
Treatment Technologies Primer

Portland Water Bureau
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The information to create this summary has been taken these primary sources:

1. EPA Guidance Manual: Alternative Disinfectants and Oxidants, April 1999.
2. EPA Ultraviolet Disinfection Guidance Manual, November 2006.
3. Handbook of Chlorination and Alternative Disinfectants, White, 1999

DISCUSSION OF TREATMENT TRADEOFFS

The EPA has released the Long Term 2 Enhanced Surface Water Treatment Rule which requires the inactivation or removal of *Cryptosporidium*. The current treatment method for the City of Portland Bull Run supply—free chlorination followed by chloramination—is ineffective for *Cryptosporidium* inactivation. Five treatment alternatives, three disinfection technologies, and two filtration technologies have been identified for meeting these new regulations. Each technology offers distinct advantages and disadvantages that need to be balanced when selecting the most appropriate treatment technology for a particular source.

The three disinfection technologies—Ultraviolet irradiation (UV), ozone, and chlorine dioxide—are proven technologies for *Cryptosporidium* control. UV irradiation does not involve chemical addition beyond the existing treatment systems. There are only a handful of UV disinfection systems in operation that are treating over 100 million gallons per day (mgd). There are numerous ozonation facilities with capacities between 100 and 200 mgd. Unfortunately, the CT that is required for *Cryptosporidium* inactivation with ozone is significantly higher than that of *Giardia*, particularly in colder waters. Ozone improves the overall aesthetic of treated water by chemically oxidizing taste, odor and color causing compounds. Chlorine dioxide is also a chemical oxidant; however, it is not as effective for *cryptosporidium* as ozone. There would be a need to examine the chlorine dioxide demand of the source water to be treated to ensure that disinfection byproducts rules can also be met. There would be a need to examine how chlorine dioxide would interact with current treatment systems and examine whether the EPA would consider chlorine dioxide and chlorine/chloramines as two different disinfection barriers. Finally, there would be a need to install a very large amount of storage to achieve the contact time required for treatment with chlorine dioxide.

The filtration technologies, though more costly, would not only ensure continued compliance with existing regulations, but they provide greater flexibility for meeting future drinking water regulations (because of their ability to remove organic materials from the water) and provide removal of turbidity.

Membrane filtration is an emerging treatment technology, with limited large-scale application; scale-up continues to be a concern. Currently the largest membrane filtration treatment in the world is 96 mgd. However, the finished water quality from a membrane facility has been proven far superior to the water quality achieved through direct filtration. Microfiltration/ultrafiltration provides an absolute barrier for particulate matter and pathogens, regulated, soon-to-be regulated, and those not yet identified as pathogenic. Membrane plants are relatively easy to operate, and require no chemical addition for particle and pathogen removal. However, with the aid of chemical pretreatment membranes are capable of removing organic compounds responsible for taste, odor and color events.

Direct filtration is a proven technology for both particle and pathogen removal. Organics, including color, can successfully be removed via chemical coagulation. There are many large-scale applications of direct filtration throughout the world. However, the success of a direct filtration plant depends upon a careful balance between the raw water characteristics and the coagulation chemicals required for particle and pathogen removal. As such, direct filtration plants require greater operator attention and intervention.

Summary of Treatment Alternatives

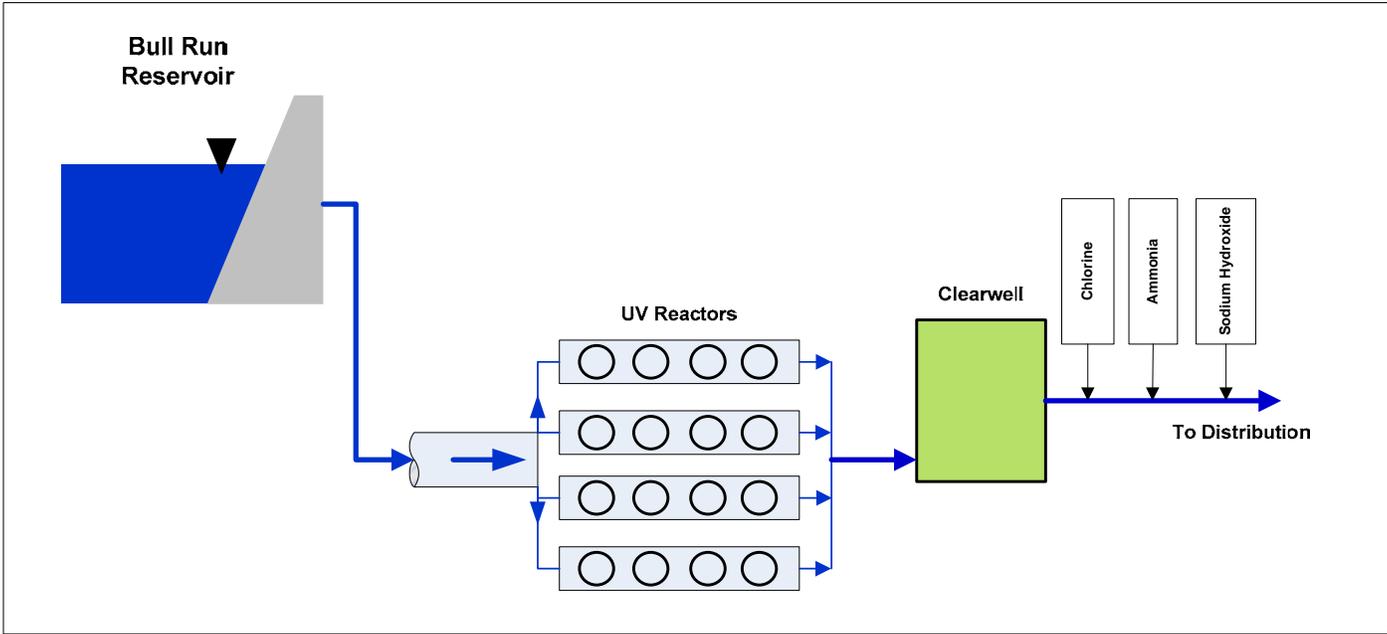
Treatment Type	<i>Crypto</i> Control	Complexity	Additional Supply	Color Removal	Turbidity Removal	More chemicals in water	Reduces Chlorinated Byproducts	New Byproducts Concerns
Existing	N	■■	N	N	N	N	N	N
UV	Y	■	N	N	N	N	N	N
Ozone	Y	■■■■■	N	Y	N	Y	Y	Y
Chlorine Dioxide	Y	■■■	N	Y/N	N	Y	Y	Y
Direct Filtration	Y	■■■■■■■	Y	Y	Y	Y	Y	N
Membrane Filtration	Y	■■■■■	Y	Y/N	Y	N	Y	N

Summary of Ultraviolet (UV) Disinfection Considerations

Consideration	Description
Process	UV Disinfection is the application of high intensity light to provide disinfection. There are three types of UV systems; Low Pressure, Low Output; Low Pressure, High Output; Medium Pressure, High Output. The difference between the three types of UV systems is the ultraviolet spectrum that provides disinfection which dictates the number of bulbs that are required to provide the disinfection. The UV system is called a reactor. The reactor fits directly in the pipeline and contains the light bulbs. As the water moves past the bulbs it is disinfected. By the time the water has passed the last bulb it has received adequate disinfection. There is a sophisticated monitoring system that ensures the proper amount of light energy is provided to the water for treatment. Bulbs are typically replaced based on age (number of hours the bulb has been "on") If a bulb burns out or breaks then water is not fully treated and creates a potential treatment violation.
History	The first reliable applications of UV light for disinfecting municipal drinking water occurred in Switzerland and Austria in 1955 (Kruithof and van der Leer 1990). By 1985, the number of such installations in these countries had risen to approximately 500 and 600, respectively. After chlorinated disinfection byproducts (DBPs) were discovered, UV disinfection became popular in Norway and the Netherlands with the first installations occurring in 1975 and 1980. As of the year 2000, more than 400 UV disinfection facilities worldwide were treating drinking water; these UV facilities typically treat flows of less than 1 million gallons per day (mgd) (USEPA 2000). Since 2000, several large UV installations across the United States have been constructed or are currently under design. The largest of these facilities includes a 180-mgd facility in operation in Seattle, Washington, and a 2,200-mgd facility under design for the New York City Department of Environmental Protection (Schulz 2004). Because of the susceptibility of <i>Cryptosporidium</i> to UV disinfection and the emphasis of the LT2 rule on controlling <i>Cryptosporidium</i> , the number of public water systems (PWSs) using UV disinfection is expected to increase significantly over the next decade.
Primary Uses	Primary physical disinfectant.
Inactivation Efficiency	Very effective against <i>Cryptosporidium</i> at low dosages. Much higher dosage required for bacteria and viruses.
Byproduct Formation	No known disinfection byproducts produced.
Special Considerations	Very few large scale systems (over 100 mgd) are in operation. Water with high concentrations of iron, calcium, turbidity, and phenols may impact UV disinfection. Requires secondary chemical disinfectant for residual in distribution system. Number of UV reactors necessary will be dependent on the type of system chosen. The catalyst in ultraviolet bulbs is mercury. A clearwell will be necessary for the operation of the UV facility to provide operational flexibility in the event of power outage or bulb breakage. The clearwell would prevent mercury from a broken bulb from entering the distribution system.

Summary of Advantages and Disadvantages of UV

Advantages	Disadvantages
<ul style="list-style-type: none"> + Inactivates <i>Cryptosporidium</i>. + pH does not affect treatment capability. + No known disinfection byproducts. + No chemical addition required for <i>Cryptosporidium</i> inactivation. + Compact facility. 	<ul style="list-style-type: none"> - Does not remove turbidity. - Does not provide additional supply. - Limited drinking water application. - Does not reduce chlorinated disinfection byproducts. - Energy intensive compared to ozone and chlorine dioxide. - Does not remove color or taste and odor-causing compounds.



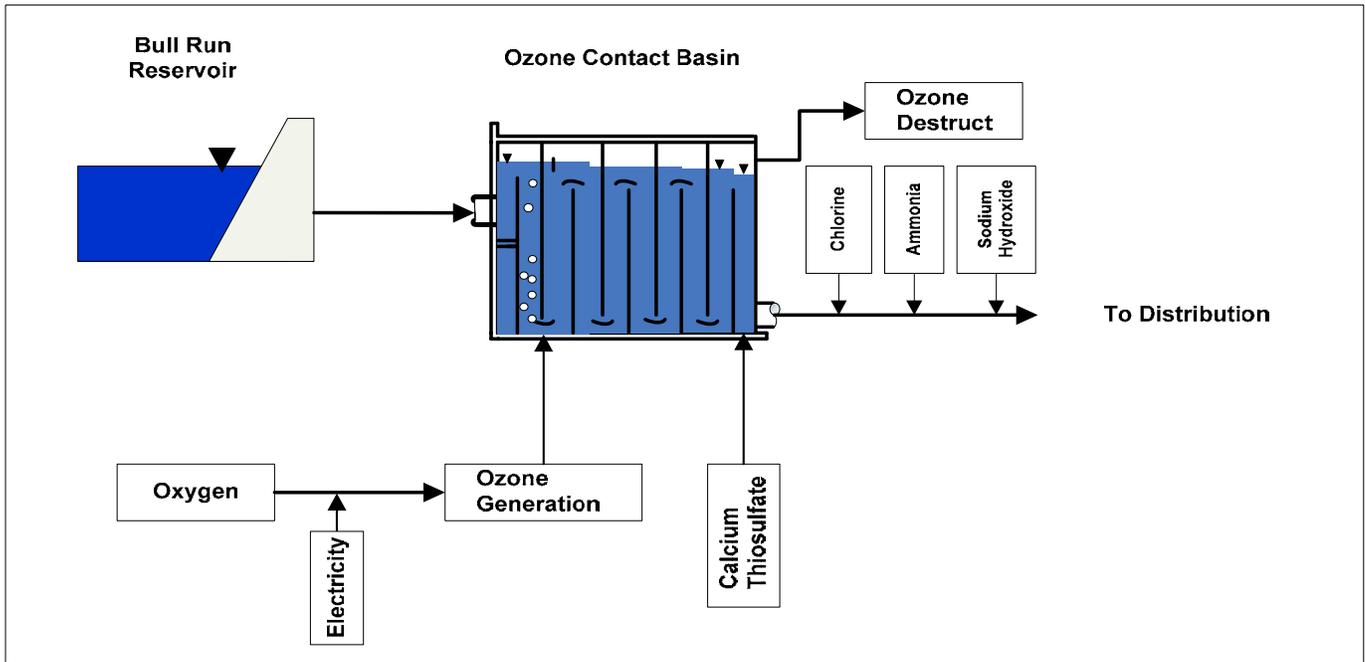
Sample UV Disinfection Schematic

Summary of Ozone Disinfection Considerations

Consideration	Description
Process	Ozone (O ₃) is created by adding a large amount of energy to oxygen gas to form an ozone molecule. An ozone system consists of an oxygen gas feeder, an ozone generator, an ozone contactor and an off-gas destruction system. Ozone is a highly corrosive and toxic gas and the ozone production and application facilities should be designed to generate, apply, and control this gas, so as to protect plant personnel and facilities. Excess ozone from the treatment process is destroyed prior to leaving the treatment facility. Because of its instability, ozone should be generated at the point of use. Ambient ozone levels in plant facilities should be monitored continuously. The oxygen gas necessary for creation of ozone can be taken from the ambient air through an on-site generation process or can be purchased and stored on-site. The potent germicidal properties of ozone have been attributed to its high oxidation potential. Research studies indicate that disinfection by ozone is a direct result of bacterial cell wall disintegration.
History	The first full-scale application of ozone for the disinfection of drinking water occurred in 1893 in the Netherlands. Ozone's popularity in the municipal drinking water industry has grown rapidly in the past 20 years. Prior to 1980, there were less than five ozone plants in the U.S. for municipal drinking water applications. Today, there are well over 260 plants; many are able to treat more than 200 million gallons per day.
Primary Uses	Primary uses include primary disinfection and chemical oxidation. As an oxidizing agent, ozone can be used to increase the biodegradability of organic compounds, eliminate taste and odors, and reduce levels of chlorination disinfection byproduct (DBPs) precursors. Ozone should not be used for secondary disinfection because it is highly reactive and does not maintain an appreciable residual level for the length of time desired in the distribution system.
Inactivation Efficiency	Ozone is one of the most potent and effective germicides used in water treatment. It is effective against bacteria, viruses, and protozoan cysts. Inactivation efficiency for bacteria and viruses is not affected by pH; at pH levels between 6 and 9. As water temperature increases, ozone disinfection efficiency increases.
Byproduct Formation	Ozone itself does not form chlorinated DBPs (which are currently regulated under the disinfection/disinfection byproducts, D/DBP, rule). However, if bromide ion is present in the raw water or if chlorine is added as a secondary disinfectant, halogenated DBPs, including bromate ion may be formed. These are also regulated as part of the D/DBP rule. Other ozonation byproducts include organic acids and aldehydes.
Special Considerations	There is the potential to form small quantities of byproducts but there should be very little impact on the biological activity in the distribution system.

Summary of Advantages and Disadvantages of Ozone

Advantages	Disadvantages
+ Inactivates <i>Cryptosporidium</i> .	- Does not remove turbidity.
+ Treats perennial color issue, tastes and odors.	- Does not provide additional supply.
+ Reduction of chlorine demand and use.	- Increased <i>Cryptosporidium</i> resistance in cold waters increases facility needs.
+ pH does not affect treatment capability.	- Ozone is highly corrosive and toxic.
+ Technology is ready for large scale application.	- Potential distribution system water quality impact.
+ Efficient disinfectant, short contact time.	- Energy intensive compared to chlorine dioxide.
+ Decomposes to dissolved oxygen.	- Introduces Ozonation by-products and their associated health risks.
+ Reduces chlorinated disinfection byproduct formation.	- Ozone requires higher level of maintenance and operator skill than UV or ClO ₂ .



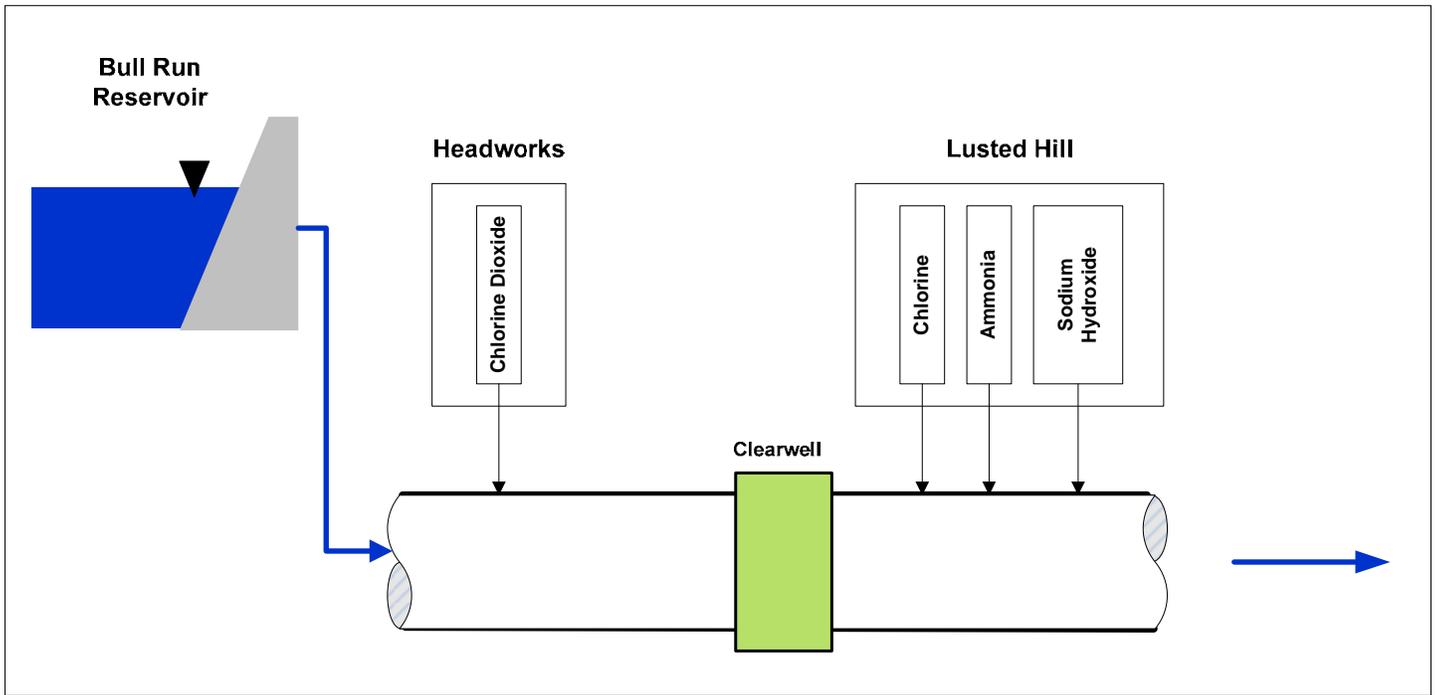
Sample Ozone Disinfection Schematic

Summary of Chlorine Dioxide Disinfection Considerations

Consideration	Description
Process	Chlorine dioxide is a liquid chemical that must be generated on-site. In most potable water applications, chlorine dioxide is generated as needed. A solution is then directly added or injected into a diluting stream, similar to what is typically done for chlorine, ammonia and sodium hydroxide. Generators are available that utilize sodium chlorite and a variety of feedstocks such as chlorine gas, sodium hypochlorite, and sulfuric or hydrochloric acid. Chlorine dioxide functions as a highly selective oxidant due to its chemical properties, wherein it attacks organic molecules, thereby inactivating them.
History	Chlorine dioxide (ClO ₂) was first used in potable water treatment, in 1944, in Niagara Falls, NY, to eliminate tastes and odors. Subsequently, in the 1970's, the use of ClO ₂ as a disinfectant for drinking water was developed. Recently growing concern about Trihalomethanes (THMs), a chlorine disinfection byproduct, has caused researchers to focus on ClO ₂ as an alternative drinking water disinfectant. Today, ClO ₂ is used in 700-900 US drinking water facilities, mainly for taste and odor control as well as to meet increasingly strict THM regulations.
Primary Uses	Chlorine dioxide is utilized as a primary or secondary disinfectant, for taste and odor control, chlorination byproduct reduction, Iron and Manganese control, and color removal.
Inactivation Efficiency	Chlorine dioxide rapidly inactivates most microorganisms over a wide pH range. It is more effective than chlorine (for pathogens other than viruses) and is not pH dependent between pH 5-10, but is less effective than ozone.
Byproducts Formation	When added to water, chlorine dioxide reacts with many organic and inorganic compounds. The reactions produce chlorite and chlorate as end products (compounds that are suspected of causing hemolytic anemia and other health effects). The use of chlorine dioxide aids in reducing the formation of Total Trihalomethanes (TTHMs) and Haloacetic acids (HAA5) by oxidizing precursors, and by allowing the point of chlorination to be moved farther downstream. Quantities of chlorine dioxide and chlorite in drinking water are regulated by the EPA because of concerns about health effects.
Special Considerations	An oxidant demand study should be completed to determine an approximate chlorine dioxide dosage to obtain the required CT value as a disinfectant. Chlorine dioxide has the longest contact time requirements of all the treatment systems evaluated. This means large amount of storage are required to provide adequate treatment. The chlorine dioxide dosage cannot exceed 1.4 mg/L to limit the chlorite concentration to less than 1.0 mg/L (which is the maximum contaminant level). Chlorine dioxide is also known to have an effect in homes. Chlorine dioxide "off-gases" from water easily and when it does so at a faucet in a home it mixes with fumes in the home such as fumes from new carpet installation and creates "mysterious odors" often described as "kerosene- or cat urine-like" odor. There is a need to examine how the use of chloramines for residual disinfection would interact with chlorine dioxide. There is also a need to examine whether the EPA would consider chlorine dioxide and chlorine/chloramines as two different disinfection barriers.

Summary of Advantages and Disadvantages of Chlorine Dioxide

Advantages	Disadvantages
<ul style="list-style-type: none"> + Inactivates <i>Cryptosporidium</i>. + Treats perennial color issue, tastes and odors. + Reduction of chlorine demand and use. + pH does not affect treatment capability. + Technology is ready for large scale application. + Lowest energy use of all proposed treatment technologies 	<ul style="list-style-type: none"> - Does not remove turbidity. - Does not provide additional supply. - Impacts on use of chloramine residuals are unknown. - Forms the byproducts chlorite and chlorate. - Chlorine dioxide decomposes in sunlight. - Chlorine dioxide must be made on-site. - Can lead to production of "mysterious odors" in some systems. - Cost of sodium chlorite is high. - Cost associated with training, sampling and laboratory testing for chlorite and chlorate are high.



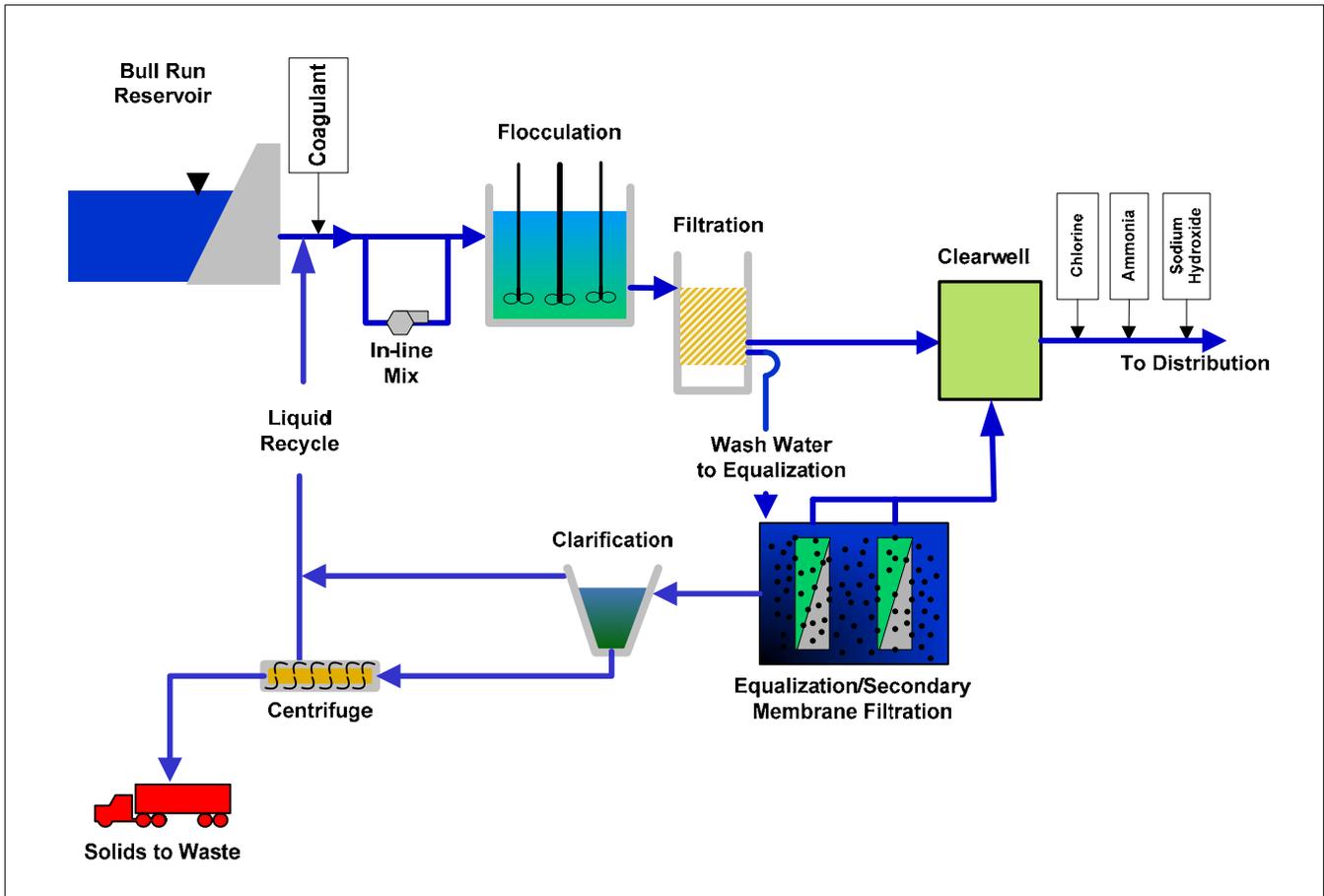
Sample Chlorine Dioxide Disinfection Schematic

Summary of Direct Filtration Considerations

Consideration	Description
Process	In its simplest form, direct filtration involves coagulant addition, mixing, flocculation and filtration. Direct filtration consists of adding a coagulant to the source water and then mixing. The coagulant combines with particles in the water to make the particles larger and heavier while providing an electrical charge; the resulting product is called "pin-floc". The coagulant will have to be determined by testing. The flocculated water is then run through a filter which is a bed of sand and gravel, which removes the floc. The water that goes through the filter is captured in a clearwell where it is disinfected with chlorine to eliminate viruses. Ammonia is added after the clear well to create chloramines and provide a residual for the distribution system. As the filter removes particles from the water it becomes harder for water to move through the filter, so periodically it is cleaned by "backwashing" clean water backwards through the filter and pushing all the particles that have been captured by the filter, to waste. The wastewater is treated by separating the particles from the water. The water from the waste stream is recycled back through the plant and the sediments are removed from the site for disposal. Direct filtration is different from Conventional filtration in the fact that direct filtration does not have a clarification (sedimentation) process.
History	Direct filtration has been in use as drinking water treatment techniques the longest of all the treatment techniques discussed for use by the PWB. Direct filtration is used around the world and has been for over a century. Direct filtration is a proven technology for treatment of raw water that contains low turbidity. There are numerous installations of direct filtration over 100 mgd. Some of the more recent installations include River of the Mountain Water Treatment Facility, Las Vegas, NV: 300 mgd; and Tolt Water Treatment Facility, Seattle, WA: 120 mgd.
Primary Uses	Organic and particle removal from water.
Inactivation Efficiency	Direct filtration will remove <i>Cryptosporidium</i> from drinking water.
Byproduct Formation	Byproduct formation would be dependent on chemicals used for coagulation and disinfection. The coagulation chemical and byproducts are mostly removed by the filters. Disinfection byproducts are significantly reduced because the filter removes most organic material associated with byproduct formation. Direct filtration has a higher byproduct formation than membrane filtration; however, byproducts would be lower than they are today.
Special Considerations	Direct filtration works well for low turbidity waters. Direct filtration would only partially deal with aesthetics such as color, taste and odor. Full removal of color, taste and odor can only be accomplished with the addition of chemicals that are specific to the problem to be addressed.

Summary of Advantages and Disadvantages of Direct Filtration

Advantages	Disadvantages
<ul style="list-style-type: none"> + Removes <i>Cryptosporidium</i>. + Removes turbidity. + Increases available supply. + Reduces chlorinated disinfection byproducts. + Improves the overall aesthetic of the finished water. 	<ul style="list-style-type: none"> - Rapid changes in raw water quality make process control difficult - Energy intensive if process requires full flow to be pumped. - Dependent on treatment chemical addition. - Requires highly trained operators. - Additional processes required for taste, odor and color removal.



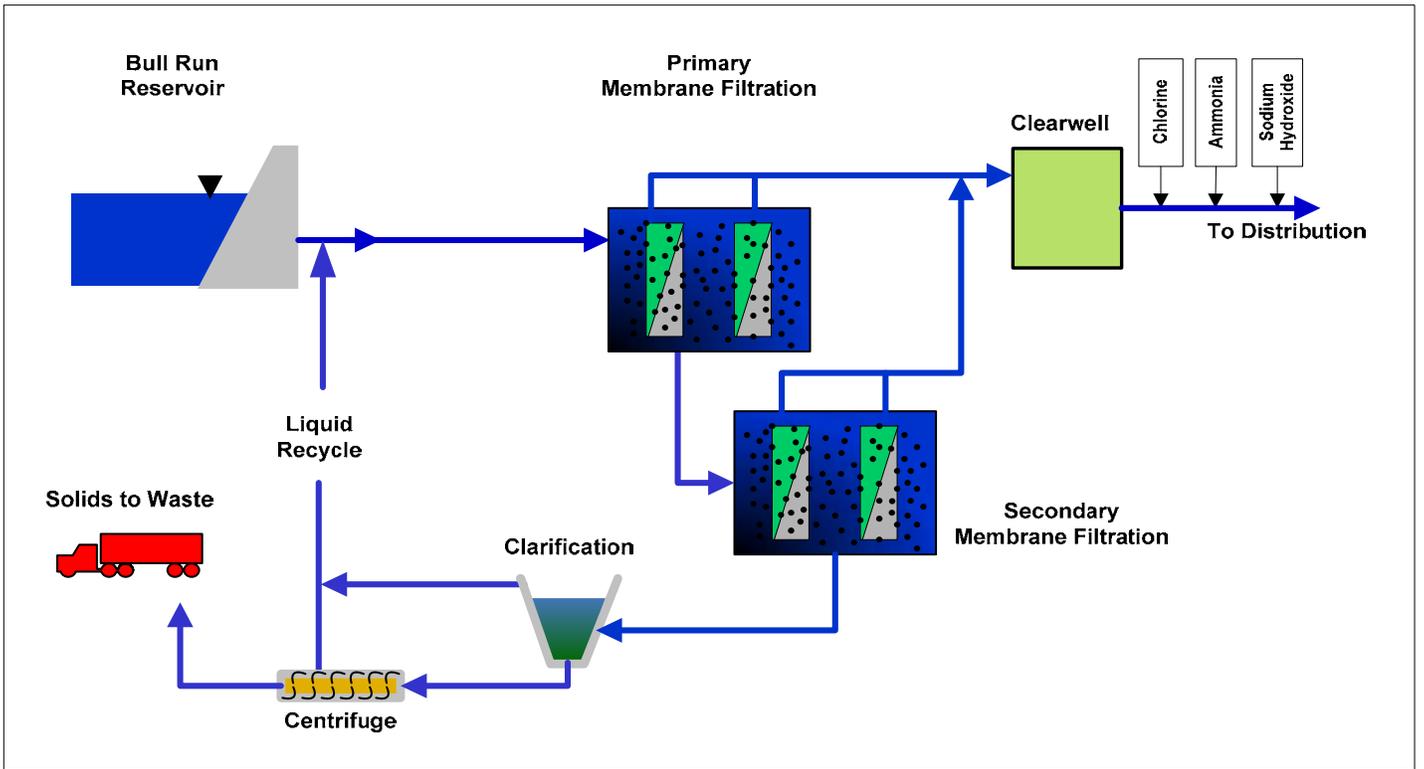
Sample Direct Filtration Schematic

Summary of Membrane Filtration Considerations

Consideration	Description
Process	Membranes provide an absolute barrier to particles and pathogens, and require limited operator skill—no chemical addition or process optimization is required for <i>Cryptosporidium</i> removal. Microfiltration/ultrafiltration (MF/UF) employs a microporous membrane and low operating pressures to remove very small particulates. To supply the required pressure, the hydraulic grade line (HGL) must be raised by an additional 20 to 60 feet above what would be required for a direct filtration plant; this pressure would be applied via pumping, either before or after the membranes, depending on whether the membrane configuration was pressure or vacuum driven.
History	The 60,000 gallon per day treatment plant at Keystone Resort, Colorado was the first full-scale application of low pressure membrane treatment in the U.S. The plant was completed in 1987. Since then, popularity of MF/UF has grown exponentially. Today (2003), the total planned and installed capacity is estimated to be greater than 528 mgd. Although most of the membrane plants are still relatively small (> 60-percent have capacities < 1 mgd), there are more than 20 plants planned or installed that are over 5 mgd. The largest operating plant in the United States is located in Minneapolis, Minnesota, with a capacity of about 70 mgd and is being expanded to 90 mgd. Singapore, Malaysia has a 72 mgd operating facility.
Primary Uses	Organic and particle removal from water.
Inactivation Efficiency	Membrane filtration will remove <i>Cryptosporidium</i> from drinking water
Byproduct Formation	No known byproducts produced.
Special Considerations	Compared to direct filtration plants, membrane filtration plants are relatively easy to operate, and are not susceptible to process upset from changes in raw water quality.

Summary of Advantages and Disadvantages of Membrane Filtration

Advantages	Disadvantages
<ul style="list-style-type: none"> + Removes <i>Cryptosporidium</i>. + Removes turbidity. + Increases available supply. + Provides an “absolute” barrier to pathogens. + Relatively easy to operate. + Improves the overall aesthetics of the finished water. + Stable performance despite rapid changes in raw water quality. + No known byproducts produced. + Reduces chlorinated disinfection byproducts. + Provides the benefits of direct filtration, with minimal chemical addition. 	<ul style="list-style-type: none"> - Efficiency decreases with raw water temperature. - Energy intensive if process requires full flow to be pumped. - Rapidly changing technology. - Scale-up issues for large plants - Additional processes required for taste, odor and color removal.



4. Sample Membrane Filtration Schematic