existing, aging infrastructure and requirements for improved water quality will continue to drive new projects. In developing countries the standard of living will drive improvements in the quality of water. As the quantity of projects increase, the opportunity for issues to arise also increases.