State of Alaska

Water Treatment Guidance Manual

Alaska Department of Environmental Conservation

Drinking Water Program

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1.0 INTRODUCTION

1.0 INTRODUCTION

The Alaska Department of Environmental Conservation (ADEC) prepared the Alaska Water Treatment Guidance Manual to assist water system engineers and designers of new public water systems or upgrading existing systems. It should also prove useful to designers in planning for operation and maintenance functions for public water systems.

A major portion of the manual is devoted to design and operation and maintenance criteria for the use of surface water as a potable water source. The design criteria and specifications contained in the manual relating to surface water treatment were derived primarily from the EPA Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources, March 1991, (EPA SWTG Manual) which are designed to satisfy the criteria contained in the EPA's Surface Water Treatment Rule (SWTR).

The Manual also serves to provide a number of different options to the water system designer in an attempt to provide the most economical system design while still meeting current regulatory requirements.

Major features of the Manual include:

- Many items for public water system design consideration that are unique to the Alaskan environment, such as source anomalies and treatment.
- Discussion of standard practice for design topics.
- Discussion of operation and maintenance of public water system facilities.
- New monitoring and reporting requirements for filtered systems resulting from the 1986 amendments to the Safe Drinking Water Act (SDWA).
- The ADEC plan submittal/review process.
- Public water system design examples.

2.0 BACKGROUND ON ALASKA WATER TREATMENT

2.0 BACKGROUND

This *Alaska Water Treatment Guidance Manual* was prepared to assist designers in the planning, design, construction, and operation of treatment facilities for public water systems.

A major portion of this Manual is devoted to design and operation and maintenance criteria for the use of surface water as a potable water source.

In June 1986, (P. L. 99-339) the U.S. Congress amended the Safe Drinking Water Act of 1974 . In these amendments Congress stated that:

- Not later than 18 months after June 19, 1986, the [U.S. Environmental Protection Agency (EPA)] Administrator shall propose and promulgate national primary drinking water regulations specifying criteria under which filtration (including coagulation and sedimentation, as appropriate) is required as a treatment technique for public water systems supplied by surface water sources;
- In promulgating such rules, the [EPA] Administrator shall consider the quality of source waters, protection afforded by watershed management, treatment practices (such as disinfection and length of water storage and other factors relevant to protection of health) 42 U.S.C. 300 g-l(b)(7)(C).

The regulation that EPA developed in response to this portion of the amendment is known as the Surface Water Treatment Rule (SWTR). The final version of the SWTR was published on June 29, 1989, and became effective December 31, 1990. The SWTR includes criteria that each state with primary enforcement responsibility ("primacy") for drinking water regulations is to use in determining which public water systems supplied by surface water sources (or groundwater sources "under direct influence of surface water,") need to install filtration and, for those systems with filtration, in determining if treatment is adequate. States with primacy are required to specify enforceable design and operating criteria for filtration on a statewide or system-by-system basis. The SWTR affects the design, construction, operation, and maintenance for all systems which use surface water or groundwater under the direct influence of surface water.

The SWTR mandates that unless stringent source water quality criteria and other site-specific conditions are met, all public water systems using surface water must be disinfected and filtered. The SWTR also specifies that all public water systems must be operated by qualified operators. The State of Alaska is allowed to specify the required qualifications.

The SWTR requires each state to incorporate requirements at least as stringent as the federal requirements into state regulations governing water systems. State rules may differ slightly from the federal requirements; where they differ, the state rules must be comparable or more stringent.

The EPA also produced a Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources, March, 1991. That manual:

- Provided background on the history and reasons for the SWTR, background information on types of filtration, and definitions of new terms used in the regulation.
- Presented all requirements for each type of water system: filtering, non-filtering, and ground water under the direct influence of surface water.
- Provided helpful suggestions for each type of system on how to improve its system or operations to meet the new requirements.
- Provided tables and definitions that are required to fully understand the regulation but are not readily available elsewhere.

ADEC established "working groups" of engineers, system operators, and informed citizens to make recommendations for incorporating the SWTR into state regulations. Their recommendations included:

- Methods for designating appropriate filtration technologies;
- Methods for determining whether coliform maximum contaminant level (MCL) violations were due to treatment deficiencies;
- A method for evaluating whether groundwater is "under the direct influence of surface water"; and
- Developing interim disinfection requirements.

This manual provides guidance for complying with the SWTR as implemented in Alaska, plus other water treatment requirements and recommendations. To implement the SWTR, ADEC has also promulgated regulations which may be found in 18 AAC 80 and the Alaska Drinking Water Procedures Manual.

The EPA manual makes recommendations that will help small and medium-sized systems meet requirements of the SWTR. It did not, however, provide specific guidance for the design, construction, operation and maintenance of the small water treatment plants which usrface water supplies in Alaska.

By comparison, this manual provides planners, designers, and operators with design and operation criteria that are the *state of the practice* in rural and urban Alaska.

For the purposes of this manual, when community size is referred to, the size definition is as follows:

Small = Fewer than 1,000 population
Medium = 1,000 to 10,000 population
Large = More than 10,000 population

3.0
SOURCES OF SURFACE WATER

3.0 SOURCES OF SURFACE WATER

Potable water sources in Alaska include:

- Shallow lakes or ponds.
- Deep lakes and reservoirs.
- Rivers or streams.
- Shallow ground water (this manual will discuss only shallow ground water or "ground water under the direct influence of surface water").
- Melt water from snow or ice.
- Rainwater.
- Brackish water.

Surface waters in cold regions are relatively free of minerals and metal salts. Because of this, they tend to be corrosive according to the Langelier or Saturation Index and aggressive using the Aggressiveness Index. Corrosive waters will attack metal pipes and tanks, shortening their life and increasing concentrations of iron, copper, lead, or other corrosion products in the water. These concentrations can quickly exceed the EPA standards for drinking water. Surface waters are usually more corrosive and aggressive during ice-free periods, because the temperature and dissolved oxygen concentrations are at or near saturation levels. Treatment to reduce corrosive properties is often necessary. It is essential to evaluate the impact of corrosion and use the information in the selection of pipe materials, in the design of controls, and in monitoring after construction.

3.1 Types of Sources

3.1.1 Lakes

Lakes are usually the most cost-effective, and sometimes the only, water source. Streams and shallow ground water usually freeze to the bottom in the winter or are easily contaminated, and deeper ground water (beneath the permafrost) is often highly mineralized or too deep to be economically developed.

3.1.1.1 Ice formation and thaw bulbs

The amount of ice formed on the surface of lakes can significantly influence the quantity and quality of the water available. Shallow lakes may freeze to the bottom or may freeze-concentrate impurities below the ice to the extent that the water is no longer of acceptable quality or must receive extensive treatment to be made potable. Some lakes, however, which are not suitable as a year-round water source may be used on a seasonal basis to fill water storage tanks ("fill and draw systems").

Thickness of the ice is proportional to the air temperature. A general expression for ice thickness on lakes is called Stefan's equation:

$$h = \left(\frac{2 \times k \times SFI}{L_v}\right)^{0.5}$$

Simplifying this equation:

$$h = \mathscr{L} \times (SFI)^{0.5}$$

where: h = ice thickness, in meters
SFI = freezing index at ground surface, °C x seconds
L_v = volumetric latent heat of fusion of water, Joules/meter^3
k = thermal conductivity of ice, watts/(meters x °C)
$\mathscr{L}$ = coefficient of proportionality, meters/(°C$^{0.5}$ x seconds$^{0.5}$)

Table 3-1 provides typical coefficiencies of proportionality.

Table 3-1
Examples of $\mathscr{L}$-Factors for Ice Thickness

$\mathscr{L}$-Factor m/(°C$^{0.5}$ x s$^{0.5}$)x 10^{-5}	**Conditions**
10.4 - 11.0	Practical maximum for ice not covered with snow
9.3	Windy lakes with no snow
8.1 - 9.3	Medium-sized lakes with moderate snow cover
6.7 - 7.5	Rivers with moderate flow
4.6 - 5.8	Rivers with snow
2.3 - 4.6	Small rivers with rapid flow

Snow cover has a significant insulating effect and can reduce the maximum accumulated ice thickness. The total ice thickness can also be greater than calculated. For instance, if the weight of snow or the lowering of the water level causes cracks in the ice, water overflows onto the surface, where it is then drawn into the snow. The resulting slush freezes and bonds to the original ice. This snow ice appears white, whereas pure water ice appears clear or black.

Impurities, such as salts and dissolved organics, are rejected from freezing water, making the ice relatively pure. The more slowly ice is formed, the more efficient the rejection process becomes. The effect of this process is that impurities concentrate in the water under the ice. As the water volume reduction of a lake or pond approaches 50 percent because of ice formation, dissolved salt concentrations double. Thermal and chemical analyses and volume estimates are required to identify a lake or pond that may freeze deep enough to create problems with high dissolved salt concentrations. A simple mass balance can be used to estimate concentrations which may be present in the remaining water.

Ordinarily, lakes that do not freeze completely will have a "thaw bulb" into the permafrost. The depth of the thaw bulb is usually equivalent in size to the length of the minimum dimension of the surface of the lake. If this dimension is greater than the permafrost thickness, the thaw bulb will probably extend through the permafrost and the lake can be a recharge source for ground water beneath the permafrost.

3.1.1.2 Thermal stratification

The density of fresh water is greatest at 4°C (see Section 4.2). This condition causes lakes in cold regions to "turn over" in the fall which will increase total dissolved solids (TDS) and suspended solids (SS) as currents bring sediments up from the lake bottom. This process also takes surface water, probably near saturation with oxygen, and circulates it to lower layers. As the surface of the lake cools, there is a continuous circulation between the top and bottom of the lake. The colder water sinks, displacing the warmer water to the surface. This turn over process generally continues until the entire lake is at 4°C. As the lake continues to cool, ice will start to form on the surface. The deeper the lake, the longer it takes ice to form. This is because there is more heat to be extracted. If a lake is deep, the water temperature at the bottom will not rise above 4°C in the summer, the turnover is milder because currents will not reach the bottom, and the sediments are not disturbed. Also, winds can keep a shallow lake so well mixed that it will not go through the fall "turnover." Figure 3-1 shows typical thermal conditions in Alaska lakes.

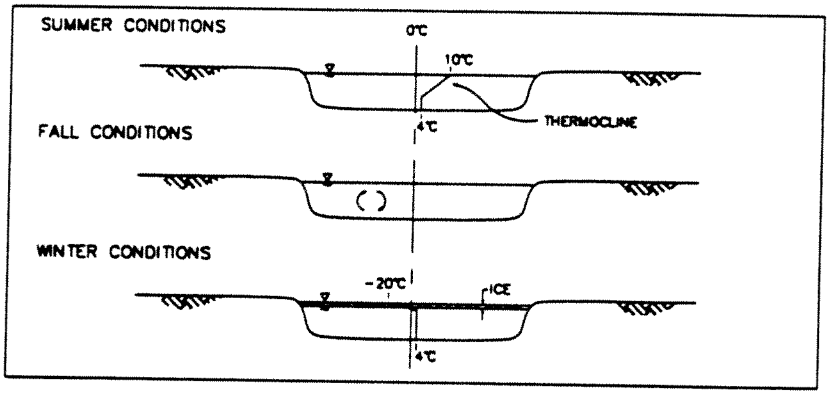


Figure 3-1. Typical Thermal Conditions in Alaska Lakes

3.1.1.3 Contamination with salt water

Coastal lakes are often vulnerable to salt water contamination when onshore winds during a storm blow waves or spray into them. In considering coastal lakes as a water supply, all available data on storm waves and tides should be examined. Most of the time this consists of:

- Salinity measurements in the proposed source lake and surrounding lakes, especially those closer to the coast.
- Location of driftwood from prior storms.
- Knowledge of elders in the community.
- Vegetation types.

These lakes can also be contaminated by tidally influenced groundwater infiltration or highly mineralized water from brine pockets within the thaw bulb that the lake has melted into the permafrost. This contamination can usually be detected by water sampling near the lake bottom.

Methods of reducing the salinity or mineralization of a lake will be covered in Section 3.1.1.5.

3.1.1.4 Recharge

Lakes are recharged by runoff (sheet flow) from rain or melting snow, precipitation directly onto their surfaces and streams that flow into them. Inflow from springs or ground water may be present in deeper lakes in mountainous terrain, but is usually not significant in lakes in continuous permafrost areas. The amount of recharge a lake receives is offset by evaporation, water withdrawn for use, and outflow. Larger, deeper lakes and lakes outside the area of continuous permafrost can also have outward seepage through the sides or bottom. An example of a calculation of water yield for a typical arctic lake is included in Appendix 3.

a. Precipitation. Much of northern and western Alaska is a "cold desert" and is underlain by permafrost. Mean annual precipitation is typically around 15 cm (6 in.), of which about half falls as snow (around 1 meter [40 in.]). On the other hand, annual precipitation in southeast Alaska can be over 4 meters (160 in.). Precipitation design values are available from the National Oceanic and Atmospheric Administration (NOAA) and can be found in the Environmental Atlas of Alaska published by the University of Alaska. When no other information is available, these references can be used as a guide. For large projects where accurate information is critical, data should be collected for several years before final design to confirm that the required yield will, in fact, be available. Snowfall recorded in flat, windy areas is often quite low because of measurement errors. In fact, snow sublimation and summer evaporation losses in the arctic appear to often equal the amount of winter snowfall that goes unmeasured, and the total <u>recorded</u> snowfall may approximate real snowmelt runoff volumes.

b. Evaporation. Measurements using standard evaporation pans indicate evaporation at 9 cm (3.54 in.) per summer in Barrow and 13.05 cm (5.14 in.) in Prudhoe Bay. A measured evaporation rate on a small lake near Prudhoe Bay indicated the actual evaporation rate was approximately 10 cm (3.94 in.). These, and other comparisons, indicate an actual evaporation/pan evaporation ratio of 0.7 to 0.75 and can be used for Alaska's North Slope. Design values for other areas can be obtained from NOAA or the Environmental Atlas.

c. Runoff Augmentation. Runoff volumes can be significantly increased using snow entrapment methods such as snow fences. Experiments at Barrow have indicated that for every meter (3.3 ft) of width of 1.5 meters high (5 ft) snow fence, properly spaced, could contribute about 10,000 liters (2,700 gal) of water to the runoff from a watershed. The amount of augmentation available will vary from location to location depending on snowfall and wind conditions.

3.1.1.5 Shallow lakes or ponds

These lakes are abundant in northern and southwestern Alaska and are often the only water supply for communities and temporary and permanent camps. Even the large lakes (over 500,000 m^2, or 120 acres) are seldom more than 2 or 3 meters (7 ft to 10 ft) deep and freeze to the bottom in the winter. They have a relatively small water mass with a large surface area. Even though they contain a large volume of water in the summer, with maximum ice formation, the liquid volume may be reduced by two thirds and the remaining water is high in organics and TDS. These high concentrations decrease rapidly in the spring when the ice melts and snowmelt brings fresh runoff water into the lake. Also, because of the number of lakes and the flat terrain, the watershed for a given lake is often not much larger than the lake itself and recharge is small. An example for an actual lake is included in Appendix 3.

a. Water Quality. In addition to the concentration of impurities in shallow lake water by the advancing ice in the winter, their limited recharge potential also contributes to poor quality. Almost all of the runoff into these lakes is concentrated into a one to two week period during breakup. This influx of water can occur while there is considerable ice still on the lake surface. Typically, the snow melts in the small watershed before the ice in the lake melts significantly. Depending on the outlet characteristics of the lake, much of this sudden influx of water in the spring can pass over the ice and out the lake outlet without being retained in the lake. Snow fences can help retain water by creating drifts which melt slowly over a period of a month or longer. This extends the period of time the lakes are being recharged past the "ice covered" stage and allows them to retain more of the higher quality runoff water.

The "spring breakup" water is usually of better quality than the recharge from the summer rains. Runoff from the rains usually filters through the lichens and mosses on the surface before reaching the lake. In draining through the plant material, the water picks up tannins and lignins which will increase color and taste problems. Most of the spring breakup water flows over the top of the frozen plant material and thus picks up relatively little organic material. This organic material (tannins and lignins) can cause high trihalomethane (THM) concentrations when the water is chlorinated for domestic use.

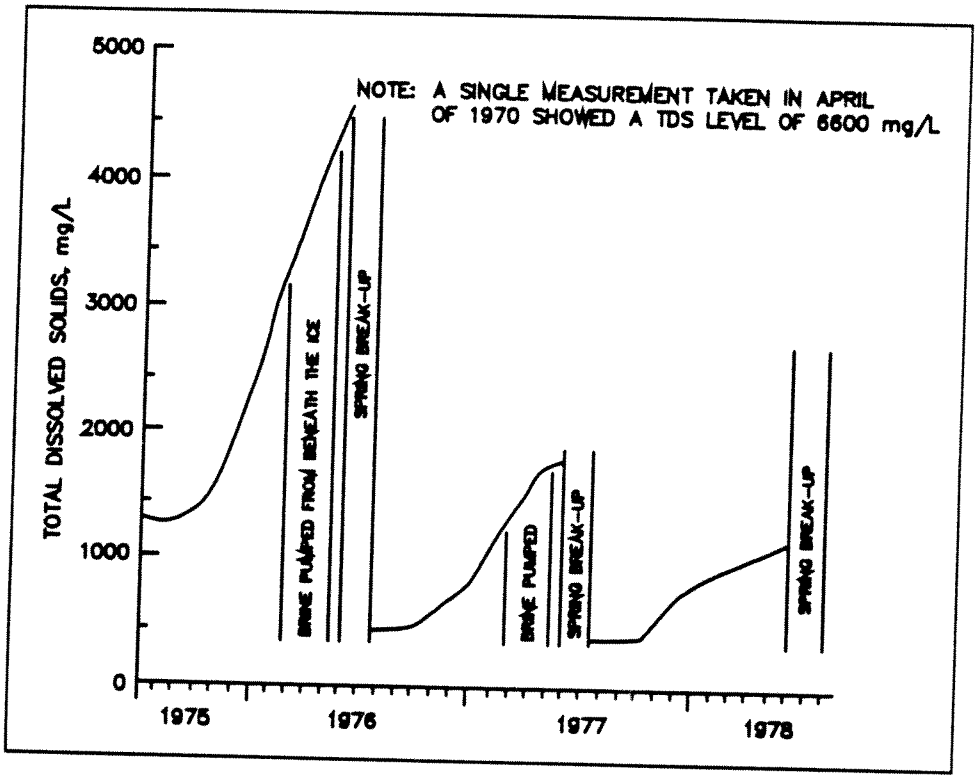
Source evaluations should include information on these seasonal fluctuations in water quality.

b. Quality Improvement. Several methods have been tried to improve the quality of water from shallow arctic lakes.

   1. Selective Pumping. For systems using large storage tanks and "fill and draw" systems, selective pumping has proven to be a successful method of improving the quality of the water that can be recovered from a shallow lake. For fall pumping, the intake should be located so it pulls in the highest quality water: above the bottom sediments but below the surface ice that is forming. Experience indicates the best time to top off tanks is after the fall "turnover" and after enough ice has formed to support a pump and protect the surface of the lake from wind-induced currents that stir up bottom sediments. Thus, the intake structure should be able to be skidded out on the thin ice in the fall for the fall filling and floated out on the water surface in the spring for the spring filling. This will allow

water to be withdrawn when lake water quality is at its best and reduce the sophistication of the treatment process and the amount of treated water storage required.

Another method of water quality improvement through selective pumping of a reservoir is shown in Figure 3.2. Brine is pumped from under the ice before breakup and discharged. Thus, contaminated water is discharged, leaving room for retention of fresh runoff water during breakup.



NOTE: A SINGLE MEASUREMENT TAKEN IN APRIL OF 1970 SHOWED A TDS LEVEL OF 6600 mg/L

Figure 3-2. Water Quality Improvement in Upper Esatkuat Lagoon

Barrow, Alaska

2. Ice Thickness Reduction. If the ice thickness can be reduced, the quality of water withdrawn during the winter can be improved. Several methods using floating, manufactured insulation have been proposed or tried with less than satisfactory results. Installation and maintenance

costs are high, because the insulation must be removed during the spring and replaced in the fall.

Several North Slope camps run circulating heat lines under the ice to reduce the ice thickness. This method is extremely expensive unless an inexpensive source of heat is readily available.

Increasing the thickness of the snow cover on the ice using snow fences has been tried, but it was found that insulating with drifted snow usually increased the overlying weight on the ice, thus depressing the ice surface and causing water to infiltrate the snow and freeze. This can result in essentially no net gain in unfrozen lake water.

3. Increasing Lake Depth. Lakes have been deepened by dredging. However, care must be taken as this will disturb the natural thermal regime of and around the lake and can cause permafrost melting and lake enlargement. Dredging can significantly increase the turbidity of the water also. Lakes can be deepened by diking the outlet and other low points around its perimeter. Again, this will completely change the thermal regime and can cause catastrophic failures including complete draining of the lake (see erosion below).

c. Erosion and Migration. On Alaska's North Slope, most of the lakes are elliptical, having axial ratios around 1.5, and their long axes generally are aligned north-northwest, perpendicular to the predominant summer winds (see Figure 3-3). These small lakes slowly migrate and drain into one another, or into the ocean, through the process of erosion. In considering a lake for a water supply, its potential for migrating or draining must be evaluated in addition to its recharge area and depth. The possibility of draining can be reduced by protecting the natural outlet from thermal erosion with insulation and erosion protection.

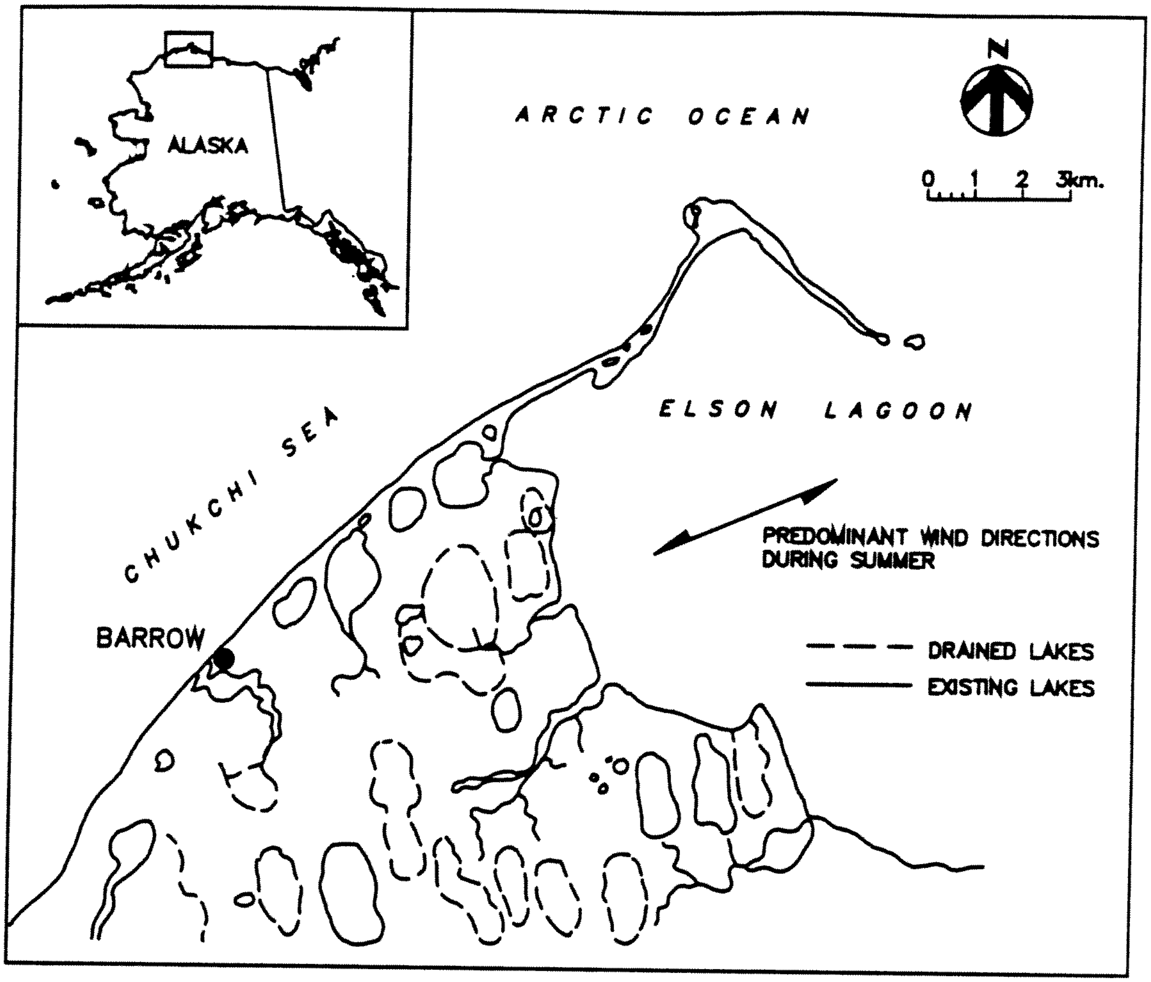


Figure 3-3. Shallow Lakes Near Barrow, Alaska

The organic content of lake water is also increased by the thawing of ice wedges around the shore and the subsequent collapse of the surface organic material into the lake. Remedial action can be taken to preserve, or even improve, the quality of lake water in cold regions. Lake banks should be stabilized, especially in the area of the intake, to reduce, or slow, thaw-collapse of banks and reduce the possibility of the lake draining. Stabilization of Kaktovik's water supply lake outlet was accomplished using board insulation covered by sand and gravel.

3.1.1.6 Deep lakes and reservoirs

Deep lakes and reservoirs formed by damming a stream are often used for water supplies. In contrast to shallow lakes, ice formation is such a small part of the total depth of a deep lake that it does not materially affect water quality except to reduce the dissolved oxygen content in the winter. Deep lakes and reservoirs can have oxygen deficiencies, at depth, year round if the climate and ground temperatures maintain a 4°C water temperature. This prevents the lake from "turning over" and mixing, as shallow lakes do. It also means the water quality stays relatively constant on a year-round basis.

A water balance must be completed to determine the amount of water that can be safely withdrawn. This is more difficult for deep lakes or lakes in discontinuous permafrost areas than for shallow lakes on permafrost because it is hard to estimate the discharge (or in some cases recharge) from the sides and bottom. Deep lakes in permafrost areas usually have a thaw bulb extending through the permafrost allowing them to provide recharge to the ground water beneath the permafrost. Reservoirs created in areas of continuous permafrost will disturb the natural thermal regime of the stream, the permafrost inundated by the lake formed, and the material under the dam. Severe settlement may be experienced. This can cause dam failures if it is not planned for in the design and maintenance. Thermopiles have been used to extract this heat supplied by the reservoir and maintain the frozen state of the material under the dam and the dam itself. Also, the flooding of vegetation (or organic material) will cause a reduction in water quality.

Reservoirs are also created by excavating high permeability areas (gravel pits) adjacent to a river or stream. These pits fill with water seeping from the river during high flow periods. They are usually 10 to 25 meters deep and, if properly sized, provide a relatively high quality, year-round water source even when the stream or river is completely frozen and contains no flow. These reservoirs or pits are used by several of the North Slope camps for domestic water.

3.1.1.7 Sheet ice forces on structures

Ice, after it forms on a reservoir or lake, can cause severe forces on dams and shore structures. The ice sheet contracts when cooled and expands when warmed. When an ice sheet contracts, it usually cracks. The cracks immediately fill with water which then freezes. Later, when the ice warms it expands and thrusts shoreward. This kind of ratchet action is all in one direction. This expansion exerts large forces on both dam faces and shore structures. The amount of movement, described as lateral thrust, varies with the thickness of the ice sheet, temperature changes, and solar radiation. This ice thrust does not significantly increase with ice sheets greater than 300 mm (one foot) thick, because the ice below this depth is not exposed to the large temperature fluctuations as it is at the surface. Snow cover also reduces the magnitude of these forces by reducing the effect of sudden air temperature changes on the ice temperature. For example, a lateral thrust of 22 tons per lineal meter could cause an overturning force on the vertical face of a dam equal to the force of the water. This pressure can be reduced considerably by slightly sloping the upstream face of the dam at the top.

3.1.2 Rivers and Streams

Larger streams and rivers that maintain a flow in the winter typically have thaw bulbs beneath them, often extending through the permafrost. These rivers can provide a year-round water supply either by direct withdrawal or from the thaw bulb using a well or infiltration gallery. Infiltration galleries or shallow wells near the river are usually the preferred method of withdrawal because of the problems encountered in designing intake structures to withstand the large ice forces encountered at breakup and the frazil ice problems on surface intakes. Another factor that must be taken into account is whether in-stream flow minimums are required by the Alaska Department of Fish and Game (ADFG).

Many smaller streams, especially those fed by surface runoff or melting glaciers, completely stop flowing in the winter. This is even true for streams in the high rainfall areas of Southeast Alaska and the Aleutian Islands during prolonged cold spells.

3.1.2.1 Ice formation

Ice formation in a river or stream follows the same process as was described above for lakes. However, with streams or rivers, the thickening ice sheet is impacted by the turbulence of the moving water. The velocity of this water has a major effect on the amount of ice formed and the speed of its formation. Rivers and streams also have thermal stratification as was discussed for lakes. At surface velocities above 0.5 m/sec (1.5 ft/sec), vertical mixing caused by the flow is usually sufficient to prevent stratification.

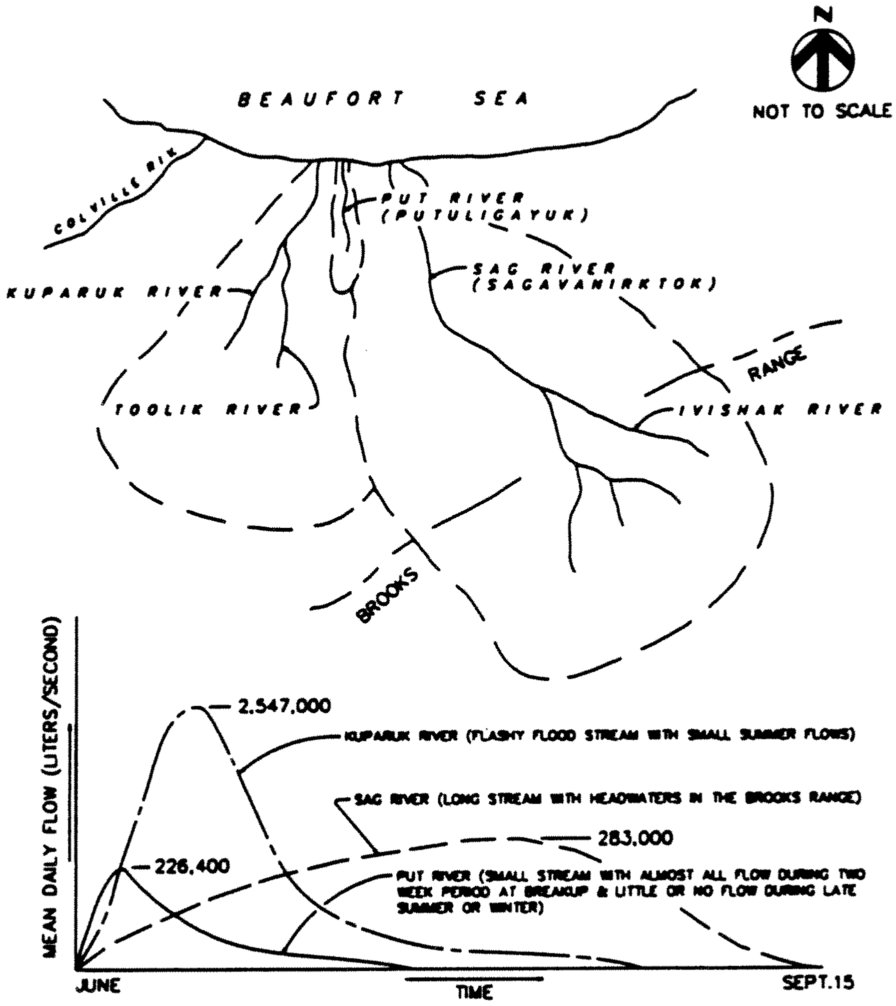
Ice formation in a stream usually starts with the water being supercooled which forms floating frazil ice. This ice comes in contact with the ice sheet forming in the slower water along the shore and sticks to it, building the ice sheet farther and farther out into the stream until a continuous cover is formed. At this point the heat loss through the ice sheet causes the ice to thicken downward. Under the same weather conditions, ice growth on rivers is less than on lakes because of the constant source of heat supplied by the flowing water.

3.1.2.2 Flow variation

From a water supply perspective, the amount of ice formed on a river or stream is not as important as the flow remaining in the river itself and under the river bed. Stream flow records over several years are very desirable but seldom available. Flows in ungaged streams can be estimated using information from gaged streams having similar climates, watershed characteristics, and flows. Measuring stream flow during the winter can be extremely difficult but may be necessary to determine minimum flow for a year-round source.

- Seasonal Variations. Streams and rivers in Alaska have wide-ranging runoff characteristics, depending on several characteristics of the stream and watershed. Figure 3-4 shows typical hydrographs and characteristics for three rivers on the North Slope.

- Icings (Aufeis). Ice buildup in the stream or river channel can store considerable water. Streams that derive a significant portion of their flows from groundwater are more prone to develop ice than those deriving their flows from surface water. On a typical stream in the Fairbanks area, for instance, 4% of the total annual flow and 40% of the winter stream flow was stored in ice. There are several ways ice can be caused to form or form naturally. The reader is referred to the various texts referenced in the bibliography, appendix 5. Ice buildup has the effect of spreading the stream's flow over a longer period—essentially throughout the summer as the ice melts. Like snow drifting using snow fences, it is a method of stream flow augmentation. Ice can also create major operation and maintenance problems at bridges and culverts.



River	Approx. Drainage Area (km^2 and mi^2)	Approx. Max. Elevation in Watershed (meters and ft)
Put	575 (222)	80 (260)
Sag	13,880 (5,360)	2,130 (7,000)
Kuparuk	9,220 (3,560)	1,220 (4,000)

Figure 3-4. Typical North Slope Watersheds and Stream Flow Hydrographs

3.1.2.3 Water quality

Rivers and large streams are usually good water sources in winter because sediment transport is minimal and overland flows, which tend to lower water quality, do not occur. The disadvantages of rivers as a supply source include low water temperatures and flowing ice during freeze-up and breakup periods, which may damage or destroy water intake structures. Breakup ice jams can occur quickly. Also, in alluvial streams it is difficult to locate a permanent channel under the ice. Seasonal water quality changes may be significant for cold region rivers. Winter flows consist of water from interflow, ground water, and spring water. Although the sediment content may be low, mineral content may be higher than in the summer. Another factor is that the lower the water temperature, the higher the viscosity and, thus the sediment carrying capacity of the river or stream. Summer river flows, which tend to be much greater than winter flows, frequently contain sediments from overland runoff or glacial rock flour from melting glaciers.

The biological quality and turbidity of surface water sources can vary considerably during the year. Variations in arctic Alaska are primarily from summer to winter, while in southeast Alaska the variation is usually due to storm events. Treatment facilities must be operated differently with these seasonal or event variations.

Where rivers or streams flow into the ocean, water quality will be influenced by the tides. The tidal change in northern and western Alaska is relatively small (1 to 2 meters), but because the gradient of the rivers is so flat, the tide affects the water quality of the Kuskokwim, Yukon, and other rivers over 120 km (75 miles) upstream. The fresh water of the river overrides the brackish water from the ocean. To avoid the intake of brackish water in these situations, intakes must pull water from near the surface, and infiltration galleries may not be suitable. This situation can add considerable complexities to the design, construction, and operation of an intake structure. Samples must be taken during high tides and, preferably, during onshore winds to define the amount of brackish water intrusion. Selective pumping may be an option where water is drawn through the intake only at low tides.

3.1.2.4 Erosion and meandering

Erosion can contribute significantly to sediment loads during the summer. Essentially, the stream thaws the permafrost at the water level on outside bends (cutbanks) undercutting the surface material. After being exposed, the overhung soil and organic material falls into the stream and is washed away. This process continues throughout the summer.

Most streams in northern and western Alaska are meandering streams. Figure 3-5 is a computer simulation of a typical meandering river in permafrost. In this simulation, the river meander is moving to the right and, probably, a gravel bar is building up on the left. An infiltration gallery or shallow well could be located in this gravel bar to take water from the thaw bulb beneath the river. A well on the right side of the river would probably end with no water, in permafrost. Meanders are continually moving by cutting on the outside. When these meanders cut to the point that they join, the loop is bypassed and considerable scour can result.

Streams and rivers in Southeast Alaska usually have shorter travel distances and do not form an ice cover. Frazil ice can be a problem on intakes and, often, color can be high because of organic material absorbed during runoff. Daily flow variations and sediment loads are concerns with streams having glaciated watersheds.

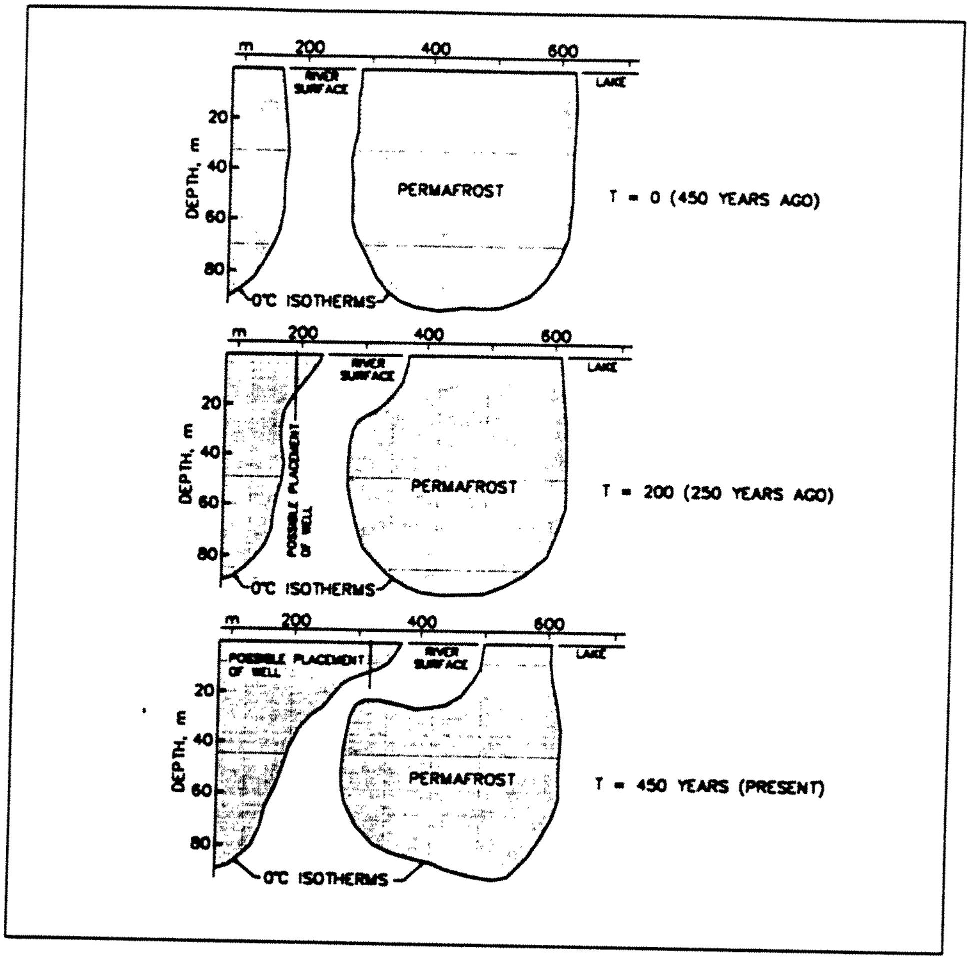


Figure 3-5. Effect of a Meandering River on Permafrost (Cross-section)

3.1.3 Ground Water Influenced by Surface Water

EPA has directed that ground water influenced by surface water must comply with the SWTR. Infiltration galleries or shallow wells less than 9 meters (30 ft) deep must be evaluated to determine if they are under the direct influence of surface water. The Alaska Drinking Water Procedures Manual is necessary for making this determination (see Sections 3.1.3.6 and 3.1.3.7).

Calculations for contact time (CT) give credit toward meeting the inactivation requirements in the SWTR. In addition, ADEC has specific requirements for the required distance between domestic wells and sources of pollution. See 18 AAC 72.015 and 18 AAC 80.

Natural filtration by soil and ecological strata can be beneficial in the removal of bacteria, viruses and protozoa. However, there is currently insufficient scientific information to allow ADEC to make quantitative judgements regarding the efficacy of pathogen removal by natural elements (i. e., "credit" for natural filtration). When such information becomes available, ADEC may allow natural filtration credit.

3.1.3.1 Frozen ground influence

Ground water is a significant resource in cold regions but often has poor quality. Wells in sporadic or discontinuous permafrost areas often produce water high in iron and manganese. At concentrations of 5 mg/L or less, iron and manganese can usually be removed using ion exchange resins in pressure filters. Wells in river thaw bulbs will pick up river water (usually of good quality) or water draining from the surrounding ground to the river, (usually high in iron and other minerals). Quality will vary depending on whether the river is losing water to, or draining water from, the surrounding water table. In evaluating a river or stream as a water source, it is important to determine whether it is a "gaining" or "losing" reach, or both. This can usually be determined by comparing the static water levels in monitoring wells, adjacent to the river with the seasonal variation in river level. The type of reach can change with the season and stage of the stream. Water of the best quality usually comes from a losing reach.

Water from wells in continuous permafrost areas and not in the thaw bulb of a river or large lake usually requires expensive treatment because of high dissolved solids. Water beneath the permafrost (sub-permafrost water) is often saline or high in minerals and TDS. What also must be addressed is the necessity to keep the well thawed through the permafrost zone while maintaining the permafrost in a frozen state. Water located in thawed pockets within the permafrost is usually highly saline or it would be frozen. The quantity in such pockets is usually extremely limited by the surrounding frozen material. Groundwater above the permafrost in the active layer is available only during a limited time when soil temperatures in the active layer are above freezing. It is easily contaminated by activities at the ground surface.

3.1.3.2 Shallow wells

Shallow wells are usually less than 9 m (30 ft) deep and penetrate an unconfined aquifer in highly permeable soil. They usually draw water from nearby surface sources or from a shallow ground water table recharged by local precipitation. Large diameter (1-2 m) shallow wells can produce large quantities of water (over 60 liters per second or 1,000 gpm). These shallow, large diameter wells are essentially infiltration galleries.

Shallow ground water must be protected from hazardous contaminants at the ground surface.

ADEC drinking water regulations require control of surface water at the well casing site.

Sanitary well seals on top of well casings are necessary to prevent contamination by surface sources yet permit easy removal of the pump. If pumps and pipes to the building can be installed below the seasonal frost line, a single pipe from the well suffices. However, if the well is installed in permafrost or pipes cannot be installed below the seasonal frost line, some method, such as heat tracing or water circulation, is required to prevent freezing of the well.

The use of bentonite grout instead of concrete for well sealing is preferred. Bentonite provides an adequate seal around the casing and reduces the possibility of damage due to frost heaving.

3.1.3.3 Infiltration galleries

Infiltration galleries are also an important source of water in cold regions. They collect water from the thaw bulb of streams in continuous permafrost areas, or the permeable area alongside streams or lakes in non-permafrost areas, and are a reliable source of domestic and industrial water.

Infiltration galleries may be constructed parallel to a water course or across a water course, either vertically or radially. Schematics of such systems are shown in Figure 3-6.

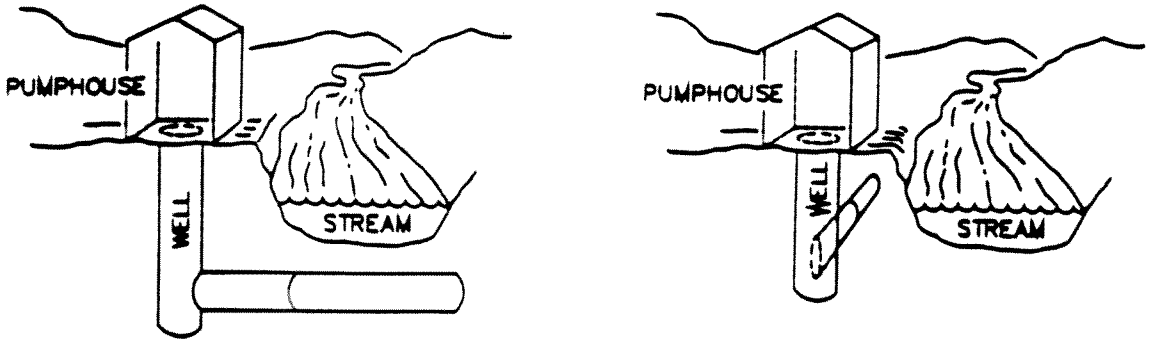
Infiltration galleries offer some advantages over conventional river or lake intakes. The most obvious advantage is that they are located away from the river and thus are removed from the hazards imposed by ice during freeze-up and breakup. Infiltration galleries placed in the thaw bulb of streams in permafrost areas can collect water even when the streams appear solidly frozen. Usually some flow of water occurs within the streambed itself, particularly when the bed material is relatively coarse.

A second advantage offered by infiltration galleries is the filtration of water by the materials surrounding the collectors. This may be a very significant advantage in streams which carry a load of suspended material such as glacial rock flour.

Galleries must be protected against freezing, especially in permafrost areas. Some sort of heating system is usually installed during construction. Both electric and steam heating systems have been successfully used. Heat lines are usually placed on the upper surface of the lateral and a second heat line is installed 0.4 to 0.6 m above the lateral. Insulation with snow is another way to reduce frost penetration. For the snow cover to be an effective insulator, the area should receive no traffic so that the snow remains uncompacted. Periodic gallery cleaning may be necessary to remove silt and other sediments that enter the laterals and sumps by jetting or reversal of flows. The use of geotextiles may reduce this requirement and improve overall system performance.

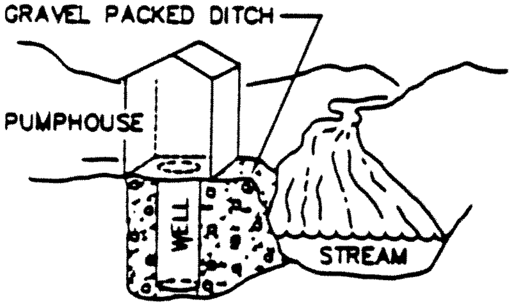
3.1.3.4 Springs

Springs can also be an important source of water. Springs are often seasonal and, to accurately determine the yields, flows must be monitored and measured for at least one year (preferably more). Spring output can also vary from year to year as a result of changes in the freezing depths in the active layer. Usually, there must be precipitation for a spring in northern or western Alaska to have a significant flow. Also, the ground surface is frozen for a major portion of the year, greatly reducing the possibility of recharge.

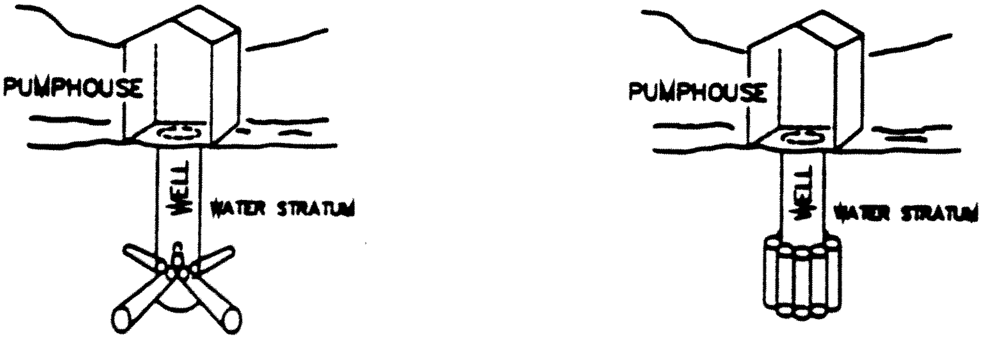


HORIZONTAL GALLERY

HORIZONTAL GALLERY



FRENCH DRAIN



RADIAL GALLERY

VERTICAL GALLERY

Figure 3-6. Infiltration Galleries

major portion of the year, greatly reducing the possibility of recharge.

Springs can be developed by installing horizontal infiltration galleries in an aquifer. This is generally an approved method, since it reduces the possibility of water contamination at the point of collection.

3.1.3.5 Quality

The quality of shallow ground water is usually very similar to the quality of surface water in the same area. However, the ground water will probably have a higher dissolved solids content (gathered from the soil during its relatively short infiltration route) and usually has fewer sediments and lower turbidity. Water quality will be similar throughout the year.

Deeper ground water also provides an advantage in that it has a more uniform temperature, on a year-round basis, than surface water. It is usually considerably warmer in the winter and cooler in the summer than surface water. The Municipality of Anchorage, for instance, uses deep (around 60 meters, 200 ft) ground water to reduce the problems with freezing in water distribution and service lines. Surface water from Ship Creek has a temperature of very near 0°C in the winter. Anchorage water utility managers found that switching to well water during the late winter considerably reduced freeze-ups in the distribution and service lines. Water from the municipal wells is about 4°C year round.

3.1.3.6 EPA protocol and ADEC Drinking Water Procedures Manual

EPA has developed a protocol to assist in determining whether or not shallow ground water is under the direct influence of surface water. This protocol is entitled "Consensus Method for Determining Ground Waters Under the Direct Influence of Surface Water Using Microscopic Particulate Analysis (MPA)(1992)" and is included as an appendix to ADEC's Alaska Drinking Water Procedures Manual. It is also available from EPA Region X in Seattle, Washington. This test method is a valuable tool for evaluation of shallow ground water and is part of the ADEC process for making the determination. (See *Alaska Drinking Water Procedures Manual*).

3.1.4 Glacial Melt Water

Streams, rivers, and lakes formed by melting glaciers are used for industrial and domestic water supplies. About 5% of Alaska (73,000 km^2) is covered by glaciers. Most of the major rivers in Alaska have flows regulated, in part, by glaciers. They exert control over the timing, quantity, and quality of the water. Glacial water is laden with sediment that can fill reservoirs and erode pumps and turbines. As ice provides a method of short-term (3-6 months) storage in a stream or river, glaciers can store large amounts of water for dozens of years. They have been termed leaky reservoirs.

3.1.4.1 Flow variation

The presence of one or more glaciers in a drainage basin alters the hydrologic regime of the watershed and affects the quantity and quality of the water in the streams and lakes. Water is stored in the winter when the domestic need is usually lower and is released in the midsummer when water needs are high. In dry, continental climates, such as interior Alaska, glacial runoff can be an order of magnitude greater than runoff from adjacent forested areas. For example, 50% of the runoff flowing in the Tanana River is produced by glaciers even though glaciers occupy only 5% of the drainage basin area. Flood analysis of glacier fed streams must consider the possibility of catastrophic mud flows and glacial outbursts. One of the hydrologic characteristics of glacial streams is a diurnal fluctuation of meltwater from glaciers during the melting season. Discharge water temperature and sediment concentration can vary widely over a day's time. The maximum discharge can be over two times the minimum. The shape of the daily stream flow hydrograph is remarkably consistent from day to day, year to year, and glacier to glacier.

3.1.4.2 Quality

As the water temperature decreases, the viscosity increases, and so does the sediment carrying capacity of the river or stream. Glacier fed streams are milky in color because of the very fine soil particles suspended in the water. Glacial streams or rivers can have sediment concentrations as high as 2,000 mg/L, which is 10-20 times greater than non-glacial streams in cold regions, which themselves usually have sediment concentrations greater than rivers in warmer climates for at least a portion of the year. Water from rivers, streams, and lakes influenced by glaciers is usually low in dissolved metals and other chemicals (TDS) but high in SS (glacial flour). The turbidity is typically low in the winter, because cold weather retards or stops the glaciers' melting. However, in the summer the glacier melts, and turbidity is high.

For example, Eklutna Lake, Anchorage's major water supply, has glaciers covering about 20% of its 287 km^2 drainage basin. Elevations within the drainage basin vary from 260 m to 2,440 m, and annual precipitation within the basin ranges from about 0.8 m to about 2.0 m. Stream flow into the lake is low in the winter and high and variable during the summer. Summer stream flow fluctuations are produced by rainfall and by melting of the glacier. Glacial melting is accelerated by solar radiation and warm air temperatures, especially when accompanied by strong winds. Rises in stream discharge are accompanied by increases in suspended sediment. The median particle size of suspended sediment in the river, before it discharges into the lake, ranges between 4 and 17 microns (10^{-6} meters).

Eklutna Lake acts as a large settling basin, and the water has a moderately constant and low concentration of dissolved solids, moderate alkalinity, moderately low hardness, and effectual calcium and bicarbonate ions. Particulate material (glacial flour) in the lake has a size of about 0.3 to 5 microns and is relatively easy to remove.

Observed values of turbidity range from 25-68 nepholemetric turbidity units (NTU) during the summer and 9-20 NTU during other seasons. Temperatures vary between a constant winter low of 4°C and a summer maximum of 13°C. The untreated natural water pH ranges from 7.7 - 8.2.

"Conventional treatment" (chemical addition/coagulation/settling/filtration) produces water quality within the desired goals during all periods of the year.

During the summer (June - September), 10-15 mg/L of alum must be added to achieve adequate removal of fine sediment. During the winter, when the natural turbidity is lower, chemical doses of only about 3 mg/L are required, and filtration is used without settling. Alum produces good flocculation and good clarification. The treatment plant was designed to handle either alum or ferric processes, but alum is preferred because it is easier to work with. Also, non-ionic or anionic polymers work better with the Eklutna

Lake water, whereas in many other applications, cationic polymers perform better. A hypothesis for this result is that silts derived from chemical decomposition have strong negative charges, whereas silts derived from physical abrasion such as glacial action tend to have less negative charges or are electrically neutral.

3.1.5 Melting Snow and Ice

Snow and ice can be melted for water, but the cost is high. Most larger communities and camps in the North American arctic have developed ground water or surface water sources and snow or ice is only used in isolated homes or temporary hunting, trapping, or oil exploration camps. In Antarctica, however, major settlements melt snow for their water supplies. In larger installations snow is usually gathered with front-end loaders and transported to melters which operate on fuel oil or waste heat collected from the engines used for electrical power generation. Because of the likelihood of exhaust contamination from the generators and heating boilers, the snow to be collected must be carefully selected, usually upwind from the camp. The soot from the engines tends to give the melted water an oily taste. Experience in Antarctica indicates the snow often contains volcanic ash which creates turbidity and taste problems. Melted snow and ice is surface water and would be subject to the SWTR.

On the Greenland icecap, a cavern is often formed in the ice cap by injecting steam into a drilled hole about 50 meters deep. The thawed water is then pumped out for use in the camp. This method has produced better quality water than melting snow, but it is still very expensive.

3.1.6 Collection of Rainwater

Rainwater collection for potable water is obviously only a 3 or 4 month source of water in arctic and subarctic Alaska, because the amount of precipitation is small. In central Alaska, for example, the rainfall in the warm months of the year averages about 160 mm (6.5 in.) Even with minimal water use of 10 litres per person per day, 23 m^2 of surface area per person would be needed. However, in Southeast Alaska it approaches a year-round source. Rainwater collection in Alaska is more frequently observed for single-house (on-site) operations. Several schools and large public buildings with relatively large roof areas and limited water needs have collected rainwater in northern and western Alaska. The water is piped to bladder tanks located below the roof or floor of the building.

Figure 3-7 illustrates a design for a rainwater holding facility. The roof washer box has to be drained after each rainfall event.

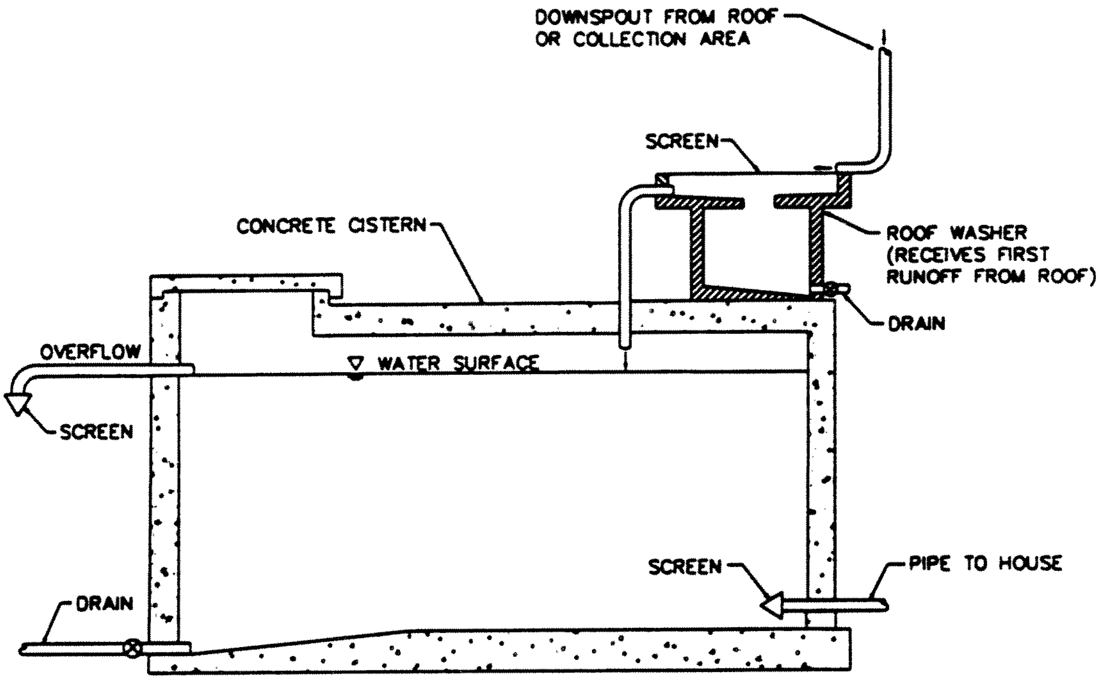


Figure 3-7. Rainwater Holding Facility with First Flow Diversion

The quality of the water is affected by the roof surface material, the collection gutters, and if used, the filtering devices. The first flow from the roof carries the maximum concentration of wind-blown or bird deposited pollution. Manual or automatic devices to provide for the bypassing of this water should be used. It is prudent to use filtering devices to remove suspended matter which may cause taste, odor, or color problems. Self-contained, prefabricated pressure filters are readily available in various capacities for home or similar on-site application. Disinfection is also needed.

3.1.7 Salt Water or Brackish Water

While desalinization of sea water is not peculiar to cold regions, there are some methods which are more adaptable, especially those using low temperatures as a resource.

As discussed, when a lake or pond freezes slowly, the salinity, turbidity, and most impurities are rejected into the remaining water below. When breakup occurs, there often is significant ice covering the lake. A large quantity of breakup water flows into the lake, and much of it fllows over the ice and out the outlet, not being retained in the lake. A unique method which can be used to "freshen" up a brackish lake is to pump the water, concentrated with TDS, from beneath the ice in early spring when the ice is at its maximum thickness. The ice will usually drop down, allowing more of the higher quality breakup water to be retained at breakup. This will allow the salinity to be considerably reduced over a period of just a few years. Figure 3-2 shows how this process was used to improve the quality of the raw water supply for Barrow, Alaska. This is a form of freeze desalinization, one of the methods experimented with to recover fresh water from seawater. The advantage of this process is that it utilizes freezing which is a normal condition from November through March in much of Alaska.

Pre-manufactured plants for desalinization include reduced pressure flash evaporators, vapor compression units, and reverse osmosis (RO) units. Vapor compression units have been used at schools, at camps, and on ships for small quantities of domestic water. This method of desalinization is efficient in Alaska only where there is a source of "waste" heat. Remote schools often need to keep electrical generators operating on a 24 hour basis with very limited use of the electricity for 10 to 12 hours per day. This excess energy can be efficiently used to desalinate seawater. This condition is also common on ships. Vapor compression desalinization units are usually the most efficient method to produce fresh water from salt water (TDS ≅30,000 mg/L). However, most of the water requiring desalinization in Alaska is brackish water (TDS < 10,000 mg/L) because the water to be treated is from lakes which occasionally are contaminated with coastal water. Even the "seawater" off the coast of northern and western Alaska is considerably diluted by fresh water rivers.

3.2 Development of Water Sources

3.2.1 General

The source of water selected for development must have an adequate quantity of water to meet the needs of the community. The water must meet current requirements of the State of Alaska *Drinking Water Regulations* with respect to microbiological, physical, chemical, and radiological qualities. Each water system should take its raw water from the best available source that is economically feasible and technically possible. In addition, any person who wishes to use a water source for water supply purposes must first secure a water use permit from the Alaska Department of Natural Resources.

3.2.2 Community Size and Location

Simple treatment technology with its inherently lower initial and operational costs is more appropriate in small and remote communities. As defined in the EPA reference, *Environmental Pollution Control Alternatives: Drinking Water Treatment for Small Communities*, a small system is one which has a flow of 9,500-380,000 liters (2,500-100,000 gallons) per day. Simple systems will perform more reliably in small and remote communities.

Bag and cartridge filtration can be appropriate for small systems but is not often considered for large communities. The operational costs of this alternative treatment are usually not competitive with the costs of other filtration technologies for large systems.

3.2.3 Source Water Quality

Source water quality must be analyzed for parameters listed in 18 AAC 80.310 of the state drinking water regulations for each candidate source considered for use of a Class A or B public supply.

3.2.3.1 Surface water

A sanitary survey and engineering study should be made of the factors, both natural and manmade, which may affect the quality of potential surface water sources. Such surveys and studies should include, but not be limited to:

- Determining possible future uses of impoundments or reservoirs.

- Determining the degree of control of a water utility will have over the watershed.

- Assessing the degree of hazard to the water supply by accidental spillage of materials that may make the treated water toxic, or harmful, or detrimental to the treatment processes.

- Obtaining samples over a sufficient period of time to assess the microbiological, physical, chemical, and radiological characteristics of the water. These samples should be representative of the water quality to be treated. The individual analyses to be conducted are as listed in the state *Drinking Water Regulations* under "Maximum Contaminant Levels," 18 AAC 80.070. For purposes of evaluating surface water as a candidate water source, the analyses should be performed over a period of one year, according to the requirements summarized in Table 3-2. It is important to identify the range of values which may influence the treatment process; for example maximum turbidity or minimum pH.

TABLE 3-2
Frequency of Analysis for Surface Water Source Evaluation*

Parameter	Frequency (per year)
Primary Contaminants	One time
Secondary Contaminants	One time
Total Coliform	Four times (seasonally)
Organic Chemical Contaminants	One time
Radioactive Contaminants	One time
Turbidity	Four times to identify the maximum and minimum values

* Identify the contaminants which may affect the treatment processes.

- Sampling to assess the quality of surface water sources, including consideration of the influence of currents, wind and ice conditions, and the effects of other contributory streams on the quality of the proposed surface water source.

- Assessing the capability of the proposed treatment process to produce water quality complying with the state *Drinking Water Regulations*.

3.2.3.2 Groundwater

For reference, this manual includes the following definition of ground water sources. Groundwater sources are those water sources that are below the surface of the ground and that are not under the "direct influence of surface water", as defined in the *Alaska Drinking Water Procedures Manual*. These sources are not regulated by the SWTR. Water quality criteria for candidate ground water sources are discussed below.

a. Microbiological Quality. Disinfection of every new, modified, or reconditioned ground water source must be provided (1) after completion of work, if a substantial period elapses prior to test pumping or placement of permanent pumping equipment and (2) after placement of permanent pumping equipment. This is required per the state *Drinking Water Regulations* under the section entitled "Source Protection," 18 AAC 80.015.

   After disinfection and flushing, a sample of the groundwater shall be submitted to a state certified laboratory for total coliform analysis, and other analyses as required by state drinking water regulations under the section entitled "Engineering Plans" (18 AAC 80.310). The analysis shall indicate the absence of coliform bacteria prior to placing the well into service.

b. Physical, Chemical, and Radiological Quality. Every newly constructed or reworked groundwater source that will serve a Class A or B public water system must be examined for the physical, chemical and radiological water quality parameters listed in the state *Drinking Water Regulations* under the section entitled "Engineering Plans." Analytical services must be provided by a state certified laboratory, with the results reported to ADEC.

   Samples shall be collected at the conclusion of the test pumping procedure for a newly constructed or reworked groundwater source and submitted for water quality testing as soon as practical.

c. Should a groundwater source become the supply for a Class A or B water system, the frequency of routine testing and monitoring must conform with the state *Drinking Water Regulations*, specifically the section entitled "Routine Sampling and Analysis," 18 AAC 80.200.

3.2.3.3 Physical and radiological characteristics

Physical and radiological water quality characteristics such as turbidity, color, odor, solids content, gross alpha, and radium affect the suitability of the source for specific treatment processes. When comparing alternative sources, those with higher turbidity, color, and solids contents require more extensive treatment in terms of multiple unit processes. Radiological contaminants can require the addition of unit processes specifically tailored to the removal of these contaminants.

Turbidity is important as a surrogate indicator of the microbiological quality of the water, unless the turbidity is due primarily to inorganic material (example, glacial flour). Color in the water is an indicator of the presence of iron, organics, or both. Odor is an indication of the aesthetic quality of the water. Excessive dissolved solids can impart taste to the water and cause excessive scaling. Brackish or saline waters have extremely high dissolved solids content and require more extensive processing to achieve potable water quality. Radioactive contaminants are more likely to be found in ground water sources than in surface waters in Alaska.

Typically surface water sources exhibit significant variation in water quality with intermittent episodes of high turbidity, color, and dissolved solids content. Pond turnover, freezing, and ocean proximity, as discussed in Section 3.1, affect these physical characteristics. Any water treatment plant should be capable of handling these seasonal and sometimes daily variations in water quality.

By contrast, most ground water sources which are not under the direct influence of surface waters exhibit less variation in water quality after the source has been developed and pumped for several months.

The allowable limits for physical and radiological contaminants are provided in the state *Drinking Water Regulations* in the section entitled "Maximum Contaminant Levels," 18 AAC 80.070.

3.2.3.4 Chemical characteristics

For many Alaska waters, naturally occurring chemical characteristics of interest are iron and manganese, dissolved organic compounds, arsenic, nitrate, hardness, alkalinity, and pH. Occasionally other contaminants such as barium are found to occur naturally in ground waters of the state.

Iron and manganese, hardness and total dissolved solids are identified as secondary contaminants in the Alaska *Drinking Water Regulations*, and are common in many Alaska surface and ground waters. The concern over these contaminants is their impact on the aesthetic quality of the water. By contrast arsenic and barium are primary inorganic contaminants with well known toxic health effects.

The pH and alkalinity of water are important to the treatment of the water where treatment involves adjusting the pH of the water.

Dissolved organic material is of interest in its potential role as a disinfection by-product precursor.

Commonly occurring chemical contaminants in Alaska waters include petroleum hydrocarbons, which manifest themselves as volatile organic contaminants, and lead, which leaches into the water from plumbing materials. These contaminants are toxic and must be reduced to acceptable concentration levels.

Nitrate occurs both from natural and manmade sources and is a recognized hazard to infants in utero and babies up to 6 months old.

The allowable limits for chemical contaminants are provided in the Alaska *Drinking Water Regulations* in the section entitled "Maximum Contaminant Levels."

3.2.3.5 Biological characteristics

The biological character of potential surface water sources is important for several reasons. For a surface water source to be considered for filtration avoidance, fecal and total coliforms must number consistently fewer than 20 and 100 per 100 ml, respectively.

For surface water sources with concentrations of *Giardia* cysts of one or more per 100 liters, the *Alaska Drinking Water Procedures Manual* recommends treatment methods which will result in greater than 3- and 4-log reductions of *Giardia* and viruses, respectively. This is explained further in Table 4-3 of the manual. Higher log removals require more extensive treatment with associated higher treatment costs.

3.2.3.6 Treatment and source selection

A water treatment plant should be designed to accommodate all water quality characteristics which the source may be expected to exhibit during the operating life of the facility. The minimum level of water treatment required is stipulated in the state *Drinking Water Regulations*.

Groundwater sources may require filtration and other treatment depending upon the quality of the water.

For further discussion on the evaluation of alternative sources refer to Section 3.3.

3.2.4 Watershed Survey and Annual On-Site Inspection

A watershed control program and on-site inspections are quality control procedures recommended for all utilities using surface water sources. They are required by the state *Drinking Water Regulations* for those systems with a filtration avoidance waiver, with a stipulation that the on-site inspection be conducted annually. The elements of a watershed control program required for filtration avoidance are outlined in the regulations under "Criteria for Avoiding Filtration," 18 AAC 80.520, and are subject to the approval of the ADEC. Some of those elements are identified below.

3.2.4.1 Surface geography and geology

The surface geography and geology of the watershed affect the quality of surface waters by influencing infiltration rates. Steep-sloped terrain or impervious soils such as frozen ground, bedrock, or tight silts at the surface afford minimal infiltration or subsurface seepage into downgradient surface water sources. By contrast, relatively flat or permeable soils will promote infiltration of rainwater and meltwater. Microbial contaminants will travel considerable distances in surface runoff but usually only limited distances when transported in subsurface ground waters. Steep-sloped terrain can also contribute significantly to surface water turbidity during heavy rains or spring breakup.

3.2.4.2 Human activity

Human activity on a watershed is considered detrimental to the quality of water produced by the watershed. Contaminants can include chemical and inorganic contaminants from such sources as motor vehicle operation and maintenance, septic systems, and agricultural fertilizer and pesticide applications. Watershed surveys and on-site inspections should note the human activities on the watershed. Even where there are no current human activities, previous activity may provide a current source of contamination. For example, abandoned contaminated sites may adversely affect local water quality.

3.2.4.3 Mammals and vegetation

Many mammals are known to be hosts of the *Giardia* cyst and of viral pathogens. The presence of these potential hosts on the watershed are considered detrimental to the quality of the water collected in the watershed. Common pathogenic hosts in Alaska are moose, beaver, wolves, fox, deer, waterfowl, voles, and humans. The vegetative cover indigenous to the watershed affects the population and diversity of animal species on the watershed and is an indicator of the probability of host organisms present on the watershed. Boreal forest with willow, spruce, aspen, birch, and cottonwood are all vegetative cover which provide habitat for the most common pathogenic hosts.

The geography of the watershed also influences the animal and vegetative species. High elevation terrain with steep slopes will inhibit the density and diversity of species present, including human activity. Relatively flat terrain will support habitat for many species, which host microbial contaminants.

3.2.4.4 Historical contamination

For watersheds where there has been a history of human activity, there is the potential for water contamination. Watershed surveys and on-site inspections should attempt to review historical activity on the watershed to identify potential previous contamination.

3.2.4.5 Impoundment characteristics

A watershed survey should note the type and condition of the impoundment used to collect and store surface waters. Factors of interest are the proximity of the impoundment to development with potential sources of contamination. Dams or lakes can produce anoxic conditions with associated odors, dissolved gases, and similar water quality problems. Constructed storage reservoirs should be examined to ensure surface coating systems are approved by ADEC.

3.2.4.6 Watershed management and control

Whether the purpose of the watershed control program is for maintenance of a filtration avoidance program or for the continued quality of a surface water source, the watershed management and control program should include a review of the above elements. Efforts should also be made to obtain ownership of the watershed, and at a minimum, the water system must be able to control the activities in the watershed which affect water quality.

3.2.5 Source Quantity

The following criteria are used for evaluating whether the quantity of source water is adequate to meet the needs of the public served.

3.2.5.1 Surface water

The quantity of water in a surface water source should:

- Meet the maximum projected water demands of the service area.

- Provide surplus storage for anticipated population growth within the service area.
- Allow for all losses such as silting, evaporation, and seepage.
- Provide ample water flow for other legal or appropriated uses of the source such as fisheries, hydropower production, or recreation.

3.2.5.2 Ground water

For areas with high yield aquifers, the total developed ground water source capacity should equal or exceed the design maximum day demand for the utility's service area. It should also equal or exceed the design average day demand with the largest producing well out of service. For areas where aquifer transmissivity is limited, it is more prudent to design the well field to produce only the average daily flow with peak day flows delivered from a supplemental storage reservoir. Future demand should also be considered. Yield must exceed demand, unless storage is available to supplement demand.

A minimum of two ground water sources should be considered for each utility. This allows more reliable service to the service area in the event of a mechanical pump failure, well screen blinding, or other problem which interrupt the supply of water. The alternative is to provide supplemental storage for maintenance of water service during interruptions to the withdrawal of water from the well (field).

To provide continuous service when the primary power has been interrupted, a power supply should be provided through (1) connection to at least two independent public power sources, or (2) portable or in-place auxiliary power.

3.2.5.3 Present and future demand

Present and future water supply demand must be considered in evaluating the adequacy of a water supply source. The future demands should include not only domestic demands but also commercial, industrial and fire protection requirements. These individual components of the total future demand should be developed as part of an overall planning process which is periodically updated to reflect changed conditions and revised demographic projections.

3.2.5.4 Climatic factors

Climate can influence the available supply of water, especially in northern and western coastal Alaska where annual precipitation is minimal. Climate also affects the seasonal quality of surface water or ground water under the influence of surface water.

3.2.5.5 Water rights acquisition

The acquisition of water rights from the State of Alaska is required to ensure the utility does not lose its supply of water through a challenge to the use of the water resource. The utility should apply for the rights to use the water it determines it will need for both when it applies and for projected future demands.

3.2.6 SWTR Provisions for Filtration Avoidance

Provisions for avoiding the requirement to filter surface water sources are listed in the state *Drinking Water Regulations* under the section entitled "Criteria for Avoiding Filtration." A summary of those criteria follows.

The fecal coliform count for raw water samples must be less than, or equal to, 20/100 ml, or the total coliform count must be less than, or equal to, 100/100 ml. These levels must not be exceeded in more than 10 percent of the samples analyzed during the 6 previous months during which the system served water to the public. If a system measures both fecal and total coliform, the fecal coliform criterion must be met.

The turbidity of raw water samples must not exceed 5 NTU, unless:

1. ADEC finds that any such event was caused by unusual and unpredictable circumstances; and
2. As a result of any such event, there have not been more than two events in the preceding 12 months during which the system served water to the public, nor more than five events in the preceding 120 months during which the system served water to the public. For purposes of this paragraph, an "event" is one day or two or more consecutive days during which at least one turbidity measurement each day exceeded 5 NTU.

In addition, there are site-specific criteria which must be met to avoid filtration (for further details, consult the drinking water regulations). The utility must maintain:

- Adequacy of the disinfection treatment process. The disinfection equipment must be sized to deliver the required rate of disinfectant and provide the necessary concentration and detention time to effect inactivation of the targeted microbial pathogens per the contact time factor. See Section 4.13.2.

- Reliability of disinfection treatment equipment. The disinfection equipment must be reliable, with redundant equipment and other safeguards as needed to assure no water is furnished to the public without disinfection.

- Maintenance of disinfectant residual in water entering the distribution system. The residual disinfectant level of 0.2 mg/L must be maintained in the water entering the distribution system.

- Maintenance of an adequate disinfectant residual in the distribution system. The residual disinfectant in water samples drawn from the distribution system shall have a detectable residual in at least 95% of the samples each month for all samples collected in any 2 consecutive month period during which the system is delivering water to the public.

- Maintenance of a watershed control program. The system must maintain an ongoing watershed control program as outlined in the regulations under the section entitled "Criteria for Avoiding Filtration."

- Annual on-site inspection. The system must maintain a program of annual on-site inspections as outlined in the regulations under the section entitled "Criteria for Avoiding Filtration."

- No identified waterborne disease outbreaks. The system must take steps to ensure it does not become a source of waterborne disease. In the event of an occurrence of waterborne disease attributable to the utility, steps must be taken to eliminate the source of the waterborne disease. Filtration may be required.

- Compliance with the maximum contaminant level (MCL) for total coliforms. The MCL for total coliforms is specified in the Alaska *Drinking Water Regulations* under the section entitled "Maximum

Contaminant Levels." The requirements for sampling and analysis for total coliforms is outlined in these regulations under the article entitled "Total Coliform Requirements."

- Compliance with the monitoring and MCL for total trihalomethanes (THMs). Application of chlorine for disinfection can create trihalomethanes (THMs). The MCL for these contaminants is listed in the Alaska *Drinking Water Regulations* under the section entitled "Maximum Contaminant Levels."

3.3 Source Evaluation Considerations

3.3.1 General

In addition to the quantity of water available, a source of water must be analyzed with respect to water quality. This is accomplished by obtaining samples over a period of time to assess the microbiological, physical, chemical, and even radiological characteristics of the water. Refer to Section 3.2.3 for a detailed discussion of source water considerations and sampling.

The results of sampling will allow the designer to assess the capability of the proposed treatment process to reduce contaminants to acceptable SDWA standards. The designer should allow for the effects of temperature, wind, and ice; and the selected process must consider the worst combinations of these conditions as well as seasonal changes in water quality during the life of the facility.

3.3.2 Microbiological Contaminants

These include waterborne microorganisms, including:

- *Giardia lamblia* (a common protozoa in Alaska).
- *Cryptosporidium* (a protozoa that has been documented in Alaska and Yukon surface water).
- Coliform bacteria.
- Viruses.
- Other waterborne parasites.

Removal or inactivation of harmful waterborne microorganisms is the most important consideration of the SWTR requirements for Alaska surface water sources. This is accomplished by effective filtration and turbidity reduction to enhance disinfection.

3.3.3 Volatile Organic Chemicals

Recent amendments to the SDWA regulations include many organic and inorganic compounds; however, the chemicals that are most likely to be encountered in surface waters and shallow ground water sources in Alaska are petroleum-based hydrocarbon and chlorinated solvent compounds, including:

- Gasoline (leaded and unleaded)
- Diesel fuel and heating oil
- Solvents (paint, cleaning, automotive)
- Hydraulic fluids
- Lubricating oils

A complete list of the volatile organic chemicals (VOCs) and the applicable MCLs that should be tested for are contained in the SDWA and amendments and 18 AAC 80 (Alaska Drinking Water Regulations). VOCs are difficult to remove in the treatment process.

3.3.4 Arsenic

A toxic heavy metal, arsenic, can be found in both surface and ground water sources in Alaska. Due to the tendency for arsenic to accumulate in human tissue, EPA and ADEC have set the maximum contaminant level (MCL) at 0.05 mg/L.

3.3.5 Total Nitrates

Nitrates can be found in both surface and ground water sources in Alaska, and are typically caused by sanitary waste contamination or decay of dead organisms (i.e., spawned fish). Excessive levels of nitrate can cause severe illness and death in infants from methemoglobinemia, a condition that reduces the ability of red blood cells to transport oxygen. The MCL is set at 10 mg/L as nitrogen.

3.3.6 Turbidity

Turbidity, that quality of water that aesthetically refers to the cloudiness of water or the amount of suspended particulates, is also an indicator of a water's microbiological health due to the ability of suspended particulate matter to harbor microorganisms, to shield microorganisms from disinfectants, and to reduce the amount of disinfectant added.

As discussed in 3.2.6, filtration avoidance is dependent on low background turbidity not exceeding certain levels, which are:

- Generally less than 1 NTU.
- Not exceeding 5 NTU, except for a set number of "events" (refer to 18 AAC 80.520):
  - 2 events in the past 12 months, or
  - 5 events in the past 120 months
- For every day the source water turbidity exceeds 1 NTU, one fecal or total coliform sample of the source water must be taken.

The state *Drinking Water Regulations* require systems with filtered water to meet the following turbidity standards:

- Conventional or direct filtration: 0.5 or less NTU for at least 95% of samples; not more than 5% of the samples can exceed 1 NTU.
- Slow sand or diatomaceous earth filtration: 1 NTU or less for at least 95% of samples; not more than 5% of the samples can exceed 5 NTUs.

However, there is a procedure in the state *Drinking Water Regulations* that allows a system to apply for an alternative turbidity limit up to 1 NTU for conventional or direct filtration, and up to 5 NTUs for slow sand filtration or alternative filtration technologies. The Alaska Drinking Water Procedures Manual should be consulted under the section entitled "Alternative Turbidity Limit."

Most community water supply systems utilizing surface water sources will be impacted by turbidity requirements. It is important to note that, even with an "exception" to the SWTR, maximum turbidity levels cannot exceed 5 NTUs after treatment.

3.3.7 Color

Many surface water sources in Alaska are affected by color, which is a result of the leaching of organics from tundra and wetlands to a pond, lake, or stream. Tannic acids and lignins impart the "tea" color to waters. The secondary MCL for color is 15 color units. Due to the organic composition of the compounds causing color, there is a high potential for formation of Trihalomethanes (THMs) in a disinfection process using residual chlorine. The MCL for total THM is 0.10 mg/L and currently only applies to public water systems that serve a population greater than 10,000.

3.3.8 Hardness

Hardness is typically associated with groundwater (and some surface sources) high in dissolved minerals, particularly calcium and magnesium. Iron, manganese, and zinc ions may also produce hardness. Hardness levels above 500 mg/L (measured as calcium carbonate) are considered excessive and should be controlled with softening (ion exchange) to prevent excessive scaling and buildup in pipes and boilers.

3.3.9 Fuel and Antifreeze Contamination

As discussed in subsection 3.3.3, petroleum fuels are very difficult to remove in the treatment process, and many of the associated VOCs are considered carcinogenic. Ethylene glycol antifreeze with corrosion inhibitors is very toxic. Propylene glycol, although not toxic, should not be ingested in appreciable amounts. Any water source should be free of both fuel and antifreeze contamination, and an active program for control of any future discharge should be implemented, because treatment, although possible, is not practical, especially for small communities.

3.3.10 Other Considerations

Additional water quality considerations are laid out in the following paragraphs.

a. Corrosive characteristics. Some surface waters are "aggressive" to metal piping and appurtenances. Water quality testing can usually determine corrosive tendencies, which can be corrected with pH adjustment or corrosion inhibitor addition.

b. Lead and copper. Covered by the Lead and Copper Rule (LCR) amendment to the SDWA, the "action level" for lead is 0.015 mg/L, and the "action level" for copper is 1.3 mg/L. If either of these metals is found to be in excess of the "action level" in raw water supplies, it must be removed in the treatment process. However, the source of most lead and copper is service lines and household plumbing and should be controlled with pH adjustment, sequestering with a corrosion inhibitor, or both, if "action levels" are exceeded at household taps.

c. Inorganic chemicals and heavy metals. Water supplies must not exceed the following MCLs:

Antimony: 0.006 mg/L
Arsenic: 0.05 mg/L
Asbestos: 7 million fibers longer than 10μ per liter
Barium: 2 mg/L
Beryllium: 0.004 mg/L
Cadmium: 0.005 mg/L
Chromium: 0.1 mg/L
Cyanide: 0.2 mg/L
Fluoride: 4.0 mg/L
Mercury: 0.002 mg/L
Nickel: 0.1 mg/L
Nitrate: 10 mg/L (as nitrogen)
Nitrite 1 mg/L (as nitrogen)
Total Nitrate/Nitrite 10 mg/L (as nitrogen)
Selenium: 0.05 mg/L
Thallium: 0.002 mg/L

In addition, secondary contaminants include:

d. Iron and manganese. Iron and manganese are associated with hardness in ground water supplies, but can also be found in surface waters. Iron bacteria growth in metallic piping can be a major operational problem in distribution systems especially if the treated water has low chlorine residuals. Both iron and manganese cause staining of fixtures and precipitate out in hot water heaters, causing staining of laundry. The recommended (or secondary) MCL is 0.3 mg/L for iron and 0.05 mg/L for manganese. Removal in the treatment process for either contaminant is typically accomplished in smaller systems by either an ion exchange (zeolite) process, or oxidation (chlorine and/or potassium permanganate).

e. Chloride, sodium, sulfate, and total dissolved solids (TDS). These parameters should not exceed the recommended (or secondary) MCLs listed:

Chloride: 250 mg/L
Sodium: 250 mg/L
Sulfate: 250 mg/L
TDS: 500 mg/L

f. Taste and odor. Taste and odor are subjective qualities of a water supply but are very important to general acceptance by users. The cause, and potential solutions, vary with each potential water source. Oxidation and GAC filters have a wide range of treatment applications to correct taste and odor problems. The secondary MCL for odor is 3 threshold odor number.

g. Radionuclides. Covered by an amendment to the SDWA, testing for radioactive contaminants in Alaska water sources typically involves gross alpha and radium in water sources. Testing for gross beta, strontium-90, and tritium are also required for systems serving more than 100,000.

h. Asbestos. All Class A systems are required to take one sample for asbestos by December 31, 1995. However, a procedure for waiving this requirement by ADEC is provided in the Alaska Drinking Water Procedures Manual.

i. Other secondary MCLs. In addition, the Alaska Drinking Water Regulations establish secondary MCLs for aluminum, color, copper, corrosivity, fluoride, foaming agents, pH, silver and zinc.

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4.0 WATER TREATMENT

4.0 WATER TREATMENT

4.1 EPA Requirements/Regulations and Alaska Regulations

4.1.1 General

Because it is difficult to monitor for *Giardia lamblia* and viruses, the state *Drinking Water Regulations*, derived from EPA regulations, emphasize treatment techniques as the condition for compliance, rather than establishing maximum contaminant levels (MCLs) for these microorganisms.

The EPA regulations do not prescribe treatment methods specific to local water qualities or conditions. Rather, they offer several alternative methods of treatment to meet the overall goal, which is removal and/or inactivation of disease-causing organisms (specifically, *Giardia* and viruses). By allowing each water system to choose the best method of treatment for its circumstances, the Surface Water Treatment Rule (SWTR) makes it possible to protect public health and still provide water at the least possible cost. To ensure that water quality goals are met, the rule contains many operation and monitoring requirements.

4.1.2 Removal or Inactivation Requirements

Under the state *Drinking Water Regulations*, most water systems that use surface water or groundwater under the direct influence of surface water must meet the following goals:

Giardia: 99.9 percent reduction/inactivation (3-log removal)

Viruses: 99.99 percent reduction/inactivation (4-log removal)

It is recommended that systems with poor source water quality meet higher reduction goals to ensure adequate protection. These higher reduction goals are identified in the *Alaska Drinking Water Procedures Manual* under the section entitled "Achieving Required Removal and Inactivation Rates in Filtered Systems".

The EPA and water treatment researchers have found it most convenient to express the reduction in the number of viable organisms as a logarithm number rather than a percent. Therefore, throughout the SWTR, the goals for reduction in the number of organisms is expressed as a log-removal. A comparison between percent reduction and log-removal is shown in Table 4-1.

It is apparent from Table 4-1 that the SWTR goal of 3-log removal/inactivation for *Giardia* and 4-log removal/inactivation for viruses refer to 99.9 percent removal/inactivation and 99.99 percent removal/inactivation, respectively.

TABLE 4-1. Percentage Reduction/Log Removal

Percentage Reduction (%)	Log-Removal
68.38	0.5-log
90.00	1-log
96.84	1.5-log
99.00	2-log
99.68	2.5-log
99.90	3-log
99.97	3.5-log
99.99	4-log
99.997	4.5-log
99.999	5-log
99.9997	5.5-log
99.9999	6-log

4.1.3 EPA Credits Allowed for Microbial Contaminant Removal

4.1.3.1 Removal capabilities of filtration processes

Conventional filtration treatment plants that are well designed and operated and that achieve turbidity levels of 1 NTU or less can be expected to achieve a 2- to 3-log removal of *Giardia* cysts and a 2-log removal of viruses through sedimentation and filtration without disinfection. Other types of filtration generally achieve a lower removal rate. Conservative estimates of the removal of *Giardia*, viruses, and coliforms for various types of properly designed and operated filtration systems are shown in Table 4-2.

4.1.3.2 Required inactivation for filtering systems

The minimum disinfection required for filtering systems is the amount that will, when combined with filtration, meet the overall treatment requirements of 3-log removal/inactivation of *Giardia* cysts and 4-log removal/inactivation of viruses.

TABLE 4-2 Removal Capabilities of Filtration Processes Without Disinfection

	Expected Log Removals		
	Giardia	Viruses	Total Coliform
Conventional Treatment	2-3	2	> 4
Direct Filtration	2	1	1-3
Slow Sand Filtration	2	2	1-2
Diatomaceous Earth Filtration	2	1	1-3

Source: Data for Giardia and Viruses taken from Table 4-1 of the EPA <u>Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources</u>, March 1991, under the section entitled "Design and Operating Criteria for Filtration and Disinfection Technology."

4.1.4 Adjusted Performance Requirements for Special Conditions

4.1.4.1 Minimum removal credit allowed for filtration

The minimum values appearing in Table 4-2 will be used as the assumed performance ability of the filtration process listed. The owner or operator of a system that wishes to use alternative filtration technologies must establish their filtration performance on a case-by-case basis, using the evaluation criteria provided in the state *Drinking Water Procedures Manual.*

4.1.4.2 Increased removal or inactivation requirements

The state *Drinking Water Regulations* require a <u>minimum</u> of 3-log removal/inactivation for *Giardia* cyst and 4-log for virus removal/inactivation. However, greater removal or inactivation rates for particular public water systems may be required. Consideration is to be given to the amount of sewage and agricultural discharges to the source water, the location of pollution discharges or other activities in relation to the water system intake and how much pollutants are diluted before they reach the intake.

The *Alaska Drinking Water Procedures Manual* suggests that systems use 4-log *Giardia* cyst and 5-log virus inactivation/removal rates for waters that are (or have the potential to be) contaminated, while systems with the potential for being highly contaminated use 5-log and 6-log removal/inactivation rates, respectively. The treatment system overall log removal required is established by estimates of the *Giardia* concentration in the source water as demonstrated in Table 4-3. The definitions of the terms "pristine", "contaminated" and "highly contaminated" that are used in the table refer to descriptions in the EPA Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources, March 1991, (EPA SWTG Manual).

> *Pristine*: originating from protected watershed with no significant source of microbiological contamination from human activities.
> *Contaminated*: waters of quality in between pristine and highly contaminated.
> *Highly Contaminated*: waters in the vicinity of sewage and agricultural wastes.

TABLE 4-3 Overall Log Removal or Inactivation Rates Required for Treatment of Surface Water Sources

Character of the Water Source	Pristine	Contaminated	Highly Contaminated
Allowable Daily *Giardia* Cyst Concentration/100 liters	≤ 1	> 1-10	> 10-100
Giardia Cyst Removal or Inactivation	3-log	4-log	5-log
Virus Removal or Inactivation	4-log	5-log	6-log

Source: *Alaska Drinking Water Procedures Manual*, section entitled "Achieving Required Removal and Inactivation Rates in Filtered Systems."

4.1.4.3 Greater removal efficiency

Some filtration systems may achieve better removal than the general recommendations. For example, conventional filtration may achieve 2.5-log or greater *Giardia* cyst removal under optimum conditions. As allowed by EPA, ADEC asks systems to demonstrate that they achieve higher removals using the procedures for particle size analyses outlined in Appendix M of the EPA SWTG. The approval procedures are contained in the Alaska *Drinking Water Procedures Manual* in the section entitled "Achieving Required Removal and Inactivation Rates in Filtered Systems." A system that proves it achieves higher removal rates may be allowed to operate with a lower log removal for disinfection. This may be especially useful for systems with THM or taste and odor problems that are accentuated by chlorine. The minimum required log inactivation rate for disinfection is 0.5-log.

4.1.5 Inactivation by Disinfection

Reduction/inactivation of the microbial contaminants targeted by the requirements of the state *Drinking Water Regulations* (i.e., *Giardia* and viruses) can be achieved through both filtration and disinfection.

The degree of credit to inactivation via disinfection processes is assessed by the state *Drinking Water Regulations* in terms of the calculated CT product for the process. The CT consists of two factors. The first is the concentration of disinfectant residual C expressed in mg/l of residual. The other is the contact time T for the disinfection process expressed in minutes. The required CT needed to achieve a particular level of inactivation is a function of both pH and water temperature. Tables of the log reductions credited to disinfection processes as functions of the water temperature and pH are provided in Section 4.13.

A Class A or B public water system using an unfiltered surface water source or groundwater under the direct influence of surface water must calculate its daily disinfection inactivation efficiency, as required by state *Drinking Water Regulations* Section entitled "Monitoring Requirements for Systems Avoiding Filtration." A system may determine inactivation efficiency of its treatment based on one point of residual measurement, or it may make this determination by developing a profile of different disinfectant residuals between the point of disinfection and the first customer. If the system uses more than one point of disinfection application before the first customer, the system must determine the inactivation efficiency for each disinfection sequence prior to the first customer, as described in the state *Drinking Water Regulations*, Section entitled "Monitoring Requirements for Systems Avoiding Filtration."

A water system that practices filtration and that provides predisinfection (disinfection prior to filtration) may count the predisinfection contact time in calculating its disinfection inactivation credit, in accordance with the procedure outlined above.

The residual disinfectant concentration should be measured each day during the peak hourly flow for each disinfectant section. If an operator knows from experience when peak flow will occur, residual measurements need to be taken only at that time. If peak hourly flow cannot be anticipated, residual measurements should be taken every hour during the peak flow period, or continuous monitoring should be used.

Although the CT value must be calculated during peak hours of flow, the disinfectant dosage needed to maintain adequate inactivation at lower flows may be considerably less due to the increased contact time through the treatment system. Continuing to feed a disinfectant at a rate based on peak hourly flow will provide more disinfection than needed. This will result in increased levels of disinfection by-products and higher chemical costs. Therefore, filtering systems should evaluate the dose needed to provide the correct CT under different flow conditions and vary the disinfectant dosage accordingly. Equipment designed for flow proportioned chemical feeding is often employed for these conditions.

System designers should also be aware of the potential to form disinfection by-products (primarily trihalomethanes-THMs) by reactions between disinfectants (usually chlorine) and precursor organic compounds in water (usually tannins and lignins). Highly colored source water, such as that draining from bogs and muskegs, usually contains elevated amounts of tannins and lignins. Designers should take this into account when contemplating a treatment/disinfection strategy to avoid formation of these regulated compounds. As of the writing of this Manual, the EPA is actively considering further restrictions on disinfection by-products in public water systems.

4.1.6 Monitoring and Reporting Requirements for Filtration

Monitoring and reporting requirements for treatment systems which provide filtration of surface waters must comply with the sections of the state *Drinking Water Regulations*, in the article on surface water treatment entitled "General Monitoring Requirements", "Monitoring Requirements for Filtered Systems," "General Reporting and Recordkeeping Requirements," and "Reporting and Recording Requirements for Filtered Systems."

Monitoring and reporting requirements for treatment systems which do not provide filtration of surface waters must comply with all applicable requiremenets of sections entitled "Criteria for Avoiding Filtration," "General Monitoring Requirements," "Monitoring Requirements for Systems Avoiding Filtration," "General Reporting and Recordkeeping Requirements," and "Reporting and Recordkeeping Requirements for Systems Avoiding Filtration."

4.1.7 Design and Operation Standards

4.1.7.1 Selecting a filtration method

The following are major factors to consider when deciding which filtration technology is most appropriate for a public water system:

- Raw water quality.
- Space limitations.
- Construction, operation, and maintenance costs.
- Technical complexity of the process.
- Availability of skilled operators.

Principal raw water considerations are the total and fecal coliform counts, turbidity, and color, as well as the range of variation in chemical quality. The general capability of various filtration systems to accommodate raw water quality conditions are shown in Table 4-4. In addition to the processes listed in Table 4-4, cartridge and bag filters are commonly used in Alaska. Published research on the performance limitations for these processes with regard to virus removal is not available at this time. It is recommended cartridge and bag filtration alternatives only be considered for raw water sources with turbidity less than 5 NTUs. Refer to Sections 4.6.9 and 4.6.10.

TABLE 4-4 General Capability of Filtration Systems to Accommodate Raw Water Quality Conditions

Treatment	Total Coliforms (number/100 ml)	Turbidity (NTUs)	Color (CU)
Conventional with Predisinfection	< 20,000	No limits	< 75
Conventional without Predisinfection	< 5,000	No limits	< 75
Direct Filtration with Flocculation	< 500	< 7-14	< 40
In-Line Filtration	< 500	< 7-14	< 10
Slow Sand Filtration	< 800	< 10	< 5
Diatomaceous Earth Filtration	< 50	< 5	< 5

Source: From the section of the state *Drinking Water Procedures Manual* entitled "Appropriate Filtration Technologies for Various Source Waters."

4.1.7.2 Design and operation

The expected capability of a particular filtration process to remove *Giardia* cysts and viruses is based on the assumption that the treatment plant is "well designed and operated." The SWTR defines the turbidity performance criteria that are associated with a "well designed and operated" filtration process. The definition of "well designed and operated" is based on design criteria given in the *Recommended Standards for Water Works* (the "Ten States Standards," 1992), with certain additions and exceptions. Details on three filtration processes are provided in the paragraphs that follow.

a. Conventional treatment

Conventional treatment is a series of unit processes consisting of coagulant addition, rapid mixing, flocculation, sedimentation, and filtration.

Conventional treatment is usually reserved for those raw water sources which are high in turbidity, color, coliform concentrations, iron and manganese, or organics which impart taste or odor problems. Conventional filtration plants are to be considered where the raw water quality conforms to the appropriate turbidity, color, and coliform limitations listed in Table 4-4.

For a conventional treatment plant to be considered "well operated," the plant should:

- Meet the operating requirements in the ten states standards.
- Use a coagulant at all times.
- Monitor and control chemical feed, rapid mix, flocculation, and sedimentation to ensure that chemical feeds are adjusted in response to variations in raw water temperature and turbidity or other characteristics.

Considerations for operating and backwashing of filters include:

- The decision about when to backwash should be based primarily on filter effluent turbidity or particle counting, and secondarily on head loss and run time.
- Flow rates should be controlled to eliminate rapid rate changes.
- Filters should be backwashed before filtered water quality is excessively degraded.

- Filters that have been out of service should be backwashed before start-up unless the state approves start-up without backwashing on a site-specific basis.
- Backwashed filters should be brought back on line with procedures which prevent turbidity spikes (sudden, brief increases) in the filtered water which could pass *Giardia* cysts and other pathogens through the filters. Techniques to prevent this include addition of polymer to the backwash water and filter to waste following completion of the backwash cycle.

b. Direct filtration

Direct filtration is a series of unit processes consisting of coagulant addition, rapid mixing, flocculation, and filtration. For some processes, the flocculation process is omitted.

Direct filtration plants are to be considered where the raw water quality conforms to the appropriate turbidity, color, and coliform limitations listed in Table 4-4. Pilot studies may not be required where the evidence of the process suitability can be demonstrated.

When only granular filtration media are used, the design must include the addition of a coagulant at all times the treatment plant is in operation. This requirement may be modified where the treatment process train includes the addition of cartridge or bag filtration downstream of the granular filtration process, and the entire treatment train conforms to the requirements for alternative technology in the state *Drinking Water Procedures Manual*.

Proper operation of direct filtration plants is essentially the same as for conventional filtration plants. The major difference is that a direct filtration plant does not have a clarifier and may not have a flocculation or contact basin. The EPA suggests that each filter have a turbidity monitor that is set to begin backwashing when the filtered water turbidity rises above 0.5 NTUs. This automatic backwashing will help plants meet filtered quality requirements and provide optimum *Giardia* cyst removal.

c. Slow sand filtration

Slow sand filtration is a process using no pretreatment. Filtration rates are comparatively slow and filter runs are relatively long. Filter cleaning is by means of scraping and removal of the filter surface as described below.

Slow sand filtration plants are to be considered where the raw water quality conforms to the appropriate turbidity, color, and coliform limitations listed in Table 4-4.

The design of slow sand filters should conform with the *Manual of Design for Slow Sand Filtration* (American Water Works Association Research Foundation, 1991).

Operation of slow sand filters includes removal of the top 2-3 cm (0.8-1.2 in) of the surface sand bed when the head loss exceeds 1-1.5 meters (3-5 ft). When repeated scrapings have reduced the depth of the sand bed to about one-half of its original depth, the sand should be replaced.

After scraping, slow sand filters produce poor quality water, so water should be filtered to waste until the effluent turbidity drops to an acceptable level. This may take many days of operation. Sufficient treated water storage must be provided to maintain service to the system service area during this time, or redundant filters must be in place.

d. Diatomaceous earth filters

The design criteria for diatomaceous earth filters in the Ten States Standards are sufficient for complying with the SWTR, with two exceptions. To comply with the SWTR, ADEC recommends that:

- The quantity of precoat be 1 kg/m^2 (0.2 lb/ft^2) of filter area, and that the minimum thickness of the precoat filter be 3 mm to 5 mm (1/8 to 1/5 in).
- Treatment plants provide a coagulant coating (alum or suitable polymer) to the filler via the body feed.

Operating requirements specific to diatomaceous earth filters are:

- Preparation of body feed and precoat.
- Verification that dosages are proper.

- Periodic backwashing and disposal of spent filter cake.
- Periodic inspection of the septum(s) for cleanliness or damage.
- Verification that the filter is producing filtered water that meets the performance criteria.

e. Alternative filtration technologies

Other filtration methods which meet the same performance standards as slow sand filtration for filtered water may be approved by ADEC on a case-by-case basis. The procedures contained in the state *Drinking Water Procedures Manual* will be used to evaluate alternative filtration technology.

4.1.8 Other Treatment Objectives

4.1.8.1 Compliance with the MCL for total coliforms

A public water system avoiding filtration must comply, on an ongoing basis, with the MCL for total coliforms in at least 11 of the previous 12 months that water was served to the public. ADEC may make an exception if it determines that failure to meet the requirement was not caused by a deficiency in treatment. For all other systems, the provisions of the coliform MCL apply year-round.

The total coliform MCL for a system is stipulated in the state *Drinking Water Regulations*, Article 1 "Requirements for Public Water Systems" under the section entitled "Maximum Contaminant Concentration Limits." The goal is for no positive total coliform samples. The MCL for fecal coliform samples is zero.

Total coliform monitoring and reporting requirements are detailed in the state *Drinking Water Regulations* under the following articles:
Article 2, "Monitoring, Analytical and Reporting Requirements,"
Article 5, "Surface Water Treatment,"
Article 6, "Coliform Bacteria Requirements."

4.2 Effects of Temperature on Water Treatment

Variations in temperature influence the physical, chemical, and biological characteristics of water. This section first discusses these influences to water and then discusses how temperature affects filtration and treatment of water.

a. Physical characteristics. Temperature affects the absolute viscosity of the water inversely (see Figure 4.1). The lower the temperature of the water, the higher its viscosity. A higher viscosity, in turn, has a greater carrying capacity of suspended material in the water, hence increasing the turbidity. Viscosity is also directly related to the amount of energy required to pump water and maintain the velocity gradient in the treatment facilities. Corrosion potential is also temperature dependent (see Section 4.12).

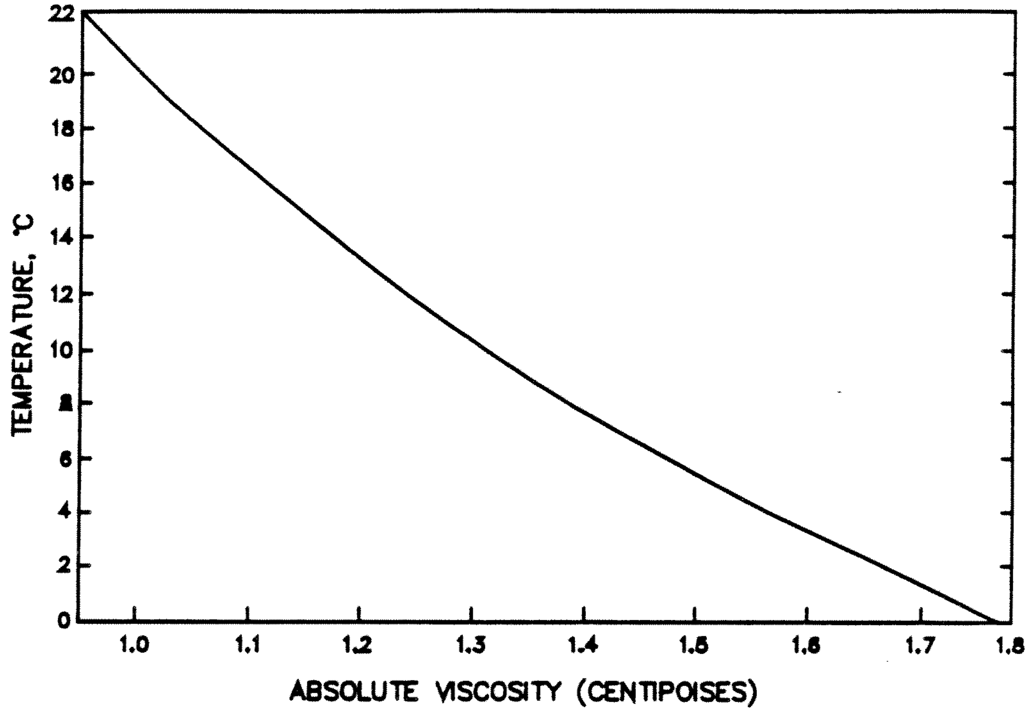


Figure 4-1 Absolute Viscosity of Water at Atmospheric Pressure

Figure 4-2 provides the density variation of water with temperature.

b. Chemical characteristics. Both inorganic and organic chemical concentrations can be influenced by temperature. Low temperatures reduce the rate of chemical reactions and solubilization and can increase the adsorption capacity of carbon for organic compounds. The extended time factor for these processes is more than offset by the length of contact time between the materials and water.

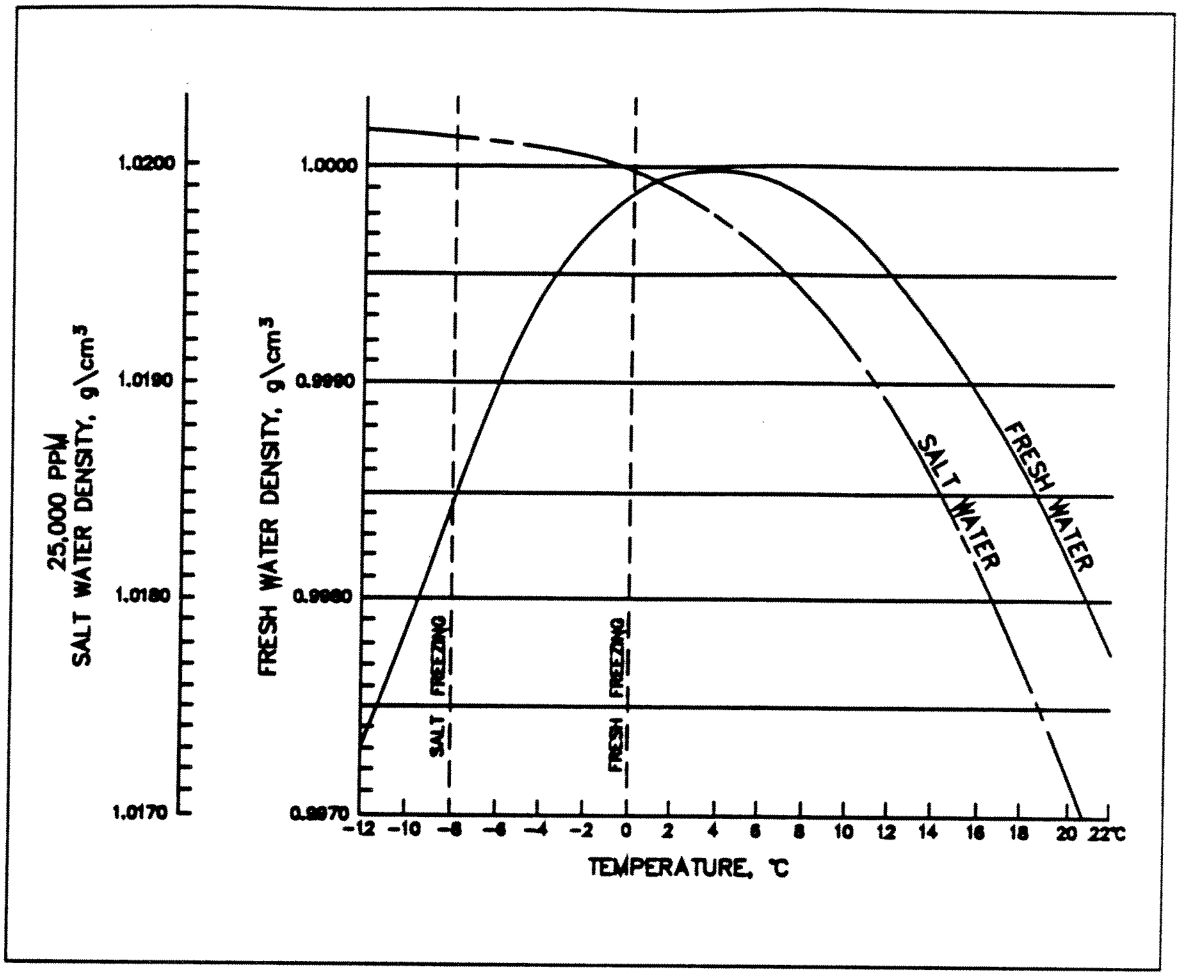


Figure 4-2. Density of Water at Various Temperatures

c. Biological characteristics. Pathogenic microorganisms as well as indicator microorganisms survive in water longer at low temperatures. This fact coupled with remote locations and simple water treatment systems means that caution must be used to prevent contamination of the drinking water system.

Special attention should be paid to the possible water transmission of viruses such as Hepatitis type A; bacteria such as *Shigella* spp and *Salmonella* spp; protozoa such as *Entamoeba histolytica* and *Giardia* spp; and helminths such as *Echinococcus multilocularis*, which cause alveolar diseases; and *E. granulosis*, which cause cystic hydatid diseases. All the above microorganisms are transmittable by water and have led to serious outbreaks of waterborne diseases in cold regions.

Alveolar hydatid disease in humans is caused by the ingestion of the eggs of *Echinococcus* spp. A tumor-like growth of larval tissue, which must be removed surgically, occurs in the liver. The disease has occurred throughout the boreal regions of the northern hemisphere. The helminth eggs causing hydatid disease are extremely persistent and resistant to disinfectants.

Water is usually heated to at least 4.5°C (40°F) at some point between the source and consumer to reduce the possibility of freezing. Water treatment effectiveness can be improved if this heating takes place before treatment.

Benefits of heating include:

- Higher settling and filtration rates.
- Reduced mixing times.
- Reduced overall plant requirements for space.
- Energy for pumping warm water is less than for cold water.

Virtually all package-type treatment systems are designed for use with water warmer than about 5°C. If incoming water is expected to be colder, it must be heated for the treatment to perform at design rates. Heating allows the use of standard design in areas of varying water temperature.

Several methods of heating water may be used.

1. Direct-fired hot water boiler. This system uses a direct-fired oil, gas, or coal furnace operated so that the jacket water is maintained below boiling, usually at about 90°C. Three basic types of boilers are water tube, fire tube, and cast iron water jacket.

   The boiler must be operated in a manner that prevents the cooling of exhaust gases below the dew point. Cold water may reduce exhaust gas temperature significantly. Condensing exhaust gases can be responsible for pitting-type corrosion of the flue.

   Antifreeze is often used in the heat exchangers. Ethylene glycol solutions are toxic and cannot be used in single-wall heat exchangers. Double-wall units must be used. Propylene glycol or other nontoxic mediums should be used when heating domestic drinking water.

2. Blending. Occasionally a source of hot water is available which can be blended with cold water to achieve the desired temperature. Such a source may be condenser water from a steam system. Fairbanks has successfully used this system to warm cold well-water. In Whitehorse, Yukon Territory, geothermal water is added to raw water and provides a substantial saving in the cost of heating the water.

Other sources of heat may be water from a central heating system or the cooling water from power generators. It is important to thoroughly evaluate the potability of the hot water before using it.

Temperature affects most treatment and filtration processes, and these effects are noted in the following subsections.

4.2.1 Precipitation, Coagulation, and Flocculation

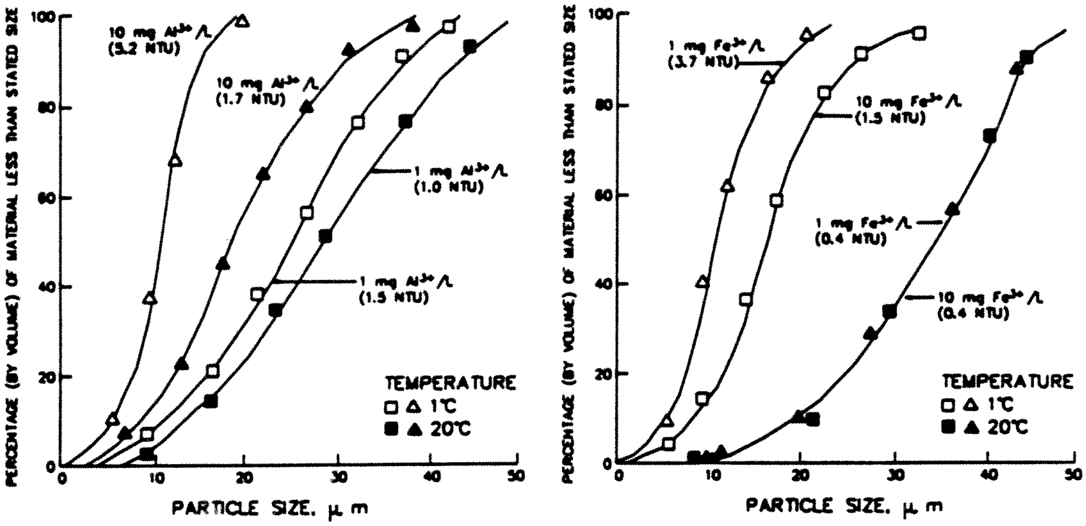
Precipitation involves a chemical reaction, the products of which are less soluble than the reactants. Precipitant can be filtered from water. Iron and manganese removal and lime water softening are examples. In some cases the precipitate requires coagulation and flocculation to bring about adequate removals.

Coagulation is a chemical process involving the destablization of colloids; it is frequently used to remove turbidity and color from water. The process is slightly temperature-sensitive in the range from 9°C to 30°C.

Flocculation is the physical aggregation of destabilized colloidal particles to a size adequate for subsequent settling. Gentle mixing is used to encourage interparticle contacts. The process is influenced by the viscosity of the water and therefore by temperature (see Figure 4-1).

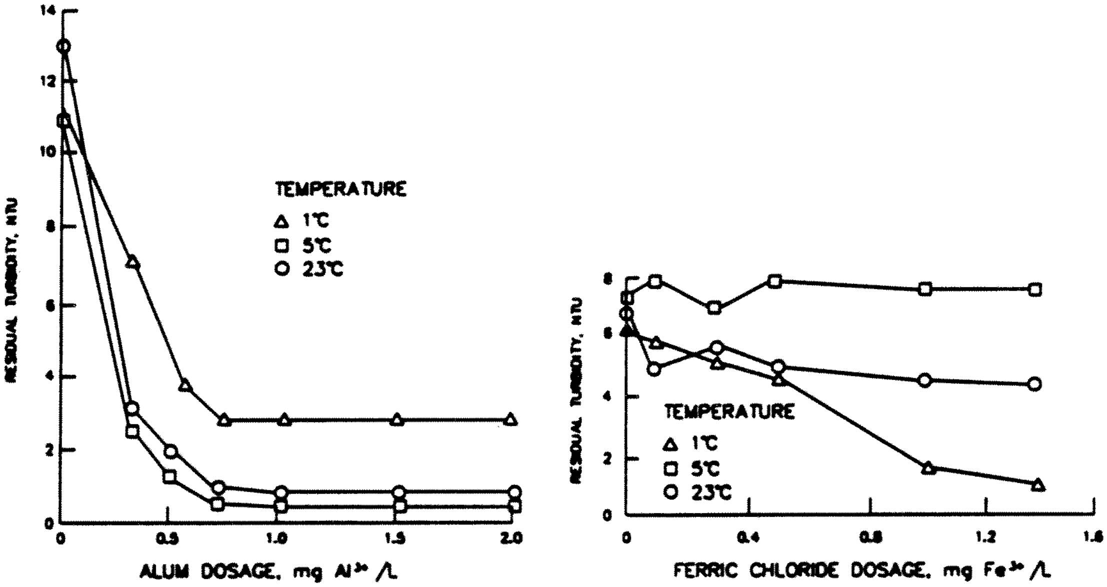
Lower water temperatures result in the need for adding increased coagulant to achieve the same degree of flocculation. The optimum pH is important and varies inversely with temperature. As the water temperature drops the preferred pH increases.

With either alum coagulation or ferric chloride coagulation, flocs at 1°C are generally smaller than those formed at 20°C. Temperature has a significant effect on turbidity removal for both coagulants, as shown in Figure 4-3.



(a) ALUM (b) FERRIC CHLORIDE

EFFECT OF SOLUTION TEMPERATURE AND DOSAGE ON PARTICLE SIZE DISTRIBUTION AND RESIDUAL TURBIDITY



(c) ALUM (d) FERRIC CHLORIDE

EFFECT OF SOLUTION TEMPERATURE ON COAGULATION EFFICIENCY (INITIAL TURBIDITY = 10 NTU)

Figure 4-3 Effects of Temperature on Coagulation Using Alum and Ferric Chloride

4.2.2 Mixing

Mixing is required for distributing chemicals, for flocculation, and for dissolving solids. Mixing is strongly dependent on temperature because temperature affects the viscosity of the liquid. Figure 4-4 can be used to make the necessary adjustments in design criteria for temperature-induced viscosity changes. It is plotted with 20°C as the base level. The power input for mechanical flocculation is directly dependent on fluid viscosity, as defined by:

$$P = G^2 x V x \mu$$

where:

P = power input (watts)
G = root mean square velocity gradient (seconds^{-1})
V = flocculator tank volume (m^3)
μ = dynamic fluid viscosity (Pascal, x seconds = Newtons per m^2 x seconds

To maintain the same velocity gradient in the tank as the liquid temperature decreases, the 20°C power requirement has to be adjusted by the multiplier derived from Figure 4-4. This relationship is valid for any type of mechanical mixing where power is directly related to viscosity.

Mixing requirements are usually selected according to the product of the root mean square velocity gradient and mixing time. Mixing requirements are influenced by the time required for desired reactions to occur and is often empirically based on the successful performance of similar units. Normal recommended detention times for flocculation in water range from 15-30 minutes. Increasing this detention time compensates for lower water temperatures, if the power input is not changed. The multipliers from Figure 4-4 can also be used for this purpose. Multiple basins in series are the most effective way to increase detention time, provided some basins can be bypassed during the summer when the water is warmer.

One alternative to extended flocculation time is the use of higher chemical doses. Another is to adjust pH to the optimum for the temperature of the water being treated. It is advisable to evaluate each alternative, since one may be more economical than another.

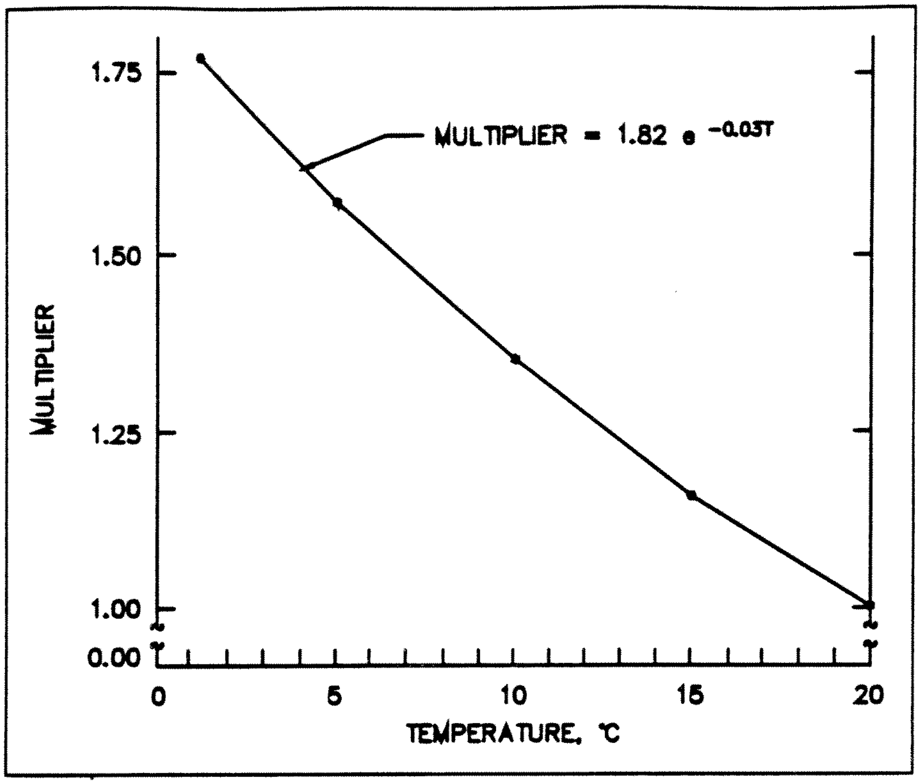


Figure 4-4 Correction Factor for the Effect of Temperature on Viscosity-Dominated Processes

4.2.3 Sedimentation and Upflow Clarifiers

The influence of temperature on the settling rate for Type 1 particles (discrete, non-flocculating particles, in a dilute solution), and Type 2 particles (discrete, flocculating particles in a dilute solution) can be explained by changes in viscosity. Type 1 particles act according to Stokes' Law. With Type 2 sedimentation, absorption and physical attachment factors vary with temperature.

The effect of temperature on zone settling is less quantifiable. Figure 4-5 provides a correction factor for zone settling detention times at various temperatures and solids concentrations.

Upflow and sludge blanket clarifiers may not be as sensitive to low temperature as conventional clarifiers. However, temperature variations cause density differences and thermal currents, which may reduce efficiency. Sludge blanket and upflow clarifiers should be operated at nearly constant temperatures.

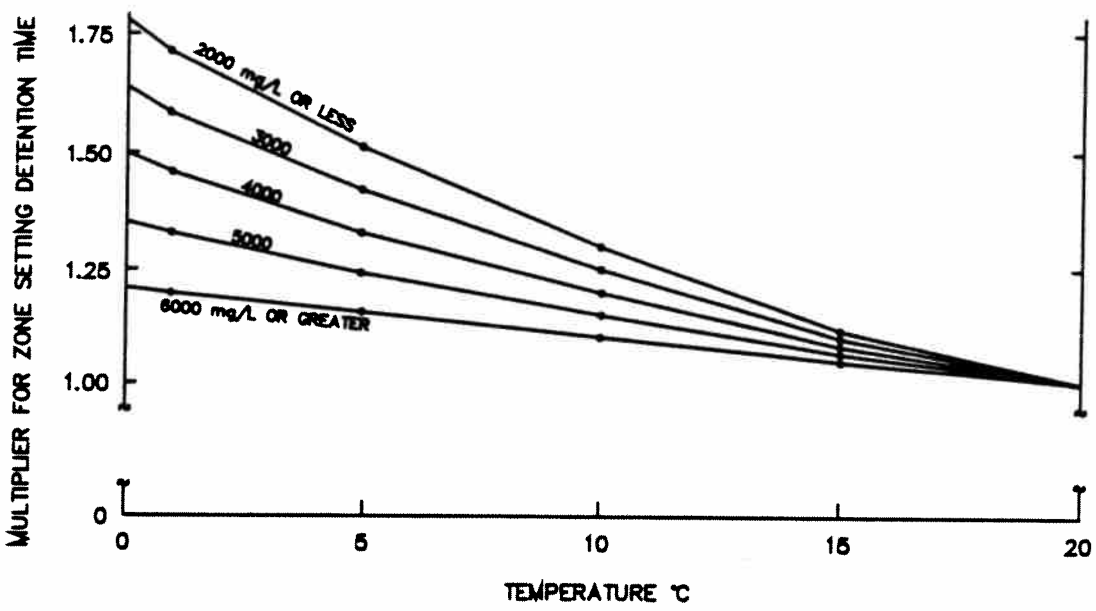


Figure 4-5 Zone Settling Detention Time Versus Temperature

4.2.4 Filtration

Filtration is affected by low water temperature to the extent that head losses through the filter are proportional to viscosity. The relative head loss changes 2.5% to 3.5% for each degree in temperature change. Rapid sand filter hydraulic loading rates are normally about 5.0 $m^3/hr/m^2$ (2 gpm/ft^2), and multi-media filter rates are about 12.0 $m^3/hr/m^2$ (5 gpm/ft^2). Therefore, multi-media filter beds would provide more efficient use of space in cold climate facilities. The multiplier values from Figure 4-4 should be used to adjust filtration head loss. For example, if the initial design head loss is 1 m at 20°C, it is about 1.5 m at 5°C.

Backwashing of filters is also affected by low water temperatures. Power for pumping varies with viscosity changes as shown in Figure 4-4. Adjustments for filtration and backwashing are based on viscosity changes. However, the minimum upflow velocities or wash rates to fluidize and clean filter media is reduced because of increased fluid density. For example, if it takes a velocity of 36 m/hr (15 gpm/ft^2) to fluidize a sand bed at 20°C, it requires only 24 m/hr (9.8 gpm/ft^2) at 5°C.

4.2.5 Disinfection

Chlorine disinfection is less effective in cold water. Disinfection contact time should be increased as water temperature decreases. The SWTR provides the necessary concentrations and contact times (see Section 4.13).

Ozone, which is also used to disinfect water, is only slightly temperature sensitive. Therefore, no appreciable modification of standard techniques is required.

4.2.6 Water Softening

Two methods of softening are used: ion exchange (see Section 4.9) and chemical precipitation.

- Ion exchange. Lower water temperatures influence the rate of flow through the exchange media because of higher viscosities even though the ion exchange rate itself is rapid enough not to limit softening at low temperatures.
- Chemical precipitation. This process is affected by low water temperatures since it involves mixing, chemical reactions, flocculation, sedimentation, filtration, and sludge-handling. This softening process can be used for reducing carbonate hardness using lime, or carbonate and noncarbonate hardness using lime-soda ash.

  When softening cold water at 1°C, hardness removal is slower (see Figure 4-6).

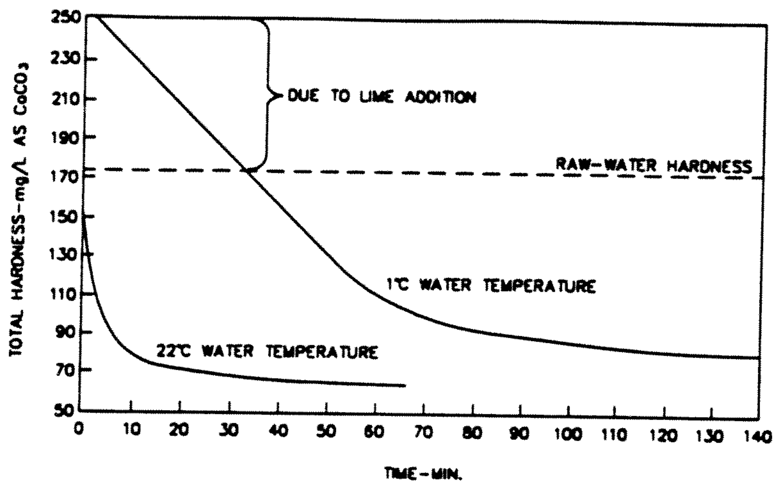


Figure 4-6 Lime-Softening Rate With 1°C and 22°C Water Temperature

4.2.7 Solubility

Generally, the solubility of solids in water increases with increasing temperature, while the solubility of gasses in water decreases with increasing temperature. Figure 4-7 shows the solubility of oxygen in water between 0°C and 30°C. Vapor pressure, other solutes, and the chemical nature of the solute affect the solubility of a material in water.

4.2.8 Protecting Facilities from Freezing

All facilities in the arctic and subarctic should be designed to reduce damage in case of freezing.

4.2.8.1 Insulation and heat addition

Insulation will not prevent facilities from freezing. It delays freezing by slowing the loss of heat and thus reduces the amount of heat which must be added. The most economical thickness of insulation to be provided depends on the cost of heat versus the cost of the insulation. The type of insulation which should be used for a given application is discussed in Section 6.2.

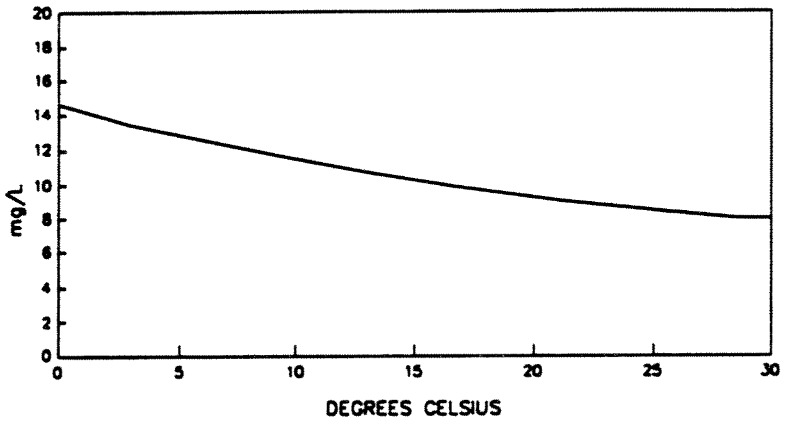


Figure 4-7 Oxygen Solubility in Water at Various Temperatures

Water should be kept at about 4.5°C (40°F) in tanks and distribution lines. This provides a small safety margin which can allow time to drain facilities if circulation and heat addition systems cannot be restarted after system failure. Also, as was discussed in the beginning of Section 4.2, heating raw water can improve the efficiency of the treatment process.

Control of condensation on equipment, walls, electrical components, tanks, and lines is an important consideration in water or wastewater treatment plants, pump stations, and other facilities (see Section 6.2). Corrosion will result from condensation.

4.2.8.2 Pipelines

All lines in houses, pump houses, pump stations, etc. should be sloped to drain to low points where a 3-way valve will permit the water to be drained. Most transmission lines, and many distribution lines, are now high density polyethylene (HDPE) pipe which can freeze without damaging the pipe. They can be heat traced to provide a method of thawing if they freeze, but HDPE pipe is sensitive to overheating. Ductile iron pipe is usually used in Southcentral and Southeast Alaska where rock is often encountered. Lines in pump houses and pump stations are usually steel or ductile iron. When they freeze, there will be damage. Pieces of pipe and, usually, fittings will split and need to be replaced. It is essentially impossible to predict where the damage will occur, normally. However, freezing can be forced to occur where it will do the least damage and be the easiest to repair. This also permits the damage to be near a floor drain or someplace where the escaping water will do the least damage. These sacrificial sections can be constructed by adding insulation to the place where freeze damage can be easily repaired. Insulation will not prevent freezing but will delay it. By delaying the freezing of the sacrificial section, the pressure built up in many feet of pipe freezing will be transmitted to the liquid water in the sacrificial section. The rupture will then usually occur at that point. The methods by which pipes freeze and the methods to calculate freezing times are presented in the *Cold Climates Utilities Design Manual* (Smith et al., 1986).

4.2.8.3 Storage tanks

Ice should not be allowed to form in water storage tanks. The water should be kept at about 4.5°C (40°F). Depending on residency time, the amount of heat added, outside air temperatures, and natural or forced circulation, insulation should be added to tanks not housed in heated buildings. Ice formation in tanks will damage interior lines and controls and can also cause serious damage to the tank itself.

Vents should be heated with heat tapes to prevent them from freezing shut. If vents freeze over, withdrawals of water can create a vacuum that can structurally damage the tank.

Inlet and outlet placement should prevent short circuiting and promote complete circulation within the tank. Inlet and heat addition lines should be located at the bottom of the tank. Thus the rising warm water will create a natural circulation. Baffles can be added to prevent short circuiting and also increase the contact time within the tank (see Section 4.13).

Heat can be added to a storage tank by drawing off water, pumping it through a heat exchanger, and discharging it back into the tank near the bottom. This is especially needed for tanks having long detention times like those serving fill and draw operations (see Section 5.5). In most remote communities, oil-fired boilers are used to provide this heat. In some locations where there is excess electrical generating capacity, electrical immersion heaters can be used to heat the tanks. This method is economically feasible in installations where generators must be run 24 hours a day with very little load at night. The immersion heaters can use off-peak power to heat the water.

4.3 Coagulation

Natural waters contain dissolved inorganic and organic substances algae, bacteria and plankton, and suspended inorganic material. To remove these substances, coagulation is generally employed before filtration. Coagulation is the most widely used process to remove the substances normally producing turbidity in raw water supplies. Substances normally producing turbidity consist largely of clay minerals and microscopic organisms. Substances producing color, as distinct from turbidity, consist either of colloidal metallic hydroxides (iron for example) or of organic compounds of smaller sizes. These substances may be removed by coagulation. Coagulation serves to agglomerate these particles into sizes that can settle or can be removed by filters. Coagulation is mandatory for systems employing conventional filtration or direct filtration to achieve log removal credits for *Giardia*. For alternative filtration technology, however, coagulation may or may not be required depending on the log removal results.

4.3.1 Process Description

4.3.1.1 Purpose

The purpose of coagulation is to destabilize particles present in water and form an agglomeration of the particles into floc masses large enough to settle out with gravity, or to filter, if filtration alone is used.

4.3.1.2 Mechanism

The interparticulate forces responsible for stability of particulates are reduced or eliminated by addition of suitable chemicals. Subsequentially, particulate collisions are induced by the molecular motion of mechanical mixing. If collisions are successful, aggregation occurs. Particle destabilization occurs by:

- Compression of the electrical double layer by indifferent electrolytes.
- Charge neutralization by specifically adsorbed, charged particles.
- Surface precipitation and formation of interparticle "bridges."
- Coagulant precipitation and entrapment (sweep floc) of particulates.

4.3.1.3 Factors affecting coagulation

Optimum coagulation treatment of a raw water requires a complex equilibrium in which many variables are involved. Conditions such as pH, raw water alkalinity, turbidity, chemical composition of raw water, type of coagulant, temperature, and mixing conditions all affect the coagulation process. The proper dose and physical conditions for coagulation are determined empirically as described in Section 4.3.2.3 below, and documented to ADEC.

4.3.1.4 Coagulation facilities involved

The coagulation process requires facilities for chemical storage, solution preparation, dosing, and rapid (flash) mixing. These are described in the following paragraphs.

a. Chemical storage

Coagulants and coagulant aids are available both in solid and liquid forms. Manufacturers' material safety data sheets (MSDS) should be used to design all storage areas.

b. Solution preparation

Coagulants and coagulant aids typically are diluted to suitable strength before addition to source waters. Acceptable practice includes manual dumping from bags or drums into small solution mixing tanks, where water is added to prepare the solution. When dry polymer (a coagulant aid) is added, it is not dumped into solution water without being thoroughly wetted first so that it will go into solution quickly and without lumping.

It is acceptable to automate coagulant solution preparation involving the use of hoppers, weighing scales, conveyors, hoists, piping, chemical metering pumps, volumetric feeders, and holding tanks.

c. Dosing

Coagulants must be accurately metered and fed into raw water. On larger systems, typical dosing equipment may use dry or wet, volumetric, or gravimetric feeders. Smaller systems typically will include a metering pump, a type of positive displacement pump. Complete coagulation feed facilities include solution tanks for mixing and dilution of chemicals as delivered, transfer pumps, dilution water lines, solution pipelines, and injection feed points.

d. Flash (rapid) mixing

Rapid agitation is essential to distribute coagulant evenly throughout the source water. Acceptable facilities to provide rapid mixing include:

- Pump diffusion rapid mixers.
- Hydraulic mixing, including static in-line mixers.
- Parshall flume, venturi meter or weir.
- In-line mechanical mixer.
- Back-mix reactor (a chamber with one or more mechanical mixers)

4.3.2 Coagulant Selection

4.3.2.1 Criteria

Selection of chemical coagulants should consider the following criteria:

- Characteristic of coagulant.
- Cost, including shipping.
- Ease of handling.
- Availability.
- Chemical stability.
- Raw water characteristics (temperature, pH, alkalinity, turbidity, color).
- Nature of turbidity present.
- Toxicity of coagulant.

4.3.2.2 Types of coagulants

Source water containing high turbidity (> 5 NTUs) and high alkalinity (> 100 mg/L) will need coagulants such as alum or ferric salts, with or without the addition of a polymer.

For high turbidity, low alkalinity (< 40 mg/L) waters, appropriate coagulants are alum and ferric salts in conjunction with base addition to control pH levels. As described above, polymers may be needed in addition.

Low turbidity, high alkalinity waters will need cationic polymers or alum or ferric salts, or such salts in conjunction with coagulant aids such as clays, activated silica, or polymers (often anionic).

Low turbidity, low alkalinity waters will need the addition of a cationic polymer and a base material such as lime or soda ash. Also possible is addition of particles (clays) and then coagulants as described above for high turbidity, low alkalinity waters.

Source water containing iron at less than 5 mg/L can be treated by the addition of aluminum salts or aeration. Water with higher iron concentrations, however, require the addition of an oxidant such as potassium permanganate. The use of a polymer may also be required to enhance the settling of floc particles. Potassium permanganate is an appropriate oxidant for the removal of manganese.

When the source water contains less than 15 color units it may be appropriate to add a polymer as the primary coagulant. At higher color units, greater than 15, the use of aluminum or ferric salts is required for proper color removal.

4.3.2.3 Procedures

The choice of coagulant should be made upon experimental comparison of performance, with due consideration of other factors such as coagulant cost, chemical storage and handling requirements, material availability, etc. Optimum conditions for coagulation should be determined empirically as described below:

a. pH and alkalinity

The optimum pH range for the water source being treated must be determined, and facilities should be provided with the means to make adjustments to raw water quality to permit coagulation to proceed within the water's optimum pH range. Reliance on low alkalinity source waters may require raising the alkalinity of the source water; experimental studies may be required to demonstrate the applicability of the coagulation process proposed. The final product should have a pH that falls between 6.5 and 8.5.

b. Salts

Specific salts at various concentrations have an effect upon the efficiency of the coagulation process. The principal effects are specific to:

- pH range for optimum coagulation.
- Time for flocculation.
- Optimum coagulant dosage.
- Residual coagulant in the effluent.

The effects of salts on the coagulation process are determined using experimental on-site treatment studies to demonstrate the applicability of the method of coagulation proposed.

c. Nature of turbidity

The nature of the turbidity needs to be considered. Turbidity caused by clay and other mineral particles may require different methods of coagulation than waters where turbidity is caused primarily by organic colloids. For example, organics in source waters with high levels of color can react with coagulants to make coagulation more difficult. Low turbidity waters can make coagulation more difficult and a coalescing or weighting agent such as clay (bentonite) may need to be added. Treatment studies may be necessary to determine the optimum coagulant for the source.

d. Physical factors

Physical factors, which include temperature, are discussed in Section 4.2.

e. Mixing

Sufficient mixing time and energy should be provided to allow hydrolysis of metal coagulants and their subsequent adsorption onto colloidal particles. The dispersion time requirement for certain treatment chemicals such as chlorine or fluoride is not as critical as it is for aluminum and iron salts. Experiments may be required to demonstrate suitable mixing for the treatment technology proposed.

There are additional methods available to determine correct doses of coagulant(s) and control the process other than laboratory jar testing. Other methods include:

- Particle counts or filterability tests.
- Measurement of turbidity reduction through sedimentation facilities.
- Measurement of coagulant residual.
- Streaming current detection.
- Filter run time measurement.
- Zeta potential measurements.

4.3.3 Design Criteria

4.3.3.1 Chemical storage

In design of filtration facilities, chemical storage areas should allow for:

a. Storage in a dry area at moderate, uniform temperature.
b. Sufficient air circulation around storage area.
c. Placement of storage area above solution preparation area to permit gravity feed to the area through hoppers, if possible.
d. Sufficient space provided for bulk storage of chemicals.
  - 30 days minimum based on maximum dosage rate at plant design flow in area accessible via road or ferry systems.
  - 180 days storage capacity or more in remote areas depending upon barge schedules.
e. Slope of all floor area to drains or collection sumps.
f. Tank materials compatible with chemicals stored.
g. OSHA or other safety rules concerning eyewash, shower, containment enclosures, or inhalation protection.
h. Earthquake considerations principally for design of proper anchors and integrity of tanks.

4.3.3.2 Solution preparation

The following should be considered in layout and design of such facilities:

a. Provide for continuous feed of coagulant.
b. Provide satisfactory mixing of chemicals with dilution water.
c. Provide protective equipment such as eyeglasses, eyewash, exhaust fans, and inhalation protection.
d. Where polymer feed is contemplated, a system should be designed to feed both liquid and dry polymers.
e. For polymer feed systems, provide curbed area to contain spills, and furnish hose bibb(s) and floor drains or collection sumps to

contain wash down wastewater. Polymer solution preparation areas should also have non-skid floor surfaces.

f. Mechanical mixers for solution preparation should be low speed (400 rpm or less) to prevent break-up of high molecular weight polymers.
g. Diluted polymer solution (1% or less) is subject to rapid degradation; batch mixing tanks should be sized to require a new batch every one to two days.
h. Construction materials should resist the corrosive nature of chemicals, effects of temperature, etc.
i. Provide for gravity feed of chemicals where practical.
j. Provide means to meter make-up water supply when preparing specific solution concentrations.
k. Protect against backflow or cross-connections with in-plant service/make-up water supply. No direct connection should exist between any sewer and a drain or overflow from the feeder, solution tank or chamber. Provide an air gap between any drain or overflow piping of at least six inches, or two pipe diameters (whichever is greater), and the hub drain, floor drain, or waste receptacle.
l. Provide means to measure liquid level in solution tanks.
m. Solution tanks should be covered.
n. Two solution tanks may be required by ADEC to assure continuity of supply in servicing a solution tank.
o. Overflow pipes should be provided, turned downward, have a free fall discharge, be screened, and be located where noticeable.
p. Provide valved drain on each solution tank.
q. Locate solution preparation equipment so that chemicals from equipment failure (e.g. lubricating greases), spillage or accidental drainage does not enter solution tanks or lines, or treatment or storage basins.

4.3.3.3 Dosing equipment

Design of dosing equipment should include the following:

a. Minimum capacity should be determined by the minimum dosage rate and minimum plant flow rate. Consider the need for low feed rate during plant start-up.
b. For each treatment chemical, provide a manifold with piping to every possible location where the chemical may be applied.
c. Avoid high doses of specific treatment chemicals (alum, lime) to avoid heavy scale in feed lines and diffusers.
d. Provide means to clean diffuser orifices; for example, heavy scale may build up in orifices if certain chemicals are injected into hard source water.
e. All chemicals should be conducted from feeder(s) to the point of application in separate conduits.

f. Chemical feeders and pumps should be designed to operate at no lower than 20% of pump capacity.
g. Locate chemical feeders as close to feed point as is practical.
h. Provide standby unit, or a combination of units, of sufficient capacity to replace the largest unit during shutdown
i. Provide separate feeders for each type of chemical used.
j. Specify spare parts to be furnished with equipment to replace parts subject to wear and damage
k. Control of feeders may be manually or automatically controlled, with automatic controls being designed to allow override by manual controls.
l. Chemical feed rates should be proportional to flow.
m. Fail safe mechanisms should be provided to measure water flow to determine chemical dosage rates and prevent overdosing.
n. Provisions should be made for measuring quantities of chemical used.
o. Cross-connection control must be provided to ensure that:
  - Service water lines discharging to solution tanks are properly protected from backflow.
  - Liquid chemical solutions cannot be siphoned through solution feeders into the water supply.

p. Feed lines should as short as possible and need to be:
  - Protected from freezing.
  - Easily accessible throughout their entire length.
  - Readily cleanable.
  - Of durable, corrosion-resistant material.
  - Designed to account for properties of solutions that form scale or deposit solids.
  - Suitably labeled or color coded.

4.3.3.4 Rapid mixing

The ability to provide rapid mixing of the coagulant is important in the system design, because the quality of the finished product is dependent upon proper mixing with the source water. There are several ways to provide for coagulant mixing. These include mechanical mixing, hydraulic mixing, diffusers and injection devices, and in-line blenders. The following information should used, as a minimum, to determine the proper design of a rapid mix unit.

- Raw water analyses representative of the best and worst conditions in quality.
- Maximum and minimum flow rates.
- Typical jar test results of all water samples.

Mixing equipment should be designed keeping the following considerations in mind:

- Minimize hydraulic head losses to allow for future changes in process without need for repumping.
- Provide a minimum of two units for rapid mix.
- The basis for velocity gradient and contact time. Typical design criteria for rapid mix units includes:
  1. Energy input: $G = 300$ to $1{,}200\ \text{sec}^{-1}$ (typical value $750\ \text{sec}^{-1}$)
  2. Contact time: 10-30 seconds
- Evaluate any pollution effects, such as noise, dripping of lubrication oils to process water, etc.
- Evaluate suitability under all local weather conditions.
- Construction of rapid mix units should permit units to be taken out of service without disrupting operation. Drains should be sized to allow dewatering in a reasonable period of time.
- Use of in-line static mixers should be considered when small (.61-.92 m or 2-3 ft) head losses can be tolerated.
- Recycled filter waste wash water, if returned to headworks of the process, should be located downstream of the flash mixing device.

4.4 Flocculation

Flocculation is used in conventional and direct filtration to promote development of floc particles which collect contaminants for sedimentation or filtration. To achieve the log removal credits for filtration associated with *Giardia* removal in conventional and direct filtration treatment schemes, flocculation must be practiced in conjunction with other unit processes described herein.

4.4.1 Process Description

The process of flocculation increases the rate of particulate collisions, which assists in the orderly agglomeration of the colloid particles into settleable or filterable particles.

Particulate collisions occur due to transport by molecular motion or mechanical mixing (flocculation). Generally, the more frequent the collisions over time, the greater the opportunity for colloidal matter to aggregate into larger particles (floc).

Factors which affect selection of the type of flocculation process include:

- The type of treatment process train employed (i.e., conventional, direct filtration, softening, etc.).
- Raw water quality (i.e., turbidity, temperature, nature of turbidity, temperature).

- Flocculation characteristics in response to changes in mixing intensity and mixing time.

The process takes place either in a basin equipped with a mixer that provides gentle agitation, or by using baffles which reduce the cross-section of the basin, inducing collision and agglomeration of particles by gentle current mixing.

4.4.2 Facilities Description

4.4.2.1 Flocculation basin

Flocculation basins are to be sized to provide sufficient detention time to promote agglomeration of particles destabilized by coagulation. Mixing (via mechanical mixers or baffling) must be gentle, and the velocity of flow through the tank must be slow enough so that floc particles are not broken or sheared. The designs of basin inlet, outlet, and internal circulation all affect floc formation and destruction and are critical to flocculation basin performance.

4.4.2.2 Mixing devices

Various mixing devices include:

- Mechanical mixers, such as:
  1. Vertical shaft with turbine or propeller blades.
  2. Paddle type with either horizontal or vertical shafts.
  3. Proprietary units
- Baffled channel basins, such as:
  1. horizontally baffled channel ("round-the-end" baffles)
  2. Vertically baffled channels ("over-and-under" baffles).
- Reactor-clarifier proprietary systems.
- Contact-flocculation (gravel packed filter).

Selection of a mixing type should be based on the following criteria:

- Local conditions (e.g., high winds, ice build up, increase in viscosity of gear oil in extremely cold periods, etc.).
- Available head loss across the plant.
- Shape and depth of basin.
- Capital and O&M costs.

Flocculation basins should be designed for indoor operation, with the exception on a case-by-case basis, such as for Southeast Alaska and other warm areas of the state.

4.4.3 Unit Process Design Criteria

4.4.3.1 Flocculation basin

Detention time determines the size and occasionally the configuration of the flocculation basin. Design criteria used must be based on worst-case conditions, including water temperature, turbidity, etc. Design criteria include:

a. Detention times typically range from 20-30 minutes for warm (> 5°C), low turbidity (< 5 NTUs) waters, and from 45-60 minutes for colder, more turbid waters. Bench scale tests should be performed to confirm selected design values. Flow-through velocities should not be less than 0.15 m per minute nor more than 0.5 m (1.5 ft) per minute.

b. The number of flocculation stages to be included in the design should be determined based on the:

    1. Type of overall treatment process (direct or conventional filtration).
    2. Quality of raw water and treatability (nature of suspended matter, turbidity level, water temperature, etc.)
    3. Degree of flow short-circuiting across basins—with or without baffles.
    4. Local conditions (space available, degree of maintenance provided, etc.).

    It is typical for systems to use two or three stages for warmer waters. However, in colder regions with occasional to frequent high turbidity source water spikes, four or more stages with over 30 minutes detention time may be necessary using conventional filtration. Large conventional filtration systems of 18,900 m^3/day (> 5 mgd), using either vertical shaft turbines with pitched blades or horizontal shaft, paddle-type flocculation systems, should be provided with four-stage flocculation.

c. Each flocculator should be compartmentalized with baffle walls. Each baffle wall should have uniformly distributed orifices (a minimum of 10 cm or 4 in. diameter) with no large holes in the baffle walls because of flow short circuiting, unless they can be blocked off during normal operation.

d. In larger systems, basins should be constructed to permit continual flow without disrupting operation if one basin is out of service. Also, the basins should have drains sized to allow dewatering in a reasonable period of time. In addition there should be a minimum of two units for conventional treatment systems, allowing series or parallel operation.

e. Minimize hydraulic head losses between units to allow future changes in processes without need for repumping.

f. Inlet and outlet conditions shall prevent short circuiting and destruction of flocs. For example, outlets may consist of a baffle wall between a flocculation zone and sedimentation zone (referred to as a diffuser wall) that produces no more than 0.23 m/sec (0.75 ft/sec) flow velocity through orifices at design flow rate to avoid breakage of flocs.

Flocculation basins in smaller packaged water treatment plants have been pre-designed by the manufacturer to meet the desired flow rate of the entire plant. The application of these plants is normally for warmer waters found outside Alaska, and the packaged plants may require additional design to meet certain conditions such as high levels of iron (> 5 mg/L), turbidity (> 5 NTUs), or low temperatures (< 5°C).

4.4.3.2 Mixing devices

The following design criteria shall be employed in layout and design of mixing devices in flocculation basins:

a. Mechanical agitators driven by variable speed drives or adjustable pitch blades, with peripheral tip speeds ranging from 0.15-.91 m/sec (0.5-3.0 ft/sec).

b. The mixing equipment should:

   1. Deliver specified G-values in each stage of flocculation to produce gentle but sufficient eddies and turbulence in entire body of water.
   2. Produce low shear at the mixing blades, especially in the last two stages of flocculation.
   3. Have low O&M costs.

c. Bench scale tests should be performed to confirm optimum velocities and reaction times in order to select proper mixing energy input for equipment. For example, high energy mixing is preferred for direct filtration and low energy input is preferred for conventional treatment to produce large and easily settleable floc.

d. If diurnal temperature differences are great, provide heating elements in the speed reducer gear boxes to avoid condensation in the gear box.

e. Avoid underwater shaft bearings for the flocculators as much as possible to reduce maintenance and down time.

f. Avoid ordinary painted steel structural steel for submerged portions of flocculators. Use Type 316 stainless steel for all wetted metals unless cost is prohibitively high.

g. For vertical shaft turbine blade mixers, the ratio of D/T, where D = diameter of mixing blade, and T = equivalent tank diameter, should be a minimum of 0.35. Typical turbine mixer speeds are in the range of 10-15 rpm.

i. For horizontal shaft flocculators, the following applies:

   1. Total paddle area should be 10-25% of cross-sectional area of tank.
   2. G value for design is usually low with 50 sec^{-1} initially, reducing to 5 to 10 sec^{-1} in the last stage of the flocculation tank.

4.4.3.3 Basin baffle walls

Design criteria for baffles placed within flocculation basins should conform to the following:

a. Top of baffle walls should be slightly submerged, 1.3 cm (0.5 in) to allow scum to flow over them.

b. Bottom of baffle walls should provide a space of at least 1.3 cm (0.5 in) to allow easy drainage and sludge washing when the tank is drained.

c. Holes in the baffle walls should be approximately 15 cm (6 in) in diameter or equivalent and evenly distributed to produce a .30-.46 m/sec (1.0-1.5 ft/sec) velocity through each orifice at design flow rate. Higher velocities are at the first baffle and the lower velocity at the last baffle. There should be enough head loss 0.61 cm (0.02 ft) through the baffle wall to promote even distribution of water flowing through the wall.

d. For vertical shaft mixers, installation of stator baffles in the flocculation compartment should be considered. These baffles are installed on opposite sides of the mixer compartments (total of 2-4 provided), each being 1/12th to 1/10th of the distance across the mixer compartment.

e. Consider effects of warpage in timber used for baffles. Wood baffles tend to warp when the span is over 3 m (10 ft) or is too thin (less than 5 cm or 2 in).

4.4.3.4 Alternate flocculation systems

a. Reactor-clarifier proprietary systems

A reactor clarifier is a solids contact unit in which the coagulation and flocculation step occurs in the same basin as sedimentation but flow does not pass upward through a sludge blanket.

Design is based upon the following:

Flocculation time	30 minutes
Settling time	2 hours
Surface loading	9×10^{-4} $m^3/sec/m^2$ (1.28 gpm/ft^2)
Weir loading	0.136 $m^3/sec/m^2$ ($28,000$ gpd/ft^2)
Upflow velocity	5.1 cm/min (2 in/min)

The design of equipment within the basin should be suitably protected from corrosion; consideration should be given to installation of a cathodic protection system or placing the unit within a concrete structure.

b. Contact flocculation

Contact flocculation or adsorption clarification is the process that combines flocculation and clarification into a single treatment step. Design criteria for contact flocculation must be established based on actual pilot scale studies performed on source water to be treated, or based on pilot scale studies of waters with similar characteristics. Flow rates through the clarifier media bed are usually approximately 7×10^{-3} $m^3/sec/m^2$ (10 gpm/ft^2).

4.4.3.5 Flocculation Design Checklist

a. Layout

- Locate the flocculation process as close as practical to the settling process.
- Provide access ways, hatches, and lifting apparatus (eye-bolts, monorails, hoists, etc.) for removal of heavy equipment.

- Provide walkways with hand rails to access mixing equipment.
- Consider the plant hydraulic profile, soil conditions, land topography, elevation of adjoining facilities, and structural constraints when determining basin depth.
- Provide adequate lighting so that floc formation can be observed at night. An underwater light .3-.6 m (1-2 ft) below the water surface allows for good visual inspection of floc.

b. Flocculation equipment

- Specify heavy-duty drives and gear reducers rated for continuous operation on mixing equipment.
- Specify spare parts for critical items.
- Consider the starting torque load on the shaft and motor, especially with paddle flocculators.
- When specifying impeller flocculators, include:
    - Required G
    - Maximum tip speed
    - Impeller type
    - Minimum impeller diameter
    - Maximum shaft rotational speed
- Select axial flow impellers with pitched blade turbine or hydrofoil blade designs. Radial flow impellers should be avoided for flocculation applications because of higher shear.

c. Flocculation process

- Verify that adequate flocculation will occur over the range of flows and water temperature.
- Provide adequate baffling inside and between flocculation chambers and before settling.
- The bulk water flow should be parallel to the flocculator shaft, except when vertical flocculators are used with over/under baffles.
- Tapered flocculation with decreasing G in each successive flocculation chamber should be used.

- G through the baffle wall should be less than that of the upstream flocculation stage.
- Provide sludge removal and drainage facilities. Provide scum removal if over/under baffles are used.
- Do not use a baffled channel as the primary flocculation process if 0.6 m (2 ft) or more of head loss is not practically available, or flow rate varies significantly from day to day. However, baffled channel flocculators can be considered as a backup flocculation process in many cases.

4.5 Sedimentation

Sedimentation is the process in conventional treatment systems of removing particulate matter in water through gravity forces.

4.5.1 Process Description

4.5.1.1 Purpose

Sedimentation is sometimes referred to as clarification, The solids removed during the process include sand, silt, grit, chemical precipitates, pollutants, flocs, and other settleable solids. It is used downstream of flocculation basins to reduce the amount of suspended material the filters have to remove in the treatment process, enabling maximum filter runs and minimizing filter maintenance. Presedimentation is sometimes used to reduce heavy sediment loads by gravity settling or mechanical separation without chemical addition or other alterations. Presedimentation, when used, is typically done before coagulation.

4.5.1.2 Factors affecting sedimentation

The following factors affect the efficiency of sedimentation:

- Poorly formed flocs degrade settled water quality and increase turbidity (solids) loading on filters. Proper design of coagulation and flocculation facilities must be practiced to avoid this situation (refer to Sections 4.3 and 4.4).
- Short circuiting within the basin also degrades settled water quality and increases loading on filters. Poor inlet baffle design, wind effects, and currents created by density differences can cause short circuiting in sedimentation basins, and baffling should be used.

4.5.1.3 Types of facilities

a. Presedimentation

Several types of facilities are acceptable. Those involved in presedimentation include:

- Raw water storage reservoirs.
- Natural impoundments.
- Solids classifiers.
- Grit removal basin.

b. Sedimentation basins

Several types of sedimentation basins are acceptable. These include:

- Horizontal flow - end feed rectangular basins.
- Horizontal flow - center feed basins (either circular or square basins).
- Horizontal flow - peripheral feed clarifiers.
- Upflow clarifiers.
- Reactor-clarifiers (recirculation or sludge blanket type).
- High rate settler modules (tube settlers or parallel plate modules).

Selection of sedimentation basins should be based upon the following criteria:

- Purpose of sedimentation, such as grit removal, alum floc removal, biological floc removal, etc.
- Overall process, such as conventional filtration, high rate filtration, lime softening, etc.
- Influent criteria for subsequent unit processes.
- Amount of sludge production and sludge withdrawal.
- Space available and ease of future plant expansion.
- Local conditions (e.g. seasonal water quality conditions).
- Capital and O&M costs.

c. Sludge collection equipment

Acceptable types of collection equipment include:

- Chain-and-flight collectors.
- Traveling bridge with sludge scraping squeegees and a cross-collector at one end of the tank.
- Traveling bridge with sludge suction headers and pumps or a siphon mechanism.
- Sludge suction headers .
- Underwater bogies supported by wires.

4.5.2 Design Criteria

4.5.2.1 Presedimentation

Waters containing high turbidity (> 30 NTUs) may require pretreatment, usually sedimentation without addition of coagulants. The design engineer should include consideration of presedimentation facilities in the design report submitted to ADEC during the plan review process if raw water turbidity is expected to exceed 30 NTUs.

Presedimentation facilities consist of basins or vessels designed in accordance with the following criteria:

- Provide hopper bottoms, or alternatively, provide a continuous mechanical sludge removal apparatus, and provide arrangements for dewatering.
- Inlet conditions must disperse incoming water across the full width of the basin to minimize short circuiting.
- Provisions should be made to bypass the presedimentation facilities.
- Detention time of gravity settling chambers should be minimum 3 hours at maximum plant flow.
- Permit series or parallel operation where more than one presedimentation unit is furnished.

Other mechanical equipment used as presedimentation facilities shall be designed on the basis of removal of all particles down to a specified size (e.g. 0.1 mm or 0.004 in) with facilities for continuous removal of underflow. Maximum available head loss through the process should be specified by the design engineer.

4.5.2.2 Sedimentation facilities

a. Conventional sedimentation units

Conventional sedimentation units in smaller "packaged" water treatment plants have been pre-designed by the manufacturer to meet the desired flow rate of the entire plant. The application of these plants is normally for warmer waters found outside Alaska, and the packaged water plants may require derating (flow reduction) or additional design considerations such as preheating to correct certain conditions such as high levels of iron (> 5 mg/L), high turbidity (> 5 NTUs), or low temperatures (< 5°C).

The following guidelines are supplied for larger systems:

1. Minimum detention time of 4 hours at maximum plant flow rate. This time may be reduced with the use of settling tubes or plates.
2. Velocities through the settling basin shall not exceed 0.15 m/min (0.5 ft/min). Basins shall be designed for minimal short circuiting.
3. Overflow rate over the effluent weir shall not exceed 3×10^{-3} m^3/sec/m (20,000 gal/day/ft) of weir length. Where submerged orifices are used as an alternate for overflow weirs, they should not be lower than 1 m (3.28 ft) the flow line with flow rates equivalent to the stated weir loadings.
4. Inlets shall be designed to distribute water equally and at uniform velocities. Open ports, submerged ports, and similar entrance arrangements are required. A baffle should be constructed across the basin close to the inlet end and should project several feet below the water surface to dissipate inlet velocities and provide uniform flows across the basin.
5. Outlet devices shall be designed to maintain velocities suitable for settling and minimize short-circuiting. Use of submerged orifices is recommended to provide a volume of flow above the orifices for storage when fluctuations in flow occur.
6. Means should be provided to establish an overflow downstream of effluent weirs. This allows for a maximum water level on downstream filters. Discharge via the overflow will be by gravity with a free fall at a location where the discharge is measured.
7. A heated, ventilated superstructure over the clarifiers is required to minimize weather induced short-circuiting and eliminate problems associated with freezing weather.
8. Provide mechanical sludge collection.
9. Provide methods to drain or pump to dewater basins at a flow rate equal to half the plant flow rate.
10. Flushing lines or hydrants shall be provided and must be equipped with backflow prevention devices.
11. Sludge removal design shall provide:
    - Sludge pipe shall not be less than 7.6 cm (3 in) diameter and so arranged as to facilitate cleaning.
    - Entrance to sludge withdrawal pipes shall prevent clogging.
    - Valves shall be located outside the tank for accessibility.
    - Observation ports, sight glass, or other means must be provided to allow visual observation of sludge as it is withdrawn. Sampling ports must be provided to sample sludge from each basin.

12. Access should be provided into the basin by ladders or handholds placed on the inside walls of basins above the water level. All equipment shall be in conformance with applicable OSHA standards or local codes.

b. Tube or plate settlers

Settling units consisting of variously shaped tubes or plates which are installed in multiple layers and at an angle to the flow may be used in the sedimentation process, following flocculation. General criteria are as follows:

1. Retention time in modules should not be less than 10 minutes due to the settling characteristics of cold water.
2. A maximum hydraulic loading rate of 0.0014 $m^3/sec/m^2$ (2 gpm/ft^2) of cross-sectional area (based on 0.61 m or 24-in long 60° inclined tubes, or 1 m or 39.5-in long 7.5° unless higher rates are successfully shown to be adequate through pilot plant or in-plant demonstration studies.
3. Inlet and outlet shall be designed to maintain velocities suitable for settling in the basin and minimizing short-circuiting.
4. Drain piping from tube settlers must be sized to facilitate a quick flush of settler units and prevent flooding of other portions of the plant.
5. Cover or enclosure around units shall be provided to prevent freezing of units.
6. Flushing lines shall be provided to maintain units and must be properly protected against backflow or siphoning.
7. In larger plants of 18,900 m^3/day (5 mgd) capacity or greater, two basins with equal flows shall be provided unless adequate provisions are made to ensure sufficient production of filtered water at all times, under all anticipated operating conditions.

c. Solids contact units

Solids contact units are generally acceptable for combined softening and clarification where water characteristics do not fluctuate rapidly, flow rates are uniform, and operation is continuous. Before such units are considered as clarifiers without softening, specific approval of ADEC shall be obtained. Clarifiers should be designed for the maximum uniform flow rate and should be adjustable to changes in flow which are less than the design flow rate and for changes in water characteristics. General criteria for such units include:

1. Installation of equipment shall be supervised by a representative of the manufacturer and start-up performed under the supervision of the manufacturer's representative.
2. Treatment chemicals shall be applied at such points as necessary to ensure adequate mixing with incoming source water.
3. A rapid mix device or chamber ahead of the units may be required by the reviewing authority to assure proper mixing of chemicals applied. Mixing devices employed shall be constructed to provide good mixing of raw water with previously formed sludge particles and to prevent deposition of solids in the mixing zone.
4. Flocculation equipment shall have adjustable speed, pitch, or both, should provide for coagulation in a separate chamber or baffled zone in the unit, and should provide flocculation and mixing for not less than 30 minutes.
5. Sludge concentrators should be provided (either internal or external) which obtain concentrated sludge with a minimum of waste water.
6. Sludge removal piping shall be not less than 7.6 cm (3 in) diameter and so arranged to facilitate cleaning and flushing. Also, the entrance to sludge withdrawal pipes should prevent clogging. Valves shall be located at an accessible location, and access ports and sight glasses should be provided on piping to permit sampling and visual observation of sludge characteristics.
7. Blow-off outlets and drains must terminate and discharge at places approved by ADEC.
8. Cross-connection control must be included for potable water flushing lines used to backflush sludge lines.
9. Detention times shall be established on the basis of raw water characteristics and other local conditions. Supporting data from pilot studies or other in-plant performance demonstrations may be used as a basis for substantiating design detention times. ADEC may alter detention time requirements.
10. Units shall be provided with suitable controls for sludge withdrawal. Total water losses should not exceed 5% if the unit is acting as a clarifier only.
11. Solids concentration of sludge bled to waste should be 3% by weight for units acting only as clarifiers.
12. Units should be equipped with overflow weirs or orifices constructed so that water at the surface of the unit does not travel more than 3.05 m (10 ft) horizontally to the collection trough. Weirs should be adjustable, and weir loading shall not exceed 0.021 m^3/sec/m (10 gpm/ft) weir length as used for clarifiers. Where orifices are used the

loading rates per foot of launder should be equivalent to weir loadings. Either shall produce uniform rising rates over the entire area of the tank.

13. Unless supporting data is submitted to ADEC to justify higher rates, an upflow rate of 7×10^{-4}/sec/m^2 (1.0 gpm/ft^2) may not be exceeded.

4.6 Filtration

4.6.1 Introduction

Acceptable filters for production of potable water meeting ADEC requirements include the following types: rapid rate gravity, granular media filters, diatomaceous earth filters, and slow sand filters. Other types of filtration processes (bag, cartridge, reverse osmosis, membrane, etc.) will require ADEC review and approval. That review would include the proposed technology, its effectiveness, and other relevant factors necessary to evaluate suitability for meeting the SWTR. The state *Drinking Water Procedures Manual* lists approval criteria for alternative filtration technologies.

The term filtration, as applied to granular media rapid rate, and direct filtration filters, describes the overall treatment process for the removal of particulate material from the flow stream. Several filtration process configurations are defined as follows:

Conventional treatment or filtration includes coagulant addition and rapid mixing, flocculation, sedimentation, and filtration. This process has broad application in terms of range of raw water turbidity, and it should be used where turbidities exceed approximately 15 NTUs. This is a recommendation of the Alaska *Drinking Water Procedures Manual*, under the section entitled "Appropriate Filtration Technologies for Various Source Waters." Higher turbidity loads will decrease filter production capability and therefore should be reduced prior to filtration.

Direct filtration excludes the sedimentation step as described for conventional filtration above. This process involves conditioning of natural particulates for subsequent retention in the filter bed but not their removal prior to filtration. Direct filtration is used for moderately low turbidity (< 15 NTUs) water sources.

A variation of direct filtration is *in-line filtration*, which excludes both the flocculation and sedimentation from the treatment process train. In-line filtration is applicable for very low turbidity (< 5 NTUs) water supplies and as such is in common use in many locations in Alaska. This type of filter equipment is available in both gravity and pressure filter configurations.

The selection of the appropriate filtration configuration should be based on the review of water quality data representing the full range of seasonal water quality variations. Pilot studies are suggested where water quality or treatment requirements are unusual and where there has been limited experience treating waters of similar quality in the local area.

The state *Drinking Water Regulations* target removal and/or inactivation of pathogenic microorganisms. One of these organisms, *Giardia lamblia*, has been identified as a major cause of acute gastrointestinal illness. The addition of a coagulant to the process flow ahead of a granular media filter is necessary for the filter to achieve removal of pathogen-sized particles and filtered water quality required by the regulations. Other options are to include bag or cartridge filters in the overall treatment process train to achieve these removals.

4.6.2 Rapid Rate Gravity Filters

4.6.2.1 General

It is desirable to position the filters as close as possible to the upstream processes (sedimentation, flocculation) to reduce floc degradation and minimize yard piping and land requirements. The filters should also be reasonably close to the backwash supply and finished water reservoir to make use of gravity flow if possible.

Provisions should be made for several chemical addition points (such as a filter aid polymer and chlorine) to the filter influent. Chemicals should be added to the entire plant flow so that all filters receive the same treatment. Additional mixing may be required.

The bottom elevation of the filter boxes should be above the floodplain (usually the 100-year flood elevation) to allow positive backwash drainage and to prevent cross connection potential.

Provisions for addition of filters in the future should be made during the initial design. Such provisions may include additional land, knockout walls, blind flanges, tees, and consideration of the depth of excavation required in relation to other structures. Influent and effluent piping and channels are often sized larger than required for the design maximum rate (sometimes 50 percent larger) to allow for higher future filtration rates, if warranted by plant operational experience. Control valves and monitoring devices should be sized for the current expected flow rates. If necessary, they can be replaced to accomodate future changes in the flow rate.

There are many alternative filter layouts. Some features of a desirable layout include:

- Filtered and unfiltered water (including backwash wastewater) are separated by an air break to reduce cross connection potential.
- Filter gallery pipes and valves are minimized by using concrete conduits. This also provides more space for equipment maintenance/removal.

4.6.2.2 Filter size

Filter size affects the layout and footprint of the filtering facility, required backwash water rate, change in filtration rate during backwash, backwash water distribution, and structural requirements. Filter area for a single filter in a conventional filtration treatment plant is typically less than 111 m^2 (1,200 ft^2). The recommended number of filters as a function of treatment plant capacity are listed in Table 4-5. These recommendations are based on the assumption that treated water storage reservoirs are sized to provide water to the service area for all normal domestic, commercial, industrial, and (fire fighting) demands during periods of filter maintenance.

TABLE 4-5 Recommended Number of Filters as a Function of Treatment Plant Capacity

Treatment Plant Capacity	Recommended Number of Filters
> 18,900 m^3/day (5 mgd)	No less than 4
1,890-18,900 m^3/day (0.5-5 mgd)	Between 2 and 4
570-1,890 m^3/day (150,000-500,000 gpd)	2
under 570 m^3/day (150,000 gpd)	1

In large plants with capacities greater than 18,900 m^3/day (5 mgd) with many large filters, each filter may be split into two sections with a common influent/backwash wastewater channel. This provides an economical design while reducing the required length of backwash troughs and filter underdrain flumes. Backwash flow rates can also be reduced if one section is backwashed at a time. However, this arrangement does increase the number of filter valves.

For filter plants with capacities of 18,900 m^3/day (5 mgd) or more, filter length-to-width ratio (L:W) is typically between 2:1 and 4:1 and depends on the site layout, underdrain system, and other site-specific factors. Filter box depth is typically 3.6-6.1 m (12-20 ft) and depends on the control strategy, hydraulics, and future provisions (i.e., future media replacement with granular activated carbon).

In small filter plants of less than 18,900 m^3/day (5 mgd) capacity, the filters are typically part of an overall package treatment system. The package plant can be delivered as a skid-mounted steel tankage or as components to be installed in cast-in-place concrete basins.

The size of the filters in these package plants is often set by the package plant manufacturer. However, the engineer should verify that the size of the filter is adequate to meet the maximum flow rate through the plant. Recommended hydraulic flow rates for the filter are discussed in Section 4.6.2.9.

4.6.2.3 Filter galleries

Larger filtration plants (> 18,900 m^3/day) with multiple filters are often configured with filters on both sides of a pipe gallery. Some plant layouts provide filters on only one side of the gallery. In either case, adequate space for walking, maintenance, and removal of piping, valves, and equipment should be provided. Replacing some major piping with concrete box conduit or encasing pipe (such as the wash water drain header) in concrete below the gallery floor provides more gallery space, but may reduce accessibility.

The top of the backwash supply piping should be located 0.6 m (2 ft) below the top of the backwash troughs to minimize the potential for air entering these pipes. Likewise, air supply pipes (for air or water backwash) should be located for at least 0.6 m (2 ft) above the maximum filter water level to prevent water from siphoning into the air line.

Galleries should have positive drainage, sloped floors, and scuppers along the walls. Adequate lighting and ventilation should also be provided, along with an adequate heating and dehumidification system.

Small package filtration plants route the required process piping as conveniently as possible for maintenance access without posing physical access problems for operational personnel in their daily routine operations. Pipe trenches in the floor of the treatment plant room are often used to satisfy this requirement. They provide easy seismic restraint and ready access for maintenance.

4.6.2.4 Underdrains

The type of underdrain system will be influenced by the type of filter media used and the backwash system (water only, air and water, or interfilter). Four major categories of filter underdrain systems are:

- Block systems
- Nozzles
- Precast concrete perforated laterals
- Perforated pipe laterals

Other underdrain systems are available (Wheeler Bottoms, Johnson Well Screens) but are less commonly used. Underdrain systems for smaller filter plants including package treatment equipment are often one of the four systems reviewed below. Smaller package treatment equipment (< 378 m^3/day [100,000 gal/day]) tends to use the simpler perforated pipe laterals in combination with either a surface wash system or an air and water backwash system.

a. Block Systems: Block underdrain systems are made of vitrified clay or high-density plastic. The plastic blocks are lighter, easier to install, and have a greater resistance to hydraulic shock. The F. B. Leopold Co. is the current major manufacturer of the plastic block underdrain system. Specifying this system only will result in limited bid competition.

The Leopold Universal underdrain can be used for both air and water or water-only backwash. This underdrain can also be fitted with an integral media support (IMS) cap to replace the gravel layer. The cap is made of sintered plastic beads and is bolted to the top of the underdrain. The IMS cap is a recent development and should be carefully evaluated, especially where the potential for plugging is higher (i.e., in lime softening).

The blocks are grouted to the concrete filter floor and anchored with steel bars. Backwash water and air enter a filter underdrain flume and then are distributed through the underdrain blocks and up through the filter media. The underdrain manufacturer should propose standard geometries for underdrain flumes. Underdrain flumes are commonly narrower near the top to accommodate installation of the flume blocks. Water velocities in the flume should not exceed 1.8 m/sec (6 ft/sec); lower velocities are preferred.

b. Nozzle Systems: Nozzle underdrain systems are typically used with air and water backwash systems. They do not require a gravel layer to support the filter media. However, in some cases, a 15 cm (6-in) layer of pea gravel over the nozzles is recommended by the manufacturer. The nozzle slit openings should be approximately one-half the effective size of the filter media covering the nozzles.

Nozzle stem height should be adjustable, thus compensating for uneven floor construction. The nozzle material must be abrasion resistant and not brittle. ABS plastic is a preferred material.

Nozzle underdrain systems typically have a plenum (open area under a false floor) under the entire filter floor area. The height of the plenum can be as little as .6 m (2 ft) and as much as 1.1 m (3.5 ft). The plenum height selected is a function of hydraulics and the desire to have access to the plenum area. The plenum area contains support walls with ports for water and air distribution. The nozzles are commonly placed in a metal or plastic framework upon which concrete is poured to form the reinforced concrete false floor.

c. Precast Concrete Perforated Lateral Systems: Precast concrete perforated lateral systems are used for interfilter backwashing filters. They have low head loss (.3 m [1 ft]) to accommodate this type of filter design. Interfilter backwashing filters do not require backwash storage pumps, piping, and valves, but are less operationally flexible.

d. Perforated Pipe Systems: Pipe lateral systems are positioned near the filter floor and are surrounded by the coarsest layer of the gravel support system for the filter media.

4.6.2.5 Backwash troughs

Backwash troughs collect filter backwash wastewater from the top of the filters and discharge it into wash water conduits that connect to drains. The conduits also help to initially distribute filter influent water over the surface of the filter.

Unsupported trough length is typically 4.6 meters (15 feet) or less for fiberglass troughs and up to 9.1 meters (30 feet) for concrete troughs. Longer troughs can be used, depending on the construction materials and structural supports provided. To maintain uniform backwashing, the troughs must be rigid and not deflect under backwash conditions.

Distance between troughs (center-to-center) is usually 1.5 to 2 times the distance between the top of the trough and the top of the filter media (unexpanded). Typical trough center-to-center distance is 1.8 m (6 ft). For filters smaller than 1.8 m (6 ft) wide, a weir at the side of the filter often replaces the backwash trough.

It is essential to keep the top of the expanded media (during backwash) below the bottom of the wash troughs. There should be approximately 7.6-15.2 cm (3-6 in) between the top of the expanded media and the bottom of the wash water troughs.

The most confining design parameters in a filter box are the freeboard and height of the backwash troughs. Additional filter box freeboard should be considered for future retrofits. Moveable backwash troughs should also be considered when future changes in media depth or type are anticipated.

The wash water conduit should be set at an elevation for free discharge of 10-15 cm (4-6 in) from the trough into the conduit. The wash water drain header should be adequately vented for proper water flow.

The width and height of a backwash trough can be estimated by the following equation:

$$Q = 13.75\ bh^{(1.5)}$$

where:

Q = Water discharge rate per trough in m^3/sec
b = Interior width of the trough in meters
h = Upstream water depth in the trough in meters (add about 6.7 to 15.2 centimeters of freeboard at upstream end of the trough)

This same equation expressed in English units is as follows:

$$Q = 2.49\ bh^{(1.5)}$$

where:

Q = Water discharge rate per trough in cfs
b = Interior width of the trough in feet
h = Upstream water depth in the trough in feet (add 3-6 in of freeboard at upstream end of the trough)

The equation was developed for a trough with a level invert and a rectangular cross section. However, it can be used to estimate upstream water depth in non-rectangular troughs.

4.6.2.6 Backwash supply sources

Filter backwash water can be supplied in a number of ways, including:

- Backwash pumps. Backwash water is delivered to the filters through backwash pumps (minimum of two), each of which is sized to deliver the maximum backwash rate. The pump typically draws water from the filter clearwell or finished water reservoir. Pump and valve controls must accommodate gradual increases and decreases in the backwash water flow rate to avoid damage to the underdrains or upsetting the support gravel layers. In large filters, the pump horsepower may be high. An elevated tank may be considered to reduce energy requirements.

- Elevated tank. An elevated tank can be used as a source of filter backwash water. The tank should be sized to provide two consecutive filter backwashes. The low water elevation should provide adequate head to backwash the most remote filter. Backwash tank refill pumps are much smaller than pumps used to directly backwash the filter. The pumps should be sized to fill the backwash tank in the minimum time between filter backwashes. High service pumps can be used as an auxiliary method for filling the backwash tank. Elevated tanks can be more economical if site topography allows placing the tank on a hill. Any elevated tank provides a source of backwash water during a power outage.

- High-service pump discharge. Water from the high-service pumps can be used to backwash filters if proper pressure reduction and flow control equipment are provided. In some cases, the high-service pump discharge is used as a backup source of filter backwash water if other backwash supply sources are inoperable.

- Interfilter backwash. With this method, the common filter effluent flume is elevated to provide sufficient head for backwashing. Deeper filter boxes and special underdrains are required. This is a special type of filter backwash system, and input from a hydraulic design specialist is required.

4.6.2.7 Auxiliary wash

Surface wash systems are required for "water only" backwash systems but are not usually used for air and water backwash systems. Two common types of surface wash systems include fixed nozzle and rotary arm systems.

Fixed nozzle surface wash systems consist of a grid of pipes and nozzles suspended over or within the filter media. Rotary arm surface washers consist of rotating arms with nozzles that make a circular sweeping motion over the filter media. Spray nozzles for both systems are commonly placed 5-7.6 cm (2-3 in) above the unexpanded filter media. Other designs for deep-bed coarse media filtration applications place some nozzles below the media surface for deeper media cleaning.

Surface wash supply piping is usually located in the filter gallery and distributed to each filter. There must be a backflow preventer or other device to prevent cross connections when filtered water is used as a surface wash source. The source of surface wash water can be from the plant's finished water discharge line if pressure is adequate (480 to 687 kN/m^2 [70 to 100 psi]) or from dedicated surface wash booster pumps if finished water pressure is low. A pressure-reducing valve may be required if finished water pressure is high (756 kN/m^2 [110 psi] or greater).

In air and water backwash systems, air can be introduced into the filter underdrains to create turbulent mixing and effective media cleaning. Air and water backwash systems require air blowers, air piping and valves, and controls, along with water backwashing facilities. A separate room is typically provided for the air blowers to isolate noise.

4.6.2.8 Filter media selection guide and specification

a. Filter Media Selection. Filter media sizes are typically specified by effective size and uniformity coefficient. Effective size (E.S.) is defined as the size opening that will just pass 10% (by weight) of a representative sample of the filter material. For example, if 10% of a media sample is finer than 0.45 mm, the filter material has an effective size of 0.45 mm. Effective size is commonly denoted as d10, or the media diameter at which 10% of the media sample is smaller.

Uniformity coefficient (U.C.) is defined as a ratio of the size opening that will just pass 60% (by weight) of a representative sample of the filter material (d60) divided by the size opening that will just pass 10% (by weight) of the same sample (d10); or d60/d10.

Specifying media effective size and uniformity coefficient is adequate in most cases. However, where a very uniform media within a specific size range is being considered, specifications may need to indicate limiting sizes. In such cases, a media design specialist should be consulted.

Three types of filter media commonly used include:

- Dual-media, consisting of a layer of anthracite over a layer of sand.

- Tri-media, consisting of a layer of anthracite over a layer of sand over a layer of garnet or ilmenite.
- Mono-media, consisting of a single deep layer of coarser anthracite or sand.

Typical ranges of media characteristics for the above media types are summarized in Table 4-6 to illustrate commonly-used filter media characteristics available for use in bench or pilot scale evaluations. Filter media that is not commercially available should not be specified or used in pilot plant investigations.

When pilot plant data are not available, the filter media characteristics listed in Table 4-7 for dual- and tri-media filters are recommended. Dual-media filters are adequate for most applications, and filter turbidities less than 0.3 NTU are readily achievable. If turbidities lower than 0.1-0.2 NTU are desired on a consistent basis, tri-media filters may be selected. However, tri-media filters will have more clean bed head loss and potentially shorter filter runs than dual-media filters. Therefore tri-media filters are more costly to operate and maintain.

Mono-media characteristics for a particular application should be chosen based on pilot plant data. See Table 4-6 for a range of mono-media characteristics that can be used as a guide for pilot plant studies.

b. Gravel Layer Selection. The primary purposes of filter gravel are:

- Support the filter media and prevent smaller particles from entering the underdrains and

- Evenly distribute backwash water (and air if applicable).

Top-layer gravel size is controlled by the finest filter media to be retained, whereas bottom-layer gravel size is controlled by the underdrain orifice size. Certain underdrain systems (i.e., nozzle underdrains) do not require gravel layers.

TABLE 4-6 Typical Ranges of Media Characteristics for Pilot Plant Studies

Media Type	Effective Size (mm)	Uniformity Coefficient	Specific Gravity	Depth	
				(cm)	(in)
Dual-Media					
Anthracite	0.8-1.2	1.4-1.7	1.4-1.8	30-91	12-36
Sand	0.4-0.6	1.4-1.7	2.5-2.7	23-61	9-24
Tri-Media					
Anthracite	0.8-1.2	1.4-1.7	1.4-1.8	30-61	12-24
Sand	0.4-0.6	1.4-1.7	2.5-2.7	23-61	9-24
Garnet	0.2-0.4	1.4-1.7	3.8-4.2	7-13	3-5
Mono-Media (either, not both)					
Anthracite	0.8-1.8	1.4-1.7	1.4-1.8	122-244	48-96
Sand	0.8-1.2	1.4-1.7	2.5-2.7	122-244	48-96

TABLE 4-7 Typical Ranges of Media Characteristics for Filter Design Without Pilot Plant Evaluation

Media Type	Effective Size (mm)	Uniformity Coefficient	Specific Gravity	Depth	
				(cm)	(in)
Dual-Media					
Anthracite	0.9-1.0	<1.55	≥ 1.6	61	24
Sand	0.45-0.55	<1.55	≥ 2.6	30	12
Tri-Media					
Anthracite	1.0-1.1	<1.55	≥ 1.6	61	24
Sand	0.45-0.55	<1.55	≥ 2.6	23	9
Garnet or Ilmenite	0.20-0.30	<2.0	>3.8	10	4

Tables 4-6 and 4-7 note:

1. Media characteristics are influenced by gravel support.
2. Conventional and direct filtration media are similar.

General guidelines for gravel-layer sizes and depths are summarized as follows (from AWWA Standard B100-89):

- The depth of each layer should be ≥ 3 times the maximum particle size in that layer, but not less than 5-7.6 cm (2-3 in).
- Four layers of gravel are typical.
- The ratio of maximum to minimum particle size in each layer should be ≤ 2.
- The minimum particle size of the top gravel layer should be approximately 4 times the d10 of the finest filter media.
- The maximum particle size of a lower layer should be ≤ 4 times the minimum particle size of the layer above it.
- The minimum particle size of the bottom gravel layer should be 2-3 times the underdrain orifice size.

For tri-media filters, a layer of dense garnet or ilmenite is placed on top of the gravel layer.

Neither the bottom gravel nor the garnet layer should be disturbed by water velocities during backwash. Air scour backwash requires special considerations to prevent gravel or garnet layer disruption. The use of nozzle underdrain systems with small openings eliminate the need for gravel and thus eliminates potential gravel disruption problems. If gravel is used with an air and water backwash system, a double-reverse graded gravel system (coarse bottom-fine middle-coarse top) can be used. An example of a double-reverse graded gravel system used with Leopold Universal underdrains in a dual-media filter is shown in Table 4-8.

TABLE 4-8 Example of Double-Reverse Graded Gravel Underdrain System

Gravel Layer	Layer Thickness	Size Limits
Top	5 cm 2 in	1.27-1.90 cm 1/2-3/4 in
Second	5 cm 2 in	0.32-0.63 cm 1/8-1/4 in
Third (Garnet)	5 cm 2 in	0.25-0.32 cm No. 10 mesh to 1/8 in
Fourth	5 cm 2 in	0.32-0.64 cm 1/8-1/4 in
Fifth	5 cm 2 in	0.64-1.27 cm 1/4-1/2 in
Bottom Layer	5 cm 2 in	1.27-1.90 cm 1/2-3/4 in

c. Compatibility of Filter Components and Auxiliary Wash. The underdrain system must be compatible with the selected filter media, the gravel support system, and the proposed auxiliary wash (surface wash or air and water backwash) program for the filter. As an example of incompatible systems, a perforated pipe lateral underdrain system is not suitable for an air and water auxiliary wash program because the air cannot be evenly distributed over the bottom of the filter.

d. Fluidization Characteristics. Backwash rates must be selected so that the larger sand and anthracite particles (d90) are fluidized at typical backwash velocities and water temperatures. If this does not occur, inadequate media cleaning may result with water-only backwash.

Filter media design must be done with full knowledge of the properties of the individual filter materials. This manual provides general criteria for filter design. It is recommended that, as the designer develops specifications for the filter materials, the designer communicate and coordinate his or her efforts with the media suppliers to confirm the availability of the proposed materials and its hydraulic characteristics.

e. Air and Water Backwash. Enhanced media cleaning can be achieved with less backwash water in an air and water backwash system. However, unless there is some means of controlling the application of air to the bottom of the filter, proper post-backwash restratification of dual- and tri-media filters may be jeopardized. Therefore, a water-only backwash program may be selected to reduce the potential for improper post-backwash restratification.

Optimum air and water flow rates will vary with the type of media. General guidelines for filter design presented in Table 4-9 for air and water backwash are usually satisfactory. However if operating experience indicates problems with insufficient backwashing, a specialist familiar with air and water backwash design should be consulted.

4.6.2.9 Filter design criteria

a. Common filter design criteria are summarized in Table 4-9 to identify the range of typical design criteria. Design criteria beyond these ranges should be verified through pilot or full-scale tests and discussion with a water plant design specialist.

TABLE 4-9 Typical Rapid Rate Filter Design Criteria

Component	Criteria
Minimum number of filters	See Table 4-5
Hydraulic loading rate	Up to 2.0-4.1 L/sec/m^2 (3-6 gpm/ft^2) Higher rates are possible but require piloting
Filter bed width	Up to 7.62 m (25 ft)
Filter bed length	Up to 13.7 (45 ft)
Filter box depth	3.6-6.1 m (12-20 ft) Depends on control scheme
Typical media depth in service mode (excluding gravel)	Multi-media 0.76-1.07 m (2.5-3.5 ft) Mono-media 4-foot minimum
Maximum water depth above media	Depends on the control scheme, but should be greater than the maximum anticipated filter media head loss to avoid air binding.
Total head loss through filters	1.5-3.6 m (5-12 ft)
Media expansion during backwash	Multi-media 25%-50% Mono-media 10%-25%
Backwash trough spacing	1.52-1.82 m (5-6 feet center-to-center)
Backwash trough length (Unsupported)	Up to 4.6 m (15 ft) for fiberglass Up to 9.1 m (30 ft) for concrete
Backwash trough elevation	Trough bottom 7.6-15.2 cm (3-6 in) above the expanded media (assume 40-50% media expansion). Consider provisions for moveable troughs and deeper filter boxes.
Surface wash rate	0.34-1.36 L/sec/m^2 (0.5-2 gpm/ft$^{2)}$ rotary (depends on arm diameter) 1.36-2.71 L/(sec-m^2) (2-4 gpm/ft$^{2)}$ fixed nozzle
Surface wash pressure (at orifice)	480-687 kN/m^2 (70-100 psi) rotary 55-103 kN/m^2 (8-15 psi) fixed nozzle
Surface wash arm elevation	5-7.6 cm (2-3 in) above unexpanded media
Backwash rate (water only)	6.8-17 L/sec/m^2 (10-25 gpm/ft^2) Depends on water temperature and media
Air and water backwash	1-2.5 cm/sec (2-5 scfm/ft^2) air 2-4 L/(sec-m^2) (3-6 gpm/ft^2) simultaneous air and water 6.8-1.7 L/(sec-m^2) (10-25 gpm/ft^2) (depends on water temperature and selected media) for final restratification

b. **Filtration Design Checklist**

1. Layout

- Provide a means for filter facility expansion (i.e., land availability, knockout walls, blind flanges, tees, etc.).
- Provide sufficient room in filter gallery for maintenance of valves and equipment. Provide accessways and lifting eyes (or crane or monorail) for removal of heavy equipment.
- Provide walkways around filters for access on at least three sides.
- Locate the filter facility reasonably close to the upstream process, backwash supply, and finished water reservoir.
- The bottom of the filter box should be above the flood level to provide for backwash drainage and to minimize a possible cross connection.
- Provide access for media removal and replacement.

2. Filtration process and mechanical

- The backwash supply water pipe should be well below the top of the wash water troughs to prevent air from entering the backwash pipe.
- The backwash supply water pipe should have air release valves at high points. This is especially important if vertical turbine pumps are used for backwash supply. The backwash pumps should be designed to start against a closed valve to expel trapped air and bring the backwash rate up slowly.
- Provide adequate venting or air release valves on wash-waste, and filter effluent headers.
- Do not use high pressure water for backwash (> 137 kN/m^2) (> 20 psi). Underdrains can be damaged and filter gravel/media can be upset.
- Include surface wash with "water only" backwash systems. The surface wash supply line should have a backflow preventer, or a vacuum break and check valve to prevent cross connection.

- Provide galleries with positive drainage, ventilation, dehumidification, and adequate light.
- Provide for polymer feed, primary coagulant feed, or both, and proper mixing to the filter influent and backwash water supply.
- Provide continuously monitoring turbidimeters, head loss gages, flowmeters, and flow totalizers on each filter.
- Provide for addition of disinfectant to the filter influent and effluent.
- An air gap should be placed between the filter-to-waste pipe and drain line. If filter-to-waste is not provided, consider provisions such as holding a filter off line to "age" before start-up, a slow initial filtration rate, and provisions for coagulant addition to the backwash water supply.
- Color code filter piping.
- Filter backwash supply should be of adequate volume for at least two complete, consecutive backwashes.
- Provide redundant backwash and surface wash pumps for any pump over 4 kW (5 hp) or whenever the labor to replace the pump exceeds 6-8 hours.
- Provide flow rate control, measurement, and flow totalization on the backwash water.
- When required by the filter control strategy, a filter effluent weir should be located at an elevation near that of the filter media to reduce air binding potential of the filter media.
- Provide an anti-vortex device in an elevated backwash tank effluent.
- Place air header piping (for air and water backwash) 0.6 m (2 ft) above the maximum filter water level to reduce the possibility of water siphoning into the air header.
- Provide 23-30 cm (9-12 in) clearance between flanges and walls.
- Provide an access port to gravity filter underdrains for inspections.

4.6.3 Rapid Rate Pressure Filters

Pressure filters are often used for direct (in-line) filtration applications for turbidity reduction in which flocculation is not required. Other pressure filter applications include sediment removal and iron and manganese removal.

4.6.3.1 General

Pressure filters are used extensively in small and medium Alaska systems. From a construction cost standpoint, their premanufactured compact configurations minimize the required installation labor and minimize the space required to house these units. The resulting reduced installation cost makes them an attractive alternative.

Another aspect of pressure filtration is their potential to reduce process pumping requirements. Raw water lifted up to open-to-atmosphere gravity filtration equipment must be pumped to storage. Using pressure filters, no additional pumping station is required for this application.

Pressure filters can be used as pretreatment for other filtration processes. For *Giardia* and virus reductions in surface water sources used by small systems one alternative which could be considered incorporates pressure filtration as a roughing filter for sediment and gross turbidity reduction. The pressure filtration process could be followed by processes using disposable micron cartridge filters, bag filters, or porous ceramic "backwashable" filters with filtered water subject to chlorination. The use of these treatment process configurations may be subject to performance verification through bench or pilot scale demonstrations. In these configurations, pressure filtration clearly will enhance the overall performance of treatment.

Pressure filters can also be used as pretreatment for ion exchange or membrane filter processes. These particular processes are both operated under pressure. Use of pressure filtration pretreatment in these applications would eliminate the need for intermediate pumping between pretreatment and the downstream process. Chief drawbacks to the use of pressure filters historically have been a tendency to operate the filters without coagulant, thereby decreasing their filtration effectiveness, and the fact that the filter media is not readily observable or accessible to allow confirmation of minimum media layer thicknesses. This last consideration can be partially alleviated by specifying observation windows and interior lighting, as discussed in Section 4.6.3.2.

4.6.3.2 Pressure filter design considerations

Rapid rate pressure filters function identically to comparable gravity filters, and therefore the design criteria specified for gravity filters relative to media selection, hydraulic loading rate, and backwash (Section 4.6.2) are applicable.

Pressure filter configurations are typically cylindrical in either a horizontal or vertical position. The horizontal configuration has the advantage of providing more filter surface area per unit area of floor space occupied by the filter. Disadvantages of horizontal filters include more difficulty in distributing the flow of applied raw water and backwash water evenly across the entire filter area and the difficulty in transporting filters in excess of 8 feet in diameter over public roads. There is also more labor involved in the removal and replacement of filter media in a horizontal filter due to limited head room inside the filter.

The temperature of raw water for most Alaska applications is cold enough to warrant consideration of some form of insulation on the exterior of pressure vessels constructed of steel. This is for condensation control. Without it, the pressure vessels would sweat and corrode. Smaller pressure vessels up to 92 cm (36 inch) diameter are available in fiberglass with the obvious advantage of corrosion resistance.

Buildings for larger horizontal pressure filters are often designed to provide housing only for the end of the filters with inlet and outlet manifolds. The remaining portion of the filter vessels are extended out through the wall of the structure and insulated to provide freeze protection. This configuration results in considerable capital cost savings for the overall treatment facility, but provision must be made to allow operational staff to observe the filters in backwash mode through viewing windows, as discussed below.

Most pressure filters are available in vessels rated for a nominal operating pressure. Steel vessels are available with an ASME rating which requires construction of the vessel to conform to long-established pressure vessel codes.

Process control options for the initiation of the filter backwash sequence include the use of a turbidimeter on the filtered water to initiate a backwash when effluent turbidity approaches 0.5 NTU. Another option is the use of a time clock preset to backwash the filter either daily or on specified days of the week where the service cycle is short enough to assure acceptable effluent turbidity. Other options include the use of a totaling filtered water flow meter for initiation of backwash and use of a differential pressure across filter to initiate backwash. In all cases, initiation of backwash must ensure acceptable effluent turbidity.

Other options to be considered in the design of pressure filtration equipment are listed below.

- Observation windows on the pressure vessel with submersible lights in the interior of the filter to illuminate the filter and facilitate visual inspection of the media both in service and backwash operations.
- Filter inlet and outlet pressure gages.
- Filter manifold control valve position indicators to facilitate operations.
- Rate-of-flow indicators and controls for each filter.
- Backwash provisions similar to gravity filters with the addition of a common daylight box, which permits visual observation and sampling of the waste wash water.
- A waste cycle for the filtered water produced immediately following a backwash cycle.
- Underdrains that both collect filtered water and distribute backwash water at rates up to 13.6 L/sec/m^2 (20 gal/min/ft^2).
- Surface wash system with positive means of detecting proper surface wash operation.
- An air release and vacuum vent valve on the high point of each filter vessel.
- An influent distributor and backwash waste collector that is high enough above the media to permit a 50% media expansion during washing without losing media in the waste wash water.

- Access manholes just the above the media level for horizontal tanks and in the domed top for vertical tanks.
- Cross-connection control in the process piping.
- Means to measure turbidity of individual filters through sample ports.

4.6.4 Direct Filtration

As described in the introduction to this chapter, "direct filtration" is the process whereby raw water is chemically conditioned, flocculated, and filtered for reduction of turbidity. It is identical to conventional treatment without the sedimentation process.

In-line filtration is a variation of direct filtration which omits the flocculation step from the overall treatment process train. For either direct filtration or its in-line filtration variation, the details of filter design are the same as presented in Section 4.6.2, for "Rapid Gravity Filters."

These processes may be configured as either open-to-atmosphere gravity filters or pressure filters. Pressure filter design considerations are reviewed in the preceding section, Section 4.6.3. Filtration equipment in either configuration is available for both large or small systems.

Minimum water quality characteristics which will support these filter processes are reviewed in Section 4.6.4.1 below.

4.6.4.1 Pilot plant studies

A bench scale, pilot, or in-plant demonstration study to confirm the performance of the direct or in-line filtration process is recommended whenever these processes are considered for source waters with water quality characteristics outside the limits identified in Table 4-10. It should be understood that should other water quality parameters for the source water be identified which filtration alone would not improve, then additional unit processes are required to produce potable water quality. Examples of this would include radionuclides, arsenic, or volatile organic contaminants.

TABLE 4-10 Source Water Quality Parameters that Warrant Demonstration Studies for Proposed Direct or In-line Filtration Processes

Source Water Quality Parameter	Limits Which When Exceeded Warrant Demonstration Study
Turbidity	7-14 NTUs
Total Coliforms	500/100 ml
Color	40 CU for direct filtration 10 CU for in-line filtration
Total Iron	0.30 mg/L
Total Manganese	0.05 mg/L
Algae Counts	2,000 ASU/mL
Total Alkalinity	500 mg/L as $CaCO_3$

Demonstration studies shall be conducted under average and adverse water quality conditions and shall emphasize, but not be limited to, the following items:

- Chemical mixing conditions including shear gradients and detention periods.
- Maximum permissible differential pressure across the filter.
- Chemical feed rates.
- Use of various coagulant aids including polymers.
- Flocculation conditions.
- Filtration rates.
- Filter gradation, types of media, and depth of media.
- Filter breakthrough conditions as identified by either particle count or effluent turbidity monitoring.

Prior to the initiation of any demonstration studies or design efforts, a report including the engineer's proposed study plan should be submitted to ADEC for review and concept approval.

4.6.4.2 Pretreatment—rapid mix and flocculation

Coagulant selection and application for rapid rate gravity filtration is reviewed in Section 4.3, "Coagulation." These guidelines also apply to direct filtration processes.

The final design of the rapid mix and flocculation basin processes should be based on any demonstration studies conducted for the project. In the absence of such studies, general guidelines for the design of flocculation and rapid mix processes are reviewed in Section 4.3, "Coagulation," and Section 4.4, "Flocculation." For small systems using package direct filtration equipment, the manufacturer's equipment configuration should be reviewed for rapid mix and flocculator mixing parameters, and detention times for the proposed process flow rates.

4.6.4.3 Filtration

Filters used for direct filtration treatment processes should be rapid rate gravity filters with dual or mixed media. The final filter design should be based either on demonstration studies or on applicable portions of Section 4.6.2, "Rapid Rate Gravity Filters."

An auxiliary wash should be provided as part of the filter backwash program for the filters in accordance with Section 4.6.2.7, "Auxiliary Wash".

4.6.5 Slow Sand Gravity Filters

4.6.5.1 General

Slow sand filtration is another filtration process identified in the Alaska *Drinking Water Regulations* which is capable of reducing the levels of *Giardia* and virus in source waters. The process is characterized by low hydraulic filter application rates and extended service between cleaning. Cleaning of the filter consists of removal of the upper portions of the filter media (as opposed to using a filter backwash cycle) followed by a relatively long filter ripening period before placing the filter into service. Coagulants or polymers addition is not practiced with slow sand filtration.

The suitability of the slow sand filter process for a given surface water is first identified by comparing the water quality parameters of the source water with the limitations listed in Table 4-4 in Section 4.1.7. Demonstration studies for the process using the water source under consideration for a particular project and local sands as filter media can establish the probable performance of the process and the required duration of the ripening period.

4.6.5.2 Raw water quality

The recommended maximum turbidity applied to a slow sand filter is variable and dependent on the occurrence and duration of turbidity spikes in the source water. Typically, less than 10 NTUs is considered acceptable without pre-sedimentation. Color should not exceed 5-10 platinum-cobalt color units. Pilot studies also identify filter performance influences by algae. The AWWARF's *Manual of Design for Slow Sand Filtration* notes a study recommending that slow sand filtration be used only for waters with chlorophyll-a levels under 5 mg/m^3.

4.6.5.3 Number of filters

At least two parallel filter units should be provided. Where only two units are provided, each should be capable of meeting the plant design capacity (normally the projected maximum daily demand) at the approved filtration rate. Where more than two filter units are provided, the filters should be capable of meeting the plant design capacity at the approved filtration rate with one filter removed from service.

4.6.5.4 Structural details and hydraulics

Slow rate gravity filters should be designed to provide:

- A cover with head room to permit normal movement by operating personnel for scraping and sand removal operations.
- Adequate manholes and access ports for handling sand.
- Filtration to waste.
- An overflow at the maximum filter water level.

4.6.5.5 Rates of filtration

The nominal hydraulic loading rate may be 31-102 $L/sec/m^2$ (45-150 $gal/day/ft^2$) of sand area, with somewhat higher rates acceptable when demonstrated by pilot study data.

4.6.5.6 Underdrains

Each filter unit shall be equipped with a main drain, a drawdown drain, and an adequate number of lateral underdrains to collect the filtered water. The underdrains shall be spaced so that the maximum velocity of the water flow in the lateral underdrain will not exceed 22.8 cm/s (0.75 ft/sec). The maximum spacing of the laterals shall not exceed 3.6 m (12 feet).

4.6.5.7 Filtering material

Filter sand shall be placed on graded gravel layers for a minimum depth of 76 cm (30 in). The effective size shall be between 0.30 mm and 0.45 mm. The uniformity coefficient shall not exceed 2.5. The sand shall be clean and free from foreign matter.

4.6.5.8 Filter gravel

The supporting gravel shall conform to the size and depth distribution provided for rapid-rate gravity filters (see Section 4.6.2.8).

4.6.5.9 Depth of water on filter beds

The depth of water over the filter media is a function of the head loss through the filter, *schmutzdecke*, and underdrain system. The effluent weir controlling the tailwater should be set to provide a minimum of 1 m (3.2 ft) of water depth over the filter media under clean filter conditions. This is to avoid disruption of the filter media from application of raw water to the filter. The maximum depth of water applied to the filter is usually between 2 and 3 meters (6.5 and 9.8 feet) according to the AWWARF *Manual of Design for Slow Sand Filtration*.

Designing for larger maximum water depths over the filter was reviewed by Hazen in 1913. He concluded that increasing the head over the filter increases the length of filter run and the amount of filtered water produced in a given filter cycle without risking solids breakthrough. However, increasing this head above the filter requires more filter basin structure, thereby increasing capital costs. The current practice of designing for maximum filter heads between 2 and 3 meters (6.5 and 9.8 feet) balances the capital cost with the operational costs associated with the frequency of filter cleaning.

4.6.5.10 Control appurtenances

Each filter shall be equipped with:

- Loss of head gage.
- An orifice, Venturi meter, or other suitable metering device, installed on each filter to control the rate of filtration.
- A filter effluent turbidimeter.
- An effluent pipe or weir box designed to maintain the water level above the top of the filter sand.

4.6.6 Diatomaceous Earth Filtration

Diatomaceous earth (DE) filters are generally considered applicable to low turbidity, low color, and low bacterial contamination as outlined in Table 4-4 in Section 4.1.7.

4.6.6.1 General

DE is a natural siliceous material (microscopic diatom skeletons) used as the filtering medium in vertical axis pressure or vacuum septum vessels. The pressure vessel contains porous tubular structures (filter elements) against which the DE is supported by the pressure differential across the DE and septum.

DE filters for treatment of public water supplies in full-scale plants following World War II was sometimes unsuccessful because of operational deficiencies. Although the operation of DE filters is now better understood, and operational guidelines are better defined, drawbacks remain.

The primary advantage of DE filters is low initial cost, whereas disadvantages include high operating cost, increased sludge production, and lack of proven experience in dealing with raw water that is not of relatively high quality. Consequently, DE filters are best suited to very small plants for which the cost of a comparable granular media plant is higher, or to plants that are used only intermittently.

4.6.6.2 Types of filters

DE filters can be operated in a pressure or vacuum mode, with vacuum being the preferred mode.

4.6.6.3 Pilot plant study

Pilot studies may be conducted to determine filtration rates, run durations, proper DE selection, precoat and body feed DE application rates, head loss accumulation, and filter effluent characteristics for the range of raw water qualities to be applied. Pilot studies must demonstrate the ability of the DE filtration system to meet all regulated filtered water quality standards.

4.6.6.4 Precoat

Provide a precoat recirculation or filter-to-waste system for application of precoat DE prior to filtration. A precoat layer of 0.16 to 0.32 cm (1/16-inch to 1/8-inch) is normally required prior to commencing filter production.

4.6.6.5 Body feed

Once precoating of the filter elements is complete, a continuous body feed of DE is required to extend the filter run by reducing the rate of head loss buildup. Continuous mixing of the slurry is required.

4.6.6.6 Filtration

The recommended nominal rate of filtration is 0.68 L/sec/m^2 (1.0 gal/min/ft^2) of filter area, with a recommended maximum of 1.0 L/sec/m^2 (1.5 gal/min/ft^2). The filtration rate should be controlled by a positive means.

The head loss should not exceed 206 kN/m^2 (30 psi) for pressure diatomaceous earth filters, or a vacuum of 38.1 cm (15 in) of mercury for a vacuum system.

A recirculation or holding pump should be employed to maintain differential pressure across the filter when the unit is not in operation to prevent the filter cake from dropping off the filter elements. A minimum recirculation rate of 0.068 L/sec/m^2 (1.0 gal/min/ft^2) of filter area shall be provided.

The filter elements should be structurally capable of withstanding maximum pressure and velocity variations during filtration and backwash cycles, and should be spaced such that no less than 2.5 cm (1 in) is provided between elements or between any element and a wall.

The filter influent shall be designed to prevent scour of the diatomaceous earth from the filter element.

4.6.6.7 Backwash

Provide a suitable method for the thorough removal and disposal of spent DE filter cake.

4.6.6.8 Accessories

Each DE filter should be supplied with the following:

- Sampling taps for raw and filtered water.
- Loss of head or differential pressure gage.
- Rate-of-flow indicator, preferably with totalizer.
- A throttling valve used to reduce rates below normal during adverse raw water conditions.
- Continuous monitoring turbidimeter with recorder and alarm shall be provided for each filter effluent.

4.6.7 Reverse Osmosis

Reverse osmosis (RO) is a process used to separate contaminants (usually dissolved salts) from water by using a pressure greater than the natural osmotic pressure to force relatively pure water through a semipermeable membrane, leaving the contaminants behind.

4.6.7.1 Mechanisms involved with reverse osmosis

In normal osmosis, water flows from the side of the membrane with the lower contaminant concentration to the side with the higher contaminant concentration to equalize the solution. By applying more pressure to the side with the higher contaminant concentration, the flow can be made to reverse. Reverse osmosis is the process of applying enough pressure on the solution with the higher contaminant concentration to accomplish flow of water through the membrane to the solution with the lower contaminant concentration. This process produces a reject concentrate waste stream in addition to the clear permeate product.

4.6.7.2 Factors affecting reverse osmosis

Factors which affect reverse osmosis include:

- Chemical addition to control pH is necessary to protect membrane materials from decomposition and to mitigate membrane scaling of solids.
- Preliminary removal of solids to eliminate the possibility of membrane fouling caused by particulate matter scaling and biofouling.
- Preliminary removal of excessive hardness, iron, and manganese to prevent scaling.
- Freezing of membrane while in storage or transit.

4.6.7.3 Pretreatment considerations

Pretreatment is required for reverse osmosis. Considerations include:

- Coagulation and filtration may be necessary to eliminate turbidity, suspended matter, iron, and manganese. Dissolved organic chemicals may need to be removed using granular activated carbon. Acid is generally used to prevent chemical scaling. Chlorine may need to be applied to control biological growths on the membrane.

- In general, water with a 15 minute Silt Density Index (SDI) of 3.0 or less is suitable for reverse osmosis without colloid or particle pre-treatment steps other than the required microfiltration with 1, 5, or 10 micron rated disposable cartridge filters.

- The calcium and sulfate concentrations in the concentrate stream are dependent on the feedwater concentrations of calcium and sulfate, and the RO system permeate recovery rate. If the calcium sulfate ion product for the concentrate stream is greater than 80% of the calcium sulfate solubility product for the particular temperature and ionic strength of the concentrate stream, pre-treatment is required, such as: lime or ion exchange softening to remove the calcium, or adding a specially formulated synthetic polymer scale inhibitor chemical. For calculation and adjustment of calcium sulfate scaling salts, see ASTM D 4692-87.

- The permeate recovery rate may need to be reduced to avoid exceeding the solubility limits of calcium sulfate. The addition of sulfuric acid to control calcium carbonate scale may cause calcium sulfate scale problems, therefore all the scale-forming constituents of the feedwater must be considered during the RO system preliminary design.

- The presence of dissolved calcium and fluoride in the feedwater necessitates comparing the ion product to the solubility product in a manner similar to that described above for calcium sulfate. Synthetic polymer scale inhibitors are available which may be capable of controlling the formation of calcium fluoride precipitate within the RO system. If suitable scale inhibitors are not available to control this constituent, then the permeate recovery rate must be reduced or other measures implemented, to prevent exceeding the solubility limits of calcium fluoride.

- Barium sulfate precipitation in the concentrate stream may limit the RO system permeate recovery rate. Synthetic polymer scale inhibitor chemicals may be able to control precipitation at the desired permeate recovery rate, or the permeate recovery rate may need to be limited.

- The addition of sulfuric acid to control calcium carbonate scale could cause barium sulfate scale problems. As little as 0.05 mg/L of barium may cause scaling problems, and most water quality laboratories do not provide barium test results with detection limits down to the level needed.

- As little as 10-15 mg/L of strontium ions may be sufficient to cause strontium sulfate precipitation in the concentrate stream. Calculations to determine the scale formation potential of strontium sulfate are similar to those for calcium sulfate, and the comparison of the strontium sulfate ion product with 80% of the solubility product is the same as for calcium sulfate comparison. Synthetic scale inhibitors may be able to increase the allowable concentration of strontium sulfate in the concentrate stream.

a. Iron removal

Laboratory analyses for iron in the feedwater should be able to detect iron down to a concentration as low as 0.05 mg/L. Complete water quality analyses and a study of the RO system feedwater delivery system must be made to properly assess the potential for iron oxide fouling of the RO membranes. Precipitation of iron hydroxides dissolved in the feedwater to an RO system may cause deposits and fouling of the membranes. To prevent iron from fouling the membranes, there are several general approaches to take:

- Oxidize the ferrous iron to ferric iron with chlorine, aeration, potassium permanganate, or another suitable oxidant, before the feedwater reaches the membrane system and then remove the iron precipitate by clarification and filtration. The effect of any residual oxidant on the membrane material must be evaluated, and scavenging of the oxidant may be required.

- Use cation exchange resins to pretreat the feedwater, however these resins may become fouled if the concentration of iron is too high.

- Keep the iron in the ferrous state by preventing dissolved oxygen (or other oxidants) from entering the feedwater and to keep the feedwater pH less than 6.0.
- Iron oxides can typically be removed by using a citric acid cleaning solution adjusted to a low pH (approximately 4.0) with ammonium hydroxide.

b. Manganese removal

Methods for the control of membrane fouling by oxides of manganese are similar to those for iron. Manganese may form deposits of manganese hydroxide, a brown or black gelatinous precipitate, which can cause severe fouling of the membranes. Manganese combined with sulfides may form a highly insoluble compound. The concentration of manganese in the feedwater should not exceed 0.05 mg/L. Processes employed for iron removal are also typically effective for reduction of manganese.

c. Aluminum removal

Fouling of RO membranes by aluminum is caused by the precipitation of aluminum hydroxide. Aluminum which enters the RO system feedwater can be precipitated onto the membranes by the pH adjustment step or by exceeding aluminum's solubility limit during the reverse osmosis process. Feedwaters with excessive aluminum hydroxides present should be pilot tested with the proposed membranes to determine the effectiveness of various pre-treatment methods and operating conditions.

d. Microbe removal

Growth of microbes in the RO membrane elements may affect system performance and cause damage to cellulose acetate based membrane material. These problems are usually classified as one of the following:

1. Biological fouling of the membranes.
2. Biological degradation of the membrane material.
3. Microbial contamination of the permeate.

e. Chlorine removal

Trace amounts of chlorine can cause severe and irreparable damage to aromatic polyamide membranes. Cellulose acetate based membranes are much more chlorine tolerant and, within limits, can withstand continuous chlorine residual in the feedwater. There are some new membrane materials made of composites of several synthetic materials which are both chlorine tolerant and bacteria resistant.

f. Hydrogen sulfide removal

If hydrogen sulfide is present in the raw water source, great care must be taken to prevent air or any other oxidants from coming in contact with the feedwater. Elemental sulfur membrane fouling or scaling is usually irreversible. If it occurs, the membrane elements must be replaced. In addition to the membrane scaling and fouling potential associated with hydrogen sulfide, there also seems to be a high susceptibility to corrosion of metal alloys containing copper. Therefore, electrical switches, contacts, and wiring should be protected from exposure. Also, hydrogen sulfide is the source of many nuisance odor complaints from neighbors of RO plants, and most air quality enforcement agencies will not permit its discharge into the atmosphere, necessitating scrubbers for the product water degassifier.

4.6.7.4 Applicability for surface water treatment

In brackish and saline waters, RO has been successfully applied to saline ground water, brackish water, and seawater. Reverse osmosis is well suited for treating water with high levels of inorganic substances, organic substances, or total dissolved solids. It has effectively treated seawater with total dissolved solids at 8,600 mg/L. Salt water or brackish waters subject to ocean circulation are not affected by the Surface Water Treatment Rule.

Reverse osmosis is also a proven technology for removal of the following contaminants:

- Radium.
- THM precursors including humic and fulvic acids.
- Pesticides.
- Microbiological contaminants (viruses, bacteria, and protozoa).
- It also removes the following additional contaminants: arsenic (III), arsenic (V), barium, cadmium, chromium (III), chromium (VI), fluoride, lead, mercury, nitrite, selenium (IV), selenium (VI), and silver. Properly operated reverse osmosis units will attain 96% removal rates, while similarly operated lime-soda softening operations will remove 75-96%.

4.6.7.5 Design criteria

The following criteria apply to design of any RO facility:

- A pilot study will be required to determine the best membrane to use, the type of pretreatment and post-treatment needed, the process efficiency, and chemical additions required.
- Parallel trains are recommended to permit continuous water production during periods of repair, cleaning, and membrane maintenance.
- Operating pressures should range from 517 to more than 1,724 kPa (75 to greater than 250 psi). Systems below 1,724 kPa (250 psi) are classified as low-pressure units, while those above 1,724 kPa (250 psi) are classified as high-pressure units.
- Membrane types shall be spiral-wound units or hollow-fiber membranes.
- Membrane materials shall be either cellulose acetate, aromatic polyamide, or thin film composites.
- Product conversion rates shall be designed for brackish ground water production of between 70% and 90% product water and seawater approximately 30%.
- The concentrate shall be disposed of in accordance with all state water quality regulations.
- Since the permeate is almost totally demineralized, the design should allow a portion of the raw water to bypass and blend with the permeate.
- Post-treatment may be provided and typically includes carbon dioxide and hydrogen sulfide removal.
- The permeate is typically corrosive due to the water being demineralized, and corrosion control treatment of the permeate should be considered. Also, disinfection of the permeate should be practiced.

4.6.8 Membrane Filters

Membrane filtration is a process used to remove undissolved, suspended, and emulsified solids. Filtering materials are either spiral wound, hollow fine fiber, tubular, or plate and frame membranes.

4.6.8.1 Purpose

Membrane filtering equipment is generally used for removal of suspended particulates, including *Giardia* cysts in water systems under controlled conditions where source water is continually low in turbidity, color, and iron. It is not a form of chemical treatment but a physical removal process.

4.6.8.2 Types of membrane filters

There are four types of membrane filters, described as follows:

- Spiral wound membranes. A spiral wound membrane consists of two flat sheets of membrane separated by porous support or backing sheets sealed on three sides to form an envelope. The fourth side is attached with an adhesive to a hollow plastic tube that collects the product water. Membranes are glued to the product water collection tube and usually connected in series in a vessel.

- Hollow fine fiber. A hollow fine fiber module is a compact bundle of thousands of longitudinally aligned fibers that surround the feedwater distribution core. Each hairlike fiber is laid in the form of a U in the bundle, and both ends are encapsulated in an epoxy resin tube sheet. The bundle is encased in a cloth overwrap and screen and installed in a pressure vessel constructed of fiberglass or epoxy coated steel.

- Tubular membrane. A tubular membrane consists of a membrane installed inside a porous tube. Pressurized feedwater enters the inside of the membrane or membrane film and exits through the porous tube.

- Plate and frame membranes. Plate and frame membranes are membranes sandwiched between circular or square plates. The modules resemble a plate and frame filter press.

4.6.8.3 Factors affecting membrane filters

The clarity of the source water is the most important consideration in selecting a membrane filter process. Influent turbidities should be equal to or less than 5 NTUs; and fouling indexes (trapping within the pores) should be less than 10. The process is not greatly affected by water temperature or pH, but it is affected by high levels of iron, color, etc.

4.6.8.4 Applicability for surface waters

Membrane filters do not exclude inorganic salts and electrolytes but are used in conjunction with other unit processes. For example, membrane filters are used for removal of microorganisms in pretreatment processes for reverse osmosis, to remove colloidal silica from boiler feed water, and for treatment of drinking water supplies. Removal of particulate matter including microorganisms is dependent on the membrane porosity as several micron sizes are available depending on the application (for removal of *Giardia* cysts, a maximum pore size of 5 microns is recommended). ADEC should be consulted for the appropriate size filter for given applications.

4.6.8.5 Design criteria

Tubular and plate and frame membranes have a small membrane area per unit volume and are usually not used in municipal potable water treatment. Although spiral wound elements may operate under turbulent flow conditions, hollow fine fiber units require laminar flow. Coagulation prior to filtration is not required, however, the quality of the influent is important and in general should have a fouling index of less than 10.

Most treatment systems have multiple barriers to pathogenic breakthrough, but membrane filters do not. Some membrane systems include features that trigger an operational shutdown or activate an alarm based on loss of flow or filter breakthrough that causes higher turbidity.

Membrane filtering equipment is generally used for removal of turbidity particles, including *Giardia*, in water systems under controlled conditions where source water is low in turbidity, color, and iron. These systems are desirable in areas of the state where the source water quality is continually low in turbidity (< 5 NTUs) and other contaminants such as iron (<1 mg/L), and color (< 5 units).

Cleaning for membrane rejuvenation is required with hollow fine fibers, however, spiral wound membranes are usually discarded after use. Cleaning is required when:

- Salt passage increases by 15% or more.
- Module pressure drop increases by 20% or greater.
- Feed pressure requirements increase by 20%.
- Product flow drops or increases by 5%.
- Brine flows change by 5%.
- Fouling or scaling is evident.

The chemical cleaning frequency is based on the levels of suspended solids in the influent. The cleaning solution is a mixture of caustic-based detergent and hydrogen peroxide disinfectant. If there is iron in the influent, hydrochloric acid may be required. Another form of cleaning requires periodic injection of gas under high pressure into the center of the hollow fibers. The membrane is designed to expand as the gas passes through, allowing removal of materials which are clogging the membrane.

One manufacturer has developed a self-cleaning, hollow-fiber membrane filter system that uses a flow of water from the outside to the inside of the fibers to clean the membranes. This system uses a more porous fiber than the more traditional design. The higher porosity of these membranes allows for treatment of influent with higher suspended solids concentrations, excludes all *Giardia* cysts, removes coliform and other bacteria, but does not remove viruses.

To dispose of concentrate, the sludge is usually dried and disposed of in a landfill.

Membrane filtration permeate is subject to the state Drinking Water Regulations and consideration of disinfection requirements, corrosion control, and other elements of the drinking water regulations should be considered with this method of filtration.

4.6.9 Cartridge Filters

Cartridge filters are considered an "alternative technology" for surface water treatment by ADEC and EPA. High-grade cartridge filters can remove particulates smaller than *Giardia* cysts (i.e., 5 μm or less in size) from low turbidity water.

4.6.9.1 Process description

Cartridge filters can be used for removal of *Giardia* cysts from certain surface waters. Typically, high-grade polypropylene or polyester filter-media filters and some fine-pore ceramic filters are the only acceptable cartridge units.

The filter media removes undissolved, suspended particles in the influent stream. Cartridge filters are available in a range of particle-size removal abilities and vary in effectiveness.

System components (such as cartridges, membranes, housings and gaskets) should conform to National Sanitation Foundation (NSF) standards 53 and 61. Equivalent testing by a qualified third party may be acceptable. Such tests must demonstrate that system components are not leaching chemicals which may have an adverse impact on human health or passing particles larger than 5 μm to the effluent water. Filters and housings with known characteristics or that have already undergone testing acceptable to ADEC do not need to undergo additional testing.

Cartridge filter effectiveness can be influenced by the following:

- Flow rate. The flow rate should be uniform and not exceed rated flow for cartridge filter units.
- Pressure. Rated cartridge operating pressure cannot be exceeded without risk of "blowout," therefore sources of excess pressure (i.e., surges, water hammer, etc.) should be mitigated. Excessive pressure drop (i.e., greater than 20% differential between influent and effluent) indicates need for changing cartridges. Manufacturers' recommendations must be followed.
- Turbidity and solids in influent. The greater the concentration of solids and particulates in a size range equal to or greater than the removal range, the faster the filters will "blind" with resulting reduction of flow, with a potential increase in pressure differential. Operating results indicate that high-grade cartridges (for *Giardia* cyst removal) should not be used directly in waters exceeding 5 NTUs turbidity. It is recommended that high-grade cartridge filters be preceded with a mechanism to reduce turbidity, such as pressure filtration, or a "roughing" bag or larger micron-rated cartridge filter unit.

When source waters have high levels of human enteric viral contamination, cartridge filters should not be the only form of filtration treatment as they are not effective for virus removal. Disinfection is necessary.

4.6.9.2 Surface water treatment applications

Use of cartridge filters for surface water treatment systems requires attention to the following:

- Salinity and TDS. Cartridge filters of 0.5 μm, nominal rating removal size and larger, do not have any appreciable effect on salinity and TDS levels.
- Turbidity. Unless the turbidity is caused by suspended particles larger than the removal rating, cartridge filters will have little, if any, impact on lowering turbidity. Turbidity caused by glacial flour is typically categorized as suspended particles smaller than 1 μm (several tests have put over 65% of the particles below the 0.5 μm range), and most high-grade filters will have no impact on removals. However, cleanable ceramic body filters packed with granular carbon, and rated at 0.35 μm have shown good removal rates of glacier flour-caused turbidity. Frequent cleaning is required and is directly related to raw water turbidity levels and flow rates.
- *Giardia* cyst removal. Pilot testing, including particle size counting and analysis, has shown that some high-quality poly-cartridge filters in the 1-2 μm nominal removal range can effectively achieve 2- to 3-log removal of particles 3 μm and larger. *Giardia* cysts are generally considered to be larger than 5 μm in size. Viruses are typically not removed by cartridge filters and should be inactivated with a good disinfection program meeting all CT requirements. Cartridge filters proposed for use must have documentation to support this rating. In addition, cartridge filters must be approved by ADEC in accordance with applicable sections of the state *Drinking Water Procedures Manual.*

4.6.9.3 Design and operation considerations

Although cartridge filters have been used in Alaska for several years, they are still considered "alternative" technology under the SWTR. Pilot testing using the actual water source may be required as part of the design process. This testing should be done in periods of higher turbidity. This alternate filtration technology must be evaluated not only from the standpoint of the finished water quality but also with consideration for the level of operational difficulty, operational constraints, reliability of system components, and the adaptability to various raw water physical and chemical qualities. The extent of pilot studies will vary with system operational capability, source water quality variability, and availability of data from similar applications on analogous source waters. See the *Alaska Drinking Water Procedures Manual*, section entitled "Alternative Filtration Technologies."

The SWTR sets performance standards for alternative filtration methods. Membrane filtration in the microscopic range of 10 μm to 0.5 μm provides a specific treatment mechanism, mechanical sieving. Because of this very specific treatment mechanism, other water quality parameters are not affected. These parameters must continue to meet ADEC drinking water standards. The designer should be aware that color, potential THMs generation, taste, odor, turbidity, corrosivity, and other water quality parameters may still require some other treatment to comply with ADEC drinking water regulations or to meet consumer demands for pleasant tasting drinking water.

Raw water quality must usually meet very high standards or have pretreatment to permit the use of membrane filters, without supplemental treatment.

Since *Giardia* removal is the key consideration for cartridge filtration, pilot testing for systems and equipment (not already certified as described in 4.6.9.1) to demonstrate removal capability can include:

- Microscopic particulate analyses (MPA), including particle counting, sizing, and identification, which determine occurrence and removals of microorganisms and other particles across a filter or system under ambient raw water source conditions, or when artificially challenged.

- *Giardia* surrogate particle removal evaluations in accordance with procedures specified in NSF Standard 53. These evaluations can be conducted by the NSF or by a third party whose certification is acceptable to ADEC.

- "Particle Size Analysis Demonstration for *Giardia* Cyst Removal Credit" procedure presented in Appendix M of the EPA "SWTR Guidance Manual."

- Live *Giardia* challenge studies that have been designed and carried out by a third party recognized and accepted by ADEC.

Pilot testing may be difficult to perform in remote communities; use of existing data and pre-certified cartridges and equipment is encouraged in these circumstances.

Typically, cartridge filters are installed in stainless steel filter bodies which hold multiple filters. The flow rating of the filter unit is the sum of the individual cartridge filters housed in that unit. Most high-grade filters are rated for a maximum of 100 psi operating pressure.

Operation and maintenance considerations include:

- Redundancy. Cartridge filter units do not offer redundancy as a stand-alone treatment process. There is a potential for "blowout" of one or several filters, if there are pressure spikes, or if blinding causes a pressure buildup on the influent side. Dual installations are recommended to allow cleaning and filter replacement of one unit, while keeping the second unit in operation; both units should be rated for the design flow.

- Maintenance. Cartridge filters should be changed on a regular basis; frequency is influenced by:

    - Blinding caused by high turbidity and solids buildup.
    - Pressure drop exceeding the values recommended by the manufacturer.
    - Regular replacement, even during periods of low turbidity, to prevent growth and buildup of microorganisms on the media. Intermittent operations can cause accelerated microorganism growth on cartridges. Carbon-packed cartridge filters can experience accelerated microorganism growth (as compared to unpacked filters).

- Disposal of Spent Cartridges. Spent cartridge filters should be deposited in secure, plastic bags and disposed of in approved landfills as they may contain harmful microorganisms and viruses. Refer to Section 4.16.1.5.

4.6.10 Bag Filters

Bag filters are similar to cartridge filters (refer to Section 4.6.9) in operational and engineering considerations. Specific differences include:

- Stainless steel filter housings are also typically used, but only one "bag" is replaced versus multiple cartridge filter units.
- Some filters have multiple layers and can be less susceptible to high-pressure blowout.
- Since some bag filters have more surface area (and greater particle holding capacity), they can have longer run times before replacement is required due to blinding or pressure drop.
- Some bag filters can be backwashed, which may increase their economic viability when compared to disposable filter elements.

4.7 Aeration

4.7.1 Process Description

The purpose of aeration in water treatment is to bring air and water into close contact, allowing the air to dissolve into the water. This process removes unwanted gases such as sulfur, oxidizes impurities such as iron and manganese and reduces certain types of tastes and odors.

There are two mechanisms used, the water-into-air system and the air-into-water system. Water and air are brought into close contact by exposing drops or thin sheets of water to the air (water into air), or by introducing small bubbles of air and letting them rise through the water (air into water). Undesirable dissolved gases enter water either from the air above the water or as a by-product of some chemical or biological reaction in the water. The scrubbing process caused by the turbulence of aeration physically removes these gases from solution and allows them to escape into the surrounding air.

Oxidation is the chemical combination of oxygen from the air with certain undesirable metals in the water, such as iron and manganese. Once oxidized, these substances come out of solution and become very finely divided suspended material in the water. The suspended material can then be removed by sedimentation and filtration.

The efficiency of the aeration process in water treatment depends upon the amount of surface contact between the air and water. The main factors that affect this process are surface area involved, water temperature and gas injection rate.

4.7.2 Applicability for Surface Waters

4.7.2.1 Carbon dioxide removal

Carbon dioxide is very soluble in water. Surface waters are usually low in carbon dioxide, but ground waters are normally high. Carbon dioxide increases the acidity of water (making it corrosive), makes iron removal more difficult, and reacts with the lime added to soften water, causing an increase in the cost of softening because more caustic chemicals must be used.

Most types of aerators remove carbon dioxide by the physical scrubbing or sweeping action caused by turbulence. For normal water temperatures and atmospheric composition, aeration can reduce the carbon dioxide content of the water to as little as 4.5 mg/L. Equilibrium between the carbon dioxide content of the air and the water prevents further removal.

Carbon dioxide can also be removed by adding extra lime during chemical softening. Unless the carbon dioxide concentration is below 10 mg/L it is generally not economical to use lime for removal.

4.7.2.2 Iron and manganese removal

Iron and manganese problems can usually be controlled by keeping iron concentrations below 0.3 mg/L and manganese concentrations below 0.05 mg/L. Aeration followed by sedimentation and filtration is commonly used to remove iron and manganese. It takes about 0.14 mg/L of dissolved oxygen (DO) to remove 1 mg of iron and 0.27 mg/L of DO to remove 1 mg of manganese. Adequate removal requires additional detention time after aeration for oxidation to completely occur.

For source water in Alaska containing over 2-3 mg/L of iron, aeration in itself is not effective in removing the iron due to cold source water temperatures. In most cases these waters require the addition of a strong oxidant such as potassium permanganate and complete treatment through flocculation, sedimentation, and filtration.

4.7.2.3 Degasification

Aeration can help remove two unwanted gases, hydrogen sulfide and methane, from drinking water sources. These two gasses are more problematic with ground water sources than surface water sources, however.

Hydrogen sulfide is a poisonous gas which occurs mainly in ground water supplies. It has a rotten-egg odor, alters the taste of beverages and food, and is corrosive to piping, tanks, water heaters, and any iron, steel, or copper alloy it contacts. Since hydrogen sulfide is very unstable in water, the turbulence created by aeration releases it to the atmosphere. There must be suitable air movement in the vicinity of the aerator or the gas will accumulate above the water.

Methane, also called swamp gas and natural gas, can be found in ground water located near natural gas deposits. It is a colorless, odorless, tasteless gas, which is highly flammable and explosive. When mixed with water, methane causes the water to taste like garlic. It is only slightly soluble in water and is easily removed by aeration.

4.7.2.4 Taste and odor removal

Aeration is effective in removing only those tastes and odors caused by very volatile materials, or tastes and odors caused by materials that can be readily oxidized. Many taste and odor problems are thought to be caused by the oils or other by-products that algae produce and aeration is only partly effective in removing them. Odors caused by some organic industrial wastes can be effectively removed by aeration.

4.7.2.5 Relationship to other unit processes

Aeration has little effect on other processes associated with meeting the requirements of the SWTR because aeration has such as limited use in treatment of the water. Unwanted gas and iron contamination is usually found in ground water supplies instead of surface water or surface water influenced systems.

4.7.3 Types of Facilities

4.7.3.1 Water-into-air

This process exposes drops or thin sheets of water to the air. Some examples of this type of aeration are:

- Cascade aerator
- Cone aerator
- Slat and coke tray aerator
- Draft aerator
- Spray aerator

4.7.3.2 Air-into-water

This process introduces small bubbles of air that rise through the water. Some examples of air-into-water aeration are:

- Diffuser aerator
- Draft-tube aerator

4.7.4 Design Criteria

The following sections provide generalized design criteria for various types of aerators. In each case, the impact of cold weather operations should be considered. For example, as source water temperature decreases, the amount of oxygen which will dissolve in water increases. Adjustments in the aeration process must be considered to maintain a correct level of DO in the water. If excessive DO is present, the corrosivity of the water increases and can cause sedimentation problems. In sedimentation basins, small bubbles of air can come out of solution and attach to particles of floc, causing the particles to float. Bubbles of excess air can also attach to filter media, particularly if the water warms as it passes through the treatment plant, and come out of solution. Air binding of the filter media results, causing the filter to behave as if it is clogged. The bubbles can also burst within the bed, causing media dislocation. Aeration design should consider aeration water temperature and temperature variations throughout the treatment process.

4.7.4.1 Spray aerators

A spray aerator has one or more spray nozzles connected to a pipe manifold. The water moves through the manifold under high pressure, leaving each nozzle in a fine spray. Spray aerators are sometimes combined with cascade and draft aerators. Spray aeration is successful in oxidizing iron or manganese and is very successful in increasing the DO level of water.

4.7.4.2 Cascade aerators

A cascade aerator is a stepped structure like a stairway or stacked rings designed to aerate in the splash areas as the water falls. The aeration action is similar to that of a natural stream.

4.7.4.3 Multiple tray aerators

Water is directed through a series of trays made of slats, perforations, or wire mesh. Air is introduced from under the trays, either with or without added pressure. Multiple tray aeration units have less surface area susceptible to clogging from iron and manganese precipitation than packed tower aeration systems, but are not as effective. Multiple tray aeration systems can experience clogging problems, in addition to biological growth and corrosion problems. They are usually available as packaged systems. The principal design considerations are:

- Tray type (usually wood or plastic).
- Tray height (range from 12-16 ft (3.6-4.8 m).
- Pressurized or unpressurized air flow (pressurized air flow is used to increase the air-to-water ratio).
- Air-to-water ratio (typically 30:1).

4.7.4.4 Diffused air aerators

This system bubbles air through a contact chamber, and the diffuser is usually near the bottom of the chamber. The air is introduced through the diffuser, usually under pressure, and produces fine bubbles that cause water-air mixing turbulence as they rise through the chamber. The main advantage is that a diffused aeration system can be created from existing structures, such as storage tanks. However, aeration is not as effective as packed column aeration. Design considerations are:

- Diffuser type and desired air bubble size.
- Chamber depth: 5-10 ft (1.5-3 m).
- Air-to-water ratio: 5:1-15:1.
- Detention time: 10-15 minutes.
- Chamber hydraulics: 0.75 m^3/sec air per m^3/sec water (0.1 cfm/gpm).

The hydraulics of the chamber and water temperature affect the uniformity with which the aeration process occurs and the completeness of removal. Baffling to achieve plug flow conditions followed by mixing is the general method used.

4.8 Chemical Oxidation

4.8.1 Process Description

Chemical oxidation involves the addition of oxidants into water causing an exchange of electrons between chemicals which changes the oxidation state of the chemicals involved. This process is referred to as reduction-oxidation (redox), because one chemical loses electrons or is oxidized while the other gains electrons or is reduced.

Chemical oxidation is used in water treatment for many purposes which include:

- Biological growth control in pipelines and basins.
- Color removal.
- Taste and odor control.
- Reduction of specific organic compounds.
- Flocculation aids.
- Iron and manganese oxidation and subsequent precipitation and removal.
- Disinfection.

The most commonly used oxidants are chlorine, chloramines, ozone, chlorine dioxide, and potassium permanganate. Other processes that generate a hydroxyl radical are under intensive study.

Oxidation is influenced by pH, temperature, oxidant used and dosage, reaction time, raw water quality, and the presence of substances that interfere with the desired reaction. Oxidation is influenced in the following ways:

- pH. The pH often affects the chemical form of the oxidizing agent that in turn affects the rate of oxidation.

- Temperature. In general, rates of chemical oxidation increase with increasing temperature.

- Reaction time. Perhaps the most overlooked factor, few treatment facilities, including packaged plants, provide enough detention time for complete oxidation to occur.

- Raw water quality. The greater the concentration of contaminant, the greater the required oxidant dosage and detention time. Under normal conditions the amount of the oxidant, in this case potassium permanganate, is approximately a 1:1 ratio. A dosage of 1 mg/L of oxidant is required for every 1 mg/L of iron and manganese.

4.8.2 Applicability

When oxidants are added to source water containing contaminants such as iron or manganese, a floc particle called an oxide is formed. These particles alone, or in conjunction with a polymer, can be easily settled prior to filtration. Conventional, packaged treatment plants have been effective in Alaska in removing these contaminants.

4.8.3 Design Criteria

4.8.3.1 Potassium permanganate addition

Potassium permanganate has been widely used in the water treatment industry for oxidation of iron and manganese. It is also used for taste and odor control and color removal, but relatively high doses are required to oxidize some tastes and odors or effectively treat highly colored waters.

Potassium permanganate is injected into the source water prior to flocculation, and a floc particle is formed. A polymer may be used to enhance settling of oxide floc particles prior to filtration. Detention times for each step of the process are roughly the same as detention times found in earlier subsections regarding flocculation and sedimentation for turbidity removal.

It takes roughly 0.5 mg/L of potassium permanganate to oxidize every 1 mg/L of iron (ferrous iron). For oxidation of manganese, 2 mg/L of potassium permanganate is required to oxidize every 1 mg/L of manganous manganese. The process is enhanced by maintaining a pH of 7.5-8.0. Overdosing of potassium permanganate is evident by the slight pink color of the product water.

Potassium permanganate has been effective in oxidation of iron at concentrations up to 100 mg/L, which is found in ground water located in the Kuskokwim Delta region of Alaska. Increased settling time is required, however, due to the abundant amount of iron oxide floc created when potassium permanganate is fed at high levels.

In source water with lower iron and manganese concentrations (< 1 mg/L), oxidation can be applied by running the water through a manganese greensand filter. This process involves recharging the filter bed once the greensand is spent.

4.8.3.2 Chlorination

Chlorination is often used for oxidation, but THMs and other halogenated by-products are known to be formed during chlorination. Chlorination is usually used in waters containing less than 1 mg/L of iron followed by filtration to remove the oxide particles.

4.8.3.3 Ozonation

The higher costs associated with ozone generation may be offset by iron and manganese precipitation, taste and odor control capabilities, and color removal and flocculent aid potentials. Tests have revealed that ozone is effective in removing aromatic compounds, alkenes, and certain pesticides. It is not effective in removing alkanes, and may form bromine by-products. Ozonation under different conditions has different results, as outlined in the following paragraphs.

- With high pH. Ozone used in source waters with pH levels above 8 rapidly decomposes into hydroxyl free radicals, which react very quickly. Many organic compounds that are slow to oxidize with ozone, oxidize rapidly with hydroxyl free radicals. The alkalinity of the water is a key parameter because bicarbonate and carbonate ions are excellent scavengers for free radicals. Also, carbonate ions are 20-30 times more effective in scavenging for hydroxyl free radicals than bicarbonate ions. Therefore, ozonation at high pH should be below pH 10.3 at which level all bicarbonate ions convert to carbonate ions.

- With hydrogen peroxide. The combination of ozone with hydrogen peroxide much more effectively reduces levels of trichloroethylene (TCE) and tetrachloroethylene (PCE) than ozone alone. A significant advantage of the peroxide process over granular activated carbon and packed tower aeration is the absence of vapor controls because the contaminants are destroyed, not just removed from the water.

- With ultraviolet radiation. This process breaks down the saturated bonds of the contaminant molecules. Typical contact time is 0.25 hours. A major advantage of this system is that it does not produce any THMs. These systems also do not require waste disposal because the contaminants are destroyed.

  There is some concern about the completeness of the oxidation process and the intermediate breakdown products. If oxidation is incomplete, some of the compounds produced in the intermediate reactions may still be available to form THMs. The influent contaminant profile also affects the performance of these systems. But, if oxidation is followed by a biological film filtration step, particularly granular activated carbon (GAC) on sand or GAC adsorber, these oxidation products are mineralized into carbon dioxide and water. As a result, THM and total organic halogens (TOX) formation potentials are lowered.

- In high humidity areas. In areas of high humidity, such as Southeast Alaska, the use of ozonation is complicated. Special precautions and attention would be necessary to design an appropriate air preparation system in designs which rely upon air with relatively high amounts of moisture in it. Excessive maintenance problems can result from the presence of excessive moisture in the feed gas, including tube fouling.

4.9 Ion Exchange

4.9.1 Process Description

Inorganics are removed by adsorption of contaminant ions onto a resin exchange medium. One ion is substituted for another on the charged surface of the medium, which is a resin, usually a synthetic plastic. This resin surface is designed as either cationic or anionic.

4.9.1.1 Purpose

Ion exchange units are used to remove any ionic substance from water, but are used predominantly to remove hardness, arsenic, and nitrate from ground water. It is also effective in removing low levels of iron and manganese (< 1.0 mg/L). Ion exchange is able to achieve very low contaminant concentrations in finished water and is especially well suited for removal of barium, radium, nitrate, and selenium.

Strong based anion exchange resins are used for nitrate removal and weak based anion exchange resins are used for chloride removal. The removal of fluoride, arsenic, selenium, silica, and humic matters are performed using packed beds of activated alumina.

Ion exchange systems, using both weak and strong acid resins in the hydrogen form, are capable of removing radium to below the MCL of 5 pCi/L. However, both systems require the pH of water to be adjusted by either air stripping or the combination of air stripping and caustic addition to the source water.

The largest application of ion exchange is for softening. Smaller water utilities sometimes prefer ion exchange softening over lime softening because of lower capital costs and ease of automation.

4.9.1.2 Mechanism

The exchange medium is saturated with the exchangeable ion before operation. During ion exchange, the contaminant ions replace the regenerant ions because they are preferred by the exchange medium. After the exchange medium reaches equilibrium with the contaminant ions, the medium is regenerated with a suitable solution, which then resaturates the medium with the appropriate ions.

4.9.1.3 Limitations

The porous exchange medium will clog when significant levels of suspended solids are in the influent. Ion exchange units are also sensitive to the presence of competing ions.

The primary disadvantage is effluent peaking which occurs when contaminant ions compete with other ions for exchange medium sites, resulting in unacceptable levels (peaks) of contamination in the effluent. It is most common with poorly adsorbed contaminants, such as nitrate, and necessitates more frequent regeneration of the exchange medium.

Ion exchangers that use sodium chloride to saturate the exchange medium may experience problems with sodium residual in the finished water. Sodium is used because it is economical, but a high sodium residual is unacceptable for people with sodium-restricted diets.

Special attention must be given to the backwash wastewater to ensure that it does not contaminate nearby waters. Regeneration of ion exchange beds can create wastes which are concentrated in specific contaminants, can have either very high or very low solution pH, and require special disposal practices. These wastes require disposal in accordance with applicable federal, state, and local regulations.

4.9.2 Applicability

The application of ion exchange units is most practical in the state when small quantities of water are required (less than 50,000 gallons per day). Since these systems are almost always involved with removal of ground water contaminants, the requirements of the SWTR have little effect on their operation.

4.9.3 Types of Ion Exchangers

4.9.3.1 Strong acid exchangers

Strong acid (cationic) exchangers should conform with the following criteria:

- Operate at any pH.
- Split strong or weak salts.
- Require excess strong acid regenerant.
- Permit low leakage.
- Have rapid exchange rates.
- Be stable and may last 20 years or more with little loss of capacity.
- Exhibit swelling less than 7% going from Na+ to H+ form.
- Be useful for softening and demineralization.

4.9.3.2 Weak acid exchangers

Weak acid exchangers should conform with the following criteria:

- Do not remove cations satisfactorily below pH 7, and therefore do not remove cations of strong electrolyte salts unless the solution is buffered.
- Can be regenerated with strong or weak acids with efficiency that is usually more than 90%.
- Have a high affinity for Ca+2.
- Allow high leakage of sodium but low leakage of calcium.
- Have capacities about twice that of strong acid resin.
- Exhibit swelling of 90% from Na+ to H+ form.
- Be more resistant to oxidants than strong acid types.
- In the presence of more than 20% alkalinity, they are useful in demineralization.

4.9.3.3 Strong base exchangers

- Operate at any pH.
- Can split strong or weak salts.
- Use excess high-grade NaOH for regeneration.
- Efficiency varying from 18-33%.
- Are irreversibly fouled by humic acids from decay of vegetation, be furnished with an organic trap such as a weak base exchanger or activated carbon to remove humic acids first.
- Although less stable than cation resins, have a life span of three years minimum.

4.9.3.4 Weak base exchangers

Weak base exchangers should conform to the following criteria:

- Do not remove anions satisfactorily above pH 6.
- Are often based on phenol-formaldehyde or epoxy matrices instead of benzene.
- Regeneration efficiency possibly exceeds 90%.
- Are resistant to organic fouling.
- Swell about 12% going from OH- to salt form.
- Do not remove CO2 or silica.
- Have capacities about twice as great as strong base exchangers.
- Are useful for following strong acid exchangers to save cost of regenerant chemicals.
- Are used as organic traps to protect strong base exchangers and remove color.

4.9.3.5 Type I and Type II exchangers

Type I and II exchangers provide silica removal from source waters. Each type of exchanger displays advantages and disadvantages, as described below. Design of systems using such exchangers should include consideration of the various advantages/disadvantages in selection of appropriate equipment.

Type I exchangers are for maximum silica removal. They are more difficult to regenerate and swell more from Cl- to OH- that Type II. Their principal use is to make the highest quality water. When they are loaded with silica, they must be regenerated with warm NaOH.

Type II exchangers remove silica less completely than Type I. They remove other weak anions, regenerate more easily, are less subject to fouling, are freer from the odor of amine, and are cheaper to operate than Type I. They are particularly useful for food products.

4.9.3.6 Difunctional exchangers

Intermediate or difunctional base exchangers contain both weak base and strong base groups, remove anions only below pH 9 after their strong base capacity is exceeded, have high capacities, and are about twice as efficient in regeneration as strong base exchangers. They can sorb silica, CO2, and phenol up to their strong base capacities, are dense, which enables them to use a higher backwash rate, and are useful as substitutes for weak base resin in a multiple-bed series.

4.9.4 Generalized Design Criteria

4.9.4.1 Sizing criteria

The resin exchange capacity is expressed in terms of weight per unit volume of the resin. The calculation of the breakthrough time for an ion exchange unit requires knowledge of the resin exchange capacity, the influent contaminant concentration, and the desired effluent quality. The process is relatively insensitive to flow rate and essentially fully operational upon process initiation. Each resin is effective in removing specific contaminants.

A resin bed depth of 0.76 m (30 in) is usually considered the minimum and beds as deep as 3.67 m (12 ft) are not uncommon. The empty-bed contact time (EBCT) chosen determines the volume of resin required and is usually in the range of 1.5-7.5 minutes. The reciprocal of EBCT is the service flow rate (SFR) or exhaustion rate, and its accepted range is 1-5 gpm/ft^3.

4.9.4.2 Number of columns

Multiple-ion exchange columns are connected in series to improve product purity. Single-ion exchange columns are run parallel to each other to increase throughput.

4.9.4.3 Pressure vessels

Pressure vessels may be vertical or horizontal. Pressure vessel construction shall comply with applicable requirements of the ASME pressure vessel code. Materials of construction shall be steel., unless approved otherwise by the reviewing authority. In both vertical and horizontal units, the shell should consist of a cylinder with dished heads and a manhole or handhole for access. The interior should have a chemically resistant lining. Some of the smaller units are galvanized, but recently most of the units have been plastic lined. Piping must be corrosion resistant and most commonly is either plastic or red brass.

Vertical units vary in diameter from 0.2-3.0 m (8 in to 10 ft). The size is limited by shipping restrictions. Horizontal units are up to 3 m (10 ft) in diameter and 7.5-9 m (25-30 ft) long. Horizontal units have a more limited use because of the hydraulic distribution, restricted head room, and loss in exchange capacity because the resin is unable to be fully used in the nonvertical walls at the sides and ends.

4.9.4.4 Underdrain manifold

The underdrain system in the bottom of the unit shall collect treated water, distribute clean water for backwashing, and collect the brine and rinse water during regeneration. The system shall evenly collect or distribute the flows during any one of these operations.

4.9.4.5 Regeneration facilities criteria

Regeneration equipment shall consist as a minimum to pumping equipment and regenerant tanks.

The facilities include domestic and small industrial systems. The brine tank serves both as both salt storage and concentrated-brine storage. During the brining cycle, the concentrated brine is withdrawn from the bottom of the tanks while fresh water is added at the top. An excess of undissolved salt in the tank provides an ample supply of concentrated brine.

In large industrial systems, the salt is dissolved in a wet-storage basin or tank, and the brine is put in a holding tank.

The regenerant backwash system should be carefully controlled to maintain the correct rate of flow to properly clean and loosen the bed and prevent loss of the resin by carryover. The rates may be controlled by means of (1) a rate of flow controller in the backwash inlet line or (2) a control valve in the backwash discharge line.

Considerations for design of ion exchangers include providing for spent brine. Spent brine is composed primarily of the chlorides of calcium, magnesium, and sodium. Small amounts of iron, manganese, and aluminum may be present. The total wastewater may vary from 1.5-7% of the amount of water softened. The wastewater will contain chlorides in direct ratio to the amount of salt used. The amount of salt to be disposed of in the wastewater may be approximated by the formula:

$$C = 35SH$$

where:
C = Chloride ion, expressed in pounds per million gallons
S = Salt, in pounds per thousand grains of hardness removed
H = Reduction of hardness, in ppm ($CaCO_3$)

The total dissolved solids in a composite sample of a typical spent brine may vary from 35,000-45,000 ppm, while the maximum instantaneous concentration of ions in the discharge may vary from 95,000-120,000 ppm.
Brine maybe disposed of by the following methods:

- Evaporation or holding ponds, which must be lined to prevent the flow of brine into fresh water aquifers. Design factors to consider include non-uniform evaporation rates, land area requirements, expenses to make the basin watertight, and wintertime operation of the pond.

- Discharging waste brine into a freshwater stream is economical, but the amount of natural water flowing must be large enough to dilute the salt to a level which will not endanger the aquatic life or deteriorate the water quality for use downstream. A wastewater discharge permit must be obtained from ADEC. A wastewater discharge permit is also required for discharge into a sewer system.

- With brine-disposal wells, the quantities of spent brine would have to be limited and the brine treated prior to injection to prevent clogging of the pores of the formation underground.

- If the plant is located near brackish water or seawater, this may be the best area for disposal. A wastewater permit must be obtained from ADEC.

- Designers should consult applicable sections of ADEC wastewater regulations (18 AAC 72) for additional information concerning disposal requirements.

4.10 Desalinization

Reverse osmosis uses membrane technology and is the typical process for desalinating brackish water and seawater. Since desalinization and membrane technology are used only in highly specific water treatment situations, special pilot studies will be required in most cases, both for design and compliance purposes. Because of the energy (in terms of preheating and pumping) and extensive pretreatment requirements, desalinization should almost always be the last resort (absence of any alternate water source). The process also creates significant amounts of brine or reject water which may require special disposal.

4.10.1 Raw Water Quality

In some cases, more than one membrane process may be suitable for an application to reduce the TDS of brackish water. In these situations, other factors must be considered in making a final decision about which process to use.

The nature and quality of the raw water source are major factors in selecting the optimal membrane process when more than one may be suitable. For instance, in a brackish water desalting application in which the raw water source is ground water containing a high concentration of silica, electrodialysis may be preferable to RO because the electrodialysis design is not limited by silica scaling considerations (RO rejects silica but electrodialysis does not). As a second example, the nature and quality of the raw water source determines the extent of feedwater pretreatment required to optimize the membrane system design and ensure successful, long-term membrane performance, as well as to control several aspects of the design. Thus, any design process should include a thorough and accurate analysis of the raw water. With microfiltration and ultrafiltration, it may be unnecessary to perform all of the inorganic ion analyses listed. Inorganic ions have little impact on the design of microfiltration and ultrafiltration processes. Obviously, for specialized removal applications such as a specific organic contaminant, or for constituents that may affect concentrate discharge permitting, the concentration in the feedwater should be identified.

The feedwater analyses serve three important functions. First, they identify and quantify constituents that, if not removed, will have a deleterious effect on membrane system performance and, in some cases, could cause system failure and the need to replace some or all of the membrane modules. Second, the water quality data will aid in the selection of the optimal membrane process and will help determine design parameters. Finally, they identify constituents that, if removed by the membrane system, will be in the concentrate stream.

4.10.2 Pretreatment Requirements

Table 4-11 illustrates the type of pretreatment steps that may be required for ground water and surface water sources. In situations in which the raw water source is a combination of the two types, the degree of pretreatment is dependent on which type dominates and on the impact of surface water aeration on dissolved gases and oxidizable substances present in the ground water. Table 4-12 shows the impact of individual raw water constituents on membrane system performance and the type of processes that must be employed to remove or minimize their effects.

TABLE 4-11 Typical Pretreatment Requirements for Raw Water Sources Receiving Reverse Osmosis Treatment

Pretreatment Method	Raw Water Source	
	Ground Water	Surface Water
Oxidation	Typically not required	Control of oxides
Disinfection (Pretreatment)	Typically not required	Control of microorganisms
Clarification	Typically not required except for cartridge filtration	Depending upon amount of particulates present, either direct filtration, in-line coagulation, or CFS[a]/filtration followed by cartridge filtration
Dechlorination	Typically not required	Removal necessary for certain composite membranes
Chemical addition	pH adjustment[b] and/or scale inhibitor addition for control of sparingly soluble solutes	pH adjustment[b] and/or scale inhibitor addition for control of sparingly soluble salts
Deoxygenation	Not required typically	Necessary to prevent degradation of certain composite membranes

[a] Coagulation/flocculation/sedimentation.

[b] pH adjustment may not be necessary for non-cellulosic membranes when calcium carbonate scaling potential is controlled by a scale inhibitor or operation is at sufficiently low recovery.

TABLE 4-12 Raw Water Characteristics that Impact Membrane System Pretreatment Requirements

Characteristics	Effect	Treatment Method
pH	Increased hydrolysis (CA) Increased scaling	Adjustment with acid or base
Temperature	Lower T values cause decreased productivity; higher T values cause increased compaction (CA), membrane degradation, and lesser permeate quality	Preheat or pre-cool raw water; use alternate membrane
Suspended Solids, Colloids	Membrane fouling; module plugging	CFS[a], filtration
Metal Oxides	Membrane fouling	Greensand filtration; pH adjustment
Sparingly Soluble Salts ($CaCO_3$; SO_4 salts of Ba, Sr, and Ca; SiO_2)	Membrane scaling	pH adjustment; antiscalant addition; reduced recovery softening
Chlorine	Membrane degradation (composites) Metal oxide fouling	Dechlorination Use CA membrane
Positive Redox Potential	Membrane degradation (some composites) Metal oxide fouling	Minimize oxygen exposure; add reducing agent
Microorganisms	Membrane fouling Membrane degradation (CA)	Disinfection; CFS/filtration
Dissolved Organics	Membrane fouling Membrane degradation	Oxidation; CFS/filtration

[a] Coagulation/flocculation/sedimentation
Note: "CA" indicates statement applies to cellulose acetate membranes.

4.10.3 Dissolved Gases

Raw water supplies typically contain dissolved gases, such as oxygen or hydrogen sulfide (H_2S). In addition, the injection of an acid to prevent carbonate scale formation will generate CO_2. Dissolved gases are not rejected by membranes and may require removal prior to or following the membrane process. The decision to remove dissolved gases during pretreatment is a critical one and depends on the following factors:

- High dissolved oxygen levels increase the potential for corrosion in highly brackish and seawater applications and increase the formation of metal oxide foulants.

- The presence of H_2S indicates an anaerobic water supply. If iron is present, it will be in the more soluble ferrous form, which is rejected to a high degree with RO and softening membranes. Oxidation results in the formation of elemental sulfur and may create iron fouling problems. Furthermore, anaerobic conditions minimize corrosion.
- CO_2 reduces pH. The removal of CO_2 increases pH and may increase mineral acid requirements to control calcium carbonate ($CaCO_3$) scaling.
- Many seawater composite membranes provide more stable, long-term performance when dissolved oxygen is absent from the feedwater. One manufacturer's membrane, for example, requires that all dissolved oxygen be removed from the feedwater with sodium bisulfite to guarantee performance.

H_2S should be removed during membrane post-treatment (rather than pretreatment) to eliminate the potential for formation of colloidal sulfur, which causes severe membrane fouling. Degasification during pretreatment can also introduce unwanted airborne contaminants into the feedwater. Degasification of the concentrate stream may also be required to remove sulfides and add dissolved oxygen for surface water discharge permitting requirements.

4.10.4 Control of Fouling

It is essential that particulate matter interfering with the operation of the membrane system or resulting in excessive cleaning and maintenance of the membrane modules be removed. Excessive levels of materials such as suspended solids, colloids, and microorganisms can cause rapid fouling of the membrane surface and module flow channels, resulting in severe losses in system productivity and degradation of permeate water quality.

4.11 Granular Activated Carbon Filtration

4.11.1 Treatment Applications for GAC

Granular activated carbon (GAC) has been identified as the best available technologies by the EPA for removal of volatile organic contaminants (VOCs) from raw water supplies. It is can also be useful in the treatment of taste and odor problems, removal of THM precursors, and removal of synthetic organic contaminants (SOCs). All of these water quality problems are similar in that they are all caused by organic contaminants.

Removal of these organic contaminants with GAC is through adsorption. Activated carbon has an affinity for adsorbing organic contaminants onto its surface. Different organic compounds are adsorbed preferentially.

The effective size and uniformity coefficient for granular activated carbon (see Table 4-13) allow it to be used as a filtering medium as well as an absorbent. When GAC is used as both a filter and organic contaminant adsorbent, the mode of operation is referred to as sand replacement. This is in contrast to the addition of GAC contactors downstream of the filtration process.

4.11.2 GAC Sand-Replacement and GAC Location in Process Train

The sand-replacement mode is common in the United States for taste and odor control, because GAC is as effective as sand as a filtration medium. Because it is a single medium, GAC provides surface rather than depth filtration; consequently, filter runs are likely to be shorter than dual-media filter runs, but similar to those for sand filters.

One problem with the sand-replacement mode in existing filter plants is that the size of the filter box is fixed, thus limiting flexibility in contact times and activated carbon handling. A graded gravel base (or an equivalent means of providing a uniformly distributed backwash) along with a surface scrubber (or air scourer) are necessary for proper filter cleansing. Some states regulatory agencies require that 15.2-30.4 cm (6-12 in) of sand be left in the bottom of the filter to prevent floc penetration. Other states, however, believe that this is an unnecessary safeguard, as long as at least 60.9 cm (24 in) of GAC with an effective size of between 0.5 and 0.9 mm and a uniformity coefficient of 1.9 or less is used. ADEC has no written policy and leaves these issues to the engineer to decide on a site-by-site basis.

Separate adsorbers following filtration offer the most flexibility for handling GAC and for varying the absorption conditions (e.g., contact time, upflow versus downflow, and series or parallel operation). Post-filter absorbers (or contactors, as they are sometimes called) are usually designed with an absorbent depth-to-diameter ratio of 1.5 or greater to effect good distribution of flow. The contactor should be designed to include backwashing, and some engineers recommend both water and air for this purpose.

TABLE 4.13 Properties of Select Commercial Granular Activated Carbon Produced in the United States*

Manufacturer	The Carborundum Company	Calgon Corporation	NICIT		Witco Chemical
Product Name	GAC 40	Filtrasorb*	Hydrodarco		Whitcarb 950
			HD-1030	83 Plus	
Base material	Western Bituminous Coal	Bituminous coal	Lignite	Bituminous Coal	Petroleum coke
U.S. standard sieve size	12 x 40	12 x 40	10 x 30	8 x 30	12 x 40
Effective size, mm	0.6	0.8-0.9	0.8-0.9	0.8-0.9	0.8-0.9
Uniformity coefficient	≤1.9	≤1.9	≤1.7	≤1.9	≤1.7
Apparent (or vibrating feed) density, g/cm^3	0.47	0.4-0.5	0.47-0.50	0.47	0.46-0.53
Washed density	401 kg/m^3 (25 lb/ft^3)	401 kg/m^3 (25 lb/ft^3)	417 kg/m^3 (23.5 lb/ft^3)	417 kg/m^3 (26 lb/ft^3)	465-529 kg/m^3 (29-33 lb/ft^3)
Iodine number, mg/g	1050	1050	600	900	1050
Surface area, m^2/g	1000-1100	1050	650	1000	1000
Available in:	27 kg (60-lb) bags, bulk	27 kg (60-lb) bags, bulk	18 kg (40-lb) bags, bulk	23 kg (50-lb) bags, bulk	23 kg (50-lb) bags, 91 kg (200-lb) drums, hopper trucks, tote bins

* "AWWA Standard for Granular Activated Carbon" (AWWA B604-74, or in Journal AWWA, vol. 66, no. 11, p. 672) provides minimum specifications on the properties of granular activated carbon used as an absorption medium for treating drinking water.

4.11.3 Pilot Studies

Treatment efficiency varies with the organic character of the water, and because this differs between locations, experimentation must be done with the actual water, preferably on site. At a minimum, pilot-scale columns are needed to study adsorption. These columns should have an internal diameter of 2.5 cm (1 in) or more. This will minimize anomalous effects from column walls by maintaining a large ratio between the amount of absorbent in a cross-sectional area to bacteria, floc particles, bubbles, and other things that cannot be scaled down. In studies in which water flow is less than 38 L/min (10 gpm), equipment should be constructed form stainless steel, Teflon®, or glass whenever possible to minimize contamination from structural materials.

Two aspects of adsorption, the critical depth and the rate of contaminant movement, must be considered in adsorber design, whether it be pilot or modular scale. The critical depth (sometimes called the mass transfer zone) is the depth of adsorbent necessary to contain the contaminant wavefront. Once contained, the wavefront then moves through the remaining adsorbent until the contaminant breaks through. Eventually exhaustion results. The critical depth and rate of movement vary among specific organics and are influenced by the approach velocity, the type of adsorbent, and the competition for the adsorption sites.

In practice the approach velocity and the amount of adsorbent are often combined and expressed as contact time. The empty-bed contact time (EBCT) is calculated by dividing the volume of media V by the hydraulic loading Q (i.e., EBCT = V/Q). Some GAC contactors are designed with an EBCT as high as 40 min; however, most designs range between 17 and 20 min. Sometimes the term "apparent contact time" is used. This is the EBCT multiplied by the porosity of the adsorbent. A pilot-scale adsorption study should incorporate several EBCTs so that an optimum can be selected.

4.11.4 Disposal Versus Regeneration

Use of virgin carbon is preferred for water treatment applications. Reuse of regenerated activated carbon may eventually present an economic advantage at larger water treatment plants but for the size of the water plants in Alaska, on-site regeneration is not economical at this time. Regeneration of spent carbon for reuse may be pursued only with the preliminary approval of ADEC. Regenerated carbon eligible for reuse in water treatment plants must have previously been used only for potable water treatment. Transportation and regeneration facilities must not have been used for carbon put to any other use.

Acceptable means of spent carbon disposal must be considered. The more common options are disposal in a landfill or shipment back to the supplier for regeneration and remarketing. The capture of contaminants on activated carbon potentially makes spent carbon a hazardous waste. Contaminants can include not only organics but radionuclides as well. In such cases, the methods of transport and disposal of the spent carbon must comply with the regulations for hazardous materials. The Toxicity Characteristic Leaching Procedure (TCLP) test, available from ADEC, should be performed on spent carbon to determine if it is a hazardous waste.

4.11.5 Biological Methodology

Removal of organics in source waters can be achieved by filtering the water through GAC which supports the growth of heterotrophic microbes. This type of treatment is practiced in Europe and has only recently been considered here in the United States. The organics and nutrients in the source water provide the substrate for these microorganisms. In theory, the organics and nutrients in the source water are taken up by the microbes to create additional biomass. Excess biomass is flushed out of the filter in periodic backwash cycles. Studies have shown that backwashing and even prechlorination do not eliminate the presence of these microbes on the media.

There are difficulties with the process. One is the control of the metabolic processes to assure the removal of the target organic contaminants. The composition of the source water's substrate is variable, especially for surface waters. Variation in the nutrient content will cause sloughing of biomass from the media and breakthrough of organics along with the biomass. In addition, this condition may result in growth of organisms in the distribution system downstream of the treatment plant. If nutrient concentrations in the process flow to the biological activated carbon (BAC) filter can be controlled, then the process can be effective. Disinfection of the BAC contactor and/or downstream processes and distribution system is needed to control coliform bacteria and HPC organisms.

4.12 Corrosion Control

4.12.1 General

Interior corrosion of metallic piping is an electrochemical process, which is influenced by water quality and is usually associated with aggressive surface water sources. The forms of corrosion are galvanic and electrolytic, with galvanic being the most prevalent. Galvanic corrosion can be caused by dissimilar metals in contact, or localized corrosion cells on a pipe wall. Electrolytic corrosion is also referred to as stray current corrosion. The need to mitigate interior corrosion can be directly related to one, or several, of the following:

- Noncompliance with the EPA Lead and Copper Rule (LCR).
- Corrosion of piping, pump bodies, and related appurtenances.
- Red water problems and complaints from customers.
- Interior corrosion problems in treated water storage tank(s).
- Pitting or pinholes in supply and house service piping.

The growth of iron- and manganese-tolerant bacteria, and sulfate reducing bacteria (SRB) in piping, commonly referred to as "tuberculation," "encrustation," or "slime growth" are not a direct form of corrosion; however, these bacteria can accelerate the corrosion process as well as the formation of corrosion by-products. Control measures for iron and manganese are discussed in subsection 3.3.10.d.

An interior corrosion control program can be justified based on the economic impact of accelerated interior corrosion of ferrous metal and copper distribution system piping, appurtenances, and individual services. If a public water system fails to meet the requirements of the LCR, then a corrosion control program with monitoring becomes mandatory.

4.12.2 Process Description

Corrosion control for smaller systems typically involves pH and alkalinity control, injection of a corrosion inhibitor as part of the treatment process, or both. Either treatment technique should be used prior to chlorination and storage. These are described below:

- pH and alkalinity control. Most aggressive surface waters have a neutral or acidic pH range (approximately 5.2-7.5), high DO, and low alkalinity and hardness (due to the absence of minerals). By controlling the chemical characteristics of treated water, corrosivity can also be controlled. Additive chemicals are used (when water quality is known and physical factors are controlled) to maintain a desired pH and alkalinity range for non-corrosive water.

- Corrosion inhibitors. This method of corrosion control employs the direct injection of an inhibitor chemical, usually phosphate- or silicate-based. The inhibitor deposits on pipe interiors and appurtenances forming a passivating layer which provides a level of corrosion control. Some inhibitors also sequester minerals and buffer the water. For some systems, inhibitors may be the preferred method of control as it may not require as much operator monitoring as direct pH and alkalinity control. However, some raw waters can be so acidic that ph control is required (to get the ph above 6.5) in conjunction with feeding a corrosion inhibitor.

4.12.3 Choosing a Corrosion Control Method

Water quality analysis and corrosion monitoring are required to determine the preferred method(s) of interior corrosion control.

Water testing can include:

- Ph.
- Color, an indicator of metal oxidation or loss.
- Alkalinity. Low alkalinity limits the formation of a carbonate barrier.
- Hardness. Low hardness provides little availability of calcium carbonate for depositing a barrier.
- TDS. The dissolved solids content is directly related to conductivity.
- Conductivity. Higher conductivity; promotes electrochemical corrosion processes.
- Temperature. Higher temperatures promote corrosion.
- Sulfates. Can be an indicator of H_2S and sulfate-reducing bacteria.
- DO. Higher DO (over 3-4 mg/L) can promote corrosion.
- Chlorides. In higher levels, chlorides can accelerate corrosion.
- Trace metals. Metals can be indicative of corrosion by-products or an accelerated oxidation process.

Using the results of water testing, estimates of the corrosivity of a water supply can be made. Two common methods of estimating corrosivity are use of the Baylis curve and calculating the Langelier Saturation Index (LSI).

The Baylis curve (Figure 4-8) provides a relationship between pH values and alkalinity (or solubility of calcium carbonate), which relates to general corrosiveness of water.

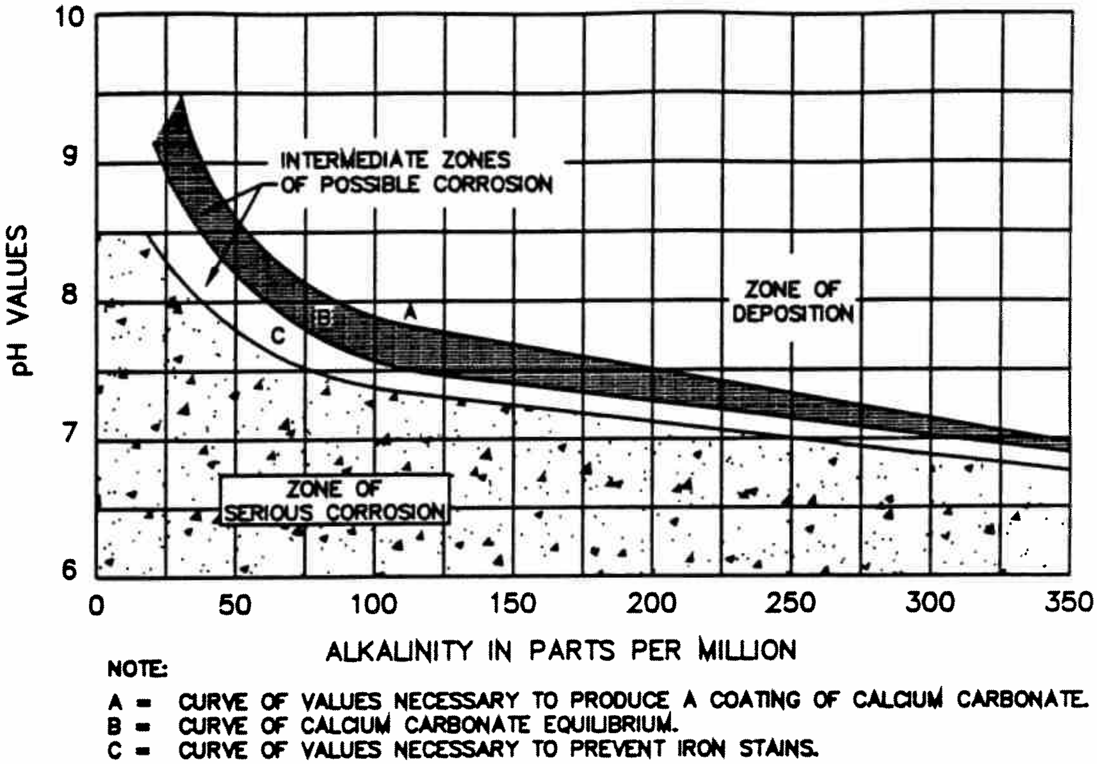


Figure 4-8. Baylis Curve

The LSI, or calcium carbonate saturation index, provides an indication of whether a water will deposit (scale) or corrode metallic piping and tanks. This method is based on the assumption that every water has a pH value at which stability is reached (neither corrosive or depositing); a condition termed saturation (pH_s). The pH_s condition is derived through a series of calculations and varies depending on hardness ($CaCO_3$), alkalinity, and temperature. The formula for the LSI is:

$$LSI = pH\ (actual) - pH_s$$

An LSI near 0 or slightly positive is considered stable and therefore desirable. A negative LSI is considered corrosive, while a positive LSI indicates the water to be depositing, or scale forming. The Ryznar Index, a modified form of the LSI, is gaining wider acceptance as an alternative corrosion index. This method incorporates observations of calcium carbonate deposition in system piping.

Corrosion monitoring and measurement techniques have made significant advancements in recent years. Methods of assessment include:

- Analyzing actual pipe and fitting specimens from a system.
- Pipe-segment coupon testing and associated metal loss measurements.
- Electrochemical (EC) methodologies to define the nature and rate of the corrosion process for uniformly corroding surfaces. EC measurements are typically made by linear polarization instruments to assess corrosion rates.

The effectiveness of alternative interior corrosion chemical treatments can be evaluated in the field by use of coupon testing or EC measurements.

Coupon testing involves installing a "loop" in the treated water piping with various metal coupons, representative of the actual system piping materials, exposed to system flows. Metal loss and corrosion rates can be determined by regular examination of these coupons.

EC measurements are more applicable to copper piping (and solders) with uniform corrosion. They can be adopted to continuous, on-line monitoring to assess a chemical additive program. EC methods would be more likely to have applications for larger systems undertaking a program to optimize corrosion control as a requirement of the LCR.

4.12.4 Maintenance

Maintenance requirements vary with the selected method of corrosion control. Chemical injection equipment for both pH/alkalinity control and corrosion inhibitors can include:

- Dry chemical feed. Dry feed can involve dry chemical handling, slaking, feeder mixing, and injection (typically flow-paced). Potential problems are: storage, operator demands for regularly opening bags of dry chemicals, filling the feeder, mixing a slurry, and potential health and safety problems caused by dust.
- Chemical slurry injection. A concentrated chemical slurry is injected (flow-paced) into the treated water stream. Storage, handling, and operator demands are lessened with this method.
- Pressure filters. Calcite filters, similar to water softener units, have been used for pH and alkalinity control on smaller systems.

All corrosion control treatment programs require regular operator attention and monitoring. Additional requirements, such as the coupon test program described in the preceding subsection, may also be necessary.

4.13 Disinfection

Disinfection is required at all surface water supplies and for ground water supplies under the direct influence of surface water as defined in the Alaska *Drinking Water Regulations*. Continuous disinfection is recommended for all water supplies.

4.13.1 Disinfectants

There are many types of disinfectants. These are described below and summarized in Table 4-14.

4.13.1.1 Primary disinfectants

Primary disinfectants are those most commonly used in current water treatment practice. These include chlorine and ozone.

a. Free Chlorine. At the present time, the maintenance of free chlorine residuals is the principal means by which water utilities ensure that the water they provide is properly disinfected. The predominant dissolved species in a chlorine solution made from mixing chlorine gas and relatively clean water of neutral pH is hypochlorous acid (HOCl) with some minor formation of hydrochloric acid (HCl). The HOCl dissociates to hypochlorite ion (OCl^-) and hydrogen ion at pH ranges above 6.0. Chlorine in this aqueous form (HOCl and OCl^-) is referred to as free chlorine.

   As chlorine is added to potable raw water sources, it reacts rapidly with constituents in the water to form chlorinated compounds. In terms of disinfection, these chlorinated compounds each display differing levels of efficiency in inactivating targeted pathogens.

   The consumption of free chlorine by water contaminants to form chlorinated compounds occurs rapidly. This consumption of free chlorine is referred to as the chlorine demand of the water. Water chlorine demand is typically exerted by inorganic compounds such as iron and manganese, H_2S, NO_2 and SO_3, by ammonia and amines, and by organics. Of these, the largest chlorine demand exerted is typically from ammonia-nitrogen compounds. Chlorine existing in chemical combination with ammonia-nitrogen is referred to as combined available chlorine. Combined available chlorine has disinfecting properties similar but less effective than free chlorine. The total chlorine residual is the sum of both free and combined available chlorine concentrations.

The chlorinated compounds created by reaction with ammonia-nitrogen are called chloramines. The forms of free chlorine and chlorinated compounds present in chlorinated water depend on the water pH, temperature, time of contact, and reactant (NH_4-N and HOCl) concentrations. For a water pH between 7 and 8, and chlorine to ammonia-nitrogen mass ratio of 5:1 or less, the predominant form of combined chlorine formed is monochloramine. At lower pH ranges, dichloramine is formed.

Chloramination is the process of using chloramines as a disinfectant. This process is reviewed in Section 4.13.1.2.

b. Hypochlorination. Hypochlorination is a chlorination process in which chlorine is introduced into the process flow from a solution of hypochlorite. The common sources of hypochlorite are calcium hypochlorite and sodium hypochlorite.

Calcium hypochlorite is a solid which is commercially available in granular or tablet form. It can be stored for extended periods without loss of effectiveness if the storage area is kept dry. Should excessive moisture come into contact with stored calcium hypochlorite, the heat of reaction can result in combustion. Use of calcium hypochlorite involves the preparation of a hypochlorite solution on site by mixing water with the dry calcium hypochlorite. The resulting mixture is metered into the process flow to maintain the desired free or total chlorine residual. Preparation of the solution typically results in the generation of a lime sludge at the base of the solution tank which must be periodically removed for disposal.

TABLE 4-14 Comparisons of Alternative Disinfectants

	Disinfectant								
	Cl_2[a]	$Cl_2/deCl_2$	Calcium Hypochlorite	Sodium Hypochlorite	Potassium Iodide	Bromine Chloride 4[b]	O_3	ClO_2	UV
Size of Plant	**All sizes**	All sizes	All sizes	All sizes	Small	Small	Medium to large	Small to medium	Small to medium
Equipment Reliability	Good	Fair to Good	Fair to Good	Good	Fair	Fair	Fair to good	Good	Fair to good
Relative Complexity of Technology	Simple to Moderate	Moderate	Simple	Simple	Simple	Simple	Complex	Moderate	Simple to moderate
Safety Concerns	Considerable	Considerable	Moderate	Moderate	Minimal	Minimal	Moderate	Considerable	Minimal
Bactericidal	Good	Good	Good	Good	Good	Good	Good	Good	Good
Virucidal	[c]	[c]	Good	Good	Good	Good	Good	Good	Good
Protozoa	Good	Good	Good	Good	Not allowed	Not allowed	Good	Good	Not allowed
Possible DPB Health Concerns	[d]	[d]	[d]	[d]	Yes	Yes	[e]	Yes	No
Persistent Residual	Long	None	Long	Long	Moderate	Short	None	Moderate	None.
Contact Time	Moderate	Moderate	Moderate	Moderate	Moderate	Short	Short	Moderate	Short
Reacts with Ammonia	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
pH Dependent	Yes	Yes	Yes	Yes	Yes	Yes	Slight	Slight	No
Process Control	Well developed	Well developed	Well developed	Well developed	Rarely used	Rarely used	Developing	Developing	Developing

[a] Includes chloramination.
[b] Bromine not recommended for potable water disinfection due to health effects risks.
[c] Moderate for free residual chlorination; poor for combined residual chlorination.
[d] Fewer by-products with combined residual chlorination.
[e] Health significance of by-products is unresolved at present.

Sodium hypochlorite is available only in liquid form and is relatively unstable, especially upon exposure to ultraviolet (UV) irradiation. Treatment plants using this form of hypochlorite must have relatively good shipping and resupply logistics established with the chemical supplier. As with calcium hypochlorite, sodium hypochlorite is metered directly into the process flow to maintain the desired free or total chlorine residual. Unlike calcium hypochlorite, sodium hypochlorite does not generate a residual lime sludge in the solution tank.

c. Chlorine dioxide. The microbial inactivation efficiency of chlorine dioxide disinfection is much less dependent upon pH than chlorine disinfection using chlorine or hypochlorination. However, the resulting inactivation is more inconsistent.

The use of chlorine dioxide is limited by two factors. First, the maximum residual that does not cause adverse taste and odor problems is 0.4-0.5 mg/L as ClO_2. Second, the chlorite produced by reduction of chlorine dioxide as demand is exerted has been found to cause certain types of anemia and other physiological effects in animals, and, therefore, the maximum $ClO_2 + ClO_2^- + ClO_3^-$ residual should be 1 mg/L to minimize this effect.

The carcinogenic nature of ClO_2^- and ClO_3^- has led to an EPA-established limit of 1 mg/L on $ClO_2 + ClO_2^- + ClO_3^-$.

Initial reports suggested that chlorine dioxide residuals have moderate stability during distribution. Whether analytical methods used can adequately differentiate chlorine dioxide from its reaction products, however, is not clear.

Chlorine dioxide used in disinfection processes is unstable, and once in solution, dissociates to chloride ion and the hydroxyl ion within a relatively short time. Because of this instability, it is typically produced at the site of its use. Chlorine dioxide is generated by mixing a solution of sodium chlorite with an oxidant such as chlorine or hydrochloric acid. Most small systems prefer to operate without the liability and risks associated with the use of using acid in their treatment process. Insofar as chlorine dioxide is produced free of chlorine (in the acid-chlorite process or in "optimized" chlorine-chlorite processes), the reactions with organic material to produce chlorinated by-products appear less significant than with chlorine.

d. Ozone. Ozone is a highly effective and lethal disinfectant against several categories of pathogens. Its use, however, is limited by the complexity and expense of generation. These factors have limited its application to small treatment systems. However, there are recent advances in the manufacture of ozonation generation systems for small systems. While the comparative costs are almost always in favor of other disinfectants, the use of ozone provides efficient and rapid inactivation of pathogens, usually with much smaller CT tank requirements, and reduced concentrations of disinfection by-products. It may be likely that ozone disinfection will be considered for small systems as more research on disinfection by-products and associated health effects becomes available.

Ozone disinfection requires on-site generation of the ozone used in the treatment process. As with chlorine dioxide, ozone is highly unstable and cannot be stored. Ozone generators operate by passing oxygen through an electronic corona discharge to convert the oxygen to ozone. The oxygen source can be either air or pure oxygen. When using air, it must be dehumidified and compressed prior to being fed to the ozone generator.

Like chlorine, the ozone is introduced into the process stream either as a concentrated solution or as a gas. Following addition of ozone, an ozone contactor must be provided to allow contact between the disinfectant and the target organisms. Ozone gas is sometimes introduced under pressure directly in the contactor. Ozone discharge gas collected from gas injection must be quenched prior to release into the atmosphere. There are catalytic units available for this conversion. Where ozone solutions are introduced into the process stream under vacuum induction conditions, the residual ozone in the process stream is often quenched by the addition of hydrogen peroxide to minimize the corrosive effects of the disinfectant for consumers immediately downstream of the treatment process. Ozone residuals are controlled by monitoring either dissolved ozone directly or by ORP (oxidation-reduction potential) monitors.

Ozone provides only a temporary transient residual. Supplemental disinfection must be used to maintain a detectable disinfectant residual in the distribution system. In addition, care must be exercised in the application of ozone to unfiltered water, as it can generate organic compounds suitable as substrate for microbial growth in the distribution system.

4.13.1.2 Other disinfectants

a. Chloramines. Chloramination is the simultaneous application of chlorine and ammonia (or the application of ammonia prior to the application of chlorine [preammonation]) to form chloramines for the specific purpose of effecting disinfection of microbial pathogens.

Chloramination was first used by Race at Ottawa, Ontario, Canada. At the time, it was argued that chloramines had a germicidal action greater than that of chlorine alone, that their use could ensure that the water produced was free of taste and odors, that a much more long-lasting residual was produced, and that the overall cost of disinfection could be reduced. The sum total of many subsequent studies has shown that (1) the germicidal action of combined chlorine may be substantially less than that of free chlorine, (2) combined chlorine is sometimes better from the taste and odor standpoint when the taste and odor of concern are the result of chlorine by-products, and (3) the combined chlorine residual is indeed longer-lasting than a free chlorine residual.

Chloramination is not often used as a primary disinfectant. The required contact time and/or concentration of disinfectants is much larger than required for chlorination. Specific lethality data suggest that for a process water pH of 7 or below, free chlorine is much more effective in the inactivation of bacteria, viruses, and other pathogens. For pH levels above 8, this issue is moot because the OCl^- ion is comparable to monochloramine in its disinfecting power.

While there would not appear to be an economic advantage to practicing chloramination as the primary disinfectant process, the process does have several benefits over chlorination. Chloramination is effective in maintaining long-term disinfection residuals in the distribution system following treatment. It can also be considered an alternate means of controlling taste and odor problems and controlling disinfection by-products formation.

Many of the plants that currently use the chloramine process add chlorine first and maintain a free chlorine residual for some time before ammonia is added.

Most utilities use between 3:1 and 4:1 chlorine-to-ammonia feed ratios by weight. Excess ammonia is generally used to make monochloramine predominant; however, some use higher ratios to form more effective dichloramine.

b. Iodination. In water, iodine can occur as iodine (I_2), hypoiodous acid (HOI), iodate (IO_3), or (I^-). Iodomaines do not form to any appreciable extent.

Potassium iodide has been used in small systems in Alaska. This application generally has been in the form of a column of dry potassium iodide granules through which a portion of the total process flow is directed. The effluent from this split flow is saturated with potassium iodide and recombined with the total process flow. The amount of flow split off and processed through the iodide granules is variable and controlled by proportioning valves on the process piping.

Once the process flow is recombined, the iodinated water must have a contactor for the disinfectant to be effective. A minimum of 30 minutes of contact time is recommended with a total residual of 1 mg/L for inactivation of total coliforms. Final iodine residuals can be measured using titrometric methods.

Iodination is not approved by ADEC for use in complying with the SWTR for *Giardia* inactivation.

c. Bromination. Bromine chloride is a fuming, dark red, highly corrosive liquid at atmospheric conditions and is more soluble in water than chlorine. It has been used as a biocide in cooling towers and wastewater treatment plants. Once in solution, it is an efficient bactericide and virucide requiring only five minutes or less of contact time to achieve inactivation of targeted pathogens. The total residual remaining after application is relatively unstable, however. Rigorous mixing is needed at the point of application to assure intimate contact with the process flow.

It is applied by metering its liquid form directly into the process flow. Containers of liquid bromine chloride are shipped with dry air or nitrogen padding to maintain a constant regulated pressure to the liquid feeder. The liquid bromine chloride is mixed with water in the feeder and conveyed as bromine chloride solution to a diffuser in the process flow. The typical design dosage is similar though often somewhat lower than an equivalent dosage of chlorine.

The use of bromine chloride as a disinfectant is limited by its health effects. There are risks of psychotic and neurological health effects associated with ingestion of source waters with concentrations of 1,600 mg/L or more. Because of this, its use in drinking water applications is not recommended. Bromination is not approved by ADEC for use in complying with the SWTR for *Giardia* inactivation.

d. Ultraviolet radiation. Disinfection of some pathogens can be effected by irradiation with UV radiation. Exposure to electromagnetic energy from a source lamp at wave lengths of 254 nanometers induces structural changes to the genetic material in the cell which prevents the cell from reproducing.

The contact times for UV disinfection systems can be quite short, generally under 1 minute. Therefore, the space required for UV disinfection units is relatively small. Because no residual is created, monitoring is difficult and some additional terminal disinfection process would usually be required. Also, UV radiation is not effective against *Giardia* cysts. The potential for UV reactions to produce organic by-products is minor, because the intensities required for UV disinfection are less than those needed to cause photochemical effects. Operationally, employing an effective cleaning program to periodically remove biological and chemical fouling materials from lamp jacket or Teflon tube surfaces is essential. Also, a supplemental disinfectant must be added to maintain a residual in the distribution system.

A photo-reactivation mechanism has been observed in some organisms inactivated with UV irradiation. The mechanism involves the organism's ability to repair UV damaged cell tissue upon irradiation with light in wavelengths between 300 and 500 nanometers. All microorganisms are not capable of this mechanism, but it has been observed in *Shigella*. This problem can be overcome through longer irradiation times or higher intensity exposure to the UV light.

UV disinfection is not approved by ADEC for use in complying with the SWTR for *Giardia* inactivation.

4.13.2 Inactivation Credits for *Giardia* Cysts and Viruses

Reductions in *Giardia* and viruses required by the state *Drinking Water Regulations* are determined by raw water quality. Section 4.1.4.2 reviews the criteria. Reductions in *Giardia* and viruses are to be achieved through a combination of filtration and disinfection. The reduction credit associated with filtration and disinfection is reviewed in Section 4.1.3.

As reviewed in Section 4.1.5, the degree of reduction credited to inactivation via disinfection processes is assessed by the state *Drinking Water Regulations* in terms of the calculated CT product for the process. The CT consists of two factors. The first is the concentration of disinfectant residual C expressed in mg/L of residual. The other is the contact time T for the disinfection process expressed in minutes.

a. Disinfection process variables

The required CT needed to achieve a particular level of inactivation is a function of both pH and water temperature. Tables of the log reductions of *Giardia* credited to chlorine disinfection as a function of the water temperature and pH are provided in Tables 4-15 through 4-20. Tables 4-21 through 4-28 present similar data for chlorine dioxide, ozone, chloramine, and also virus inactivation by free chlorine, chlorine dioxide, ozone, chloramine and UV disinfection. These tables are from the *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* (U.S. EPA, 1991) (EPA SWTG Manual).

The following equation, developed by CH2M-Hill, provides a reasonable estimate (for planning purposes and use within a computer program) for CT requirements for inactivation of *Giardia* cysts by free chlorine. The formula is especially useful for interpolation between published table values.

$$CT = (\text{Log Inactivation})(5.057)(e^{a})(e^{b})(e^{c})$$

where:

Log Inactivation can vary from 0.5 to 3
e = natural logarithm, approximately 2.71828
$a = -0.0693 \times \text{Temp } ^{\circ}\text{C}$
$b = 0.361 \times \text{pH}$
$c = 0.113 \times \text{Chlorine concentration, mg/L}$

Example calculation:

given:

Log Inactivation = 3.0
Temp = 5.0°C
pH = 7.5
Cl_2 = 0.8 mg/L

CT from tables = 175

$$\text{CT from formula} = (3)(5.057)(e^{-0.0693(5.0)})(e^{0.361(7.5)})(e^{0.113(0.8)}) = 176$$

The choice of which disinfectant to employ in a treatment facility depends on the potential for forming disinfection by-products, operator skills, availability of alternate disinfectants, and O&M costs. Once a disinfectant is selected, the design of the disinfection process must be sized and operated to provide the required CT for the disinfectant used. The required CT is indicated by the data in Tables 4-15 through 4-28.

b. Short circuiting and tracer studies

Design of disinfectant contact basins and reservoirs to meet CT requirements on the basis of CT data <u>requires</u> that the time of contact be established. The state <u>requires</u> that the time of contact be established by either one of three methods:

1. Use of tracer studies.
2. Use of detention time baffle factors published by EPA in its SWTG.
3. Documented studies

In a tracer study, a tracer chemical is introduced in controlled amounts at the inlet of a reservoir. Through repeated analyses of the chemical residual at the outlet, one can determine the time it takes for flow to pass through the reservoir.

For purposes of determining compliance with the requirements of the state *Drinking Water Regulations*, the contact time T for a reservoir must be the time at which 90 percent of the water passing through the unit is still retained or, stating it another way, the time at which 10 percent of a quantity of water introduced at the inlet has passed to the outlet. This time, which is used in making the CT calculation for a reservoir, is designated T_{10}.

Factors having an impact on the contact time in a reservoir are flow rate, water level in the reservoir, reservoir water balance (emptying or filling), shape of the reservoir (round, square, or oblong), inlet and outlet locations, type and locations of baffles, seasonal variations, sludge depth, and thermal density stratification.

When tracer testing is conducted to determine the T_{10} value for the reservoir, the state requires that a minimum of two tests be conducted, one for average flow and the other for peak flows equal to a minimum of 91% of the maximum hourly flow experienced by the section. The results of these tests are to be used to calculate T_{10} data (which for purposes of this discussion will be designated T_{10calc}) for other flow rates. Using the T_{10} measured from the high flow condition, T_{10calc} data for other flows would be calculated as the product of the measured T_{10} from the tracer test, and the ratio of the flow used in the tracer test divided by the flow for which the T_{10calc} is to be determined. Complete sets of T_{10calc} data are to be developed over the entire spectrum of operating flow ranges, one set of data for each of the tracer-test-determined T_{10} values. The lower of the resulting two T_{10calc} values should be used to determine the required disinfectant concentration C needed to achieve the overall CT for the process.

TABLE 4-15
CT VALUES FOR INACTIVATION OF *GIARDIA* CYSTS BY FREE CHLORINE AT 0.5°C OR LOWER (mg-minutes)/L

CHLORINE CONCENTRATION (mg/L)	pH<=6						pH=6.5						pH=7.0						pH=7.5					
	Log Inactivations						Log Inactivations						Log Inactivations						Log Inactivations					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	23	46	69	91	114	137	27	54	82	109	136	163	33	65	98	130	163	195	40	79	119	158	198	237
0.6	24	47	71	94	118	141	28	56	84	112	140	168	33	67	100	133	167	200	40	80	120	159	199	239
0.8	24	48	73	97	121	145	29	57	86	115	143	172	34	68	103	137	171	205	41	82	123	164	205	246
1	25	49	74	99	123	148	29	59	88	117	147	176	35	70	105	140	175	210	42	84	127	169	211	253
1.2	25	51	76	101	127	152	30	60	90	120	150	180	36	72	108	143	179	215	43	86	130	173	216	259
1.4	26	52	78	103	129	155	31	61	92	123	153	184	37	74	111	147	184	221	44	89	133	177	222	266
1.6	26	52	79	105	131	157	32	63	95	126	158	189	38	75	113	151	188	226	46	91	137	182	228	273
1.8	27	54	81	108	135	162	32	64	97	129	161	193	39	77	116	154	193	231	47	93	140	186	233	279
2	28	55	83	110	138	165	33	66	99	131	164	197	39	79	118	157	197	236	48	95	143	191	238	286
2.2	28	56	85	113	141	169	34	67	101	134	168	201	40	81	121	161	202	242	50	99	149	198	248	297
2.4	29	57	86	115	143	172	34	68	103	137	171	205	41	82	124	165	206	247	50	99	149	199	248	298
2.6	29	58	88	117	146	175	35	70	105	139	174	209	42	84	126	168	210	252	51	101	152	203	253	304
2.8	30	59	89	119	148	178	36	71	107	142	178	213	43	86	129	171	214	257	52	103	155	207	258	310
3	30	60	91	121	151	181	36	72	109	145	181	217	44	87	131	174	218	261	53	105	158	211	263	316

CHLORINE CONCENTRATION (mg/L)	pH=8.0						pH=8.5						pH<=9.0					
	Log Inactivations						Log Inactivations						Log Inactivations					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	46	92	139	185	231	277	55	110	165	219	274	329	65	130	195	260	325	390
0.6	48	95	143	191	238	286	57	114	171	228	285	342	68	136	204	271	339	407
0.8	49	98	148	197	246	295	59	118	177	236	295	354	70	141	211	281	352	422
1	51	101	152	203	253	304	61	122	183	243	304	365	73	146	219	291	364	437
1.2	52	104	157	209	261	313	63	125	188	251	313	376	75	150	226	301	376	451
1.4	54	107	161	214	268	321	65	129	194	258	323	387	77	155	232	309	387	464
1.6	55	110	165	219	274	329	66	132	199	265	331	397	80	159	239	318	398	477
1.8	56	113	169	225	282	338	68	136	204	271	339	407	82	163	245	326	408	489
2	58	115	173	231	288	346	70	139	209	278	348	417	83	167	250	333	417	500
2.2	59	118	177	235	294	353	71	142	213	284	355	426	85	170	256	341	426	511
2.4	60	120	181	241	301	361	73	145	218	290	363	435	87	174	261	348	435	522
2.6	61	123	184	245	307	368	74	148	222	296	370	444	89	178	267	355	444	533
2.8	63	125	188	250	313	375	75	151	226	301	377	452	91	181	272	362	453	543
3	64	127	191	255	318	382	77	153	230	307	383	460	92	184	276	368	460	552

TABLE 4-16
CT VALUES FOR INACTIVATION OF *GIARDIA* CYSTS BY FREE CHLORINE AT 5°C (mg-minutes)/L

CHLORINE CONCENTRATION (mg/L)	pH<=6 Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0	pH=6.5 Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0	pH=7.0 Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0	pH=7.5 Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	16	32	49	65	81	97	20	39	59	78	98	117	23	46	70	93	116	139	28	55	83	111	138	166
0.6	17	33	50	67	83	100	20	40	60	80	100	120	24	48	72	95	119	143	29	57	86	114	143	171
0.8	17	34	52	69	86	103	20	41	61	81	102	122	24	49	73	97	122	146	29	58	88	117	146	175
1	18	35	53	70	88	105	21	42	63	83	104	125	25	50	75	99	124	149	30	60	90	119	149	179
1.2	18	36	54	71	89	107	21	42	64	85	106	127	25	51	76	101	127	152	31	61	92	122	153	183
1.4	18	36	55	73	91	109	22	43	65	87	108	130	26	52	78	103	129	155	31	62	94	125	156	187
1.6	19	37	56	74	93	111	22	44	66	88	110	132	26	53	79	105	132	158	32	64	96	128	160	192
1.8	19	38	57	76	95	114	23	45	68	90	113	135	27	54	81	108	135	162	33	65	98	131	163	196
2	19	39	58	77	97	116	23	46	69	92	115	138	28	55	83	110	138	165	33	67	100	133	167	200
2.2	20	39	59	79	98	118	23	47	70	93	117	140	28	56	85	113	141	169	34	68	102	136	170	204
2.4	20	40	60	80	100	120	24	48	72	95	119	143	29	57	86	115	143	172	35	70	105	139	174	209
2.6	20	41	61	81	102	122	24	49	73	97	122	146	29	58	88	117	146	175	36	71	107	142	178	213
2.8	21	41	62	83	103	124	25	49	74	99	123	148	30	59	89	119	148	178	36	72	109	145	181	217
3	21	42	63	84	105	126	25	50	76	101	126	151	30	61	91	121	152	182	37	74	111	147	184	221

CHLORINE CONCENTRATION (mg/L)	pH=8.0 Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0	pH=8.5 Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0	pH<=9.0 Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	33	66	99	132	165	198	39	79	118	157	197	236	47	93	140	186	233	279
0.6	34	68	102	136	170	204	41	81	122	163	203	244	49	97	146	194	243	291
0.8	35	70	105	140	175	210	42	84	126	168	210	252	50	100	151	201	251	301
1	36	72	108	144	180	216	43	87	130	173	217	260	52	104	156	208	260	312
1.2	37	74	111	147	184	221	45	89	134	178	223	267	53	107	160	213	267	320
1.4	38	76	114	151	189	227	46	91	137	183	228	274	55	110	165	219	274	329
1.6	39	77	116	155	193	232	47	94	141	187	234	281	56	112	169	225	281	337
1.8	40	79	119	159	198	238	48	96	144	191	239	287	58	115	173	230	288	345
2	41	81	122	162	203	243	49	98	147	196	245	294	59	118	177	235	294	353
2.2	41	83	124	165	207	248	50	100	150	200	250	300	60	120	181	241	301	361
2.4	42	84	127	169	211	253	51	102	153	204	255	306	61	123	184	245	307	368
2.6	43	86	129	172	215	258	52	104	156	208	260	312	63	125	188	250	313	375
2.8	44	88	132	175	219	263	53	106	159	212	265	318	64	127	191	255	318	382
3	45	89	134	179	223	268	54	108	162	216	270	324	65	130	195	259	324	389

TABLE 4-17
CT VALUES FOR INACTIVATION OF *GIARDIA* CYSTS BY FREE CHLORINE AT 10°C (mg-minutes)/L

CHLORINE CONCENTRATION (mg/L)	pH<=6						pH=6.5						pH=7.0						pH=7.5					
	Log Inactivations						Log Inactivations						Log Inactivations						Log Inactivations					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	12	24	37	49	61	73	15	29	44	59	73	88	17	35	52	69	87	104	21	42	63	83	104	125
0.6	13	25	38	50	63	75	15	30	45	60	75	90	18	36	54	71	89	107	21	43	64	85	107	128
0.8	13	26	39	52	65	78	15	31	46	61	77	92	18	37	55	73	92	110	22	44	66	87	109	131
1	13	26	40	53	66	79	16	31	47	63	78	94	19	37	56	75	93	112	22	45	67	89	112	134
1.2	13	27	40	53	67	80	16	32	48	63	79	95	19	38	57	76	95	114	23	46	69	91	114	137
1.4	14	27	41	55	68	82	16	33	49	65	82	98	19	39	58	77	97	116	23	47	70	93	117	140
1.6	14	28	42	55	69	83	17	33	50	66	83	99	20	40	60	79	99	119	24	48	72	96	120	144
1.8	14	29	43	57	72	86	17	34	51	67	84	101	20	41	61	81	102	122	25	49	74	98	123	147
2	15	29	44	58	73	87	17	35	52	69	87	104	21	41	62	83	103	124	25	50	75	100	125	150
2.2	15	30	45	59	74	89	18	35	53	70	88	105	21	42	64	85	106	127	26	51	77	102	128	153
2.4	15	30	45	60	75	90	18	36	54	71	89	107	22	43	65	86	108	129	26	52	79	105	131	157
2.6	15	31	46	61	77	92	18	37	55	73	92	110	22	44	66	87	109	131	27	53	80	107	133	160
2.8	16	31	47	62	78	93	19	37	56	74	93	111	22	45	67	89	112	134	27	54	82	109	136	163
3	16	32	48	63	79	95	19	38	57	75	94	113	23	46	69	91	114	137	28	55	83	111	138	166

CHLORINE CONCENTRATION (mg/L)	pH=8.0						pH=8.5						pH<=9.0					
	Log Inactivations						Log Inactivations						Log Inactivations					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	25	50	75	99	124	149	30	59	89	118	148	177	35	70	105	139	174	209
0.6	26	51	77	102	128	153	31	61	92	122	153	183	36	73	109	145	182	218
0.8	26	53	79	105	132	158	32	63	95	126	158	189	38	75	113	151	188	226
1	27	54	81	108	135	162	33	65	98	130	163	195	39	78	117	156	195	234
1.2	28	55	83	111	138	166	33	67	100	133	167	200	40	80	120	160	200	240
1.4	28	57	85	113	142	170	34	68	103	137	172	206	41	82	124	165	206	247
1.6	29	58	87	116	145	174	35	70	106	141	176	211	42	84	127	169	211	253
1.8	30	60	90	119	149	179	36	72	108	143	179	215	43	86	130	173	216	259
2	30	61	91	121	152	182	37	74	111	147	184	221	44	88	133	177	221	265
2.2	31	62	93	124	155	186	38	75	113	150	188	225	45	90	136	181	226	271
2.4	32	63	95	127	158	190	38	77	115	153	192	230	46	92	138	184	230	276
2.6	32	65	97	129	162	194	39	78	117	156	195	234	47	94	141	187	234	281
2.8	33	66	99	131	164	197	40	80	120	159	199	239	48	96	144	191	239	287
3	34	67	101	134	168	201	41	81	122	162	203	243	49	97	146	195	243	292

TABLE 4-18
CT VALUES FOR INACTIVATION
OF *GIARDIA* CYSTS BY FREE CHLORINE
AT 15°C (mg·minutes)/L

CHLORINE CONCENTRATION (mg/L)	pH<=6						pH=6.5						pH=7.0						pH=7.5					
	Log Inactivations						Log Inactivations						Log Inactivations						Log Inactivations					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	8	16	25	33	41	49	10	20	30	39	49	59	12	23	35	47	58	70	14	28	42	55	69	83
0.6	8	17	25	33	42	50	10	20	30	40	50	60	12	24	36	48	60	72	14	29	43	57	72	86
0.8	9	17	26	35	43	52	10	20	31	41	51	61	12	24	37	49	61	73	15	29	44	59	73	88
1	9	18	27	35	44	53	11	21	32	42	53	63	13	25	38	50	63	75	15	30	45	60	75	90
1.2	9	18	27	36	45	54	11	21	32	43	53	64	13	25	38	51	63	76	15	31	46	61	77	92
1.4	9	18	28	37	46	55	11	22	33	43	54	65	13	26	39	52	65	78	16	31	47	63	78	94
1.6	9	19	28	37	47	56	11	22	33	44	55	66	13	26	40	53	66	79	16	32	48	64	80	96
1.8	10	19	29	38	48	57	11	23	34	45	57	68	14	27	41	54	68	81	16	33	49	65	82	98
2	10	19	29	39	48	58	12	23	35	46	58	69	14	28	42	55	69	83	17	33	50	67	83	100
2.2	10	20	30	39	49	59	12	23	35	47	58	70	14	28	43	57	71	85	17	34	51	68	85	102
2.4	10	20	30	40	50	60	12	24	36	48	60	72	14	29	43	57	72	86	18	35	53	70	88	105
2.6	10	20	31	41	51	61	12	24	37	49	61	73	15	29	44	59	73	88	18	36	54	71	89	107
2.8	10	21	31	41	52	62	12	25	37	49	62	74	15	30	45	59	74	89	18	36	55	73	91	109
3	11	21	32	42	53	63	13	25	38	51	63	76	15	30	46	61	76	91	19	37	56	74	93	111

CHLORINE CONCENTRATION (mg/L)	pH=8.0						pH=8.5						pH<=9.0					
	Log Inactivations						Log Inactivations						Log Inactivations					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	17	33	50	66	83	99	20	39	59	79	98	118	23	47	70	93	117	140
0.6	17	34	51	68	85	102	20	41	61	81	102	122	24	49	73	97	122	146
0.8	18	35	53	70	88	105	21	42	63	84	105	126	25	50	76	101	126	151
1	18	36	54	72	90	108	22	43	65	87	108	130	26	52	78	104	130	156
1.2	19	37	56	74	93	111	22	45	67	89	112	134	27	53	80	107	133	160
1.4	19	38	57	76	95	114	23	46	69	91	114	137	28	55	83	110	138	165
1.6	19	39	58	77	97	116	24	47	71	94	118	141	28	56	85	113	141	169
1.8	20	40	60	79	99	119	24	48	72	96	120	144	29	58	87	115	144	173
2	20	41	61	81	102	122	25	49	74	98	123	147	30	59	89	118	148	177
2.2	21	41	62	83	103	124	25	50	75	100	125	150	30	60	91	121	151	181
2.4	21	42	64	85	106	127	26	51	77	102	128	153	31	61	92	123	153	184
2.6	22	43	65	86	108	129	26	52	78	104	130	156	31	63	94	125	157	188
2.8	22	44	66	88	110	132	27	53	80	106	133	159	32	64	96	127	159	191
3	22	45	67	89	112	134	27	54	81	108	135	162	33	65	98	130	163	195

TABLE 4.19
CT VALUES FOR INACTIVATION OF *GIARDIA* CYSTS BY FREE CHLORINE AT 20°C (mg·minutes)/L

CHLORINE CONCENTRATION (mg/L)	pH<=6 Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0	pH=6.5 Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0	pH=7.0 Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0	pH=7.5 Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	6	12	18	24	30	36	7	15	22	29	37	44	9	17	26	35	43	52	10	21	31	41	52	62
0.6	6	13	19	25	32	38	8	15	23	30	38	45	9	18	27	36	45	54	11	21	32	43	53	64
0.8	7	13	20	26	33	39	8	15	23	31	38	46	9	18	28	37	46	55	11	22	33	44	55	66
1	7	13	20	26	33	39	8	16	24	31	39	47	9	19	28	37	47	56	11	22	34	45	56	67
1.2	7	13	20	27	33	40	8	16	24	32	40	48	10	19	29	38	48	57	12	23	35	46	58	69
1.4	7	14	21	27	34	41	8	16	25	33	41	49	10	19	29	39	48	58	12	23	35	47	58	70
1.6	7	14	21	28	35	42	8	17	25	33	42	50	10	20	30	39	49	59	12	24	36	48	60	72
1.8	7	14	22	29	36	43	9	17	26	34	43	51	10	20	31	41	51	61	12	25	37	49	62	74
2	7	15	22	29	37	44	9	17	26	35	43	52	10	21	31	41	52	62	13	25	38	50	63	75
2.2	7	15	22	29	37	44	9	18	27	35	44	53	11	21	32	42	53	63	13	26	39	51	64	77
2.4	8	15	23	30	38	45	9	18	27	36	45	54	11	22	33	43	54	65	13	26	39	52	65	78
2.6	8	15	23	31	38	46	9	18	28	37	46	55	11	22	33	44	55	66	13	27	40	53	67	80
2.8	8	16	24	31	39	47	9	19	28	37	47	56	11	22	34	45	56	67	14	27	41	54	68	81
3	8	16	24	31	39	47	10	19	29	38	48	57	11	23	34	45	57	68	14	28	42	55	69	83

CHLORINE CONCENTRATION (mg/L)	pH=8.0 Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0	pH=8.5 Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0	pH<=9.0 Log Inactivations 0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	12	25	37	49	62	74	15	30	45	59	74	89	18	35	53	70	88	105
0.6	13	26	39	51	64	77	15	31	46	61	77	92	18	36	55	73	91	109
0.8	13	26	40	53	66	79	16	32	48	63	79	95	19	38	57	75	94	113
1	14	27	41	54	68	81	16	33	49	65	82	98	20	39	59	78	98	117
1.2	14	28	42	55	69	83	17	33	50	67	83	100	20	40	60	80	100	120
1.4	14	28	43	57	71	85	17	34	52	69	86	103	21	41	62	82	103	123
1.6	15	29	44	58	73	87	18	35	53	70	88	105	21	42	63	84	105	126
1.8	15	30	45	59	74	89	18	36	54	72	90	108	22	43	65	86	108	129
2	15	30	46	61	76	91	18	37	55	73	92	110	22	44	66	88	110	132
2.2	16	31	47	62	78	93	19	38	57	75	94	113	23	45	68	90	113	135
2.4	16	32	48	63	79	95	19	38	58	77	96	115	23	46	69	92	115	138
2.6	16	32	49	65	81	97	20	39	59	78	98	117	24	47	71	94	118	141
2.8	17	33	50	66	83	99	20	40	60	79	99	119	24	48	72	95	119	143
3	17	34	51	67	84	101	20	41	61	81	102	122	24	49	73	97	122	146

TABLE 4-20
CT VALUES FOR INACTIVATION OF *GIARDIA* CYSTS BY FREE CHLORINE AT 25°C (mg·minutes)/L

CHLORINE CONCENTRATION (mg/L)	pH<=6 Log Inactivations						pH=6.5 Log Inactivations						pH=7.0 Log Inactivations						pH=7.5 Log Inactivations					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	4	8	12	16	20	24	5	10	15	19	24	29	6	12	18	23	29	35	7	14	21	28	35	42
0.6	4	8	13	17	21	25	5	10	15	20	25	30	6	12	18	24	30	36	7	14	22	29	36	43
0.8	4	9	13	17	22	26	5	10	16	21	26	31	6	12	19	25	31	37	7	15	22	29	37	44
1	4	9	13	17	22	26	5	10	16	21	26	31	6	12	19	25	31	37	8	15	23	30	38	45
1.2	5	9	14	18	23	27	5	11	16	21	27	32	6	13	19	25	32	38	8	15	23	31	38	46
1.4	5	9	14	18	23	27	6	11	17	22	28	33	7	13	20	26	33	39	8	16	24	31	39	47
1.6	5	9	14	19	23	28	6	11	17	22	28	33	7	13	20	27	33	40	8	16	24	32	40	48
1.8	5	10	15	19	24	29	6	11	17	23	28	34	7	14	21	27	34	41	8	16	25	33	41	49
2	5	10	15	19	24	29	6	12	18	23	29	35	7	14	21	27	34	41	8	17	25	33	42	50
2.2	5	10	15	20	25	30	6	12	18	23	29	35	7	14	21	28	35	42	9	17	26	34	43	51
2.4	5	10	15	20	25	30	6	12	18	24	30	36	7	14	22	29	36	43	9	17	26	35	43	52
2.6	5	10	16	21	26	31	6	12	19	25	31	37	7	15	22	29	37	44	9	18	27	35	44	53
2.8	5	10	16	21	26	31	6	12	19	25	31	37	8	15	23	30	38	45	9	18	27	36	45	54
3	5	11	16	21	27	32	6	13	19	25	32	38	8	15	23	31	38	46	9	18	28	37	46	55

CHLORINE CONCENTRATION (mg/L)	pH=8.0 Log Inactivations						pH=8.5 Log Inactivations						pH<=9.0 Log Inactivations					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	8	17	25	33	42	50	10	20	30	39	49	59	12	23	35	47	58	70
0.6	9	17	26	34	43	51	10	20	31	41	51	61	12	24	37	49	61	73
0.8	9	18	27	35	44	53	11	21	32	42	53	63	13	25	38	50	63	75
1	9	18	27	36	45	54	11	22	33	43	54	65	13	26	39	52	65	78
1.2	9	18	28	37	46	55	11	22	34	45	56	67	13	27	40	53	67	80
1.4	10	19	29	38	48	57	12	23	35	46	58	69	14	27	41	55	68	82
1.6	10	19	29	39	48	58	12	23	35	47	58	70	14	28	42	56	70	84
1.8	10	20	30	40	50	60	12	24	36	48	60	72	14	29	43	57	72	86
2	10	20	31	41	51	61	12	25	37	49	62	74	15	29	44	59	73	88
2.2	10	21	31	41	52	62	13	25	38	50	63	75	15	30	45	60	75	90
2.4	11	21	32	42	53	63	13	26	39	51	64	77	15	31	46	61	77	92
2.6	11	22	33	43	54	65	13	26	39	52	65	78	16	31	47	63	78	94
2.8	11	22	33	44	55	66	13	27	40	53	67	80	16	32	48	64	80	96
3	11	22	34	45	56	67	14	27	41	54	68	81	16	32	49	65	81	97

TABLE 4-21

CT VALUES FOR INACTIVATION OF VIRUSES BY FREE CHLORINE

(mg-minutes/L)

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

TABLE 4-22

CT VALUES FOR INACTIVATION OF GIARDIA CYSTS BY CHLORINE DIOXIDE

(mg-minutes/L)

	Temperature (C)					
Inactivation	<=1	5	10	15	20	25
0.5-log	10	4.3	4	3.2	2.5	2
1-log	21	8.7	7.7	6.3	5	3.7
1.5-log	32	13	12	10	7.5	5.5
2-log	42	17	15	13	10	7.3
2.5-log	52	22	19	16	13	9
3-log	63	26	23	19	15	11

TABLE 4-23

CT VALUES FOR INACTIVATION OF VIRUSES BY CHLORINE DIOXIDE pH 6-9 (mg-minutes/L)

	Temperature (C)					
Removal	<=1	5	10	15	20	25
2-log	8.4	5.6	4.2	2.8	2.1	1.4
3-log	25.6	17.1	12.8	8.6	6.4	4.3
4-log	50.1	33.4	25.1	16.7	12.5	8.4

TABLE 4-24

CT VALUES FOR INACTIVATION OF *GIARDIA* CYSTS BY OZONE (mg-minutes/L)

	Temperature (C)					
Inactivation	<=1	5	10	15	20	25
0.5-log	0.48	0.32	0.23	0.16	0.12	0.08
1-log	0.97	0.63	0.48	0.32	0.24	0.16
1.5-log	1.5	0.95	0.72	0.48	0.36	0.24
2-log	1.9	1.3	0.95	0.63	0.48	0.32
2.5-log	2.4	1.6	1.2	0.79	0.60	0.40
3-log	2.9	1.9	1.43	0.95	0.72	0.48

TABLE 4-25

CT VALUES FOR INACTIVATION OF VIRUSES BY OZONE (mg-minutes/L)

Inactivation	Temperature (C) <=1	5	10	15	20	25
2-log	0.9	0.6	0.5	0.3	0.25	0.15
3-log	1.4	0.9	0.8	0.5	0.4	0.25
4-log	1.8	1.2	1.0	0.6	0.5	0.3

TABLE 4-26

CT VALUES FOR INACTIVATION OF *GIARDIA* CYSTS BY CHLORAMINE pH 6-9 (mg-minutes/L)

Inactivation	Temperature (C) <=1	5	10	15	20	25
0.5-log	635	365	310	250	185	125
1-log	1,270	735	615	500	370	250
1.5-log	1,900	1,100	930	750	550	375
2-log	2,535	1,470	1,230	1,000	735	500
2.5-log	3,170	1,830	1,540	1,250	915	625
3-log	3,800	2,200	1,850	1,500	1,100	750

TABLE 4-27

CT VALUES FOR INACTIVATION OF VIRUSES BY CHLORAMINE
(mg-minutes/L)

Inactivation	Temperature (C)					
	<=1	5	10	15	20	25
2-log	1,243	857	643	428	321	214
3-log	2,063	1,423	1,067	712	534	356
4-log	2,883	1,988	1,491	994	746	497

TABLE 4-28

CT VALUES FOR INACTIVATION OF VIRUSES BY UV
(mg-minutes/L)

Log Inactivation	
2.0	3.0
21	36

For futher information on conducting tracer studies, Appendix C of the EPA SWTR Guidance Manual (referred to in the description of Method 2 of this subsection) should be consulted.

For the inactivation of *Giardia*, CT credit is allowed from the first point of application of a disinfectant suitable for inactivation of *Giardia*. For example, where filtration is practice, CT credit is permitted in a raw water pipeline, prior to filtration. CT then accumulates through a treatment facility as long as the monitoring parameter can be confirmed (time, temperature, pH, residual, and contact efficiency).

4.13.3 Chlorine Disinfection By-Products

Chlorination of source waters containing organic contaminants can lead to formation of other pollutants known as disinfection by-products (DBP). Trihalomethanes are currently the only DBPs covered by the state *Drinking Water Regulations*. Although the EPA suggests increased levels of disinfection for various source water conditions, a utility should not implement such a change without considering the potential conflict with the requirements of existing or future disinfection by-product regulations.

EPA intends to promulgate national primary *Drinking Water Regulations* to regulate levels of disinfectants and disinfection by-products when it promulgates disinfection requirements for groundwater systems. EPA is concerned that changes required in water system disinfection practices to meet the recommended inactivations for the SWTR might be inconsistent with treatment changes needed to comply with the forthcoming regulations for disinfectants and disinfection by-products. For this reason, EPA recommends that primacy agencies exercise discretion, sensitive to potential disinfection by-product concerns, in determining the level of disinfection needed for filtered systems to meet the overall treatment requirements specified in the SWTR or recommended based on source water quality.

4.13.3.1 TTHM Maximum Contaminant Level

The total trihalomethanes MCL is under consideration for change by EPA. The current TTHM MCL will probably be reduced before 1995.

As of the middle of 1993, EPA has established an MCL of 0.1 mg/L for TTHM for utilities serving populations over 10,000 people.

4.13.3.2 THM formation rate

Lab experiments on the rate and limit of THM formation for a particular source can provide valuable information on the potential for THM formation and the maximum disinfectant dose that does not violate the TTHM MCL. Seasonal variations in flow, organic content, temperature, etc. can effect the rate and limit of THM formation.

4.13.3.3 Avoiding DBPs during superchlorination

In the process of superchlorination-dechlorination, which has generally been employed when treating poor-quality water (with high ammonia nitrogen concentrations, or perhaps with severe taste and odor problems), chlorine is added beyond the break point. This oxidizes the ammonia nitrogen present. Generally, the residual chlorine obtained at this point is higher than may be desired for distribution. The chlorine residual may be decreased by the application of a reducing (dechlorinating) agent, such as a sulfur compound or activated carbon.

A modern application of chlorination-dechlorination in water treatment may be the judicious application where both high degrees of microbial inactivation as well as low organic by-product formation are desired. Holding water with free chlorine for a period (sufficient to ensure disinfection, but not so long as to produce substantial by-products) then partially or completely dechlorinating the water to minimize the production of organic by-products may be possible.

4.13.4 Disinfectant Application

4.13.4.1 Criteria

Criteria such as by-product formation potential, process flexibility, and effect on unit processes are important considerations in determining the point or points of disinfectant application. It is always good practice to provide the ability to periodically apply high-concentration disinfectant slugs to sterilize basins and tanks.

4.13.4.2 Contact time

Due consideration should be given to the contact time of the disinfectant in water with relation to pH, ammonia, taste-producing substances, temperature, bacterial quality, by-product formation potential, and other pertinent factors. Disinfectant should be applied at a point which will provide adequate contact time.

4.13.4.3 Where applied - surface water treatment

At plants treating surface water, provisions should be made for applying disinfectant to the raw water, settled water, filtered water, and water entering the distribution system.

4.13.4.4 Where applied - ground water treatment

As a minimum, at plants treating ground water, provisions should be made for applying disinfectant to the disinfection process reactor vessel, basin, or tank inlet and the point where water enters the distribution system. This will avoid costs associated with retrofitting the treatment process at a later date when the regulations for disinfection of groundwater are implemented.

4.13.4.5 Free residual contact time

The designer of a new disinfection process treatment facility must first determine the required CT from the appropriate data in Tables 4-15 through 4-28. Once the design CT is established for the peak flow, the required hydraulic detention time must be provided based on (1) the hydraulic characteristics of the proposed detention basin and (2) the proposed disinfectant residual concentration, as measured at the outlet of the disinfection process reactor vessel, basin, or tank. An example design procedure is presented in Appendix 3.

4.13.4.6 Pretreatment application

Chemical conditioning, rapid mixing and flocculation are unit processes used in conventional and some direct filtration processes. Application of a disinfectant in these processes can provide additional overall detention time. It could enhance the treatment process, especially when oxidation of contaminants is part of the overall treatment objective. Such is the case for source waters with iron and manganese.

4.13.4.7 Intermediate application

Application of a disinfectant at the pre-sedimentation or filtration stage of treatment can provide contact time flexibility to compensate for seasonal variations in process flow temperature and pH. In the winter, process flow temperatures can be lower than in summer. This requires a higher CT than for summer conditions. This higher CT can be met, at least in part, by the addition of disinfectant at intermediate points in the treatment process train. For a system providing filtration treatment, credit for CT is allowed at any point in the treatment process, including raw water transmission lines.

4.13.4.8 Post-treatment application

Application of a disinfectant following treatment is most commonly used to establish a measurable residual in the distribution system. This practice allows the most control over the final finished water disinfectant residual concentration.

4.13.5 Chlorination Equipment

4.13.5.1 Type

Chlorination equipment is selected on the basis of the type of chlorine used in the treatment process. The most common alternatives are gas chlorination or hypochlorination. General chemical feed equipment is reviewed in Section 5.1.2.

Gas chlorination systems use chlorine shipped in steel tanks under pressure. Commercially available sizes are 150-lb cylinders, 1-ton cylinders, 15-17 ton tank trucks and 16-90 ton rail cars. When full, the volume of chlorine inside the tank in liquid form is approximately 85% of the total volume. For smaller treatment plants typically under 3,750 m^3/day (1 mgd), the gas above the liquid is withdrawn under a vacuum leaving the liquid phase undisturbed. This gas is metered through a chlorinator and inducted either into a split stream of process flow to form a chlorine solution for addition to the process flow or inducted directly into a rapid mixing device immersed in the process flow. For larger plants, liquid chlorine is withdrawn and evaporated in temperature controlled evaporators. The evaporated gas is metered through a chlorinator and downstream solution mixing devices similar to those used in smaller treatment plants.

Use of calcium hypochlorite in hypochlorination systems requires on-site solution preparation. Sodium hypochlorite is delivered as a liquid. In either case, the liquid hypochlorite solution is metered into the process flow with positive displacement pumps or through induction mixers immersed in the process flow.

4.13.5.2 Capacity

The chlorinator capacity is normally such that a free chlorine residual of at least 2 mg/L can be maintained in the water after contact time of at least 30 minutes when maximum hourly flow rate coincides with anticipated maximum chlorine demand. The equipment used should operate accurately over the desired feeding range.

4.13.5.3 Standby equipment

Where chlorination is required for protection of the supply, standby equipment of sufficient capacity should be available to replace the largest unit. Spare parts should be available to replace parts subject to wear and breakage. If there is a large difference in feed rates between routine and emergency doses, a gas metering tube should be provided for each dose range to ensure accurate control of the chlorine feed.

Where chlorination is practiced by unfiltered systems, the requirements of the state *Drinking Water Regulations* section entitled "Disinfection Requirements for Unfiltered Systems," must be followed.

4.13.5.4 Automatic switchover

Automatic switchover of chlorine cylinders is one of the two options available to surface water systems or systems utilizing ground water under the direct influence of surface water to satisfy the disinfectin requirement s of the state *Drinking Water Regulations* sections entitled "Disinfection Requirements for Unfiltered Systems," and "Criteria For Avoiding Filtration ."

4.13.5.5 Automatic proportioning

Automatic proportioning chlorinators will be required where the rate of flow or chlorine demand is not reasonably constant. Residual analyzers are commonly employed as part of the chemical equipment control systems to provide this proportioning flow-paced chemical feed feature.

4.13.5.6 Cross-connection protection

The chlorinator water supply piping should be designed to prevent contamination of the treated water supply by sources of questionable quality. At all facilities treating surface water, pre- and post-chlorination systems must be independent to prevent possible siphoning of partially treated water into the clear well. The water supply to each chlorinator should have a separate shut-off valve. No master shut-off valve will be allowed.

4.13.5.7 Pipe material

The pipes carrying elemental liquid or dry gaseous chlorine under pressure must be Schedule 80 seamless steel tubing or other materials recommended by the Chlorine Institute (never use PVC). Rubber, PVC, polyethylene, or other materials recommended by the Chlorine Institute must be used for chlorine solution piping and fittings. Nylon products are not acceptable for any part of the chlorine solution piping system.

4.13.5.8 Housing

Chlorine is a strong oxidant and with sufficient exposure can be deadly. The design of structures to house chlorination equipment must be compatible with potential leaks, spills, or other types of exposure to chlorine. Surface coatings used in the structure, electrical system components for lighting, power distribution, and control systems; and the access/egress for the chlorine storage and equipment areas must be designed for compatibility with leaks and spills. Design of housing for chlorination facilities must comply with the Uniform Fire Code, Uniform Mechanical Code, Uniform Building Code, and National Electrical Code. Local codes should also be consulted.

4.13.6 Chlorine Safety

Chlorine gas is the most economical form of chlorine used for water treatment plants. However, it is the most hazardous form of chlorine in use. The release of chlorine gas to the atmosphere is extremely threatening to public safety. Hazards associated with the use of chlorine gas have been reduced with the use of chlorine gas delivery systems which convey the gas under vacuum conditions to the point where it is used to make a chlorine solution. These systems significantly reduce the potential for a major gas leak from the gas piping between the storage cylinders and the chlorinators. Hazards related to the escape of gas from the storage cylinders can be reduced with the use of chlorine gas scrubber systems.

Hypochlorination uses a liquid form of chlorine which has greatly reduced potential for release of large amounts of chlorine gas into the atmosphere. Sodium or calcium hypochlorite are good alternatives to chlorine gas, especially for small systems, because of easier handling and increased safety. Refer to Section 4.13.1.

The design should address concerns such as storage, leak detection, alarms, ventilation, exhaust treatment, and safety equipment. Guidance for these issues is available through the latest editions of the *Chlorine Institute Manuals*, published by the Chlorine Institute, 2001 L St., N.W., Washington, D.C. 20036, (202) 775-2790.

All containers must be well secured to avoid earthquake-induced breakage of connecting piping or direct damage to the container itself.

Chlorine gas or liquid chlorine scrubbers of appropriate capacity (able to handle catastrophic failure of pressurized containers) are normally installed and tied to an automated leak detection system. Scrubber requirements are documented in the latest edition of the Uniform Fire Code.

4.13.7 Chlorine storage and feed facilities

A list of items to check when designing chlorine storage and feed facilities is presented below. This list should be reviewed during every design.

- Make sure rotometer sizing is appropriate for the anticipated chlorine feed rates to meet all CT requirements.

- Make sure the following items are specified for gas chlorination systems:
  - Chlorine leak detector and alarm system for all chlorine gas systems.
  - Repair kit.
  - Self-contained breathing apparatus with spare cylinder.
  - Chlorine residual analyzer and alarm system.
  - Spare parts for critical equipment (chlorinator, injectors, evaporators, vacuum regulator).
  - Chlorine scales and trunions.
  - Expansion tanks for liquid chlorine lines.
  - Cylinders and larger containers restrained from movement.

- Review state for codes for hazardous gas storage, handling and scrubber installation requirements. Check ventilation capacity and location of air discharge.

- Ventilation and storage of chlorine should conform to recomendations in industry standards such as American Water Works Association (Water Chlorination Principles and Practices and Introduction to Water Treatment, Vol. 2), 6666 W. Quincy Ave, Denver, CO 89235, (303) 795-2114; or Chlorine Institute (Chlorine Manual), 2001 L St. N.W., Washington, D.C. 20036, (202) 775-2790.

- Check the water supply flow rate, pressure, back-pressure required, and pipe size for chlorine injection.

- Check the maximum withdrawal rate through active gas containers versus required design capacity.

- Provide adequate heat for storage (15.6°C, [60°F] min.) and feed (20°C, [68°F] min.) rooms. Provide protection from overheating gas storage containers with sunlight.

- Check for adequate clearance around equipment and access for maintenance and removal.

4.13.8 Monitoring

4.13.8.1 Residual determination

Monitoring requirements for determining disinfectant residuals are stipulated in the state *Drinking Water Regulations*, under the sections entitled "General Monitoring Requirements," "Monitoring Requirements for Systems that do not Provide Filtration," "Monitoring Requirements for Systems Using Filtration," and "Groundwater Disinfection."

Residual disinfectant concentrations should be determined according to the state *Drinking Water Regulations*, under the requirements of the section entitled "Analytical Requirements."

4.13.8.2 Manual or automatic dosage control

The control of disinfectant dosage to the treatment process flow may be controlled in either a manual or automatic mode. The manual mode of control should be reserved for those systems with a constant rate of process flow and operator adjustment should be based on daily determinations of disinfectant residual. An automatic mode of dosage control should be employed where the process flow is variable.

4.13.8.3 Alarms/automatic supply shutdown

For unfiltered systems utilizing surface water or groundwater under the direct influence of surface water, or systems avoiding filtration, automatic water supply system shutdown that is interlocked with the chlorine delivery system is one of the options available in the disinfection fail-safe provisions of the state *Drinking Water Regulations*, section entitled "Disinfection Requirements for Unfiltered Systems," unless this poses unreasonable risk to health or would interfere with fire protection. Automatic shutdown of the water supply system is to occur when the disinfectant residual drops below 0.2 mg/L. Automated shutdown of the system should be accompanied by remote alarms to on-call responsible parties, especially for Alaska systems where interruption of water flow could result in freeze damage.

4.14 Fuels and Antifreeze

4.14.1 Raw Water Sources

All anticipated sources of raw water for any water system should be thoroughly tested for drinking water contaminants in accordance with 18 AAC 80 to check that the sources do not contain unacceptable levels of hazardous or toxic compounds. This information will also provide baseline data for any future development of the source. In addition, a survey of the area for potential sources of contamination should be made.

4.14.2 Operation and Maintenance

Design for the storage of fuel and antifreeze products at water treatment facilities should be included in the operational plan. The storage and use of these products should conform to all local, state and federal regulations.

4.14.2.1 Applicable processes

In areas of the state where the source water is heated to enhance the treatment process, heat exchangers are used which contain antifreeze (propylene glycol) solutions (never use ethylene glycol in heat exchangers associated with potable water suppliers). All applications of heat exchangers should comply with the National Mechanical Code and National Plumbing Code. In addition, oils and lubricants are used for maintenance of mechanical equipment associated with the plant operation. An area of the facility, or a nearby building, should be dedicated for storage of these materials.

Fuel oils are used for emergency generator operations in most of the facilities throughout the state to provide an uninterrupted supply of water for the community. The design should include storage of these fuels which comply with all current federal, state, and local regulations.

4.14.2.2 Description of processes

There are many types of hazardous or toxic compounds found in petroleum based products which can adversely affect water quality. Particular requirements for testing of such contaminants are described in the state *Drinking Water Regulations*. Several treatment processes have been used to reduce these contaminant levels in water, and the application of each is based on site-specific factors ranging from site location and contaminant type to level of contamination. Because there is insufficient experience to establish design standards that apply to all situations, pilot studies and early consultation with ADEC are needed when contaminant removal is warranted. Engineering studies should be performed and results submitted to ADEC. Since this process can be complicated, lengthy, and costly, alternative source development may be warranted.

Where treatment is proposed, use of the best available technology should reduce contaminants to the lowest practical levels. Operations and maintenance of proposed systems should be considered in evaluation and acceptance of specific treatment systems.

Examples of treatment technologies that may be applicable include:

- Air stripping of volatile organics (packed tower aeration).
- Granular activated carbon (see Section 4.11).
- Existing treatment process modifications.
- Alternate source development.

Except for temporary, emergency treatment conditions, particular attention should be given to development of information that addresses issues noted in the following paragraphs for surface water and ground water.

For contaminants found in surface water, it is important to note information about:

- The type of chemical, source, concentration, frequency of occurrence.
- Possible treatment plant modifications to lower contaminant level, including results from bench, pilot, or full-scale testing demonstrating treatment alternatives and effectiveness.
- Determination of quality and operational parameters which serve as best measurement of treatment performance and the corresponding monitoring and process control program.

For contaminants found in ground water sources, it is important to note:

- Types of chemicals, sources, concentrations, estimate of residence time within the aquifer, and flow characteristics.
- Results of bench or pilot studies and demonstrate treatment alternatives and effectiveness.
- Determination of the quality and operational parameters which serve as the best measure of treatment performance and a corresponding monitoring and process control program.

Discussion of site-specific treatment technologies and associated design criteria is outside the scope and intent of this manual.

4.15 Combining Individual Processes

4.15.1 Matrix of Unit Processes

A designer is faced with making decisions about which unit processes to use to produce a design that is reliable, cost-effective, and flexible. In Table 4-29 general treatment technology guidelines are shown for typical Alaska surface water and groundwater under the influence of surface water. The table shows various treatment process trains for waters including: glacial surface waters; shallow-well and infiltration gallery supplies; surface springs; salt water or brackish water supply; freshwater streams, creeks, rivers, or surface impoundments; tundra or muskeg impoundments; and waters that are contaminated with fuel, antifreeze, or other VOC contaminants. Site-specific considerations should govern final selection of treatment processes to be used for a given water source.

4.15.2 Evaluation of Unit Processes

Any treatment plant design report should include the advantages and disadvantages of each type of treatment technology for the given water source. The designer should address the:

- Complexity of operations.
- Regulatory problems.
- Costs (capital, operation, and maintenance).
- Reliability, redundancy, parallel units, standby equipment, energy requirements.
- Operator issues (process control, monitoring requirements, safety, operator qualifications, equipment availability, maintenance complexity, etc.).

In selection of individual unit processes for treatment technology, the overall objective is to select a treatment technology, or combinations of technologies, that provides acceptable removal of all contaminants and ensures the potable water supply will meet the quality requirements of current and proposed MCLs as set by EPA.

TABLE 4-29 Matrix of Acceptable Treatment Technologies for Various Water Sources

Water Source Characteristics	Treatment Technologies										
				Filtration Technologies							
	Coagulation	Flocculation	Sedimentation and Precipitation	Sand/Mixed Media	Cartridge Filters	Reverse Osmosis	Membrane Filters	Bag Filters	Slow Sand Filters	DE Filters	Greensand Filters
• High turbidity, low temp. (glacial origin)	•	•	•	•					•		
• Shallow well, including infiltration galleries				•							
(iron and manganese removal < 3 ppm iron)					•				•		•
(iron and manganese removal > 3 ppm iron)	•	•	•	•							•
• Surface spring(s)			•	•	•				•		
• Saltwater and/or brackish water supplies					•	•	•				
• Freshwater stream, creek, river or other surface impoundment:											
(high turbidity, color and solids)	•	•	•	•							
(low turbidity, color and solids)				•							
(low turbidity and color)				•					•	•	
(low turbidity, color and solids)					•						
(ice covered impoundments)	•	•	•	•							
(high color and/or turbidity)	•	•	•	•							
(low turbidity, low bacteria contaminant)										•	
• Tundra or muskeg surface impoundment	•	•	•	•							
(w/low color, turbidity, and solids)					•			•			
(with high color)	•	•	•	•							

TABLE 4-29 Matrix of Acceptable Treatment Technologies for Various Water Sources (Continued)

Water Source Characteristics	Treatment Technologies												
								Disinfection Technologies					
	Aeration	Chemical Oxidation	Ion Exchange	GAC Filtration	Air Stripping	Corrosion Control	Softening	Free Chlorine	Chlorine Dioxide	Ozone	Chloramines	Ultraviolet	Other Halogens
• High turbidity, low temp. (glacial origin)						●		●	●	●	●	●	
• Shallow well, including infiltration galleries							●	●			●		
(iron and manganese removal < 3 ppm iron)	●	○	○					●		●	●	●	
(iron and manganese removal > 3 ppm iron)		○						●		●			
• Surface spring(s)			○					●	●	●	●		
• Saltwater and/or brackish water supplies			○					●	●	●	●	●	
• Freshwater stream, creek, river, or other surface impoundment:									○		●	●	
(high turbidity, color and solids)									●		●	●	
(low turbidity, color and solids)								●		●	●		
(low turbidity and color)								●		●	●		
(ice covered impoundments)	●							●			●		
(high color and/or turbidity)				●					○		●	●	
(low turbidity, low bacteria contaminant)								●		●	●		●
• Tundra or muskeg surface impoundment													
(w/low color, turbidity, and solids)						●		●			●	●	●
(with high color)				●					●		●	●	
• Fuel, Antifreeze or Solvent (VOC) contaminated water sources		●		●	○			●	●	●	●		

4.16 Waste Disposal and Recycling

4.16.1 Wastes Generated by Treatment Processes

4.16.1.1 Backwash waste

Backwash waste is a volume of wash water (typically 1%-5% of total plant production) containing a low solids concentration produced by the filtration process. The site should be equipped with suitable facilities to receive and convey such flow for holding, processing, and disposal in accordance with current state wastewater regulations. If MCLs of organics are exceeded in the backwash water it will be necessary to provide the proper treatment equipment for removal of these contaminants. The designer should refer to the state wastewater and water quality regulations and assess the impact of such discharges during facility planning and design.

4.16.1.2 Spent regenerant

In GAC systems, activated carbon is usually used to reduce odor and taste. The relatively high cost of activated carbon ensures that the doses are not excessive and therefore the contribution of activated carbon to the volume of water-treatment residues is small. The determination of the chemical oxygen demand (COD) on water treatment plant residues containing activated carbon will yield high oxygen demand values, perhaps on the order of 10,000 mg/L.

In ion exchange systems, spent brines from the regeneration of ion exchange units range in volume from 3%-10% of the treated water. The residues consist primarily of the regenerant salt, NaCl, plus the calcium and magnesium ions displaced from the exchange resin.

4.16.1.3 Concentrates

For reverse osmosis, reject water may range from 25%-50% of the volume of raw water pumped to the reverse osmosis unit. This may present a problem for both source availability and waste treatment capabilities. The amount of reject water from a unit may be reduced to a limited extent by increasing the feed pressure to the unit; however, this may result in a shorter membrane life.

For other concentrates, ion exchange softener regeneration, ion exchange demineralizers, and blowdown from cooling towers and boilers are sources of waste brines. They have characteristics much like those described above for reverse osmosis. They produce wastes high in dissolved solids and low in suspended solids.

4.16.1.4 Waste sludges

Sludge is generated from the settling basins and from the filters as filter waste wash water. Plants should be designed to process and dispose of waste sludges in a manner acceptable to ADEC.

Coagulation sludges are produced by the coagulation and settling of natural particles that cause turbidity by adding coagulant chemicals. Facilities should be provided to convey and remove such sludges from hydraulic structures and take them to acceptable holding or disposal areas.

Lime sludges are produced from the precipitation of calcium carbonate and magnesium hydroxide in the lime-soda softening process. They may be essentially pure chemical sludges, or they may include suspended materials from the raw water if turbidity removal is combined with softening.

4.16.1.5 Cartridge and bag filter material

Wastes from cartridge and bag filters may include the solids retained on the filter, as well as the filter media itself. Disposal of materials must be in conformance with state and local disposal regulations. For further information, see Section 4.6.9.3.

4.16.1.6 Sanitary waste

Sanitary wastes from treatment plants, including process washdown waters, must receive treatment. Waste from these facilities must be discharged directly to a sanitary sewer system, when available and feasible, or to an adequate on-site waste treatment facility in accordance with 18 AAC 72.

4.16.2 Requirements for Disposal

4.16.2.1 Disposal permit requirements

Nondomestic wastewater and sludge disposal each require a permit issued by ADEC. The department may require that the sludge be treated before disposal if it determines treatment is necessary to protect public health or the environment (18 AAC 72.500). The waste disposal permit applies if the waste is transported to an approved facility or is disposed directly onto the land or into the waters of the state. Hazardous waste may only be disposed of at a facility that is approved for the disposal of each specific type of waste, or only in accordance with a specific permit issued by the department (18 AAC 60.087).

4.16.2.2 Waste storage, processing, and handling

Sludge handling includes a partial dewatering of wet sludge and recycling of extracted water with or without clarification treatment. The degree of dewatering depends upon the method of final sludge disposal. A dewatered solids concentration of 10% or higher is typically required for landfilling.

Applications for plan review of new or modified treatment facilities should specify sludge handling techniques for storage, processing, and treatment prior to disposal. Data describing the various wastes, their volume and proposed treatment, and points of discharge should be provided.

4.16.2.3 Best management practices for disposal

For planning a new project, the source water selection process should include consideration of waste residues to be produced and the effect on waste streams. In selecting a water treatment process, disposal costs should also be considered since disposal may cost many times more than treatment processes itself. The quantity of residue produced will vary with the process chosen.

Source water with lower turbidity or fewer solids may be preferred because it will produce less residue, and waste will be minimized. New treatment technologies should be considered where waste disposal options are limited. For example, use of polymers instead of aluminum sulfate for coagulation may reduce the quantity of treatment sludges. Recovery of certain constituents also needs to be considered, if economical. Recycling of decanted water may be considered, although quality of decant water is to be evaluated to determine whether the result leads to reintroduction of water of unacceptable quality.

The handling and final disposal of all waste products from the water treatment process should be addressed in the operational plan. All phases of waste handling and disposal should be designed to comply with current applicable regulations.

a. Ion exchange

The uncontrolled discharge of spent brines into waterways is not permitted. Waste brines flowing into a sanitary sewer system may seriously upset downstream treatment processes. Corrosion of mains, pumps, and equipment is also a factor when brines flow into the sewer system. No discharges of spent brines should be permitted unless approved by the authority having jurisdiction over the sanitary sewer system in which brines are to be discharged.

The following disposal methods should be considered:

- Evaporation ponds. Evaporation ponds should be lined to prevent the flow of brine into fresh water aquifers. Design considerations include: nonuniform evaporation rates and evaporation rates versus rainfall, land area requirements, the extent to which evaporation exceeds precipitation, and the expense to make the basin watertight.

- Controlled dilution and mixing zone. Requests for discharge of waste brine into natural receiving waters must undergo permit approval by ADEC. Requests for mixing zones should be evaluated to determine the extent of dilution to be provided. Discharges to sewer systems should be approved by the authority having jurisdiction over the system. Discharges that are detrimental to the sewage collection system, wastewater treatment works, or receiving waters are prohibited by state wastewater disposal regulations, 18 AAC 72. Where required by the authority having jurisdiction, holding tanks of sufficient size should be provided to allow controlled discharges at acceptable dilution ratios.

- Brine disposal wells. For disposal in wells, the quantities of spent brine should be limited and the brine may require treatment prior to injection to prevent clogging of the pores of the formation underground. Consult with ADEC for regulated activities of injection wells.

- Ocean disposal. If the plant is located near brackish water or saltwater, discharges may be permitted upon review and approval of permit applications made in conformance with 18 AAC 72.

b. Reverse osmosis

Acceptable methods of waste disposal include discharge to the municipal sewer system, a lagoon, or a lined evaporation pond if approved by ADEC.

c. Waste sludges

Since aluminum and iron salts are generally used to accomplish coagulation, hydrated aluminum and iron oxides, often referred to as aluminum and ferric hydroxides, are the chief constituents of sludges from water treatment plants practicing chemical coagulation. In addition, the residues contain entrained particulate matter, both organic and inorganic. Most of the matter entrained in coagulation is inorganic in nature and consists of fine sands, silts, and clays.

Following are disposal options for waste sludges:

- Lagoon. The lagoon option generally has low capital costs (if land is available) and low operating and maintenance costs. During long freezing periods, freezing and thawing aids in the drying process.

  Lagoons should be designed to produce an effluent that complies with current state discharge standards. ADEC approval of the system and a discharge permit are required. The design should provide:

  - A location free from flooding.
  - Dikes, deflecting gutters, or other means of diverting surface water so it flows away from the lagoon, as necessary.
  - A minimum usable depth sufficient for calculated storage volume requirements.
  - Freeboard of two feet minimum.
  - An adjustable decanting device.
  - An effluent sampling point.
  - Adequate safety provisions.

- Mechanically-aided dewatering. If this option is proposed, a pilot plant study may be required before design. Results should be provided to ADEC to obtain approval. Consideration should be given in pilot studies to the proper disposal or recycling of wastewaters generated from dewatering processes.

To dispose of residuals to a surface water, a National Pollutant Discharge Elimination System (NPDES) permit may be required by the EPA in lieu of state permits. State permit applications should be in conformance with procedures outlined in 18 AAC 72 and should accompany plans for treatment facilities submitted to the ADEC for review.

Dewatered sludges to be disposed of on land should be dewatered to a concentration approved by the authority having jurisdiction over the disposal facility (10% solids by weight minimum), and disposal practices will be governed by ADEC.

For treatment plants disposing of residuals on land, sufficient holding tank capacity should be provided at the plant to accommodate regularly scheduled or unplanned maintenance of mechanical dewatering equipment so that plant production is maintained at all times. Discharge of residuals to land must be approved by the ADEC.

- Disposal to sanitary sewer systems. The type and quantity of liquids and solids that may be added should be limited by the capacity of the sewer, the capacity of the wastewater treatment plant, or the types of processes and operations at the wastewater facility. ADEC approval of discharges to the sewer is required. A condition of discharge may be continuous monitoring of the organic strength and solid content of the residual flow.

  Approval of this method should be dependent upon approval of the discharge by the authority having jurisdiction over the sewer system. Holding tanks may be required to prevent overloading sewers.

d. Filter wash water

Wastewater from washing filters at surface water treatment plants should have suspended solids reduced to a level acceptable to ADEC before being discharged. Alternatively, it may be recycled to the inlet end of the treatment plant, provided the wash water does not introduce unacceptable levels of contaminants (e.g., filtered *Giardia* cysts, algae, etc.) to the process, as discussed in Section 4.16.3.1, below.

4.16.3 Recycling Options

4.16.3.1 Backwash waste

In an attempt to reduce the total volume of backwash wastewater requiring dewatering, holding tanks may be used in conjunction with recycling of wash water to the inlet end of the plant. This technique may also be useful if the volume of backwash waste is a significant percentage of the total water production available from the facility.

If included in the design, holding tanks should be sized to contain the anticipated volume of waste wash water from filters calculated by using a minimum 15 minute wash at 0.014 $m^3/sec/m^2$ (20 gpm/ft^2). In plants with several filters, the size of the holding tank will depend on anticipated hours of operation. Waste filter wash water should be returned at a rate of less than 10% of the raw water entering the plant to minimize the effect of turbidity on the system.

Filter backwash water should not be recycled when the raw water contains excessive *Giardia* cysts or algae, when water taste and odor problems are encountered, or when THM levels in the distribution system may exceed allowable limits. The recycling of backwash wastewater requires approval from ADEC. Particle size analysis testing may be required to determine if recycling is an option.

4.16.3.2 Waste sludges

Residues from water softening are generally stable, dense, inert, and relatively pure. The recovery of lime by recalcination is an attractive proposition, but it is probably economic only for large plants.

Acid treatment of sludge for alum recovery may be a possible alternative, although pilot studies should be required for this type of residuals management. Treatment with sulfuric acid can be used to reclaim iron or aluminum sulfate from hydrated iron or aluminum oxide residues. However, recovery of the adsorbed, colored organic materials along with the alum and the need for intermittent lime softening should be considered in pilot studies of alum recovery processes.

4.17 Upgrading Existing Facilities

The Safe Drinking Water Act amendments of 1986 brought a large number of previously unregulated or minimally regulated contaminants under tighter controls through setting MCLs and requiring changes in plant operations, such as the addition of coagulation in all surface water systems prior to filtration. Increasingly stringent regulations will impact all phases of water system development from source selection to treatment design. When upgrading existing facilities to meet new regulations, a goal of design should be to produce a system that can consistently provide acceptable water quality and prevent significant future add-on costs. Some general design considerations include:

- Selecting the best source of water for treatment.

- Locating all potential existing and future sources of contamination.

- Striving for flexibility in treatment plant design to account for potential future changes in regulated contaminants.

- Proposing significant changes in process design only with the understanding of owners and personnel responsible for operation of the existing facilities.

4.17.1 Facilities Planning and Pre-design

Before existing facilities are expanded, planning and pre-design studies should be completed by qualified engineers and operations personnel. ADEC encourages a "conceptual" review meeting early in the process to prevent problems from occurring farther into the review plan process.

4.17.1.1 Elements

Planning and pre-design conceptual reviews should generally include:

- A description of existing facilities.
- Review of water quality and drinking water regulations applicable to the system.
- A water source evaluation.
- Review of plant capacity and staging alternatives.
- Review of process alternatives.
- Bench and/or pilot treatment studies.
- A design criteria summary, preliminary plant hydraulic studies, and operational considerations.

- Siting and layout considerations.
- Project cost estimates.

4.17.1.2 Issues

The following issues should be typically addressed in the preparation of a facilities planning and pre-design effort:

- Advantages and disadvantages of all potential raw water sources considering changes throughout the year to quality and quantity.
- All treatment technique requirements associated with each source for contaminant reduction and coagulant control.
- Operator requirements for effective operation of the equipment for proper water treatment with changes in source water quality.
- The effectiveness of storage for CT.
- The effect of each scenario upon the system or community including cost and level of operator expertise required.

4.17.1.3 Categorizing issues

Issues should be addressed in the facilities planning and pre-design effort by priority category.

- Category I issues: Imminent public health problem (e.g. inadequate disinfection practices).
- Category II issues: Design or operational features that have potential to lead to short-term (less than 5 years) public health problem (e.g. insufficient detention time for CT required at peak flows projected to occur in the future).
- Category III issues: Design or operational features that are not specifically process related that need to be adjusted to bring the system into full compliance with the SWTR (e.g., providing redundancy specified in the SWTR).

4.17.1.4 Timing and phasing considerations

The planning effort should include a plan to remedy problems and bring the facility into compliance with all drinking water regulations. This involves establishing an implementation schedule for bringing the facility into compliance, while keeping the existing facility on line and operational at optimum performance. The plan should contain:

- Time frames segregated by categories of problems.
- A plan that includes operational procedures as well as specific capital improvements.

5.0 DESIGN, OPERATION, AND MAINTENANCE OF FACILITIES

5.0 DESIGN, OPERATION, AND MAINTENANCE OF FACILITIES

5.1 Chemical Feeding

Chemicals such as coagulants, disinfectants, adsorbents, and alkali chemicals play an essential role in water treatment. Therefore the design and operation of chemical handling and feeding systems require special attention.

5.1.1 Application Points

Proper chemical feeding and the correct application point is critical to obtain the best treatment performance. As many application points as necessary should be provided to ensure that chemical injection points can be altered in the system if required. This flexibility provides for easier optimization of chemical dosages. This issue is critical in Alaska due to the variation in water temperatures, color, and turbidity throughout the year. Chemical reaction rates are longer in cold waters than in warm waters and more contact time must be provided, especially for coagulation.

5.1.1.1 Process related considerations

When coagulation is required for the removal of contaminants, one or more chemicals are added to form a floc particle in the water. The floc-forming coagulant, such as aluminum sulfate (alum) must be added far enough upstream of the filters or other treatment device to allow the floc particle to properly develop (see Section 4.3.1). This is extremely important when direct filtration is the treatment method. It is not as critical with conventional treatment in which a flocculation chamber allows the proper detention time for the coagulation process to occur. If the coagulant is not added early enough in the treatment system, allowing complete coagulation to occur, floc particles may develop in the distribution system. This situation causes unacceptable turbidity in the distribution system and usually leads to loss of water due to required flushing of the system.

When chlorine is used for disinfection it must be applied at a point in the system that provides the correct contact time for bacterial inactivation prior to the water reaching the first customer. In addition, there must be enough chlorine in the system to obtain the required residual throughout the distribution system. For further discussion of chlorination application points refer to Section 4.13.

5.1.1.2 Treatment objectives

Treatment objectives are to provide a means by which all selected contaminants in the raw water can be effectively removed or inactivated. The types of chemicals used and forms of treatment vary based upon the contaminant and other physical properties of the water.

5.1.1.3 System flexibility

There must be enough flexibility in the application points to allow chemical introduction throughout the system. This must also take into account changes in the raw water, especially temperature, as more time for coagulation will be required with cold waters. The following may be used as a guideline for application points of some commonly used chemicals.

Chemical		ApplicationPoint of Injection
Aluminum sulfate	Direct filtration	Before mixing and filtration
	Conventional	Before flocculation
Polymer	Direct filtration	Before mixing and filtration
	Conventional	Before flocculation
Potassium permanganate	Conventional	Before mixing flocculation
Chlorine	All treatment	Before or after filtration

5.1.2 Types of Chemical Feeding Systems

Chemical feeding systems are built for handling dry, liquid or gaseous chemicals. The type of chemical used is usually based upon the size of the system, water quality, site location and operator experience.

5.1.2.1 Dry feed

Any chemical delivered and stored in a dry form but fed as a liquid or slurry is considered a dry chemical. Examples include aluminum sulfate, potassium permanganate, soda ash, ferric chloride, and dry polymers. Equipment required to correctly feed these chemicals includes a scale for weighing, volumetric or gravimetric feeder, a solution tank, a mixer, and a chemical feed pump or other solution injection mechanism. Typical dry chemical feeding system layout is shown in Figure 5-1.

5.1.2.2 Liquid feed

Any chemical delivered, stored, and fed in a liquid form is considered a liquid chemical. Examples include liquid polymer and liquid alum. These chemicals are not used in some places in Alaska due to the cost of shipping such solutions, which do not contain a high percentage of actual product. Much of the product is usually water. A liquid feeding system schematic is shown in Figure 5-2.

5.1.2.3 Gas feed

Any chemical delivered and stored either as liquefied gas or gas and fed in a solution form is considered a gaseous chemical. Examples include chlorine, carbon dioxide and sulfur dioxide. A typical chlorine feeding system is shown in Figure 5-3.

5.1.3 Capacity and Reserve Provisions

5.1.3.1 Number of units

One complete set of dedicated chemical mixing and feeding equipment for each chemical used in the treatment process is to be provided at a minimum. In addition, chlorine neutralization systems must be installed that meet the requirements of the Uniform Fire Code. See Section 6.5, "Safety."

5.1.3.2 Standby provisions

Each pumped chemical used should have a spare pump unit on hand for standby while chemical feed pump repairs are being made. However, if the same type and model of pump is used for two chemicals, it is normally acceptable to have only one standby pump on site. Sufficient spare parts and any special tools required for maintenance should be provided for each pump to permit continuous operation of chemical feeding equipment at all times. Spare parts and tools should be specified with each purchase of chemical feed equipment. Specific requirements exist for disinfectant delivery by unfiltered surface water systems-see the state *Drinking Water Regulations*.

5.1.3.3 Criteria for capacity

The feeding equipment capacity should be based upon jar testing information obtained through on-site testing or from data available from similar sized systems. Where batch solution tanks are used to store chemicals ready to feed, the solution tank should be large enough to provide at least four to five days of chemical for the system. However, in the case of polymers, it may be necessary to make new solutions more frequently based upon operational experience and manufacturers' recommendations. In addition, the solution strength in the tank and chemical feed pump stroke rate or pump speed need to be coordinated so the pump can provide the desired dosage near the midpoint of its total output. Chemical feeding equipment should also be capable of operating over a minimum 5:1 range of output, or as required to achieve minimum and maximum output for the treatment process, whichever is greater (See Section 5.1.4.4).

Chemical feed pumps may either be continuous feed or pulse feed pumps, for either conventional treatment or direct filtration in which the volume pumped is determined by the plant flow rate or other variable.

5.1.4 Storage Provisions

5.1.4.1 Space criteria

Storage space is dependent upon how often chemical delivery is made to the site. Although more building space is required to hold several months of chemicals, as compared to one month, the building storage cost is offset by the cost to send chemicals by air freight to the site if ground or water delivery is not possible.

All chemicals should be stored in accordance with the manufacturers' recommendations and the requirements of all federal, state, and local codes. In most cases this includes providing a cool dry area for all chemicals. The design shall also include the requirements for storing noncompatible chemicals.

Essential chemicals include all chemicals used for disinfection or coagulation in treatment. Due to the geographical location of some systems in the state in which they are not served regularly by road, rail or water transportation, chemical storage areas should be designed to properly store chemicals for up to a year.

Non-essential chemicals are those used for corrosion control and taste and odor control. It also includes fluoride. Room should be available to store a minimum of 90 days worth of chemicals.

5.1.4.2 Storage type criteria

Different storage provision should be made for liquid, dry, and gaseous chemicals with regard to handling, safety, and corrosion.

For dry chemicals, storage should allow for access corridors between stacks of packaged chemicals. Combustibles and toxic chemicals should be stored separately. Provide ample space between materials that may interact, such as ferrous sulfate and lime.

For wet chemicals, provide agitation for slurries such as carbon or lime; not less than 1 hp mixing per 2.8 m^3 (100 ft^3). Consult manufacturers' literature and recommendations for designing feed equipment (pumps, pipe sizing, etc.). Check corrosion resistance of bulk storage linings. Isolate hazardous or toxic solutions such as fluorosilicic acid as per the requirements of Title III of the Superfund Amendments and Reauthorization Act (SARA).

For gaseous chemicals, provide cool, dry areas in which there is good access to all containers. Provide a safe route to move containers in and out of the feed area. Notify local fire personnel of chemicals in storage and specific location of the storage areas. Additional safety and handling data is found in Section 6.5.

5.1.4.3 Layout of space

Facilities should be arranged so that the chemicals are easily moved into storage, out of storage, and to the chemical feeding tanks.

Adequate work space should be provided around all feeding devices to enable easy preparation of solutions and so that equipment can be correctly operated and maintained. Piping should be arranged to facilitate access to and around equipment. Ideally, the equipment should be housed in a room separate from all other functions.

The design should include an area for weighing chemicals and a clean area to store safety equipment for handling chemicals. There should also be a separate room for laboratory equipment. Emergency eyewash stations, showers, and lockers should be provided.

Potable water will be needed for chemical solution preparation and wash down. Curb, slope, and provide drainage for the area. It is important to know where the drain water is piped, as chemicals going into the drains can be harmful to the environment if not handled correctly. Proper drainage disposal is part of the designer's responsibility. Drain piping materials are to be resistant to corrosive, abrasive, or other harmful characteristics of the solutions prepared. Adequate lighting, heating, ventilation, and fire protection should meet local codes, ordinances, and manufacturers' literature and material safety data sheets.

5.1.4.4 Control of chemical feeding

The control of chemical feeding is one of the most important items of proper water treatment to maintain safe potable water quality.

a. Monitoring

By determining the volume of chemical being delivered by the feeding equipment it is possible to determine the chemical dosage and to optimize plant performance. Chemical feed pumps should be calibrated to determine the volume delivered at different settings. This should be performed initially during plant start-up and once every three months during normal plant operation. It should also be performed as required when raw water changes are noted or when treatment results are unacceptable.

By installing monitoring devices in the raw water flow it is possible to monitor changes in source water quality. These devices can be used to send signals to chemical feeding equipment to either increase or decrease dosages based upon changes in source water quality. The results of chemical feeding can be monitored by other less expensive methods including visual observation, residual analyzers, flow meters, turbidimeters, compound loop controls, etc. In smaller plants, as a minimum, laboratory equipment should be provided to measure the source water and treated water contaminant levels that are not sent to a laboratory for analysis. Examples of such equipment include those for measurement of pH, chlorine residual, turbidity, and temperature.

b. Solution preparation

Chemicals must be properly weighed when they are added to make a solution water for feeding into the source water. Upon depletion of the chemical in a batch solution tank it is very important between batches to drain and clean the solution tank to ensure the correct concentration is actually achieved. Without proper cleaning it is impossible to determine the actual chemical concentration in the solution tank from one batch to another. See Appendix 3 for examples of solution preparation.

c. Dosage mechanisms

If the delivered volume of the chemical feed pump, the solution tank strength, and raw water volume is known, it is possible to determine the exact chemical dosage being applied. This is important when making chemical dosage changes to optimize treatment results. One way of determining the dosage is as follows:

Feed Rate (ppm or mg/L) = ml/min. (chemical) x % solution in tank x 10/flow (gpm) x 3.785

Example: Determine the dosage of alum being fed if 95 ml/min. of a 12% solution is being added to a flow of 378.5 liters (100 gallons).

Feed rate = 95 ml/min. x 12% solution strength x 10/100 gpm flow x 3.785

Feed rate = 30 mg/L alum

In larger plants chemical feed rates should be controllable both at the pump as well as in a central control room. The capability to have both manual and automatic adjustments is also important. Manual changes in the chemical feed rate are performed by the operator based upon noted changes in the raw water quality. Automatic feed rate changes are usually associated with flow proportional equipment which increases or decreases the chemical feed pump output based upon changes in water flow through the plant. Design equipment to operate as per manufacturers' recommendations. Other forms of equipment are available which change the chemical feed flows based upon turbidity or other residual readings such as chlorine.

d. Operational adjustments

It is extremely important to log all operational data daily using dedicated forms regarding the raw water, treated water, and chemicals used and their dosages. As the raw water characteristics change from season to season it is possible to look at the previous operational data and determine the approximate chemical dosages required. In addition, jar testing may also be used. These methods may only identify acceptable dosages and the operator will need to make additional fine adjustments to optimize dosages.

5.2 Facility Disinfection

To allow for the capability to flush and clean all treatment units, the following is suggested:

5.2.1 General Design Considerations

Facility design of systems utilizing surface sources or groundwater under the direct influence of surface water should include allowance for the inactivation of pathogenic bacteria and other microorganisms such as *Giardia* to meet the requirements of the SWTR. This requires arrangements for continuous disinfection.

To allow for the capability to flush and clean all treatment units, the following is suggested:

5.2.1.1 Drainage and flushing

Provide all equipment with proper drains, sized to allow draining and flushing of the unit(s) or internal sections. Locate the drains at elevations which allow efficient removal of the contents using gravity.

Provide water to allow flushing and cleaning of all units. Provide potable water near the chemical feeding equipment to allow flushing the chemical feed lines when the equipment is not in operation. When equipment is taken out of service, the equipment and associated piping should be drained, flushed, and then isolated. Before using the equipment and associated piping again, especially following long periods of isolation, equipment and piping should be flushed and disinfected.

5.2.1.2 Building

Design building foundations for the subgrade soil conditions. Design the building layout to provide drainage for all areas by using sloping floors to the drains. Connect drains to a containment area to allow cleanup of contaminants if required. The chlorine room must be provided with an alarm system to comply with the Uniform Fire Code and Uniform Building Code.

5.2.2 Routine Operating Procedures

5.2.2.1 Line flushing and sanitizing

Design the system to include high pressure water and cleanouts for proper flushing of all drain lines to minimize plugged drains. Drains should be capable of meeting anticipated flushing flows to eliminate the possibility of flooding the building during flushing and sanitizing operations.

5.2.2.2 Filter cleaning and chlorination

Provide water at gravity filters to clean any scum from surface areas during backwash operation. Regular monitoring of filters is required, and scheduled flushing of filters with a strong disinfectant solution in accordance with the filter manufacturer's instructions is necessary.

5.2.2.3 Plant cleaning and protection of unit processes

Provide potable water hose bibs for overall plant cleaning to allow protection of all equipment from chemical dusts and for cleaning of storage areas.

5.2.2.4 Clearwell and storage areas

Disinfect all wells, pipes, clearwells, tanks and equipment in accordance with current AWWA procedures before plant start-up. Outline the procedures, and include the disinfectant dosage, contact time, and method of testing the results for each procedure in the project design manual.

5.2.2.5 Maintenance of sedimentation and clarification

Provide high pressure wash water for cleaning of sedimentation and clarification basins or compartments. Design drains to meet or exceed the hydraulic flows.

5.2.3 Emergency Disinfection Procedures

Include an operating plan with procedures for emergency disinfection and include specific information and equipment available to provide emergency disinfection.

5.3 Interruptions in Service and Standby Components

5.3.1 Redundancy

Provide a redundancy of unit processes when possible to allow any unit to be shut down for maintenance or cleaning. Provide a redundancy of process equipment such as chemical feed pumps to allow for interchanging of components or to ensure the system will not be shut down while waiting for parts.

5.3.2 Treated Water Storage

Evaluate the need to provide more than one treated water storage tank for maintenance and cleaning of each without affecting the normal overall production and consumption requirements. An evaluation of the effect of required CT time shall also be made when one tank is out of service for maintenance and cleaning.

A volume of treated water storage sufficient for emergency needs at the treatment plant should always be maintained. These needs include fire protection, process washdown, and backwashing. During periods of interruptions of service, treated water storage should be monitored so that supplies for the treatment facility are reserved for operation when service resumes.

5.3.3 O&M Manuals

Operation and maintenance manuals for any treatment plant should contain preventive and unscheduled maintenance procedures for equipment. Follow manufacturers' recommendations. Adherence to a comprehensive preventive maintenance program minimizes the potential for interruptions in service.

5.3.3.1 Preventive maintenance

Each treatment facility should have a preventive maintenance program or list of procedures which are adhered to by the plant operations staff. Preventive maintenance work tasks should be a regular work item associated with plant operations, and documentation of preventive maintenance work tasks is necessary. Use of computerized preventive maintenance programs should be evaluated for each facility, in that these programs provide a comprehensive framework by which a program can be readily established. Either a manual or computerized program should be implemented which is best suited for the type plant being operated and the skill level of the plant operator.

5.3.3.2 Unscheduled maintenance

Unscheduled maintenance occurs when equipment fails to perform as intended. This work is minimized by careful attention to equipment operation and implementing a detailed preventative maintenance program, in accordance with the equipment manufacturers' recommendations. Each plant should have contingency plans prepared in anticipation of unscheduled maintenance on key process equipment.

5.3.4 Hydraulic Considerations

Included in design considerations should be the possibility of service interruptions and the effect on the system hydraulics. The plant should be able to function with the largest unit of each unit process out of service. Sufficient redundant units should be provided to permit the facility to continue operations and convey water through the plant. During such a scenario, water needs beyond what the facility can meet with one unit out of service should be met by drawdown from emergency storage.

5.4 Intermittent Operations

5.4.1 Facility Considerations

Design intermittent water treatment systems (those not operated continuously) with special emphasis on protection of equipment due to harsh weather conditions. The operation and maintenance literature should be simple to understand yet thorough enough to enable any operator to perform proper operation, maintenance, and winterization. Designers should:

- Design the treatment process to be as simple as possible yet meet the minimum requirements of treatment and disinfection.
- Provide all process equipment and treatment units with operation and maintenance information to allow all cleaning and maintenance to be easily performed.
- Design systems and feed lines with the capability to be flushed of chemical solutions and solution tanks with the capability to be drained and cleaned between uses.

- Provide equipment to allow accurate volume measurements of the treated water in storage at all times. Consideration should be given to the volume of treated water storage needed during periods of no water production. Factors that must be considered include public demand, fire protection, treatment plant use for start-up, and plant process needs. Provide sufficient storage to accommodate such water demands.

5.4.2 Operation Considerations

5.4.2.1 Disinfection of treated water in storage

Include provisions to allow disinfection of treated water in storage (e.g. in clearwells) to meet residual requirements throughout the system at all times. When necessary, water should be disinfected again through rechlorination.

5.4.2.2 Varying water quality

Design the treatment system to be capable of treating varying water quality which may range from turbidity removal in the summer to color removal in the winter. An operational plan should be included in facility O&M manuals to outline how the treatment system is intended to be operated for varying water quality. Special attention to equipment usage and bypasses is necessary for treatment plants where intermittent operation is practiced. Special treatment processes or equipment may be used for a seasonal water quality problem, and it is necessary that such equipment is suitably isolated from the system when not in use.

5.4.2.3 Source chemical quality

Test the water source for chemical and physical contaminants seasonally to determine the worst case conditions for proper treatment design. When significant seasonal changes in raw water quality or quantity occur, such as during spring breakup periods, water quality should be tested for purposes of determining treatment requirements.

5.4.2.4 Sizing components

Analyze the water treatment, storage, and distribution components so that all components are logically sized and are compatible with the varying water demands on the water system.

5.4.2.5 Personnel requirements

It is necessary to take into consideration the number of personnel that will be required to operate the system under an intermittent mode of operation. The availability of qualified operators to operate the system should be discussed with the local government, utility, or water system managers.

5.5 Fill-and-Draw Operations

As was discussed in Section 3.1, many fill-and-draw installations in permafrost areas must use shallow lakes for their water supply. These shallow lakes freeze to the bottom or form enough ice that the remaining water is extremely expensive to treat in the winter. To get around these problems, large storage tanks are filled in the fall while the lake water is of good quality and again in the spring after the ice melts. Enough water must be stored in tanks, 3.8-19 million liters (1-5 million gallons), to meet the installation's needs for about nine months during the long winter. Because of limited storage, fill-and-draw systems are not feasible for piped distribution systems. They usually support self-haul or community-haul systems.

5.5.1 Water Quality Considerations

Section 3.1 presented information on when the best quality water can be obtained. The treatment facilities needed and their sizing will depend on the overall water quality in the summer and how late in the fall or early in the spring pumping can or must take place. The primary water quality problem is organic material. It comes from the vegetative material the water travels through to reach the lake and material that has fallen into the lake because of erosion around the edges. Treatment usually consists of a coagulant or polymer feed, followed by pressure sand filtration, followed by carbon filtration and disinfection. The key is to remove enough of the organics to control the formation of THMs when the water is disinfected. Even if organics are not a problem, treatment must meet the requirements of SWTR.

Intakes must be designed so they can be skidded out on the ice if winter pumping is planned. The actual intake should be kept up off the lake bottom so the settled silt and organic materials are not pulled in. Intakes are usually provided with floats for summer use. Again, the actual intake should be supported off the bottom with the draw depth adjustable so water can be pulled from the depth having the best water quality. This can vary with surface wind conditions, lake turnover, and thermal stratification. The shallow tundra lakes usually become quite warm on the surface (over 15°C or 60°F) but are quite cold (4°C or 39°F) near the bottom. Treatment requirements and design are affected by water temperature (Section 4.2).

5.5.2 Storage

Storage tanks are a key part of a fill-and-draw system. The design of the tanks is no different, except probably the size, than that for any water tank in a cold region. All domestic water tanks should be constructed according to AWWA specifications, and the materials used must be certified for potable water use in accordance with U.S. Department of Agriculture, Food and Drug Administration (FDA) requirements. The four items that seem to cause the most maintenance problems for water tanks in cold regions are (1) tank foundation, (2) tank insulation, (3) corrosion prevention, and (4) water quality and temperature. These are described in the following paragraphs.

a. Foundation

The tanks are often located on permafrost. Unlike petroleum storage tanks, the water tanks and their contents must be kept at 4.5°C (40°F) or higher. This means there will be heat transfer outward through the tank bottom. This heat must be transferred horizontally to the atmosphere and not allowed to thaw the permafrost beneath the tank. This is sometimes accomplished by placing the tank on piling or wood cribbed foundations which allow cold air to circulate under the tank carrying the heat away. Because of the weight of water tanks, piling must be closely spaced and must be firmly frozen in the permafrost. A detailed soils program, including drilling, is recommended to make sure there are not thawed pockets beneath the site. Pilings placed in thawed pockets will not support the required weight. Also, care must be taken to make sure pilings around the perimeter of the tanks, which are usually not heavily loaded, are placed into the permafrost far enough that they do not frost heave. This is usually accomplished by placing the piles at a depth into the permafrost at least 3-4 times the estimated thickness of the active layer after the tank is constructed. The active layer under or near a tank will usually be deeper than in the undisturbed tundra because the insulating vegetative mat is usually disturbed during construction. Also, all pilings should be wrapped with several layers of 6 to 8 mil visqueen through the active layer to prevent the frozen active layer material from adhering to the piling. It is also very important that no bond breaking material such as grease, visqueen, or creosote be used on the piling in the length in the permafrost. Piles can be driven in an under-drilled hole or slurried into an over-drilled hole. However they are installed, it is important that they are completely frozen in before they are loaded. Pilings can be steel pipe, H-piles, or wooden piles.

When gravel is available, a pad foundation is usually the most economical tank foundation. The pads must be thick enough or contain insulation enough to prevent the heat lost through the tank bottom from thawing the permafrost. Thermopiles placed in the gravel can also be used to carry away this heat during the winter. Ventilated pads have also been used. Large diameter culverts are placed through the pad and fixed so they can be closed in the summer to prevent warm air from entering and thawing the permafrost. To accelerate freezing or heat removal, fans have been placed to blow cold air through these tubes in the winter.

b. Insulation

Nearly all water tanks in arctic areas are insulated. In subarctic Alaska, tanks with long detention times are usually insulated, especially if the water must be heated. The insulation thickness will depend on the cost of providing heat to the water versus the cost of the insulation. Insulation placed in the foundation or any other location where it may come in contact with water must not absorb the water or it must be well covered with a waterproof coating (Section 6.2.2). Tanks are usually insulated with 7.5-15 cm (3-6 in.) of sprayed urethane insulation covered with aluminum sheeting strapped in place or covered with a rubber based paint to protect it from physical damage, weather, and ultraviolet radiation. Insulations, if protected from light, moisture, solvents, and physical damage, will have the same life as the tank.

c. Interior Painting for Corrosion Prevention

Certain vinyl or epoxy based paints are both approved for use in domestic water tanks. The National Sanitation Foundation listing for Standard 61 should be consulted for approved coatings. If properly applied, either will provide corrosion protection for steel water tanks. However, for added protection it is recommended that tanks be further protected with an impressed current sacrificial anode system. The problem in northern Alaska is finding weather conditions which will allow the paint systems to be properly applied and cured. Both systems should be applied in several thin coats rather than a few thick coats. Between coats the paint must be properly cured in accordance with the manufacturer's instructions. At the same time, the tank must be well ventilated so the phenols and other by-products of curing can be removed from the paint. VOC monitoring may be requested to confirm adequate curing and minimum leaching of the lining.

Maintaining the required temperature and ventilating the tank (at the same time) can be very expensive when outside air temperatures seldom get above 10°C (50°F). As a result, the proper conditions are usually not provided and the paint application is seldom perfect. Tanks should be drained and thoroughly inspected at the end of the first year of operation and at least once every five years thereafter for corrosion. Rust spots should be thoroughly sanded and repainted.

d. Maintenance of Temperature and Water Quality

Maintaining the temperature of the water in the tank at or above 4.5°C (40°F) is critical to prevent the formation of ice. The maintenance of water quality is usually accomplished by a high level of initial treatment and subsequent disinfection of the water as it is continuously circulated to add heat. This circulated and heated water can also be filtered using charcoal or carbon filters if needed to maintain the "freshness." Aeration can be provided to maintain dissolved oxygen levels.

5.6 Filter Concerns

5.6.1 General

The descriptions of filter problems and concerns that follow are specifically oriented toward conventional high rate granular media filters. The context of many of the comments are equally applicable to pressure filters, diatomaceous earth filters, and to some degree slow sand filters.

5.6.2 Underdrains

Occasionally, the operator should allow the filter to drain down to a point where the water level falls below the media surface. As the surface of the media dries, the operator observes whether the media is uniformly level. Mounds or depressions are indicators that there may be underdrain problems. At the same time, the operator should determine any change in media surface elevation. An abrupt lowering of media surface is indicative of underdrain failure or disruption of the grading of support gravel. A slow drop in media surface over time for filters furnished with anthracite coal is normal since the brittle coal particles chip during backwashing, with the resultant fine coal pieces being discharged in the backwash waste. This is normal, and replacement coal should be added periodically.

5.6.3 Surface/Auxiliary Wash

Nozzles should be removed and inspected, and piping should be flushed periodically. Media retainage nipples over the nozzles should be replaced as they embrittle or erode away. Rotating units should be observed for free rotation. Worn parts should be replaced before other problems develop, like mud balls in the media.

5.6.4 Backwashing

Observation should be made regularly of each filter during backwashing. Operators should be looking for any unusual or irregular aspects of the wash. Does the media wash uniformly? Are the wash troughs level? Is excessive media lost over the wash troughs? All of these items are indicators of filter system condition. Irregularities should be repaired.

The backwash rate for proper media fluidization varies with changing water temperature. In many locations, 20-30% higher wash rate is required in the summer than in the winter when water is colder and more dense. Consult with the media supplier for the prescribed wash rate at the extreme water temperatures experienced and for the particular media provided.

Backwash steps should be sequenced generally, as follows:

1. Hydraulic wash with auxiliary/surface wash.

    - With water level drawn down to the wash trough, operate the auxiliary/surface wash for roughly 1 minute before starting the backwash flow.

    - After slowly increasing the wash rate to the prescribed rate for 30-50% media expansion, operate the surface wash for another 1-2 minutes before stopping the surface wash.

    - Upon completing the backwash, slowly reduce the backwash rate. Do not stop the backwash abruptly. Gradual reduction of flow will restratify the dual media or mixed media components, which is desirable.

2. Hydraulic wash with auxiliary air scour.

   - With water level drawn down to 5-7.6 cm (2 or 3 in.) above the media surface, commence the air scour operation.

   - After several minutes, bring backwash rate slowly up to about 3.4 l/sec/m^2 (5 gal/min/ft^2). Allow the air scour with water rinse to continue until the water surface rises to within several inches of the wash trough. Discontinue the air scour at this point to avoid losing media into the wash triangle.

   - Increase the backwash flow rate required for media fluidation as described in number 1, above.

   - The final step is the same as that in number 1, above, providing slow decrease in wash rate to restratify the media.

   If an air release occurs at the beginning of each filter backwash, air may be accumulating in the backwash piping. If the release is violent, damage to the underdrain can occur; also, the gradation of support gravel, if present, can be disturbed. Release of air at the high point in the piping before the backwash flow starts can eliminate this problem, or pressurizing the backwashing piping can prevent air from entering the pipe.

5.6.5 Filter Operation

a. Filling Dewatered Filter

When filling a dewatered filter, the filling must proceed slowly to avoid underdrain damage or displacement of support gravel. Either fill using the backwash system at a very low rate — say, 3.4 L/sec/m^2 [5 gpm/ft^2 or less — or use a hose and splash board to avoid media displacement.

b. Negative Head in Media

Avoid extending filter runs to the point where a negative head occurs in the media, gravel, and underdrain. Negative pressure leads to the accumulation of released dissolved gases from solution. These accumulated gases can release abruptly when the filter is stopped or during the start of backwash. Abrupt air release can damage underdrains or disrupt support gravel or both.

c. Record Clean Filter Head Loss

Keep a record of the clean filter head loss at the start of each new filter run. An increase in clean filter head loss over time can indicate plugging of the underdrain or perhaps mud ball formation in the media. Similarly, individual filter turbidity records should be recorded and reviewed. Changes from normal can provide a warning of a serious problem before the problem occurs.

d. Ice Formation

For winter operations where ice may form when filters are not operating at night, maintaining even a low rate of flow will help reduce ice formation. A thin skin of ice causes no problem, whereas a thick cake ice may not break up during backwash to the extent the pieces of ice will pass through the waste system. Also, backwash troughs are not usually designed for an ice load and could be damaged.

e. Media Disinfection

In plants that do not practice prechlorination, it may be beneficial to disinfect the media with a dose of 20-50 mg/L of chlorine to kill algae growth in the media and on the filter walls and troughs. Take care not to discharge the strong chlorine solution directly to natural waterways.

f. Turbidity Spikes in Effluent

Avoid high turbidity spikes in the filter effluent. Steps to avoid or reduce such turbidity spikes include:

- Operating the filter-to-waste system following backwash.
- Condition the filter media at the end of a backwash with addition of coagulant or coagulant aid. This helps reduce the turbidity spike that occurs when a washed filter is brought on line. Also, avoid starting and stopping filters during a filter run.
- Avoiding changes to the filtration rate during a filter run or if rate changes are unavoidable, making the rate changes very slowly.

g. Cross-connections

Avoid cross-connections. Be sure there is an air break in the backwash system between the backwash waste pipe and the waste drain system.

5.7 Monitoring and Reporting for Filtered Systems

5.7.1 Turbidity Monitoring Requirements

The purpose of the turbidity sampling and monitoring requirements for systems which use filtration is to ensure acceptable performance of the treatment process. The treated water turbidity is an indication of:

- *Giardia* cyst and particulate removal for conventional treatment and direct filtration.
- General particulate removal for diatomaceous earth filtration.
- Possible interference with disinfection for all filtration processes.

To comply with the state *Drinking Water Regulations'* monitoring requirements for turbidity, samples of the system's filtered water must be collected and the turbidity analysis must be performed.

5.7.1.1 Sampling location

For purposes of treatment process control, the sampling locations which should be considered include:

- Combined filter effluent prior to entry into a clearwell.
- Clearwell effluent.
- Plant effluent or immediately prior to entry into the distribution system.
- Average of measurements from each filter effluent.

The selection of sampling locations for demonstrating compliance with mandatory turbidity monitoring is left to the system operator, with concurrence from the ADEC.

5.7.1.2 Sampling frequency

Continuous turbidity monitoring of the effluent turbidity from each individual filter is recommended. According to the state *Drinking Water Regulations*, the turbidity of the filtered water at a minimum must be determined at least once every four hours that the system is in operation.

The sampling frequency may be reduced to once per day for systems using slow sand filtration or filtration treatment **other** than conventional treatment, direct filtration, or diatomaceous earth filtration, if the system can prove to ADEC that less frequent monitoring is sufficient to indicate effective filtration performance.

For systems serving 500 or fewer people, the sampling frequency may be reduced to once per day regardless of the type of filtration used if ADEC determines that less frequent monitoring is sufficient to indicate effective filtration performance.

5.7.1.3 Continuous monitoring validation

A system may substitute continuous turbidity monitoring for grab sample monitoring if it validates the continuous measurement for accuracy on a regular basis using a protocol approved by ADEC. Calibration of continuous turbidity monitors should be verified at least twice per week according to the procedures established in Method 214A of the 16 Edition of AWWA's *Standard Methods*.

5.7.1.4 Additional monitoring

If continuous monitoring of each filter effluent cannot be implemented, the following is recommended by EPA on a quarterly basis:

- Monitor each filter, either by grab samples or continuous monitors, through the course of a routine cycle of operation, i.e., from restart to backwash.
- Visually inspect each filter where appropriate for indications of physical deterioration.

These are general suggestions. The operators of filtration systems are encouraged to work with ADEC to determine the best overall monitoring program(s) for their particular filtration plant to establish the status of the filter units. Each filter within a system should be maintained so that each filter effluent meets the turbidity performance criteria for the combined filter effluent.

5.7.2 Disinfection Monitoring Requirements

The state *Drinking Water Regulations* should be consulted for details on the monitoring and reporting requirements for disinfection processes.

5.7.2.1 Sample location

Sampling locations should follow the guidelines below:

- The operator of each system must monitor the disinfectant residual of the water as it enters the distribution system and record the lowest disinfectant residual each day.
- The operator of each system must also measure the disinfectant residual in the distribution system at the same frequency and locations at which total coliform measurements are made pursuant to the requirements in the Alaska *Drinking Water Regulations*, in the section entitled "General Monitoring Requirements."
- For systems which use both surface and groundwater sources, ADEC may allow substitute sampling sites which are more representative of the treated surface water supply.

5.7.2.2 Sampling requirements

Each system that serves water to more than 3,300 people must continuously monitor the disinfectant residual of the water.

If there is a failure in the continuous monitoring equipment, the system may substitute grab sample monitoring every 4 hours for up to 5 working days following the equipment failure. Systems serving 3,300 people or fewer may take grab samples in lieu of continuous monitoring at frequencies as follows:

TABLE 5-1 Disinfectant Sampling Frequency

Population Served	Samples/Day
≤ 500	1
501 - 1,000	2
1,001 - 2,500	3
2,501 - 3,300	4

The grab samples must be taken at different times during the day, with the sampling intervals subject to ADEC review and approval.

If the free residual concentration falls below 0.2 mg/L, the system operator must take another sample within four hours and notify ADEC as soon as possible, but no later than the end of the next business day, even if the residual is restored to 0.2 mg/L or greater within four hours. If the residual is not restored to 0.2 mg/L or greater within four hours, the system is in violation of a treatment technique requirement.

5.7.3 Operators Monthly Reports

Filtering systems must report to ADEC on a monthly basis, within 10 working days after the end of each month water is served to the public, per the Alaska *Drinking Water Regulations*. The following subsections outline the contents of the monthly reports.

5.7.3.1 Treated water turbidity

Reports must include information on treated water turbidity. Information should include (descriptions refer to portions of ADEC form):

- The treated water turbidity measurements made during the month.
- For turbidity measurements that were equal to or less than the turbidity limits specified in the state *Drinking Water Regulations* for the type of filtration being used, the report must have the number of measurements below the limit during the month, and the percentage of total number of measurements below the limit.
- If one or more turbidity measurement exceeds 5 NTUs, the system must report the date of each occurrence and the value of each excessive measurement.

5.7.3.2 Disinfection

Systems must report on the disinfectant residual of water entering the distribution system, including:

- The lowest measurement for each day of the month.
- The date and duration of each period when residual was below 0.2 mg/L.

- The date ADEC was notified each time the residual fell below 0.2 mg/L.

5.7.3.3 Distribution system monitoring

Information to be included on the monthly report regarding distribution system monitoring includes:

- The number of disinfectant residuals measured.
- The number of instances when residual was not measured but HPC was measured.
- The number of instances when disinfectant was measured and not detected and HPC was not measured.
- The number of instances when residual was detected and when HPC was greater than 500/ml.
- The number of instances when residual was not measured and HPC was greater than 500/ml.
- The monthly value of V in the computation formula:

$$V = [(c+d+e)/(a+b)]x100$$

where:

a = The number of instances when the residual disinfectant concentration is measured.
b = The number of instances when the residual disinfectant concentration is not measured, but HPC is measured.
c = The number of instances when the residual disinfectant concentration is measured but not detected, and no HPC is measured.
d = The number of instances when no residual disinfectant concentration is detected, and when HPC is greater than 500/ml.
e = The number of instances when the residual disinfectant concentration is not measured, and HPC is greater than 500/ml.

- The value of V in the previous month.

Forms for use in monthly reporting are available from ADEC.

5.7.4 Special Reports

A system operator must report to ADEC as soon as possible, but not later than by the end of the next business day, the following:

- Discovery that a waterborne disease outbreak may be traced to the water system.
- Instances when the turbidity exceeds 5 NTUs.
- Instances when the disinfectant residual of water entering the distribution system falls below 0.2 mg/L.

5.8 Operational Plan for Facilities

An operational plan for any treatment plant should provide a concise description and implementation schedule of major topics concerning the proper administration and functioning of the facility. This plan should be developed prior to start-up of new or expanded facilities.

5.8.1 Budget

A section shall be devoted to the budget for operating and maintaining facilities in good working order. Budgets should be established for:

- Administration.
- Supplies.
- Utilities.
- Labor.
- Routine operations, preventative maintenance, and major maintenance.
- Capital replacement.

5.8.2 Financial Management System

The management system may be manual or computerized, but at a minimum, the operations plan should include samples of the following:

- Accounting of system expenditures and revenues.
- Inventory control.
- Payroll.

5.8.3 Staffing and Training

There should be a staffing plan which includes staffing patterns, salary schedules, staff structure and organization, and operator training or certification requirements.

Regulatory requirements for operator certification or qualification depend upon the size of the water system. Operator qualifications and certification must conform to regulations, discussed in Section 5.9.

The operational plan should include a section addressing training needs of operators for the specific water system. Elements of the training plan should specify:

- Start-up and operation of facilities.
- Continuous employee safety and operations training.

5.8.3.1 Staffing structure and organization

Proper plant design will consider what type and organization of operators and technicians will be available to operate and maintain the facility. Based on availability of trained and capable personnel, a plan should be generated to provide all required technical skills to operate the facility.

An employee polices and procedures section of the plan must address items such as hiring a chief operator, technicians, and other support personnel; hours of work; staff rotation; and administrative procedures.

5.8.4 Emergency Operations

The operational plan should include sections addressing emergency operating procedures. Elements of the emergency operations plan must include:

- Vulnerability analysis.
- Emergency response program to maintain water quality and water quantity.
- Protection of health and property.
- Public notification procedures.

5.8.5 System Performance Monitoring

The operations plan should include an analysis and description of performance monitoring of the facilities. Topics to be addressed include:

- Process control.
- Chemical feed calculations for contaminant control.
- Consumption calculations.

- Reporting procedures.
- Monitoring plan to ensure compliance with SWTR.
- Laboratory procedures.
- Quality assurance and quality control procedures.

5.8.6 Start-up Services

The plan should outline start-up services to be used for new or expanded treatment facilities. Services must include:

- Assistance for the operator during start-up from equipment manufacturers' representatives, the designer, construction personnel, and the owner's maintenance personnel. Services should include plant equipment field testing, supervision of process start-up, initial calibrations, performance testing, and troubleshooting.

- Operator training in operation and maintenance of specific treatment processes and equipment, detailed laboratory procedures, maintenance management procedures, and records management procedures.

5.8.7 Development of O&M Manuals

Development of an O&M manual is an essential part of the plan of operation and is required by Alaska *Drinking Water Regulations* under the section entitled "Engineering Plans." The O&M manual should provide essential information and guidance for the treatment plant for day-to-day operations. Equipment manufacturers' technical manuals can be used to provide some of this information. As a minimum, the manual should include:

- Process design assumptions and criteria.
- Unit process information.
- Start-up, shutdown, routine, and abnormal operating procedures for each unit operation and piece of equipment.
- Maintenance management system including schedules and procedures for routine adjustments, lubrication, and other preventative maintenance procedures, as well as spare parts inventory.
- Laboratory test procedures.
- Safety procedures.
- Troubleshooting guidelines.
- Emergency operating procedures.

O&M manuals shall be complete and available for use as indicated in the current ADEC drinking water regulations.

5.9 Operator Requirements and Training

5.9.1 General

All Class A and Class B public water systems that fall under the SWTR must be operated by a "qualified operator." Certified operators, as defined in 18 AAC 74, are required for systems serving more than 500 people or having over 100 service connections. The State of Alaska has the responsibility for determining the minimum qualifications to operate water systems. As water systems are modified and upgraded to meet the SWTR, the operator certification and ongoing training requirements will be defined based on the level of complexity of the facility, monitoring requirements, and other related issues.

5.9.2 Proposed Minimum Qualifications

Current water and wastewater operator certification regulations (18 AAC 74) have been in effect for a number of years. The SWTR as adopted in Alaska did not affect these regulations. The existing certification regulation does not apply to the smaller water systems (i.e., those serving less than 500 persons or 100 service connections). However, many smaller system operators have applied for certification under 18 AAC 74 over the years, and ADEC continues to actively encourage this.

To adopt the SWTR, ADEC issued revised drinking water regulations in March of 1993. In doing so, ADEC has defined "qualified operator." The smaller Class A and B systems not subject to the normal certification regulations have two options for complying with "qualified operator" requirements.

Option 1: Apply for operator certification under the current operator certification regulations of 18 AAC 74 at an Operator-In-Training (OIT) level or higher. To be eligible for certification at the OIT level, an applicant must have graduated from high school or received a GED and must have at least three months of experience operating a water treatment system. Instead of the three months of experience, an applicant who has taken an approved training course can be considered eligible for examination and certification.

Option 2: Successfully complete an ADEC approved training course, either a short course or correspondence course. The intent of the training course requirement is to qualify owner-operators to maintain their own systems. Completing an approved training course does not qualify a person who completes the course to operate a system which requires a certified operator under 18 AAC 74.

ADEC continues to strongly encourage all Class A and B system operators to pursue Option 1 and become certified under 18 AAC 74 (especially the Class A system-operators).

For qualified operators not certified under 18 AAC 74, the following requirements apply for renewal and revocation.

- A qualification and each subsequent renewal are valid for a three-year period. ADEC will renew a qualification only if an operator has actively and continuously performed the duties of a water treatment operator during the three-year period, or if an operator has successfully completed an approved refresher course and exam by the end of the three-year period.

- During sanitary surveys, on-site inspections, or other site visits, the ADEC will evaluate the operator's proficiency in operating the water treatment system. If the operator is unable to demonstrate proficiency, ADEC will require additional training and examination, which may include an on-site "over the shoulder" practicum. If the operator does not successfully complete the required training within the time specified by ADEC, ADEC will, in its discretion, revoke the operator's qualification.

- ADEC will, in its discretion, revoke a qualification upon a finding of fraud or deceit in obtaining the qualification, fraud or deceit in reporting or record keeping, or gross negligence in the operation or maintenance of a system. If ADEC revokes an operator's certification, the operator may not apply for certification for one year after revocation.

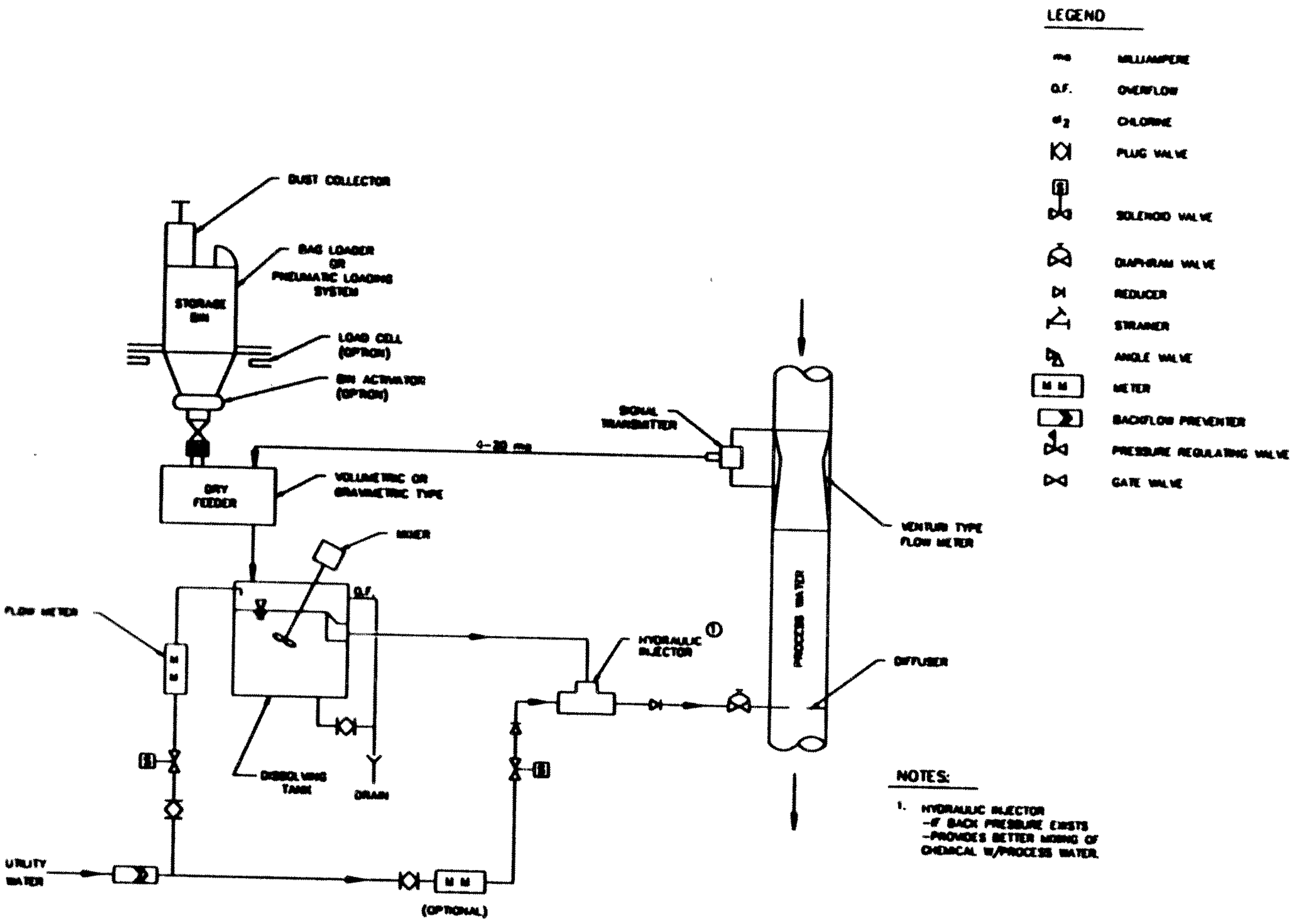


Figure 5-1 Dry Chemical Feeding System with Dissolving Tank

NOTES:

1. TANKS, HORIZONTAL OR VERTICAL.
2. FLOW PACING—VARIABLE SPEED MOTOR DOSAGE SETTING—PUMP STROKE.
3. VOLUME OF ENCLOSURE AROUND STORAGE TANK SHALL BE SLIGHTLY GREATER THAN LIQUID VOLUME OF TANK.
4. MAGNETIC FLOW METER FOR MONITORING (OPTIONAL).
5. PROGRESSIVE CAVITY TYPE PUMP MAY BE USED IF RANGE OF FEED CONDITIONS CAN BE MET.

NOTE:

SEE FIGURE 5-1 FOR LEGEND

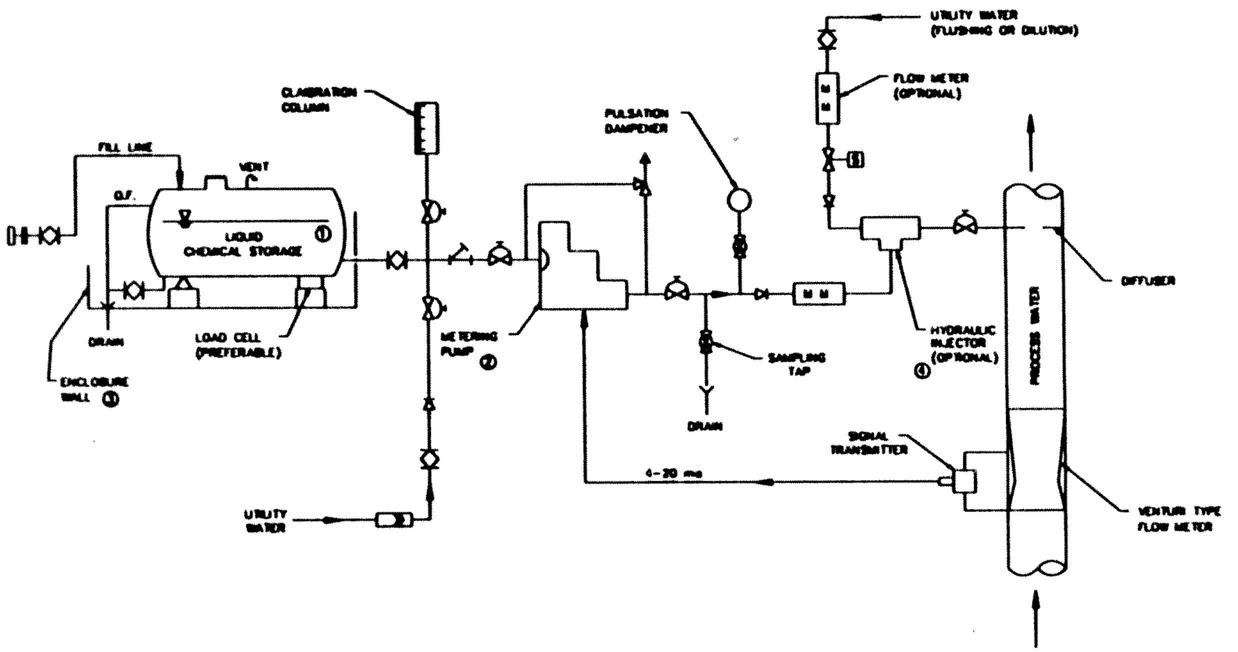


Figure 5-2 Liquid Chemical Feeding System (Metering Pump System)

NOTE:
SEE FIGURE 5-1 FOR LEGEND

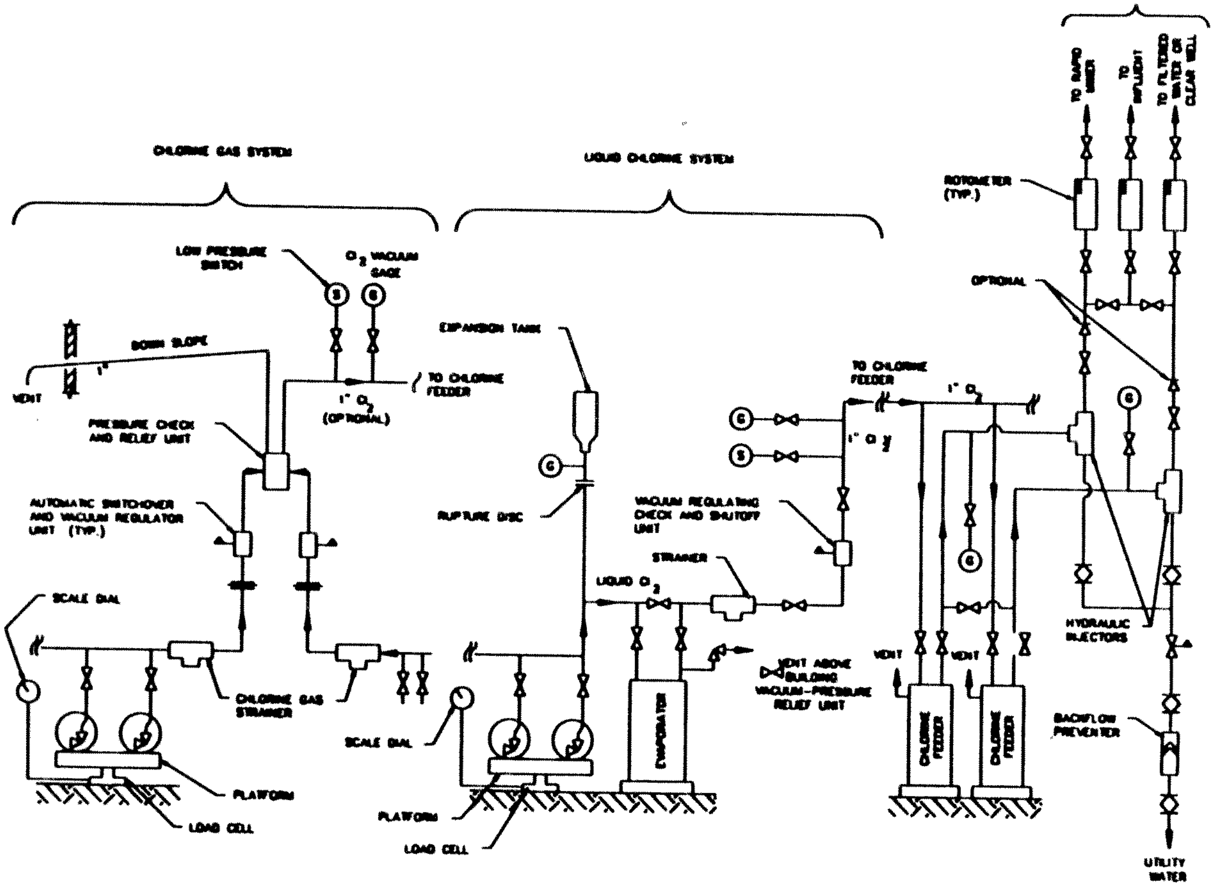


Figure 5-3 Gas (Chlorine) Feeding System

6.0
OVERALL PROJECT DESIGN CONSIDERATIONS

6.0 OVERALL PROJECT DESIGN CONSIDERATIONS

6.1 Hydraulic Design Criteria

6.1.1 Plant Capacity

6.1.1.1 General

Community water systems should provide a dependable supply of potable water to meet the needs of the community.

6.1.1.2 Design capacity

Data on water consumption in Alaskan communities indicate a wide range in water use rates. Both the latest water use rate and the demand growth trend for the system being designed should be used in establishing the design rate. If actual use rates are unavailable, then rates of 180-378 liters per capita per day (50-100 gallons per capita per day), depending on location, are appropriate for a system with new piping. Water use in older systems may exceed 757 liters per capita per day (200 gallons per capita per day) due to intentional winter water wasting and system leaks. Conversely, rural systems may only have a water consumption rate of 75-114 liters per capita per day (20-30 gallons per capita per day). Where data is lacking for non-rural communities, an estimate of 285 liters per capita per day (75 gallons per capita per day) is commonly used.

6.1.1.3 Water consumption

Total water consumption should be computed using the best available use rate and accurate population for a 20-year growth. If unavailable, then use a design population based on a 50 percent increase in the number of dwelling units. The facility should be designed for easy expansion. This will usually involve laying out future facilities during the initial design.

6.1.1.4 Water demand ratios

Water consumption varies considerably over the year and during the day and differs in various communities. Some of the variations are attributable to climatic conditions, socioeconomic levels of the community, the relative amount of commercial and industrial development, percentage of customers metered, and water rates.

While not a domestic demand, the water supply system should be designed considering the community fire protection needs. Fire flows and reserve storage can be a large part of the total water supply and storage requirement for a small community.

In many Southcentral and Southeast Alaska communities, intentional water wasting is practiced as a freeze prevention method. This can seriously impact the water supply and demand projections for the community.

Because of these many variables, historical water use records in Alaska communities are more valuable in forecasting future requirements than records from Lower 48 communities. Each water system should have records of consumption by various classes of consumers or, as a minimum, a record of meter readings at the source. With such statistics of past operations and a reasonable estimate of future developments, it is possible to forecast requirements for the future. This method is recommended over the commonly used population per-capita use method.

Annual and diurnal variations in water demand are usually expressed as ratios to the average demand. General estimates for demand ratios are shown in Table 6-1.

TABLE 6-1
Water Demand Ratios

Ratio of Rates	Normal Range	Average
Maximum Day: Average day	(1.5 to 3.5):1	2:1
Maximum Hour: Average day	(2.0 to 7.0):1	4.5:1

The daily maximum flow is used in selecting sources of supply and sizing of raw water and treatment facilities. Minimum operating pressure in the distribution system is typically assumed to be 137 kN/m^2 (20 psi) at service conditions or during fire flows.

The hourly maximum water usage is used in the design of treated water storage and pipelines to meet the peak demands of the system.

Peak hour instantaneous flows are typically not of interest to the system designer unless the system is delivering treated water on demand with no interim treated water storage.

6.1.2 Limiting Velocity Gradients

Velocity gradients are an important facet of the hydraulic character of a treatment plant. They are means of comparing the relative shear forces and degree of turbulence for individual unit processes. Some of their applications are discussed below.

- The velocity of the process flow after flocculation should be greater than 0.15 m/sec (0.5 ft/sec) to avoid deposition of the flocculent material prior to the sedimentation basins.
- The velocity of the process flow after flocculation should be less than 0.91 m/sec (3.0 ft/sec) to avoid floc breakup.
- In any chemical conditioning process, velocity gradients should be high enough to ensure ample turbulence for chemical dispersement and mixing.
- Excessive inlet turbulence may scour the filter media's surface. Excessive inlet turbulence should be avoided and, in general, the velocity of water in pipe and conduits to the filter should be limited to 0.61 m/sec (2.0 ft/sec). Other options to avoid media disturbance include baffling and distribution headers upstream of the filter boxes.
- Hydraulic designs should provide for even flow distribution to parallel process units. This is necessary to ensure proper operation of the process units. For larger treatment plants, flow splitting boxes with weir gates are often used to achieve this. On smaller plants, flow meters and modulating control valves can also be used to effect an even distribution between parallel processes.

6.1.3 Head Loss Limitations

6.1.3.1 Granular media filters

Excess head loss across either pressure or gravity granular filters can cause turbidity breakthroughs, underdrain damage, and negative pressure on the bottoms of the filters, which can lead to air binding.

In general, filters should be backwashed when the operating head loss across them approaches 2.4-3.0 m (8-10 ft). A clean filter may have between 0.3-0.9 m (1-3 ft) of head loss across it depending upon the construction and condition of the media.

6.1.3.2 Diatomaceous earth filters

The head loss across a DE filter should not exceed 137 kN/m^2 (20 psi) for pressure DE filters. Excessive head loss may cause septum damage and turbidity breakthrough.

6.1.3.3 Membrane filters

Head loss across membrane filters should not exceed manufacturers' recommendations. Excessive head loss and over-pressurization may cause membrane damage or failure.

Failure in membrane filters can be monitored by on-line particle counters. The particle counters should be part of the filter instrumentation and control system, providing automatic shutdown of flow through the affected membranes upon detection of breakthrough.

6.2 Structures

There are several important aspects of water treatment structure design in cold regions. Nearly all functions of water treatment must be housed for protection as well as ease of maintenance and operation of equipment. Certain process units require heated shelter, while for others, an unheated shelter may suffice, depending on air and water temperatures in the area. Generally, processes which include equipment such as pumps and exposed piping must be housed and heated to prevent damage from freezing.

Combining different functions under one roof rather than in a group of smaller buildings reduces surface area and heating requirements. Piping and electrical runs may be shorter and less expensive to install and maintain. Possible expansion in the future should be considered when selecting the single-building concept. The floor plan can be critical to building efficiency. Designers should place areas which require stable heat in the interior of the building. Rooms for storage and other less vital functions can be allotted the space along the outer walls. In this manner, heat lost from the interior is used to heat other space before escaping outdoors. Building shape can be optimized to reduce surface area, and buildings can be oriented to take advantage of the low winter sun (most windows should face south).

6.2.1 Construction Materials

Exterior building walls are often composite (sandwiched) and can be preconstructed and shipped to the site. They usually consist of a plywood interior with metal or wood siding on the outside and the space between filled with urethane insulation. Plumbing should all be kept on or in interior walls to reduce the possibility of freezing. It is also best to keep wiring in interior walls or the attic. If it must be placed in exterior walls, care should be taken not to damage the integrity of the vapor barrier when the wiring is installed. Stick built (on-site) buildings usually use conventional methods with fiberglass insulation. Care should be taken to not have bolts, nails, or other metal fixtures extend from the interior of the building to the exterior. Heat will be transferred quickly through the metal and considerable ice can form on the interior around the object.

Windows are necessary, but they are a high heat loss and maintenance item, and therefore, should be designed to provide the most benefit with the smallest area. Window orientation toward the south, multiple glazing, and wood casings maximize insulation and energy savings. Windows extending above and below eye level should be avoided, but it is important to be able to see outdoors while sitting or standing. Since windows are of little visual value during darkness, insulated shutters or curtains should be provided to reduce heat loss. The most economical number of panes for a given location can be calculated knowing window costs and heating costs.

Building entrances should not be placed in the windward or leeward sides of buildings. These locations are prone to drifting snow. A double-door system (arctic entry) should be used with a space between the doors large enough for one door to be closed before the second one is opened. This greatly reduces the air exchange when people go into or out of a building. All doors and entrances must be protected from snow and ice falling from the roof. Serious accidents have occurred when, after a door is slammed, ice falls on someone leaving the building.

6.2.2 Insulation

Buildings should be insulated to minimize the total annual cost of heat. Since insulation must be kept dry, vapor retarders are a very important part of any building in cold regions. Information is available concerning vapor retarders and types of insulation suitable for different applications. Absorption of 8% moisture (by volume) reduces the insulating value of insulation by 50%. An impermeable or low water-absorption insulation must be used in damp or wet locations. The reduction of heat loss during air exchange is often as important as insulation in reducing heat losses from buildings. Air-to-air heat exchangers can be used to recover heat from this exchange air as some air exchange in buildings is necessary. Equivalent quantities vary with use, and quantities are usually stipulated in building codes. Anything over these minimums should be avoided.

The appropriate type and thickness of insulation for piping and structures in cold regions must be selected. The thickness may be determined from economic analysis or other considerations such as freeze-up time or building comfort. Common insulating materials are plastics, minerals, natural fibers, and composite materials. For design purposes, the structural and thermal properties for the worst conditions should be used. These conditions usually occur after the insulation has undergone aging, compaction, exposure to moisture, and freeze-thaw cycles. Other selection considerations are ease of installation, vapor transmission, burning characteristics, and susceptibility to damage by vandals, animals, chemicals, and the environment.

The insulating value of a material depends on the volume of entrapped gas it contains. If the material becomes wet and the voids fill with water, the insulating properties are lost, because the thermal resistance of air is about 25 times that of water and 100 times that of ice. The availability of rigid closed-cell plastic foam insulation with low thermal conductivity and high resistance to water absorption has dramatically influenced the design of utility systems in cold regions. Knowledge of the properties and limitations of insulating materials is essential.

6.2.2.1 Polyurethane

Polyurethane foam is used extensively in cold regions to insulate pipes, storage tanks, and some buildings and foundations. Urethane bonds to most materials. Piping, sandwiched building panels, or other components can be pre-insulated, or polyurethane can be prepared on site from the raw chemicals (which are about 1/30 the final volume) and then applied. Field applications are restricted by low temperatures. The ideal formation temperature is about 20°C (70°F). The density and thermal conductivity are often poorer than values attainable under factory conditions. The foam must be protected from ultraviolet radiation during shipping and use. Only a metal skin has proven effective to prevent "aging"—the loss of entrapped heavy gas. Entrapped heavy gas increases the thermal conductivity by about 30% above the theoretical minimum value. Depending on the formulation, urethanes can have a higher flame spread rating than other building materials. They are combustible, and a flame-protective barrier is usually required by building insurers and building codes. If ignited, plastic foams release smoke and toxic gases. Foams with densities over 100 kg/m^3 are essentially impermeable, but lighter foams, which are better insulators, require coatings to prevent water absorption, since cycles of freezing and thawing of moisture in the insulation can lead to its deterioration. Table 6-2 presents properties of several materials. These values are representative, but most materials have a variation in thermal properties.

6.2.2.2 Extruded polystyrene

Extruded polystyrene, particularly the higher-density products (50 kg/m^3), deteriorates least from moisture absorption and freeze-thaw cycles, but the outer 5 mm of unprotected buried insulation should be disregarded in thermal analyses. It is available only in board stock. Molded (expanded) polystyrene absorbs some moisture and should not be used in moist conditions. Expanded polystyrene is available in board stock or beads. Beads are useful for filling voids in utilidors for maintaining easy access to pipes and in walls. Table 6-2 presents some typical thermal properties.

6.2.2.3 Fiberglass

Glass fiber batt insulation is the most common building insulation, primarily because it is fire-resistant and relatively inexpensive. But glass fiber insulation is not water resistant. Wetness or compacting reduces its insulating value significantly: by half, if 8% by volume is water, for example. For this reason, glass-fiber should not be used underground or anywhere it will come in contact with water or be compacted. It is commonly used in building walls, floors, and ceilings where the structure is stick built at the site. A continuous vapor retarder is important.

6.2.2.4 Other types

Cellular glass is very water resistant, but is seldom used because it is brittle, difficult to work with, and deteriorates with freeze-thaw cycles. Lightweight insulating concrete made with polystyrene beads, pumice, or expanded shale can be formulated for relatively high strength and thermal resistance. It can be poured into place around piping but should be protected from moisture to prevent freeze-thaw deterioration. Many other insulating materials, including new products, such as sulphur foam and urea-formaldehyde, may also find specific applications in cold region engineering.

6.2.3 Construction Methods

There are three major construction techniques: on-site fabrication ("stick built"), prefabrication, and modular. With on-site fabrication construction the materials are shipped to the site, and all cutting and fabricating is done on site. With prefab construction, parts of a structure and equipment are prefabricated at the point of manufacture and assembled at the site. Modular construction means large components are constructed at the point of manufacture and shipped to the site already constructed.

Each technique can be useful under difficult circumstances. Modular construction has a definite advantage where the construction season is short, where there is a labor shortage, or when labor is expensive at the site. Shipping limitations may dictate on-site fabrication or possibly prefabrication rather than modular construction. Modular construction may allow the facility to be placed in operation with most of the defects worked out at the point of manufacture, but field changes to fit varying site conditions are more difficult and expensive to make.

TABLE 6-2
Thermal Properties of Materials

Materials	Dry Density kg/m^3	Specific Heat Capacity kJ/(kg x °C)	Thermal Conductivity W/(m x °C)
Air, no convection (0°C)		1.00	0.024
Air film, outside, 24 km/h wind (per air film)			0.86 0.24
Air film, inside (per air film)	32	1.67	0.024
Polyurethane foam	30	1.26	0.036
Polystyrene foam	55	0.84	0.040
Rock wool, glass wool	85	2.09	0.08
Snow, new loose	300	2.09	0.23
Snow, on ground	500	2.09	0.7
Snow, drifted and compacted	900	2.09	2.66
Ice at -40°C	900	2.09	2.21
Ice at 0°C	1,000	4.19	0.58
Water (0°C)	250	2.09	0.07
Peat, dry	250	1.34	0.14
Peat, thawed, 80% moisture	250	0.92	1.73
Peat, frozen, 80% ice	1,140	1.67	0.70
Peat, pressed, moist	1,700	0.92	0.9
Clay, dry	1,700	1.76	1.6
Clay, thawed, saturated (20%)	1,700	1.34	2.1
Clay, frozen, saturated (20%)	2,000	0.80	1.1
Sand, dry	2,000	1.21	3.2
Sand, thawed, saturated (10%)	2,000	0.84	4.1
Sand, frozen, saturated (10%)	2,500	2.72	2.2
Rock typical	600	2.51	0.17
Wood, plywood, dry	500	2.09	0.12
Wood, fir or pine, dry	700	0.88	0.17
Wood, maple or oak, dry			
Insulating concrete (varies)	200 to 1,500		0.07 to 0.60
Concrete	2,500	0.67	1.7
Asphalt	2,000	1.67	0.72
Polyethylene, high density	950	2.26	0.36
Polyvinyl chloride, PVC	1,400	1.05	0.19
Asbestos cement	1,900		0.65
Wood stave (varies)			0.26
Steel	7,500	0.50	43
Ductile iron	7,500		50
Aluminum	2,700	0.88	200
Copper	8,800	0.42	375

6.2.4 Humidity Control

Humidity is an important consideration in cold regions, especially inland. Outside humidity drops to extremely low levels with cold weather. For comfort, typical building relative humidity is usually kept at about 30% using humidifiers. Just the opposite condition is usually encountered in water treatment facilities. A high relative humidity (above 50%) can cause serious problems from condensation on windows and walls and in insulation. During warm spells or in the spring, this frozen condensate can ruin paint and insulation and can cause corrosion or even destroy the building by inducing wood rot. In very humid areas, such as pump houses or sewage lift stations, moisture control or dehumidifiers are often necessary.
Exhausting warm humid air outdoors in the winter can cause significant ice fog. Ice fog can become a safety problem if it reduces visibility.

The high humidity in a treatment plant or pump house can cause rapid deterioration of electrical controls because of corrosion, especially in the presence of chlorine disinfection facilities. Electrical facilities used in these locations should be rated for the high moisture situation they will encounter. Buried facilities such as pump stations and lift stations should never be left without heaters or dehumidification equipment once they are installed or the electrical components will deteriorate rapidly.

6.2.5 Hydrology and Drainage

Structures must be protected from erosion and flooding damage. This damage can be caused by the flooding of streams or rivers or by poor site drainage. The ground should be sloped away from the structure so rainfall and runoff are removed. It is also critical to provide adequate floor drains for all water utility structures. Sooner or later pipes or tanks will leak or need to be drained. Floors, even concrete, must be thoroughly waterproofed and sloped to drain adequately. Standing water cannot be permitted in any facility.

Erosion is a constant threat along streams and rivers, as is discussed in Section 3.1.2.4. The amount of erosion to be expected at a given site can be estimated, and erosion protection must be provided if the structure cannot be placed where it will not be damaged over its life. Cutbanks are a good indication that a stream channel is moving and that the stream will continue to erode into the bank. Sandbar deposits usually indicate the stream channel is moving away from those deposits.

6.2.6 Heating

All water treatment or pumping structures must be kept above freezing at all times. However, unless needed for operator comfort, they should be maintained at a temperature below 8°C (45°F) to conserve heat, lower operational costs, and reduce condensation problems.

In remote areas, heat is usually supplied using oil fired heaters. Electric heaters are sometimes used where electrical generators must be run continuously for other needs or where a very small amount of heat is needed (such as Southeast Alaska). If natural gas is available, it is usually the most economical fuel to use. All gas or oil fired heaters or boilers must be vented to the outside and need a source of combustion air from the outside, especially small buildings. Heat distribution within the structure is usually hot water with unit heaters having fans or radiators. These circulating systems should be charged with a mixture of glycol and water, approximately 50-50, for protection from freezing. Because the facility is for potable water, it is advisable to use propylene glycol rather than ethylene glycol.

Another very important and economical source of heat to consider is "waste" heat from the engines driving electrical generators. Approximately one-third of the energy in the fuel is converted to electricity and one third goes up the exhaust stack. This portion can be recovered, but not as economically and easily as the remaining one-third which is dissipated by the fan and cooling system. Prepackaged heat exchangers are available for most units to easily recover this heat and use it to heat water tanks and structures.

6.2.7 Lighting

In cold northern climates, adequate lighting is important, both inside and outside of structures, to compensate for reduced winter daylight. Controls for lighting circuits can be designed so that minimum light is provided in unoccupied areas with supplementary lights available as needed. Unless relatively small lighting circuits are provided, appreciable power may be used for a function not actually needed. Use several small lighting circuits rather than one or two larger circuits.

Electrical energy can be conserved by using fluorescent lights over incandescent lights. Incandescent lights convert only about 10% of the electrical input into light, whereas fluorescent lights convert about 25%. The fluorescent lamp is rated for 18,000 hours of life; the incandescent bulb is rated for 1,000 hours. The remainder of the energy from each is in the form of radiation or convected heat. Even more efficient light sources are the sodium halide lamps. The choice of light source must depend on other factors as well, such as the mounting height and location and the use of the light.

Most lighting is manufactured to operate at a minimum of -29°C (-20°F). Temperatures lower than this have a direct influence on the life and efficiency on the various lights normally used outdoors. The problems, which must be considered, include:

- Ionization of the fill gas.
- Starting voltage and times.
- Freezing temperature of the equipment.

The best light for use outside in cold weather is actually an incandescent light because of its fast starting. Fluorescent lighting should not be used below -18°C (0°F), because the mercury freezes in the tube. Mercury and metal halide lights are very good for light output, but starting time and voltage increase significantly below -29°C (-20°F). High-pressure sodium with special capacitors are probably the most efficient light for use under arctic and subarctic conditions.

6.3 Geotechnical Issues

Geotechnical considerations should be documented in an engineering report describing each of the elements listed below as a minimum. Any other site-specific geotechnical-related characteristics that may impact the project should also be discussed. The work should be supervised by a geotechnical engineer experienced in Alaska geotechnical design. This person should be registered as a professional engineer in the state of Alaska.

6.3.1 Initial Site Characterization

Prior to field exploration, existing information should be reviewed to develop an understanding of site surface and subsurface conditions within a geologic framework. A site reconnaissance is often a useful part of initial site characterization. Areas to be addressed as part of site characterization include:

- Soil and rock characteristics.
- Ground thermal regime, including dry permafrost and active layer.
- Seismicity.
- Topography.
- Ground and surface water.

- Environmental considerations.
- Area practices and experience.

Typical sources for locating information about a site include:

- Previous explorations in the area.
- Local public agencies.
- Area geologic and topographic maps (USGS).
- Historical records.
- Interviews with knowledgeable individuals.
- Aerial photographs.

6.3.2 Field Exploration

A field exploration program should be planned and carried out to assess site subsurface site conditions, including soil, rock, ground water, and the ground's thermal regime as required to provide adequate information for project siting and design. The responsible geotechnical engineer should plan the exploration program based on the results of the initial site characterization and on project needs. The field exploration program may include the following elements:

- Soil borings and test pits.
- Soil sampling.
- In situ testing.
- Ground temperature monitoring.
- Ground water monitoring.

6.3.3 Laboratory Testing

Laboratory tests should be conducted on recovered soil and rock samples to aid assessment of pertinent engineering properties. The laboratory testing program should be developed considering the conditions expected both during construction and long-term operation of the facility. Typical types of laboratory tests are listed below:

- Classification and index.
- Strength and compressibility (thawed or frozen soils).
- Corrosivity.

6.3.4 Engineering Evaluations and Recommendations

The geotechnical engineer should perform evaluations as required to develop recommendations for adequately founding the proposed facilities and other related geotechnical issues. Typical evaluations may include:

- Foundation support — Type of foundation system and design criteria.
- Ground thermal regime.
- Settlement — Short-term and long-term.
- Earthwork — Site grading, excavation, material type and sources, compaction criteria.
- Lateral earth pressures.
- Slope stability.
- Seismicity considerations — Liquefaction, imposed loads, uplift resistance.

6.4 Reliability

A water treatment system is reliable if it provides a continuous and adequate supply of water to meet variations in demand. This also includes the raw water source and treated water storage available to meet the local fire requirements. Reliability also refers to the inherent dependability of a piece of equipment or unit process to achieve the design objective. Redundancy is defined as having multiple treatment units and equipment, to improve reliability. The overall reliability of a water treatment plant design should be dictated by the potential consequences of loss of the use of part or all of the plant for a time, or of water failing to meet drinking water standards.

The design of treatment facilities should be based on the premise that failure of any single plant component must not prevent the plant from operating at the design flow or from meeting drinking water standards.

6.4.1 Principles of Design

6.4.1.1 Plant design

Plant design should function satisfactorily throughout entire potential range of flow rates; sufficient operational flexibility should be included in the design to handle a variable raw water quality.

6.4.1.2 Redundant capacity

Reserve or redundant capacity should be provided.

6.4.1.3 Recycle flows

Plan for recycle flows and solids streams in the overall plant process design.

6.4.1.4 Operator monitoring

Design should allow for monitoring and observation by the operator. This includes:

- Providing metering facilities for the operator to determine the quantity of water produced.
- Alerting the operator to rapid changes in raw water quality.
- Alerting the operator to rapid changes in finished water quality.
- Alerting the operator to critical conditions—loss of disinfectant, chlorine leaks, low or high water levels, excessive turbidity, etc.

6.4.1.5 Cold weather process considerations

The performance and reliability of certain processes and equipment is affected by temperature. For example, reliability is affected when:

- Due to the change in viscosity, filtering of colder water requires additional hydraulic head to maintain rate of flow.
- Backwashing rate has to be reduced for colder water to prevent media carry-over.
- Air binding is more prevalent in colder water so additional head at filter cells during cold water operation is needed.
- Flocculation and mixing energy are temperature-dependent which affects the size of unit required to deliver "G".
- The solubility of certain chemicals is affected by cold water which causes slower reaction times.

6.4.2 Elements of Design

6.4.2.1 Standby power and lighting

Standby power is necessary during power outages so water can be treated and pumped to the distribution system without interruption, unless the water system possesses sufficient reserve capacity to meet system demand from storage. Criteria for emergency storage should be considered in conjunction with determining standby power needs to that enough standby power is provided at the treatment facility to meet the demand on the water system. Criteria should be established by the water system owner to address the need for standby power at the treatment facility depending upon storage availability and the owner's commitments for providing an uninterrupted water supply.

a. Critical equipment

During design, plant electrical loads should be classified as critical or non-critical for purposes of determining standby power requirements of the facility. It may be necessary, due to limited standby generation facilities, to determine which loads should be served by standby power, and which are not critical to the treatment process.

b. Lighting

Provide emergency lighting within plant facilities that conforms to applicable health, safety, and building codes. Dual level lighting should be considered: normal to dim lighting for routine periods and high intensity lighting for emergency repairs or infrequent activities. With limited standby power, consideration should be given in design to provide separate lighting circuits, to enable partial lighting during periods of using standby power.

c. Automation and controls

Any computerized control systems should be provided with an uninterruptible power supply (UPS), or manual control of unit processes should be possible while the computer controls are inactive.

6.4.2.2 Unit process configuration

In systems of greater capacity than 3,800 m^3/day (1 mgd), it is recommended that a minimum of two component units be provided for each of the unit processes that are primarily responsible for meeting drinking water standards. For a surface supply, such processes might include coagulation, flocculation, sedimentation, filtration, and disinfection, as a minimum. Processes that would not normally be required to have at least two components could include waste wash water handling facilities, sludge processing facilities, or certain chemical feeds, such as fluoridation. Units that combine two or more process functions are inherently less reliable than single-purpose-unit processes. Figure 1 illustrates a design that minimizes the impact of any single failure on plant performance, and eliminates the possibility of both trains being out of service simultaneously.

The design philosophy employed should be that failure of any single structure, piece of mechanical or electrical equipment, element of pipe, or valve should not put the entire facility out of service.

Appurtenant parts including flowmeters, valves, chemical feed equipment, pumps, instrumentation and controls, liquid level controls, piping, turbidity and process monitoring equipment should be furnished as necessary to achieve this philosophy.

6.4.2.3 Gravity flow and pumping

In layout of facilities, the plant hydraulics should be analyzed for reliability in the following manner:

- Use of gravity flow to minimize pumping should be considered. Where alternatives exist in process layout, design should incorporate gravity flow in unit processes critical to producing finished water.
- Locating chemical feed equipment so that gravity feed is possible should be considered, although not all chemicals can be gravity fed.

6.4.2.4 Disaster considerations

Planning facilities involves consideration of conditions that could occur if a disaster were to occur.

- The location, design, and operation of a treatment plant must consider the potential for natural disasters. Such disasters should influence the location and structural design of the treatment plant. Attention to items such as floods, earthquake, avalanches, and fires should be given in siting and design.
- Disruptions or damage to equipment caused by vandalism should be considered in the design. Plant vulnerability should be established during design, and measures should be taken to

lighting, alarms, telemetry, and security should be established during design.

- Safety precautions should be included in the design of treatment facilities. For example, measures for fire protection and for emergency access and egress should be considered.

6.4.2.5 Operation and maintenance

Proper operation and maintenance is crucial to plant reliability. To maintain a facility in reliable operation, it is necessary to consider spare parts and preventive maintenance during design.

An adequate spare parts inventory as recommended by manufacturers and monetarily affordable by the community should be included in the design of facilities.

Maintenance schedules should be established and adhered to. Records should kept of what maintenance was performed and when. Special cold weather operation and maintenance precautions must be taken to ensure plant reliability. Examples include:

- Provide space heaters in electric motors installed outdoors.
- Specify synthetic oil for gear boxes exposed to the outdoors. This permits either year around operation or warm weather operation with synthetic oil acting as preventive maintenance during cold non-use periods.
- Provide insulated covers over chain and flight gearing/chain that reaches to the drive head.

6.4.2.6 On-site storage

On-site storage of chemicals is necessary for reliable facility operation. This is discussed in Section 5.1.4.

6.4.2.7 Plant automation

In design of treatment facilities, plant automation options should be reviewed and considered in terms of reliability. The options include:

- Manual control

- Semi-automatic
- Automatic
- Supervisory/computer-based

Computer based supervisory equipment and controls are more advantageous than conventional manual or automatic controls. In the future, most of the technological advances in process monitoring and control applicable to the water treatment plant may well occur in computer based systems. However, if the water treatment plant is located in a remote area of the state, total reliance on a computer based system may be a less reliable design if a failure should occur and a computer technician has to be flown in.

Consideration of the specific site, operator capabilities, location and logistics, ease of maintenance, etc., should be included in establishing plant automation as the system should be designed to meet the requirements of the community it is to serve and the level of sophistication available.

Some combination of automation strategies may be the most reliable alternative.

6.4.2.8 Plant-wide support systems

a. Utility water and make-up water

A plant designer should consider having redundant sources of utility water and make-up water for critical process water uses such as chemical feed and disinfection. Such consideration should include cross-connection control to ensure that no contamination can occur between piping, troughs, tanks, or other treatment units. It should also include provision to maintain utility water in periods of cold weather. For example, the following provisions may be made:

- Use nonfreeze hose bibbs and provide a place for the hose bibb standpipe to drain.
- Use warm water in making up certain chemicals, such as polymers, that react slowly when mixed with cold water.

b. Heating and ventilation

Treatment facilities should be designed to ensure sufficient heating is provided at all times to the potable water supply, under all anticipated weather conditions. This may include designing facilities for preheating, heating, circulating, or pumping the water supply. The plant itself, storage facilities, clearwells, etc. should be properly heated and vented to account for ambient weather conditions. Considerations are outlined below.

- If pipes are exposed and will be operated in cold weather, use heat trace, and insulate. If not operated in freezing temperatures, provisions should be made to drain piping.
- Route piping in basins of water if possible to minimize the amount of heat tracing needed. Heat tracing is cumbersome and should be considered as a last resort.
- Consider channel agitation if quiescent conditions and low velocities are expected during cold weather operation.
- Piping should drain by gravity to atmosphere, i.e., a drain to sludge lagoon should be checked to make sure it always drains free regardless of lagoon gradeline; otherwise it may freeze.
- Construction materials must be compatible with local conditions.
- Depth of burial to tops of pipes should be consistent with local frost depth conditions, or other suitable precautions should be taken.
- For the treatment building itself and storage facilities, consider vapor retarders in building construction to reduce condensation, special roofing systems for freezing and thawing of ice and snow, freeze protection, and reservoir ventilation.

6.5 Safety

6.5.1 Cross-connection Control

The piping layout should be designed to eliminate the possibility of cross-contamination in flushing lines for chemicals and any other contaminants such as sludge which could affect the water supply. Blow-off outlets and drains must terminate and discharge at locations that comply with current ADEC regulations.

6.5.2 Fire Protection

All areas of the plant including storage and handling areas for chemicals and control areas should be evaluated for fire protection. These areas should be easily accessible, and local fire personnel should be advised to the types and quantities of chemicals that are at the facility. The facility should be inspected by inspectors with jurisdiction to check that it meets the requirements of local and national fire codes. Special attention should be paid to installation of fire protection systems (e.g., wet pipe sprinkler systems) in areas where chemicals such as chlorine are present. Systems appropriate for the area to be protected and its classification should be determined.

6.5.3 Pipe Marking

Pipes throughout the water treatment facility should be color coded with directional arrows and labeled using the scheme in Table 6-3:

TABLE 6-3
Pipe Marking Standard

Chemical	**Color**
Alum or primary coagulant	Orange
Ammonia	White
Carbon slurry	Black
Caustic	Yellow w/green band
Chlorine (gas and solution)	Yellow
Fluoride	Light blue w/red band
Lime slurry	Light green
Ozone	Yellow w/ orange band
Phosphate compounds	Light green w/red band
Polymers or coagulant aids	Orange w/green band
Potassium permanganate	Violet
Soda ash	Light green w/orange band
Sulfuric acid	Yellow w/red band
Sulfur dioxide	Light green w/yellow band
Waste Lines	
Type	**Color**
Backwash waste	Light brown
Sludge	Dark brown
Sewer (sanitary or other)	Dark gray

Additional Lines	
Type	**Color**
Compressed air	Dark green
Gas	Red
Influent Water Line	Olive Green
Effluent Water Line	Dark Blue
Other Lines	Light gray

In situations where two colors do not have sufficient contrast to easily differentiate between them, a six-inch band of contrasting color should be on one of the pipes at approximately 30-inch intervals. The name of the liquid or gas should also be on the pipe.

6.5.4 Fuel Handling

The facility should be checked for fuel storage, handling, and piping to ensure that contamination is highly unlikely and so that the system meets the requirements of current codes. Fuel handling is usually required for heating and standby generator operations. If natural gas, fuel oils, or gasoline is used at or near the facility, proper warning signs must be installed and maintained in good order. The installation of these systems must meet all applicable codes.

6.5.5 Chemical Handling

Design the equipment and machinery required for handling and feeding all the chemicals with proper safety features, as outlined in the following subsections.

6.5.5.1 Chlorine

Since the chemical gases used in water treatment are generally toxic and the pressures in the storage vessel are high, all storage and handling of these chemicals must follow applicable regulatory codes.

For example, chlorine handling and feeding systems should be designed, installed, and used per the manufacturer's requirements. All construction materials should be verified as being in conformance with the equipment manufacturer's recommendations and as specified by trade organizations such as the Chlorine Institute.

In addition, make special provisions for proper ventilation of chlorine feed and storage rooms. Equipment for the scrubbing of chlorine-saturated vapors should be provided to meet the requirements of the 1991 Uniform Code when this code is applicable to facility design. This requires the treatment system to be designed to reduce the maximum allowable discharge concentration of the gas to one-half of the concentration immediately dangerous to life and health. This concentration for chlorine is 30 ppm at the point of discharge to the atmosphere. To comply with this code the design and operation of scrubbing equipment should be included in the design submittal.

Respiratory protection equipment meeting OSHA requirements should be made available where chlorine gas is handled, and it should be stored at a convenient location, but not inside any room where chlorine is used or stored. The units are to use compressed air, have at least a 30-minute capacity, and be compatible with or exactly the same as units used by the authority responsible for fire protection of the plant.

Further, protective measures such as leak detection equipment should be furnished at the plant. A bottle of ammonium hydroxide, 56% ammonia solution, should be available for chlorine leak detection. Where chlorine cylinders are used, leak repair kits approved by the Chlorine Institute should be provided. Continuous chlorine leak detection equipment is recommended. Where a leak detector is provided it should be equipped with both an audible alarm and a warning light. Where local authorities responsible for fire protection are expected to respond to leaks of gas, such as chlorine gas, the plant should be furnished with standard warning placards detailing the chemicals at the site (i.e., National Fire Protection Hazard Identification Labels).

For further discussion on chlorine safety, please see Section 4.13.6.

6.5.5.2 Other disinfection systems

Other forms of disinfection such as ozonation include a gas compressor system, gas drying, a gas meter, flow control devices, and a gas contact chamber for diffusion. The components of these systems must be designed for compatibility with all other equipment and be installed to operate safely. In the case of ozone generation systems, the potential harmful effects of ozone can be minimized by incorporating features such as:

- Locate the ozone generator in normally unoccupied room which has ventilation equipment.
- Monitor ozone concentrations with an ambient ozone monitor that displays ozone concentration and indicates an alarm condition if concentrations exceed 0.1% by volume.
- Minimize ozone leaks by using proper construction materials.
- Establish routine monitoring plan for small releases of ozone at fittings and small monitoring equipment (e.g., pressure and temperature gauges).

6.5.5.3 Dry chemicals

Dry chemicals must be stored in a cool, dry place, and an adequate area must be provided to ensure that the bags can be segregated and are not subject to damage under normal operation. Adequate ventilation and protective clothing must be provided for handling dry chemicals.

a. Coagulants

Provide coagulants, such as alum, with a flushing mechanism to prevent scale buildup in the feed lines. In the system design, include goggles, rubber or plastic gloves, an emergency eyewash station, and a shower located close to the coagulant preparation area.

b. Lime

The main hazard of lime in the treatment plant is the chemical dust created during handling. Proper ventilation and protective clothing, including masks, must be provided. Hydrated lime tends to absorb carbon dioxide, and outside air should be provided.

c. Soda ash

The main hazard of soda ash in the treatment plant is the chemical dust. Proper ventilation and protective clothing must be provided.

d. Sodium silicofluoride

The dust is poisonous, and solution feeds are corrosive. Precautions must be taken so operators are informed and properly protected from the dusts while making solutions.

e. Dry polymer dusts

These are hazardous and, once wetted, the chemical is extremely slippery if spilled. Water and floor drains should be provided in the solution preparation areas to wash down any spilled material.

f. Activated carbon

In the powdered form, activated carbon is considered a fire-hazard and the design should be made accordingly. A fresh air supply should be available when handling carbon. Special attention should be given to electrical classification of equipment operating in an area where powered activated carbon is handled. Normal safety precautions include wearing protective clothing, respirators, neck cloths, gloves, and goggles when handling powdered activated carbon. Manufacturers' recommendations concerning safe handling procedures for such material should be followed.

g. Potassium permanganate

In large quantities, this chemical presents a fire hazard. Explosions are likely to occur when it is brought into contact with organic or readily oxidizable materials either in solution or in the dry state. It should not be stored where it can come into contact with activated carbon, as such mixtures are knows to be spontaneously combustible. It can be stored in the usual storage bins and fed with conventional dry-feed equipment, but is typically made in a dilute solution for ease of handling, which minimizes fire hazard.

6.5.5.4 Liquid chemicals

Liquid chemicals are also usually considered hazardous and the design for their use should include the appropriate equipment.

a. Sodium hydroxide

Solutions of sodium hydroxide should be stored in reinforced fiberglass or steel tanks. The solutions must be kept indoors or stored in areas above 12°C (54°F) due to crystallization.

b. Liquid polymers

These are hazardous if spilled since they are extremely slippery. Water and floor drains should be provided to wash down any spilled material.

c. Acids

Sulfuric acid and other acids are highly corrosive once diluted and should be housed in rubber, plastic or glass-lined containers. Provide corrosion resistant pumps, valves, and pipes. Acids may be diluted to any strength for feeding.

6.5.6 Additional Requirements

Include additional items in the design which are associated with the storage and handling of chemicals to meet both state and federal OSHA requirements. A hazardous materials communication plan should be developed which includes material safety data sheets on each chemical used in the water treatment system. Include an emergency response plan in the operation and maintenance manuals.

6.5.7 Operator Training

Operator training is the responsibility of the facility owner or operator. Plant operators must be trained and made aware of the hazards present at the treatment plant. Regular operator training sessions should be held to review safety procedures employed at the plant, and the operators should be made aware of the communities and workers' right-to-know laws established by the U.S. Department of Labor and the EPA 40 CFR 370. Safety meetings, supplemented by training sessions in specialized areas, should also be held. Associated with regular training sessions, periodic inspections by the local fire protection authority and other state and local officials should be conducted to ensure that the plant is maintained in a safe condition. Plant operators should participate in inspections to be continually trained in safe working practices.

6.6 Suggested Design Checklists

The following checklists are provided as an aid to the system designer for various aspects of water system design. The checklists in this section are not mandatory checklists used by ADEC to determine completeness of plans.

6.6.1 General Design Factors and Criteria

- Long-term dependable yield of the water source.
- Reservoir surface area, volume, and a volume-versus-depth curve, if applicable.
- Area of watershed, if applicable.
- Estimated average and maximum day and peak hour water demands for the design period.
- Number of proposed services.
- Fire fighting requirements.
- Flash mix, flocculation, and settling basin capacities.
- Retention times.
- Unit loadings.
- Filter area and the proposed filtration rate.
- Backwash rate.
- Chemical feeder capacities and ranges.
- Basis for sizing treatment plant.

6.6.2 General layout

Project drawings should include:

- Suitable title.
- Entity responsible for the water supply.
- Scale.
- North arrow.
- Datum used, survey control.
- Boundaries of the area to be served.
- Imprint of professional engineer's seal with signature.
- Location and nature of any existing water works structures and appurtenances affecting any proposed improvements.

6.6.3 Detailed plans

Detailed plans should include:

- Water line profiles having a horizontal scale of not more than 100' = 1" and a vertical scale of not more than 10' = 1" (when possible). Yard piping plans do not generally require profiles.

- Location and size of the property to be used for ground water development. References such as roads, streams, section lines, or streets should be shown.

- Topography and location of existing or planned wells and structures, with contour intervals not greater than 2 feet.
- Elevations of the highest known flood level, when appropriate.
- Log of well construction showing diameter and depth of drill holes, casing and liner diameters and depths, grouting depths, elevations and designation of geological formations, and water levels.
- Location of all existing and potential sources of pollution within the watershed or 305 m (1,000 ft) radius of wells and springs.
- Size, length, and identity of all utilities, including sewers, drains, water mains, electrical lines, telephone lines, cable television lines, etc., and their locations relative to plant structures.
- Schematic diagrams and hydraulic profiles of the proposed plant or addition.
- Plant piping with sufficient detail to identify flow through the plant and treatment processes.
- Locations of chemical storage area, feeding equipment, and points of chemical application.
- Locations, sizes, elevations, etc. of all proposed plant facilities and treatment processes.
- Locations of sampling taps.
- Description of features not covered by the specifications.
- Identification of materials approved by a third party (UL, FM, AWWA, etc.).

6.6.4 Technical and Construction Specifications

- Provisions for keeping existing water works facilities in operation during construction of new facilities.
- Existing conditions as evidenced by source water quality analyses, results of geotechnical investigations, and site control issues.
- Laboratory facilities and equipment if applicable.

- Any chemical feed and process equipment.
- Any disinfection equipment.
- Backflow prevention protection.
- Materials of construction.

6.6.5 Facility layout and location

- Allow adequate space around tanks and equipment for maintenance and operation.
- Allow adequate space around pumps and feeders for maintenance. Pumps should be placed on stands or equipment pads so they are elevated off the operating floor and protected from spills or minor flooding.
- Provide lifting apparatus (monorails, hoists, etc.) for heavy pieces of equipment that require removal for maintenance. Provide doors and runways for easy exit and transport of heavy equipment.
- Limit electrical conduit routing in the chemical containment area floor. Route electrical conduit to equipment in containment area overhead where possible and practical. Conduit and pipe penetrating the containment area should do so above the flooded level.
- Chemical feed facilities should be located near the majority of chemical application points and near the chemical storage facility where possible.
- Sealed, ventilated rooms should be provided for volatile chemicals such as sodium hypochlorite, ammonia, and strong acids.
- Dry chemicals should have dust handling facilities, dehumidification where necessary, and ventilation separate from that for other chemicals.
- Surfaces within the containment areas may or may not require protective coatings. Chemical resistant coatings should be specified only in areas where chemical leaks can be anticipated, such as transfer pumps, unloading areas, and tank overflow lines.

Applying chemical resistant coatings to all containment surfaces can be very expensive, both in initial costs and maintenance costs.

Gratings around chemical containment areas must be capable of withstanding both direct chemical spills and chemical fumes. Grating and walkways above the containment level should be available to access critical equipment in a spill event.

- Chemical storage facilities should provide easy truck access and turn around space. A looped drive for truck drive-through is preferable.

- Stands or pedestals for pumps should be protected against leaking chemicals. Alternatives include carbon steel with chemical resistant coatings; alloys, suitable for the chemical exposure; or concrete with appropriate protection, such as coatings, acid resistant cements, or acid brick.

6.6.6 Chemical Storage and Feed Facility

Table 6-4 outlines safety equipment that should be used in handling chemicals. Table 6-5 outlines piping materials that may be used with various chemicals. These tables provide general guidelines only, and final selection should be based on actual design conditions and manufacturers' recommendations. These tables were taken from U.S. EPA, Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources (American Water Works Association, 1991).

Table 6 1 Safety Equipment for Chemical Handling

Chemical	Positive Ventilation	Protective Clothing	Rubber Gloves	Rubber Boots	Goggles	Face Shields	Respirator	Gas Mask	Eyewash and Safety Shower
Alum (D)	X	X			X		X		X
(L)		X	X		X	X			X
Ammonia (G)	X	X	X			X	X	X	X
(L)	X	X	X		X		X		X
Chlorine (G)	X	X	X			X	X	X	X
Ferric Chloride (L)		X	X	X	X	X			X
Ferric Sulfide (L)		X	X	X	X	X			X
Fluoride (L)		X	X	X	X	X			X
Lime (D)	X	X	X		X		X		X
Polymer (L)			X	X		X			X
Potassium Permanganate (L), (D)	X	X	X	X	X	X			X
Powdered Activated Carbon (D)	X	X	X		X		X		
Sodium Carbonate (D)	X	X	X		X		X		X

Sodium Hydroxide (L)		X	X	X	X	X			X
Sulfuric Acid (L)	X	X	X	X	X	X			X
Zinc Orthophosphate (L)			X		X	X			

D = Dry
L = Liquid
G = Gas

Table 6 5 Chemical Piping Materials General Guidelines

Chemical	PVC[1]	Polypropylene[1]	FRP	Polyethylene[1] HMW	Iron or Steel	316 Stainless Steel	304 Stainless Steel	Tygon Tubing[1,2]
Alum	X[3]	X	X	X		X		
Activated Carbon (slurry)	X		X			X		X[3]
Ammonia, Aqua	X				X[3]	X		
Chlorine Gas - Dry, Pressure					X			
Chlorine Gas - Dry, Vacuum	X			X				
Ferric Chloride	X[3]	X	X	X				
Ferric Sulfate	X[3]	X	X	X		X		
Fluosilic Acid	X[3]	X		X				
Lime (slurry)	X	X		X	X	X	X	X[3]
Polymer	X[3]	X	X	X		X		
Potassium Permanganate (2% solution)	X[6,4,3]	X	X	X	X	X		
Sodium Carbonate (solution)	X[3]	X		X	X			
Sodium Hydroxide (50%)	X[4,3]	X	X	X	X	X	X	
Sodium Hypochlorite	X[3]	X	X	X				
Sulfuric Acid (50%)	X[4,3]	X	X	X		[5]		
Zinc Orthophosphate	X[3]		X			X		

NOTES:

[1] Chemical temperatures typically less than 150°F.

[2] Pressures less than 100 psi.

[3] Preferred material.

[4] Use CPVC for higher temperatures.

[5] Type 316 stainless steel may be used at velocities to 6 ft/sec. Dilution of 93% acid is very critical. Consult with Corrosion and Materials Engineering for details of designing such systems.

[6] Do not connect threaded PVC to steel in a heated water system.

6.6.7. Equipment

- Pumps should have positive suction head whenever possible (i.e., bottom of tank should be at or above pump suction inlet).
- Back pressure valves ≥100 kN/m^2 (≥15 psi) should always be placed on metering pump discharge lines to improve accuracy and repeatability of metering.
- Metering pump feed lines should be as short as possible. If long feed lines are unavoidable, dilution water (where applicable, depending on the chemical) may be injected into the metering pump feed line to help convey the chemical to the application point. Make sure the water is compatible with the chemical.
- Provide required safety equipment.
- Specify spare parts for critical items such as metering pump diaphragms, transfer pump impellers, pump seals, bearings, gaskets, and O-rings.
- Separate dust collectors should be provided for each dry chemical. **Never** collect two different chemicals in the same dust collector. Do not manifold bins of the same chemical to a common dust collector; use one dust collector per bin.
- Bin vibration should not be continuous for fine dry chemicals such as quicklime, hydrated lime, dry polymer, or soda ash. Intermittent vibration or air fluidization should be provided.
- Never pump slaked lime directly out of the slaker before stabilization.
- Chemical feed and transfer pumps should not have water flush seals.
- Avoid or minimize buried chemical feed lines. If they are required, consider encasing them in larger pipes and providing access manholes at bends for cleaning.

6.6.8. Manufacturers' Specifications and Certificates

6.6.8.1 Shop Drawings

Shop drawings are detailed drawings of the water system components such as pumps, feeders or other items of equipment, or of contractor fabricated components such as tanks, etc. ADEC does not have the responsibility for the review of contractor prepared shop drawings. Review of shop drawings is normally the responsibility of the design engineer. The following considerations are provided as a guide to the design engineer, and not as a plan review condition.

Shop drawings should identify and indicate:

- Pertinent drawing sheet(s) and detail number(s), products, units and assemblies, and system or equipment identification or tag numbers.
- Critical field dimensions and relationships to other critical features of work.
- Exceptions and changes to the design.

Shop drawing preparation should include:

- Detail: Present in a clear and thorough manner and in sufficient detail the kind, size, arrangement, and function of components, materials, and devices and compliance with contract documents.
- Product data: Clearly mark each copy to identify pertinent products or models and show performance characteristics and capacities, dimensions and clearances required, wiring or piping diagrams and controls, and external connections, anchorages, and supports required.
- Equipment and component titles: Identical to title shown on the project drawings.

Designers should include design data and:

- Design systems, equipment, and components, including supports and anchorages, in accordance with the provisions of the latest edition of Uniform Building Code and to withstand seismic loads in addition to other loads.
- Provide an appropriately licensed professional engineer to perform design; oversee preparation of shop drawings, manufacturing, and

installation, as appropriate; and stamp and certify that shop drawings conform to design requirements of governing agencies.

- Provide project-specific information as required and as necessary to clearly show calculations, dimensions, logic and assumptions, and referenced standards and codes upon which design is based.

7.0
PLAN SUBMITTAL AND REVIEW PROCESS

7.0 PLAN SUBMITTAL AND REVIEW PROCESS

Regulations governing the plan review and approval process for construction and operation of a public water system in Alaska are contained in Article 3 of the state *Drinking Water Regulations*, 18 AAC 80. No person may construct, install, alter, renovate, operate, or improve a public water system, or any part of one, without prior written department approval of engineering plans. Written approval is not required for emergency repairs or routine maintenance, although Class A and B water systems are required to notify ADEC of these actions, as stated in Article 3 of the state *Drinking Water Regulations*.

7.1 Scope of ADEC Public Water System Plan Review

ADEC's review of public water system designs will be based on any applicable requirements contained in the drinking water regulations, including the applicable design criteria contained in the "Review Standards; Design Criteria" section of the drinking water regulations. ADEC will also use the Alaska Drinking Water Procedures Manual and the Alaska Water Treatment Guidance Manual in reviewing water system plans. The review of engineering plans, or, where allowed by ADEC, other plans regulated under the drinking water regulations, will be limited to areas relating to drinking water quality, and public health and environmental protection. ADEC will not review those portions of plans and specifications falling outside these areas.

7.2 Sequence of the Plan Submission and Approval Process

The basic elements of the process for obtaining approval of a water system for operation (i.e. distributing water for consumption) are:

1. **Preapplication Conference**

   At the discretion of the submitter of water system plans, ADEC meets with the prospective water system owner and/or the project engineer to discuss the conceptual plan for the water system and to bring up any issues specific to the particular design being submitted.

2. **Initial Submission of Plans**

Plans for the water system are submitted to ADEC, along with full payment of the plan approval fee required by state *Drinking Water Regulations*. All applicable items described in Article 3 of the *Drinking Water Regulations* and in the applicable submittal checklist (checklist avaliable from ADEC District and Regional Offices) are submitted.

For new groundwater sources the system owner or engineer needs to obtain ADEC approval prior to construction of the well to confirm adequate separation distances.

For new surface water sources, source water testing should be completed prior to submission of plans so that the analysis results can be submitted with the system's plans, as required by 18 AAC 80.310.

3. ADEC Approval To Construct

If all items required for submission are satisfactory and ADEC approves the plans, ADEC will issue a Construction and Operation Certificate with the Construction Section completed. The water system may then be constructed. ADEC may issue a conditional approval to allow completion of previously unmet conditions at some later time. Incomplete plans or plans not meeting design criteria described in Article 3 of the Drinking Water Regulations will be returned to the water system owner or engineer within 30 days of submittal with deficiencies identified.

The approval to construct issued by ADEC is valid for a period of two years, after which the plans must be resubmitted and reapproved by ADEC, as required by the drinking water regulations.

4. Changes to Water System Plans

Any significant changes to the water system plans following initial construction approval by ADEC must be approved by ADEC. The Change Order section of the Construction and Operation Certificate will be used to reflect ADEC approval of such changes.

5. Interim Approval to Operate

Following completion of construction of the system, results of finished water analyses for coliform bacteria and any raw water contaminant that exceeded a primary MCL are submitted to ADEC. If the results are satisfactory, ADEC grants interim operation approval to the water system for a period of 90 days by completing the interim operation section of the Construction and Operation Certificate. At ADEC's discretion, a new Construction and Operation Certificate will be completed and sent to the water system.

Well logs must be submitted to ADEC within 30 days of construction of a production, fire, standby, or emergency well.

6. Final Approval to Operate

The water system owner has 90 days from the date of interim operational approval to provide ADEC with as-built plans and specifications. If the as-built plans reflect that the system was constructed as approved by ADEC, including the use of lead-free pipe, solder, and flux, ADEC will sign the final approval section of the Construction and Operation Certificate. If the water system fails to meet this deadline, ADEC will, in its discretion, revoke the Construction and Operation Certificate.

7.3 Plan Review Checklists

Checklists designed to assist the plan submitter in complying with all items required by ADEC for review of plans are available from ADEC's District and Regional Offices.

8.0

BEST AVAILABLE TECHNOLOGIES FOR ORGANIC AND INORGANIC CHEMICALS AND TOTAL COLIFORM RULE

8.0 BEST AVAILABLE TECHNOLOGIES FOR ORGANIC, INORGANIC CHEMICALS AND TOTAL COLIFORM RULE

8.1 Best Available Technologies (BAT) for Organic and Inorganic Chemicals

The ADEC identifies and recommends following best available technologies (BAT) for achieving compliance with the maximum contaminant levels for inorganic and organic chemicals in drinking water.

Table 8.1

Best Available Technologies for Organic Chemicals

	Contaminant	Packed Tower Aeration	Granular Activate Carbon
1	Benzene	X	X
2	Carbon tetrachloride	X	X
3	1,2-Dichloroethane	X	X
4	Trichloroethylene	X	X
5	Para-Dichlorobenzene	X	X
6	1,1 Dichloroethylene	X	X
7	1,1,1-Trichloroethane	X	X
8	Vinyl Chloride	X	
9	cis-1,2-Dichloroethylene	X	X
10	1,2-Dichloropropane	X	X
11	Ethylbenzene	X	X
12	Monochlorobenzene	X	X
13	o-Dichlorobenzene	X	X

	Contaminant	Packed Tower Aeration	Granular Activate Carbon
14	Styrene	X	X
15	Tetrachloroethylene	X	X
16	Toluene	X	X
17	trans-1,2-Dichloroethylene	X	X
18	Xylenes (total)	X	X
19	Alachlor		X
20	Aldicarb		X
21	Aldicarb sulfoxide		X
22	Aldicarb sulfone		X
23	Atrazine		X
24	Carbofuran		X
25	Chlordane		X
26	Dibromochloropropane	X	X
27	2,4-D		X
28	Ethylene dibromide	X	X
29	Heptachlor		X
30	Heptachlor epoxide		X
31	Lindane		X
32	Methoxychlor		X
33	PCB's		X
34	Pentachlorphenol		X
35	Toxaphene		X
36	2,4,5-TP		X

Table 8.2

BAT for Inorganic Compounds

Chemical Name	BAT(s)
Asbestos	2,3,8
Barium	5,6,7,9
Cadmium	2,5,6,7
Chromium	2,5,6,7,b
Mercury	2,a,4,6,a,7,a
Nitrate	5,7,9
Nitrite	5,7
Selemium	1,2,c,6,7,9

1= Activated Alumina
2= Coagulation/Filtration (not BAT for systems < 500 service connections)
3= Direct and Diatomite Filtration
4= Granular Activated Carbon
5= Ion Exchange
6= Lime Softening (not BAT for system < 500 service connections)
7= Reverse Osmosis
8= Corrosion Control
9= Electrodialysis
a= BAT only if influent Hg concentrations < 10 ug/L
b= BAT for Chromium III only
c= BAT for Selenium IV only

8.2 Best Available Technologies (BAT) for Total Coliform Rule (TCR):

To achieve compliance with the maximum contaminant level for total coliforms, ADEC recommends the following best available technologies (BAT):

(a) Appropriate placement and construction of wells to achieve their protection from coliforms as noted in 18 AAC 80.015--18 AAC 80.030.

(b) Adequate maintenance of a disinfectant residual, as described in 18 AAC 80.060, throughout the distribution system of a public water system.

(c) Proper maintenance of the distribution system through appropriate pipe replacement and repair schedules, main flushing programs, proper maintenance and operation or reservoirs and storage tanks.

(d) Continuous maintenance of positive water pressure in all parts of the distribution system of a public water system.

(e) Use of filtration and /or disinfection of surface water as noted in 18 AAC 80.530-.532 or disinfection of groundwater, described in 18 AAC 80.060, using a strong oxidant such as chlorine, chlorine dioxide or ozone.

APPENDICES

Appendix 1: Conversion Table

Conversion Table

Multiply	by	to obtain
acres	2.471	hectare
acres	43560	sq ft
acres	4047	sq m
acre-ft	43560	cu ft
acre-ft	325851	gal (US)
acre-ft	0.32585	mgd
acre-ft	1233.5	cu m
atm	29.92	in of mercury
atm	33.90	ft of water
atm	76.0	cm of mercury
atm	14.70	psi
bbl cement	376	lb cement
bags or sacks-cement		94
Btu	778.17	ft lb
Btu	3.930×10^{-4}	hp-hr
Btu	2.930×10^{-4}	kwh
Btu	0.2520	kg cal
Btu	107.5	kg m
Btu/min	12.96	ft lb/sec
Btu/min	0.02356	hp
Btu/min	0.01757	kw
cm	0.3937	in
cm of mercury	0.01316	atm
cm of mercury	0.4461	ft of water
cm of mercury	27.85	psf
cm of mercury	0.1934	psi
cm/sec	1.969	fpm
cm/sec	0.0328	fps
cm/sec	0.6	m/min
cu ft	7.48	gal
cu ft	1728	cu in
cu ft	0.0370	cu yd
cu ft	28.32	liters
cu ft	2.832×10^{4}	cu um
cu ft	0.02832	cu m
cfm	0.472	l/sec
cfs	0.6463	mgd (US)
cfs	448.8	gpm (US)
cfs	1699	l/min
cu in	16.39	ml
cu in	5.787×10^{-4}	cu ft
cu in	1.639×10^{-5}	cu m

Multiply	by	to obtain
cu yd	764.6	liters
dr (avdp)	27.34375	grains
dr (avdp)	0.0625	oz
dr (avdp)	1.7718	g
fathoms	6	ft
ft	30.48	cm
ft	0.3048	m
ft of water	0.8826	in of mercury
ft of water	0.4335	psi
ft of water	62.43	psf
ft of water	0.02950	atm
lb cement	ft of water	304.8kg/sq m
fpm	0.508	cm/sec
fps	30.48	cm/sec
fps	18.29	m/min
fps	1.097	km/hr
ft lb	1.285×10^{-3}	Btu
ft lb	5.050×10^{-7}	hp-hr
ft lb	0.1383	kg m
ft lb	3.766×10^{-7}	kwh
ft lb/min	3.030×10^{-5}	hp
ft lb/min	2.260×10^{-5}	kw
gal (US)	3.068×10^{-4}	acre-ft
gal (US)	0.1337	cu ft
gal (US)	231	cu in
gal (US)	3785	ml
gal (US)	3.785×10^{3}	cu m
gal (US)	3.785	liters
gal (Imp)	1.20094	gal (US)
gal (US)	0.83267	Imperial gal
gal water (US)	8.345	lb of water
gpm	2.228×10^{-8}	cfs
gpm	0.0631	liters/sec
gpm	8.0208	cfh
grains (troy)	1.216	grains (avdp)
grains (troy)	0.06480	g
grains (troy)	7000	lb
grains/US gal	17.1	mg/l
grains/US gal	142.86	lb/mil gal
grains/Imp gal	14.254	mg/l
g	15.43	grains

Multiply	by	to obtain
cu in	4.329×10^{-3}	gal (US)
cu in	1.639×10^{-2}	liters
cu m	35.31	cu ft
cu m	1.308	cu yd
cu m	264.2	gal (US)
cu m	10^{3}	liters
cu yd	27	cu ft
cu yd	46656	cu in
cu yd	0.7646	cu m
cu yd	202.0	gal (US)
hectare	0.4046	acre
hp	0.7457	kw
hp (boiler)	33479	Btu/hr
hp (boiler)	9.803	kw
in	2.540	cm
in of mercury	1.133	ft of water
in of mercury	0.4912	psi
in of mercury	345.3	kg/sq m
in of mercury	0.0334	atm
in of water	0.0736	in of mercury
in of water	0.0361	psi
joule	0.7375	ft/lb
joule	9.48×10^{-4}	Btu
kg	2.205	lb
kg cal/min	51.457	ft lb/sec
kg cal/min	0.0936	hp
kg cal/min	0.0698	kw
kg/sq cm (force)	14.223	psi
kg/sq m	3.281×10^{-3}	ft of water
mercury		
kg/sq m	1.42×10^{-3}	psi
km	3281	ft
km	0.6214	mi
km/hr	0.9113	fps
km/hr	27.78	cm/sec
kw	56.88	Btu/min
kw	737.6	ft lb/sec
kw	1.341	hp
kw	14.34	kg-cal/min
liters	0.2642	gal (US)
liters	61.025	cu in
liters	0.0353	cu ft
lumen/sq m	0.092	ft candle/sq ft
m	3.281	ft
m	39.37	in
m	1.094	yd

Multiply	by	to obtai
g	0.0353	oz
g	980.7	dynes
g/l	58.4	grains/gal
g/l	8.345	lb/1000 gal
g/l	1000	mg/l
ha	2.471	acres
hp	42.44	Btu/min
hp	33000	ft lb/min
hp	550	ft lb/sec
lb	16	oz
lb	7000	grains
lb	453.5924	grams
lb	1.215	lb (troy)
lb of water	0.0160	cu ft
lb of water	27.68	cu in
lb of water	0.1198	gal
lb/cu ft	0.0160	g/ml
lb/cu ft	16.02	kg/cu m
lb/cu ft	5.787×10^{-4}	lb/cu in
lb/ft	1.488	kg/m
lb/in	178.6	g/cm
poise	14.88	lb/sec ft
poise	1.0	gm/SEC cm
psf	0.0160	ft of water
psf	4.883	kg/sq m
psi	2.307	ft of water
psi	2.036	in of
psi	0.0680	atm
psi	703.1	kg/sq m
quires	25	sheets
reams	500	sheets
sq cm	0.1550	sq in
sq cm	1.076×10^{-3}	sq ft
sq ft	144	sq in
sq ft	0.0929	sq m
sq ft	2.29×10^{-5}	acres
sq in	6.452	sq cm
sq km	247	acres
sq km	10.76×10^{6}	sq ft
sq km	1.196×10^{6}	sq yd
sq km	10.76	sq ft
sq m	1.196	sq yd

Multiply	by	to obtain
mi	5280	ft
mi	1.609	km
mi/min	88	fps
mi/min	1.609	km/min
mg/l	1	ppm
(mg/l)	8.345	lb/mil gal
(mg/l)	0.07016	grains/US gal
(mg/l)	1.547	grains/Imp gal
mgd	1.547	cfs
mil gal	306.89	acre ft
ml	3.531×10^{-5}	cu ft
ml	6.102×10^{-2}	cu in
ml	2.642×10^{-4}	gal (US)
ml	10^{-6}	cu m
ml	10^{-8}	liter
miner's in	1.5	cfm
Newton	0.2248	lb (weight)
Newton/sq m	0.00014	psi
oz (avdp)	28.3495	g
oz (avdp)	437.5	grains
oz (avdp)	0.9115	oz (troy)
oz (fluid)	1.805	cu in
oz (fluid)	29.57	ml

Multiply	by	to obtain
sq mi	640	acres
sq mi	2.590	sq km
sq yd	9.0	sq ft
sq yd	0.8361	sq m
sq yd	2.1×10^{4}	acres
tons (long)	1016	kg
tons (long)	2240	lb
tons (long)	1.12	tons (short)
tons (metric)	10^{3}	kg
tons (metric)	2205	lb
tons (short)	2000	lb
tons (short)	907	kg
tons of water/24 hr		0.1664gpm
watt	0.056	Btu/min
watt	0.7376	ft-lb/sec
watt	1.34×10^{-3}	hp
watt	0.0143	kg-cal/min
yd	0.9144	m

Conversion of °C to °F or °F to °C = $\frac{C}{100} = \frac{F-32}{180}$

Appendix 2: Definitions

List of Definitions

active layer:	The layer of soil which freezes and thaws annually as seasons change (also called seasonal frost).
alluvia:	Clay, silt, sand, gravel, or similar material deposited by running water.
anadromous fish:	Fish that journey up rivers from the sea at certain seasons for breeding (salmon, smelt, etc.)
anchor ice:	See ice, anchor.
arctic:	Regions where no mean monthly temperature is greater than 10°C and where at least one month has a mean monthly temperature of 0°C or colder.
Arctic Circle:	Latitude 66° 31'N: the latitude at which on at least one day the sun does not set in the summer or rise in the winter).
aufeis:	Ice that is formed as water flows over a frozen surface.
beaded streams:	Streams that contain enlargements or "beads" that are caused by the melting of blocks of ground ice along its course.
bentonite:	A clay substance used for grouting well casing; it has the ability to expand when water is added to it.
blackwater:	Wastewater which contains only human toilet waste and a small amount of flushing water.
bleeding:	The continuous running of water through taps to maintain a flow in the mains, service lines, and sewers to prevent freezing of the pipes.
BOD:	Biochemical oxygen demand; a measure of the amount of oxygen required by bacteria to oxidize water aerobically to carbon dioxide, water, and other relatively stable end products.
BOD_5:	The amount of oxygen required by bacteria during the first five days of decomposition (at 20°C).
bog:	A wet peatland which is extremely nutrient-poor, acidic, and has a tree cover of less than 25% of its area.

brackish water:	Saline or mineralized water with a total dissolved solids concentration of about 1,000 mg/L to 10,000 mg/L.
breakup:	The melting time at which (a) ice on rivers break and start moving with the current; (b) lakes can no longer be crossed on foot; and (c) previously frozen mud is soft, and most of the snow is gone.
central facility:	A community facility where one or more sanitary services (washrooms, showers, etc.) are available.
central water points:	A potable water supply centrally located within a community where hand-carried containers and/or water hauling vehicles are filled.
COD:	Chemical oxygen demand; a measure of the amount of oxygen required to chemically oxidize wastewater.
coliforms:	Rod shaped bacteria, which are gram-negative and will ferment lactose at 35°C, producing gas within 24 hours. Two classifi-cations are of importance here: total coliform and fecal coliform. The latter are from fecal matter of warm-blooded animals.
continuous permafrost:	An area underlain by permafrost with no thawed areas except under large lakes and rivers that never freeze solid.
CT:	The product of the disinfectant residual concentration C expressed in mg/L, and the detention or contact time in a disinfection process reactor tank or vessel expressed in minutes.
degree-days:	A quantity expressed as the product of "degrees variation from a base" and "time in days." Example: If the temperature averages 5°C for 10 days, there is an accumulation of 50 degree-days for "thaw." (Base for freezing and thawing degree-days is 0°C and base for heating degree-days usually is 18°C.
discontinuous permafrost:	An area underlain mostly by permafrost but containing small areas of unfrozen ground, such as on south-facing slopes.
DO:	Dissolved oxygen; oxygen dissolved in water.
evapotranspiration:	The passage of water as a vapor into the atmosphere through the processes of evaporation and transpiration.

facultative lagoon:	A lagoon that treats wastes through a combination of aerobic or anaerobic processes.
fill point:	In a truck haul system, this is the location where a water truck fills its water tanks; it also refers to the point on individual houses where ice or water is delivered.
frazil ice:	See Ice, frazil.
freeze-rejection concentrate:	The natural process whereby water slowly freezes, excluding impurities and forming crystals of pure water; impurities rejected from the ice are concentrated in the remaining liquid.
freezeup:	The transition time when moisture at the ground surface freezes forming a hardened surface.
freezing index:	The integrated number of degree-days colder than the freezing point in a winter season.
frost creep:	A gradual movement of soil, clay, or loose rock due to alternate freezing and thawing.
frost heaving:	The expansion of soil due to the growth within it of an extensive ice lens, which causes the displacement of the soil surface.
frost jacking:	When soil, bonded to an object, moves upward through frost heaving and carries the object with it. Upon thawing, the object does not return to its original elevation.
frost-susceptible soil:	A soil that retains and permits migration of large amounts of water, encouraging the growth of ice lenses during freezing, from which frost heaving develops; also defined as a soil passing more than 3% through a No. 200 sieve.
glacial flour:	Finely powdered rock material produced by the grinding of a glacier on its bed.
greywater:	Wastewater from kitchen sinks, showers, and laundry, excluding human toilet wastes.
heat capacity:	The quantity of heat required to raise the temperature of a mass by one degree. Therefore, the heat capacity of a body is its mass multiplied by its specific heat.
heating index:	The integrated number of degree-days colder than some base figure (usually 18°C) during a heating season.

heat trace system:	An electrical system having thermostats and sensing bulbs along the pipe in question, thereby keeping it from freezing; operates on a continuous or as-needed basis.
HPC:	Heterotrophic plate count; a measure of the number of live heterotrophic bacteria in water.
ice—anchor:	Ice formed below the surface of a body of water; the ice attaches itself either to a submerged object or to the bottom.
frazil:	Ice crystals that form in flowing, supercooled water and collect on any channel obstruction; usually frazil ice formation occurs at night because of the high rate of heat radiation away from the water.
icebergs:	Huge mass of ice broken or calved from a glacier.
ice field:	An extensive sheet of sea ice that can be several square kilometers in area.
ice fog:	Fog composed of particles of ice, usually caused by moisture or steam released into the cold environment or by a large open body of water exposed to air.
icing:	Mass of surface ice formed by successive freezing of sheets of water that can seep from the ground, a river, or a spring. When the ice is thick and localized, it may be called an icing mound. Icing (also known an glaciering or aufeis) can be 3 m thick and nearly a kilometer long.
ice-rich ground:	Soil containing ice in excess of its thawed voids-volume.
ice wedges:	Vertically oriented V-shaped masses of relatively pure ice occurring in permafrost. The head of the wedge is on top and can be up to 4 m wide, whereas the wedge itself can be 10 m high.
insulating layer:	A layer of sand, gravel, wood, or other low heat-conductive material for the purpose of reducing heat transfer. Frequently related to the protection of permafrost.
intra-permafrost water:	Ground water within the permafrost: usually has high concentration of minerals which keep it from freezing.
latent heat:	The amount of heat required to melt a unit volume of a substance at standard pressure.

lignins:	A long-chain organic molecule which causes a brown color in water; normally from mosses and other organic materials.
mg/L:	A unit of concentration expressed as milligrams of mass per liter of volume.
muskeg:	An Indian (Algonquin) word for bog or peatland.
non-frost-soil:	A soil that does not retain water, thereby not encouraging the growth of ice wedges.
northern communities:	Those communities that lie in the arctic and subarctic regions.
on-shore wind	Wind moving onto or toward the shore; landward.
package treatment plant:	A treatment system available as prefabricated "packaged" units.
pathogenic bacteria:	An organism capable of producing disease in humans.
peat:	Highly organic soil, 50% of which is combustible, composed of partially decayed vegetable matter found in bogs (muskegs). It is very frost-susceptible.
permafrost:	Soil, bedrock, or other material that has remained below 0°C for two or more years.
permafrost table:	The dividing surface between the permafrost and active layer.
polygonal ground:	Patterned ground with recognizable trenches or cracks along the polygonal circumference (a surface relief); produced by alternative freezing and thawing of the surface soil above the permafrost.
seasonal frost areas:	Areas where ground is frozen by low seasonal temperatures and remains frozen only through the winter; in permafrost this refers to the active layer.
self-haul system:	A system where water is carried in containers from a central water point to the home for use or storage.

slump:	A depression or landslide on the land due to the removal of the natural vegetation which causes the underlying massive ground ice in the permafrost to melt.
sludge:	A semi-liquid substance consisting of settled sewage solids combined with varying amounts of water and dissolved materials.
snow fences:	A barrier erected on the windward side of a road, house, etc., to encourage the dropping of wind-borne snow and therefore serving as protection against drifting snow. Also used to encourage snow deposition as a later source of meltwater.
sporadic permafrost:	Isolated masses of permafrost located within an area generally thawed during the summer.
sublimation:	To change a solid to a gaseous state without going through an intermediate liquid state.
subpermafrost layer:	The layer below the permafrost.
suprapermafrost layer:	The layer between the ground surface and the permafrost table; this layer contains the active layer, year-round thawed areas (taliks) and temporarily frozen areas (pereletoks).
talik:	A layer of unfrozen ground between the active layer and the permafrost; the term applies also to an unfrozen layer within the permafrost, as well as to the unfrozen ground below the permafrost.
tannin:	Astringent complex pheudic substances of plant origin dissolved in water and usually leaving a yellow or brown color.
thaw bulb:	A thawed section in the permafrost due to the warming effect of a house, river, lake, etc.
thawing index:	The yearly sum of the differences between 0°C and the daily mean temperature of the days with means above 0°C.
thermal erosion:	The undercutting of a frozen bank or shore by melting of the soil from exposure to running water and/or wave action.
thermal inertia:	The degree of slowness with which the temperature of a body approaches that of its surroundings.
thermal resistance:	The resistance of a body to the flow heat.

thermal stratification:	The layering effect of temperature in an enclosed body of water or air due to lack of mixing or density differences.
tundra:	Term applied to the treeless vegetation in the arctic and subarctic and at high elevations.
unstable permafrost:	Permafrost that is not physically stable in its thermal environment (i.e. it is on the verge of thawing).
utilidor:	An above- or below-ground conduit, often insulated, that acts as an enclosed corridor for a network of pipes and cables which supply community services to individual homes and businesses.
vehicle-haul system:	A water delivery system whereby water trucks fill at a central point and deliver water to individual holding tanks.
"warm" permafrost:	Arbitrarily defined as permafrost that has a temperature of -4°C or greater.
water wasting:	See bleeding.
watering point:	A central point for users to obtain potable water for domestic purposes.
wetlands:	General term to name any poorly drained area.

Appendix 3: Examples

Design Examples

Design Example of Water Availability in Tundra Pond

Actual example of water availability from Kaktovik's water supply lake:

> This lake with a surface area of about 465,000 m^2 (5 million ft^2) will typically average about 2.5 m (8 ft) deep with maximum depths of 3-3.7 m (10-12 ft). This is extremely significant for consideration as a water supply, because although the lake contains approximately 1,500 million liters (400 million gal) of water during the ice-free periods, it contains only about 95 million liters (25 million gal) of thawed water at maximum ice accumulation of 2-2.5 m (7-8 ft).
>
> Most impurities from the total lake volume will be concentrated into the smaller amount of water beneath the ice. Treatment of this "under ice water" is substantially more complicated than treating summer water.
>
> The very limited recharge capability for these shallow lakes can be demonstrated. The flatness of the terrain and the number and spacing of the lakes usually limits the watershed to an area no more than a few tens of meters around the lake plus the lake surface. Considering the limited annual precipitation (approximately 15 cm or 6 in/year), there is a potential of about 113.7 million liters (30 million gal) of recharge. Typically, this lake contains no inflow other than runoff from its small watershed and precipitation on the lake itself. Subtracting out evaporation leaves a potential recharge of only about 43 million liters (11.4 million gal) for this large shallow lake.

Design Example of a High Rate Filter

Given:

Plant design flow rate: 0.8 mgd

Filtration rate: 5 gpm/ft^2 with all filters operating, 6 gpm/ft^2 max.

Media consists of: 12 inches sand, E.S. = 0.5 mm, U.C. = 1.5; 24 inches coal, E.S. = 1.0 mm, U.C. = 1.4

Leopold block underdrains

Water only backwash

1. Determine filter size:

Try 2 filters.

The maximum filtration rate (one filter out for backwash)

= (5 gpm/ft^2) × (1 Filter) = 5.0 gpm/ft^2. Ok.

Total Filter Area:

(0.8 mgd × (694 gpm/mgd))/(5 gpm/ft^2) = 111 ft^2 of total filter area.

Individual Filter Area:

111 ft^2/(2 filters) = 55 ft^2 per filter

Filter Geometry:

For such a small filter, a square is acceptable.
Filter width = filter length = 7.45 ft.

2. Filter Media Backwash Rate Design

The specification of the filter media is provided in terms of the effective size and uniformity coefficient. The effective size of a filter medium is the sieve size for which 10% of the medium by weight passes through. This size is designated as d_{10}. The uniformity coefficient a measure of the variation in the range of material sizes for a single filter medium. It is the ratio of d_{60}/d_{10}.

The following equation can be used to estimate the sieve size through which a given%age of the media's total weight will pass.

$$d_{(x)} = (E.S.)(10)^{[\left(\frac{x-10}{50}\right)\log U.C.]}$$

where:

x = the%age of the total media weight passing

$d_{(x)}$ = the sieve size which will pass the%age x of the total media weight

E.S. = the effective size of the filter media (the d_{10})

U.C. = the uniformity coefficient for the filter media (the ratio of d_{60}/d_{10})

<u>For sand</u>

$$d_{(x)} = (0.5.)(10)^{[\left(\frac{90-10}{50}\right)\log .1.5]}$$

d_{90} = 0.95 mm

<u>For coal</u>

$$d(90) = (1)(10)^{[\left(\frac{90-10}{50}\right)\log 1.4]}$$

d_{90} = 1.71 mm

Figure A3-1 illustrates the recommended backwash rate for media cleaning.

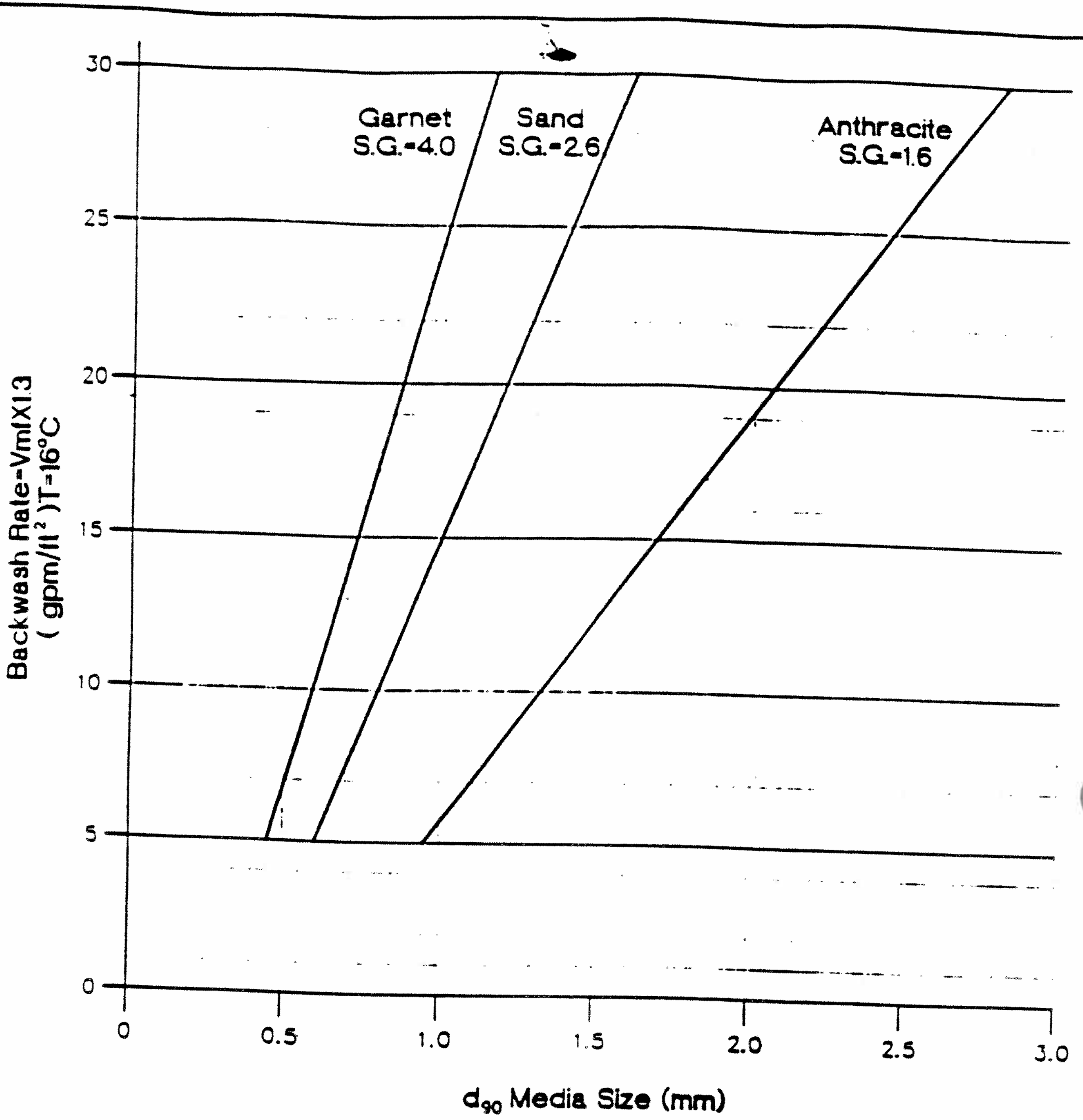
Based on the data in Figure A3-1 the backwash rate required for the individual media components at 17°C are:

<u>For sand</u>

Backwash rate = 14.5 gpm/ft^2 @ 1.6°C

Corrected for temperature ≈ 14.8 gpm/ft^2

06-02-93



Temperature Correction: Approximate Correction Factors To be Applied for Temperatures Other Than 16°C	
Temperature (C°)	Multiply the 16 C° Backwash Rate By
31	1.32
26	1.20
21	1.09
16	1.00
11	0.91
6	0.83

FIGURE A3-1
BACKWASH RATE FOR MEDIA CLEANING

For coal

Backwash rate = 15.5 gpm/ft^2 @ 1.6°C

Corrected for temperature = 15.8 gpm/ft^2

Based on the given media sizes and a water temperature of 17°C, a backwash rate of 15.8 gpm/ft^2 is chosen.

The total backwash flow rate = (15.8 gpm/ft^2)(450 ft^2) = 7,110 gpm

Design Example of a Slow Sand Filter

Given: Two filter cells will be used; when one cell is out of operation, all flow will pass through the cell in service. The design per capita water use is taken to be 250 gpcd which is the peak day demand for the summer. The peak day demand for winter, when residents of the community bleed the water lines to prevent them from freezing, is about 800 gallons per capita per day (gpcd).

Determine the hydraulic loading rate (HLR) assuming two filters with a maximum size of 1,600 ft^2:

HLR = Q/A

HLR = 1.0-10 mgad (typical range)

$A_{1\ filter}$ = 1,700 ft^2 = 0.0367 acres

$$HLR = \frac{(250\ gpcd)(1{,}000\ persons)\ x\ (10^{-6}\ MG/G)}{0.0367\ acres}$$

= 6.81 mgad

This is within the range of 1-10 mgad

Check the HLR for combinations of HLR and population

Table A3-1

Per Capita Use (gpcd)	Flow (gpd)	HLR	
		Two Filters	One Filter
250	250,000	3.40	6.81
800	800,000	10.89	21.79

From the above analysis, it is apparent that the filter area and/or number of filters will need to be adjusted to keep the HLR within the range of 1.0-10.0 mgad.

Repeat by trial and error until all parameters are within the HLR of 1 to 10 mgad.

Design Example of an Impeller Type Flocculator

Given:

Design flow rate: 100 gpm
Detention time: 20 min at design flow rate
Minimum temperature: 33°F
Water viscosity (μ) $= 3.74 \times 10^{-5}$ lb-sec/ft^2
Velocity Gradient, G (s^{-1}) $= 45$
1 process train; 1 chamber per process train
Water depth: 7 ft
Flow path: horizontal flow through
Treatment application: direct filtration

Find:

Basin dimensions
Power input
Impeller diameter
Impeller speed

1. Basin dimensions

Volume of basin:

$$\frac{100\ \text{gal}}{\text{min}} \times 20\ \text{min} \times \frac{\text{ft}^3}{7.48\ \text{gal}} = 267\text{ft}^3$$

Plan area of basin: 267 CF/7 ft depth = 38 ft^2

$$267\ ft^3/7\ ft = 38\ ft^2$$

A square basin would have the dimensions of 6.2′ × 6.2′.

2. Power Input

$$\bar{P} = (\bar{G})^2 \mu V$$

where:

$\bar{P}$ = average power input (ft•lb/sec)
$\bar{G}$ = average velocity gradient = 45s^{-1}
μ = water viscosity 3.74×10^{-5} lb•sec/ft^2 @ 33°F
V = mixing chamber volume = 267 CF

$$\begin{aligned}\bar{P} &= (45/\text{sec})^2 \times 3.74(10^{-5}) \text{ lb-sec/ft}^2\\ &= 20.22 \text{ ft-lbs/sec}\end{aligned}$$

Converting units to horsepower, the result becomes:

$$P = \frac{20.26 \text{ ft-lb} \cdot \text{sec}}{550} = 0.04 \text{ hp}$$

Even assuming an electrical motor efficiency of 70%, the motor horsepower is very small.

$$\text{Motor hp} = 0.04/0.7 = 0.06 \text{ hp}$$

As with most small systems, the physical sizes of the components are relatively small. For the motor in this case, the required motor size might be a fractional horsepower DC motor with a SCR variable speed controller for optimum process control.

Note: The starting torque on flocculation mixers is high. Make sure the motor and shaft can handle it.

Similar calculations can be made for other treatment plants of different size by substituting the appropriate flows, number of flocculation stages, shear factors and water viscosity.

3. Impeller Diameter

The sizing of the flocculator diameter for the foregoing example is explained below. The equation for determining this diameter is as follows:

$$D = 0.35\,(L \times W)^{1/2}$$

where:

D = Impeller diameter, ft
L = Impeller chamber length, ft
W = Impeller chamber width, ft

For the foregoing example, the resulting diameter is:

$$D = 0.35\,(6.2 \times 6.2)^{1/2}$$
$$= 2.2 \text{ ft}$$

4. Impeller Speed

The flocculator impeller speed is obtained from the following equation:
where:

$$N = \left(\frac{P}{\rho \times D^5 \times Np} \right)^{1/3}$$

N = impeller rotation speed, revolutions/sec
P = average power input
= 20.22 ft-lb/sec
ρ = water density
= 1.94 slugs/ft^3 @ 33°F
D = impeller diameter = 2.2 ft
Np = power number, dimensionless

The power number is determined empirically by the mixer manufacturer and depends on:

- Type of impeller
- Impeller dimensions
- Basin configuration and baffling
- Blade width and angle

A 45° pitched blade (4 blades) turbine impeller with blade width equal to 0.24 D is chosen in this example. The power number is 1.6 for the conditions in this example. Power numbers should be obtained from established mixer manufacturers.

$$N = \left[\frac{20.22}{(1.94)\,(2.2)^5 \times (1.6)}\right]^{1/3}$$

$$= 0.51 \text{ rev/sec} = 30 \text{ RPM}$$

$$\text{Impeller tip speed} = \frac{\text{RPM} \times D}{(60/\pi)} = \frac{30 \times 2.2}{19.1} = 3.5 \text{ fps}$$

Tip speed is less than the maximum of 9 fps. If tip speed was greater than 9 fps, try increasing the impeller diameter, increasing the blade width or angle (which increases Np), or decreasing $\bar{G}$.

Design Example for Cl_2 Dosage

Assume an unfiltered water source is to be disinfected with Cl_2. The water temperature is 0.5°C, the pH of the water is 7.5 and the Cl_2 residual to be maintained is 0.6 mg/L. 99.9% inactivation (3-log removal of *Giardia* cysts is required. The Cl_2 demand is 0.4 mg/L.

The state *Drinking Water Regulations* require use of a CT factor of 239 for these conditions.

1. To maintain a 0.6 mg/L residual with a 0.4 mg/L demand, what dosage of liquid Cl_2 will be required to treat the water?

   Solution:
   demand (0.4 mg/L) + residual (0.6 mg/L) = dosage of 1.0 mg/L

2. How many pounds of Cl_2 will be required to treat 1 million gallons per day (mgd)?

   Solution:
   1.0 mg/L x 8.33 lbs/gal x 1 MG = 8.3 lbs Cl_2
   1.0 mg/L = 1 lb/million lbs

3. how many pounds of Cl_2 will be required to treat 6 mgd?

   Solution:
   1.0 mg/L = 8.33 lbs/gal x 6 MG = 50 lbs Cl^2

4. How many gallons of a 15% sodium hypochlorite mixture will be required to treat #2 (1 mgd Cl_2) and #3 (6 mgd Cl_2) above?

Solution:

One gallon of 15% sodium hypochlorite contains 1.25 lb available Cl_2 according to the table:

Table A3-2

Available Cl_2 in Sodium Hypochlorite[a]				
Percent available Cl_2	1	5	10	15
Pounds of available Cl_2 per gal	0.083	0.42	0.83	1.25

[a] Based on weight-per-unit volume.

$$\frac{lbs\ Cl_2\ req'd/day}{lbs\ Cl_2\ available/gal\ mixture} = gal/day$$

$$a.\quad 1\ mgd: \quad \frac{8.3\ lbs/day}{1.25\ lbs/gal} = 6.6\ gals/day$$

$$b.\quad 6\ mgd: \quad \frac{50\ lbs/day}{1.25\ lbs/gal} = 40\ gals/day$$

5. How many pounds of 70% hypochlorite powder will be required to treat #2 and #3?

Solution:

$$\frac{lbs\ Cl_2\ req'd/day}{\%\ Cl_2\ available\ (powder)} = 6.6\ gals/day$$

$$a.\quad 1\ mgd: \quad \frac{8.3\ lbs/day}{0.70} = 11.9\ lbs/day$$

$$b.\quad 6\ mgd: \quad \frac{50\ lbs/day}{0.70} = 71.4\ lbs/day$$

Preparation of Solutions

1. How many gallons of a 15% solution must be diluted with water to prepare 55 gallons of a 2% solution?

   Solution:

$$\frac{gal\ dil.\ sol.\ x\ \%\ dil.\ sol.}{\%\ conc.\ sol.} = gal\ conc.\ sol.$$

$$\frac{55\ gal\ x\ 2\%}{15\%} = 7.33\ gal\ conc.\ sol.$$

2. How many pounds of dry hypochlorite powder containing 70% available Cl_2 must be dissolved in 55 gals of water to make a 2% solution?

   Solution:

$$\frac{gals\ (8.33\ lbs/gal) \times \%\ Cl_2\ solution}{available\ \%\ Cl_2} = lbs\ hypochloritepowder$$

$$\frac{55\ gal \times 8.33\ lbs/gal \times 0.02}{0.70} = 13\ lbs\ hypochloritepowder$$

Determination of Dosage Applied

1. Determine the dosage rate of Cl_2 if 6 mgd of water is disinfected with liquid Cl_2 (100% available) at a rate of 120 lbs/24 hr.

   Solution:

$$\frac{lbs/day}{8.33\ lbs/gal \times flow\ (10^6\ gals)} = lbs/10^6\ lbs$$

$$\frac{120}{8.33 \times 6} = 2.4 \ mg/l$$

2. Determine the dosage rate of Cl_2 if 6 mgd of water is disinfected with a 2% solution of hypochlorite at a rate of 180 gals/day.

   Solution:

$$gal.\ sol. \times 8.33\ lbs/gal \times \%\ Cl_2\ available = lb\ Cl_2$$

$$180\ gals \times 8.33\ lbs/gal \times 0.02 = 30\ lbs\ Cl_2$$

from solution to #1. (above)

$$\frac{30\ lbs/day}{8.33\ lbs/gal \times 6 \times 10^6\ gals/day} = 0.6\ mg/L$$

Design Example of Disinfection CT Calculation for Sizing a CT Contact Tank

Given:

Peak hourly flow rate:	200 gpm
Water temperature:	0.5°C
pH:	6.5
Free Cl_2 residual:	0.8 mg/L

Assume unfiltered surface water source requiring 3-log inactivation of *Giardia* cysts and 4-log inactivation of viruses.

From Table 4.15 of this manual, the most restrictive CT value for these conditions is 172, which is required for 3-log inactivation of *Giardia* cysts.

$$T_{10}\ (\text{contact time}) = CT/Cl_2\ \text{residual}$$

$$T_{10} = 172/(0.8\ mg/L) = 215\ \text{minutes}$$

To determine reservoir size, the baffling efficiency must be considered. Table A3-3 is a summary of baffling conditions and corresponding baffling efficiency factors.

TABLE A3-3
CT Tank Baffling Efficiency Factors

Baffle Condition		Baffle Factor T_{10}/T
Unbaffled	No baffling, agitated basin, low length-to-width ratio	0.1
Poor	Single or multiple unbaffled inlets and outlets, no intra-basin baffles	0.3
Average	Baffled inlet or outlet with some intra-basin baffles	0.5
Superior	Perforated inlet baffle, serpentine or perforated intra-basin baffles, outlet weir or perforated launders	0.7
Perfect	Theoretical plug flow through tank	1.0

The size of the contact tank or reservoir is dependent upon:

- Water temperature
- pH
- Cl_2 residual at outlet of reservoir
- Baffling condition
- Peak hour flow rate

The design of the tank should evaluate water supply and quality data for all anticipated pH and temperature conditions to determine which prevailing design condition requires the largest reservoir.

The calculation for required tank size is as follows:

$$V = \frac{Q \times (\text{CT Factor})}{C \times (T10/T)}$$

where:

V = volume of tank or reservoir in gals
Q = peak hourly flow rate in gal/min
C = residual concentration of disinfectant used in mg/L
CT Factor = the CT value for the pH, temperature, and disinfectant used from Tables 4-15 through 4-22 of this manual
(T_{10}/T) = baffle factor from Table A3-3

For the assumed conditions, the tank sizes for different baffle conditions are presented in Table A3-4.

TABLE A3-4
Comparative CT Tank Sizes for Different Baffle Conditions

		Tank Size (gal)
		(200 gpm x 215 *min) (T10/T)
Unbaffled	0.1	430,000
Poor	0.3	143,000
Average	0.5	86,000
Superior	0.7	61,000
Perfect	1.0	43,000

* CT/C = T_{10} = 215 mins

It is also important to note that the temperature and pH of the water are critical to the determination of the size of the tank. Coldest water conditions may not always determine the required tank size. Assume, for example, that the 200 gpm design flow above warms up in the summer to 5°C with a pH of 8.0 and a residual of 0.8 mg/L is still needed. The CT is then 210. The corresponding T_{10} is 262 minutes, and the required tank sizes are approximately 22% larger than for the colder winter water temperatures.

Design Example for Surface Water Filtration
Retrofit of an Existing Pressure Filtration System

Description of Existing Conditions

General

The existing system serves a rural Alaskan community located on an interior Alaska river system. There are a total of 500 individuals served by the system. Connections for the system consist of the year-round watering point at the washeteria, a dozen summer watering points, and the service connection for the school. The water source provides an average of 2.5 million gals of water to the system annually.

Source Water Quality

The water source is a shallow well at the river which has been determined to be under the direct influence of the surface water. The area is entirely underlain by permafrost, and no ground water source has been developed. The existing source water quality characteristics are as follows:

- Average turbidity is 5 NTUs
- Seasonal turbidity during breakup ranges between 20 and 40 NTUs
- Color of 20-50 CU
- Iron of 4-6 mg/L
- Manganese of 0.07-0.1 mg/L
- Temperature of 33-36°F
- Calcium of 20-25 mg/L as $CaCO_3$
- Alkalinity of 20-30 mg/L as $CaCO_3$
- pH of between 7.0 and 7.4
- Conductivity of 300-500 micromhos/cm

Based on other limited sampling and analyses, there are no other primary contaminants believed to be in the source water.

Existing Treatment System

Source water is pumped directly to the filters in the service mode at a rate of between 35 and 55 gpm. Filtered water is chlorinated with calcium hypochlorite, fluoridated with sodium fluoride and stored in a 96,000-gallon storage tank located immediately adjacent to the treatment facility and washeteria. Service pumps provide potable water to the system's service connections. A dedicated pair of backwash pumps use water stored in the potable water storage tank for backwashing the filters. Wastewaters from the backwash and filter rinse cycles are conveyed to the community wastewater lagoon.

The existing filtration system consists of a pair of 4-foot diameter pressure filters operated in parallel. The filter media is 20 inches of sand underlain with 12 inches of gravel support media. The filters are fitted with manually operated Solomatic valves to select the service cycle, backwash cycle, or rinse cycle. Differential pressure gages are provided for each filter and to determine when the filters need to be backwashed. Meters provide a record of the water used, and a gage indicates the water level in the storage tank.

Design Requirements

The upgrade of the water treatment facility must comply with the surface water treatment requirements in the state *Drinking Water Regulations*. Filtration avoidance is not applicable as the source water turbidity routinely exceeds 1 NTU. The system will have to upgrade both its filtration and disinfection processes if it is to meet the SWTR and maintain the use of surface water as its source.

Selection of Filtration Method

Log Removal-Inactivation Requirements and Goals

In the Alaska *Drinking Water Regulations*, most water systems that use surface water or ground water under the direct influence of surface water must meet the following goals:

Giardia: 99.9% reduction (3-log removal)

Viruses: 99.99% reduction (4-log removal)

Systems with poor source water quality are required to meet higher reduction goals in order to ensure adequate protection. Consideration is to be given to the amount of sewage or other contaminants discharged to the source water, the location of pollution discharges or other activities in relation to the water system intake, and whether pollutants are diluted before they reach the intake. Higher reduction goals are identified in the *Alaska Drinking Water Procedures Manual* under the section entitled "Method to Determine Whether Filtered Systems are Achieving Required Removals". Since the water supply is a major river located in a remote, largely undeveloped location, excessive contamination is not anticipated. The 3-log *Giardia* and 4-log virus reduction requirements are reasonable.

Filtered Water Turbidity Goals

SWTR regulations require filtered water to meet 0.5 or 1 NTU (depending on the treatment technique) at least 95% of the time. As mentioned in

Chapter 3, there is a mechanism in the SWTR that allows a system to petition for an "exception" to allow for turbidity levels up to 5 NTUs. This can be done if pilot testing shows:

- The filtration technique removes particulates smaller than *Giardia* cysts (i.e. 5 μm).
- Turbidity is caused by inert materials (i.e., glacial flour) that are typically below 2 μm in size.
- Disinfection efficiency is not affected, and minimum Cl_2 residuals or compliance with the (alternative) heterotrophic plate count (HPC) monitoring program is maintained.

Since the water source for this community regularly exceeds 5 NTUs, this exception does not apply. The filtered water must meet 0.5 or 1 NTU (depending on the treatment technique) at least 95% of the time.

Filtration Techniques

Filtration system capabilities as a function of the source water quality is reviewed in Chapter 4 and included in the Alaska *Drinking Water Procedures Manual*. For source waters with turbidity generally in a range of 7-14 NTUs, conventional filtration is identified as the technique which is most commonly applied to achieve the targeted 0.5 NTU at least 95% of the time.

To achieve conventional filtration performance without replacing existing filters, the use of contact clarification in conjunction with an upgrade of the existing pressure filter equipment is addressed.

The contact clarifier is a prefilter in a pressure vessel format. Media can be anthracite, sand or other adsorption media. These units have been operated in both upflow and downflow modes with the sand and anthracite media most often used in downflow mode. Use of a clarifier should significantly reduce the solids loading to the existing filter. The clarifier is preceded by polymer chemical addition, rapid mix, and coagulation. A reaction vessel may be needed for the formation of floc, especially with the use of long-chain polymers in cold water.

Upgrades to the existing filtration equipment which should be considered are:

- Addition of a viewing window and internal lighting to allow observation of the filter media and backwash operations.

- Inspection and, if necessary, replacement of the filter media.

- Addition of surface wash to the filter media.
- Addition of auxiliary air wash or surface wash to the backwash cycle and modification of the existing filter underdrain system to accommodate the air wash. This would include the installation of a media air scour system in the filter and the provision of low pressure air blowers.
- Addition of individual continuous recording turbidimeters to monitor the effluent quality from each of the filters. These units could be interlocked with the filter controls to automatically initiate the filter backwash cycle or simply terminate the filter run and notify the operator of the need for a backwash. They can also be used to control the rinse cycle duration to minimize turbidity spikes in the filter effluent after backwash.
- Addition of pilot operated hydraulic control valves at each filter inlet to maintain a constant rate of flow to each filter. This will eliminate the need for flow paced controls on the chemical feed equipment. Also, flow limiting orifices should be installed for the backwash inlet ports to minimize the potential for accidental media upset.
- Addition of flow meters to the individual filters to provide a record of the amount of flow through each filter between backwash cycles. This would help identify media which could potentially become plugged.
- Addition of insulation to the exterior of the filters for condensation control and prevention of exterior rust.
- Provision of sampling ports on the filter effluent to be used to collect samples for monitoring filtered water performance.
- Provision of filter media slurry removal ports. During media replacement, these ports can be used to convey media slurry out of the filter and thereby expedite the media removal process.
- Inspection and if necessary, replacement of the surface coating systems on both the interior and exterior of the filter vessels.
- Provision of an air gap for visual observation of pressure filter and waste contact clarifier backwash wastewater. This allows operators to better determine when the backwash cycle is complete.

Alternative technology can be considered for the required log removals of *Giardia* and viruses, especially for small systems. One alternative approach is the use of bag or cartridge filtration downstream of the existing pressure filters, in place of using contact clarification upstream of the filters. While this is a relatively simple retrofit for an existing system, its use on this example source water may not be appropriate.

- Chlorination of the source water without prior color removal may result in the formation of unacceptably high THM.
- The solids loading to the small micron cartridge filtration equipment may result in a short filter runs and frequent replacement of the filter elements with resulting high costs.
- The system customers may object to the level of color in the finished water.

On-site Pilot Testing

The source water quality in this example poses some particular challenges (i.e. cartridge filters) to the water treatment plant designer. Use of either conventional filtration or an alternative approach should be evaluated with an on-site demonstration test procedure prior to selecting the configuration of the upgraded treatment equipment. The pilot demonstration should include the peak turbidity event for the source water.

Some of the pilot demonstration evaluations which should be made are reviewed below.

- The chemical coagulation program should be confirmed. Alternative primary coagulants should be tested along with coagulant aids to determine the chemical feed program which provides the best performance.
- The requirement for a reaction vessel versus in-line mixing following chemical addition should be evaluated for alternative coagulants.
- Filter media options should be evaluated including dual and tri-media configurations with garnet, sand, and anthracite.
- Maximum filter surface loading rates should be established.
- Required filter backwash flow rates should be established.

- Expected length of filter runs and backwash durations should be established.
- Quality of finished water should be established. This information is used in determining disinfection CT requirements (i.e., finished water Cl_2 demand and pH), in establishing THM formation potential, and in evaluating and selecting system corrosion control programs (i.e. finished water pH, alkalinity, conductivity, temperature, calcium concentrations, and phosphate demand).

For sites considering alternative filtration using micron cartridge/bag filtration in place of contact clarification, the following information, in addition to the data listed above, should be established.

- The service life of the micron filter elements should be demonstrated.
- The color of the filtered water.
- The THM of the filtered water.
- The O&M cost of the micron filter element replacement.

Pilot Testing Results

For purposes of this example, it is assumed a pilot demonstration test is conducted with the following results and conclusions.

- The combination of O&M costs (due to cartridge replacement) and the potential for unacceptable THM formation in treated water for the option direct filtration options followed by micron filtration makes this option not viable. Therefore, a more conventional filtration system will be used for the upgraded system.
- A contact clarifier operated in downflow mode with 3 mm anthracite media was simulated with the pilot equipment. A surface loading rate of 5 gpm/ft^2 was used successfully with the selected chemical coagulation program.
- The filters simulated were tri-media filters with garnet, sand, and anthracite. Acceptable final turbidities were achieved with filter loading rates up to 3.2 gpm/ft^2. Backwash rates found to be sufficient were 15 gpm/ft^2 with auxiliary air scour of 3.5 standard cfm/ft^2 of filter surface area.

- The primary coagulants which removed turbidity to less than 0.5 NTU were alum and ferric sulfate. Both required use of a high molecular weight cationic polyelectrolyte coagulant aid. Both showed improved performance in terms of turbidity and color removal with the use of supplemental alkalinity. For the pilot evaluation, soda ash was used as the source of this supplemental alkalinity. The alum had slightly better performance and was easier to work with in terms of staining and corrosive character. The coagulant required a rapid mix process with a minimum G factor of 900 sec-1. Successful alum coagulant dosages ranged between 30 and 60 mg/L. Polyelectrolyte dosages ranged between 0.8 and 3.0 mg/L.

- Color was not completely removed in the filtered water. Filtered water color levels were in the range of 5-20 cu. Iron concentrations of 0.5-2 mg/L measured in the filtered water indicated iron was likely complexed with organics in the water and responsible for the suspected cause of this color. Several options were evaluated for removal of this iron, as follows:

    - One option would be the use of an excess lime coagulation program. However this would require recarbonation prior to filtration to prevent cementing the filter media with $CaCO_3$.

    - Another option would be oxidation of the iron subsequent to color removal followed by removal of the oxidized iron floc. This could be implemented with chlorination after contact clarification and prior to filtration with reaction time provided as needed for oxidation and floc formation. A filter aid polyelectrolyte could be needed for this alternative.

    - A third option would be the use of greensand filtration for iron removal. While the source water concentrations for iron and manganese are within the performance range for greensand zeolite removal of iron and manganese, the complexation of iron and manganese with organics can hinder the process performance.

    - As a fourth alternative, oxidation of iron, manganese, and some of the color causing organics could be achieved with the use of lime addition upstream of the primary coagulant addition. Lime addition to a pH of 10.0 followed by a reaction period of several minutes prior to alum addition would oxidize most of the organically complexed iron and manganese and provide the alkalinity source for the alum floc formation. By evaluating the carbonate chemistry of this source water, the required stoichiometric lime requirement would be approximately 10 mg/L to achieve pH of 10.0. This would be followed by an alum addition of around 60-70 mg/L to achieve the desired coagulation pH range for alum of 6.0-6.5.

- As a fifth alternative, the system could apply for a waiver of the secondary MCLs for iron, manganese, and color. The waiver would be based on an indication of non-objection from the customers served and determination that these parameters would not interfere with achieving compliance with turbidity and disinfection requirements, or produce unacceptable disinfection by-products.

Of these alternatives the last is obviously the least expensive. However, should the system decide it wishes to address the secondary contaminants, the O&M economics will likely favor the lime and alum addition alternative over the excess lime and recarbonation alternative, even with consideration of lead and copper corrosion control requirements.

Design of Upgraded Treatment System

Chemical Feed System

For purposes of this example, assume that both turbidity and secondary contaminants (i.e., iron, manganese and color) will be removed. The pilot test results indicate that the color must be reduced to avoid exceedance of the THM MCL. The chemical feed program will therefore consist of applying:

- Lime - to achieve a concentration range of 10-15 mg/L
- Alum - to achieve a concentration range of 60-70 mg/L
- Polyelectrolyte - as a coagulant aid for a concentration range of 0.8-3.0 mg/L
- Calcium hypochlorite - for a concentration range of 2.0-4.0 mg/L
- Fluoride - for a target of 1.0 mg/L fluoride

In addition, a corrosion control program using phosphate passivation and an orthophosphate, for a concentration range of 0.4-4.0 mg/L, is proposed.

The filters are to be operated at a constant flow rate. This will be accomplished by the addition of a pilot operated diaphragm valve on each filter's inlet to maintain a constant rate of flow to each filter. This will eliminate the need for flow-paced controls on the chemical feed equipment.

The current well yield will sustain a delivery of 35 gpm to the water plant. At this flow rate the surface loading rate will be 1.4 gpm/ft^2 as calculated below. This is within the performance range demonstrated by the pilot test.

$$\frac{flow\ gpm}{area\ ft^2 \times no.\ of\ filters} = gpm/ft^2$$

The required chemical feed pump capacities are calculated as follows:

$$Req'd\ capacity\ (gal/hr) = \frac{(target\ conc.\ mg/L)(design\ flow\ rate\ gpm)(60\ \underline{min}/hr)}{(chem.\ solution\ conc.\ mg/L)(chem.\ purity\ \%)}$$

$$For\ 10\%\ alum\ solution\quad \frac{(60\ mg/L)(35\ gal/\underline{min})(60\ \underline{min}/hr)}{(100{,}000\ mg/L)(1.0)} = 1.26\ gal/hr$$

The required process chemicals are:

- Alum
- Lime
- Polyelectrolyte
- Calcium hypochlorite
- Sodium fluoride
- Soda ash (post pH adjustment)
- Orthophosphate

The use of soda ash for post pH adjustment is needed to optimize the performance of orthophosphate in a corrosion control program.

Contact Clarifier

The contact clarifier will be fabricated as a single unit to pretreat water for either one or both existing filters on line. The unit will be constructed with a reaction and sedimentation tank as part of the package equipment. For example purposes, assume that the pilot test indicated a required reaction time for oxidation of the iron was 4 minutes. The corresponding required reactor volume will be 140 gals.

$$35\ gpm \times 4\ \underline{min} = 140\ gal$$

The surface loading rate for the contact clarifier was demonstrated to be 5 gpm/ft^2. The corresponding required media surface area for the contact clarifier is 7 square ft.

$$\frac{35\ gpm}{5\ gpm/ft^2} = 7\ ft^2$$

The filter backwash pumps should be capable of delivering up to 376 gpm for simultaneous backwash of both filters. A separate pair of backwash pumps should be used to backwash the contact clarifier in an upflow mode at a rate of 15 gpm per square foot. These additional backwash pumps would be sized for 105 gpm.

$$15\ gpm/ft^2\ x\ (\pi/4)(4\ ft^2)(2\ filters) = 376\ GPM$$

Air blowers should be provided for auxiliary backwash air and operated so that one blower will backwash one filter. Each should be sized to deliver a total of 44 scfm at 6 psi.

$$(\pi/4)(4\ ft)^2(3.5\ scfm/ft^2) = 44\ scfm/filter$$

For the surface wash option, two pumps would be required to deliver water to the filters. One pump would serve one filter for a total of 63 gpm for that filter, at a pressure at the surface wash nozzle of 75 psi.

$$(\pi/4)(4\ ft)^2(1\ filter)(5\ gpm/ft^2) = 63\ gpm/filter$$

CT Tank Requirements

The provision for a tank meeting CT parameters is required by the SWTRs. This can be done by either modifying the existing storage tank with baffles (or other means of preventing hydraulic short circuiting), or by providing a new, entirely separate tank to meet CT. The required CT tank volume is based on several parameters. Assume:

- Finished water temperature is 2.5°C
- pH is 7.5
- Tank baffle efficiency is 0.5
- Peak hour flow out of the storage tank is 45 gpm
- Final Cl_2 residual out of the tank is 0.6 mg/L
- Required log inactivation for *Giardia* is 1.0

The required CT tank volume is then 10,500 gals. Although a 0.5-log inactivation is the minimum requirement for conventional filtration, a 1.0-log removal is recommended to provide the system additional protection.

CT @ 0.5°C pH 7.5 1.0-log removal = 80

CT @ 2.5°C pH 7.5 1.0-log removal = 70
CT @ 5.0°C pH 7.5 1.0-log removal = 57

$$Req'd\ volume = \frac{(CT)(peak\ hour\ flowrate\ gpm)}{(chlorine\ residual\ mg/L)(baffle\ efficiency\ factor)}$$

$$\frac{(70)(45\ gpm)}{(0.6\ mg/L)(0.5)} = 10{,}500\ gal$$

Appendix 4: Bibliography

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TABLE OF ABBREVIATIONS

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ADEC	Alaska Department of Environmental Conservation
AWWA	American Water Works Association
BAT	Best Available Technology
BDD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DBP	Disinfection By-Products
DE	Diatomaceous Earth
DO	Dissolved Oxygen
EPA	U. S. Environmental Protection Agency
FDA	U.S. Food and Drug Administration
GAC	Granular Activated Carbon
LCR	Lead and Copper Rule
MCL	Maximum Contaminant Level
MPA	Microscopic Particulate Analysis
MSDS	Material Safety Data Sheet
NSF	National Sanitation Foundation
NTU	Nephelometric Turbidity Unit
O & M	Operation and Maintenance
OSHA	Occupational Safety and Health Administration
RO	Reverse Osmosis
SDI	Silt Density Index
SDWA	Safe Drinking Water Act

SOC	Synthetic Organic Contaminant
SS	Suspended Sediment
SWTR	Surface Water Treatment Rule
TCE	Trichloroethylene
TCR	Total Coliform Rule
TDS	Total Dissolved Solids
THM	Trihalomethane
TTHM	Total Trihalomethane
UV	Ultraviolet
VOC	Volatile Organic Contaminant